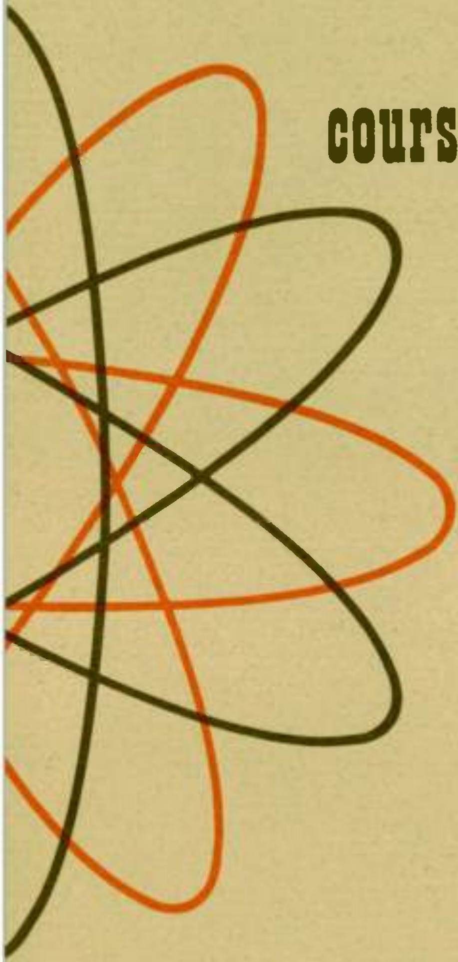
RADIO AND TELEVISION SERVICE AND REPAIR

COURSE 52-11



course lesson outline

AUDIO VISUAL KIT
HOME LABORATORY KITS
DESCRIPTION AND SCHEDULE

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ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

IMPORTANT INSTRUCTIONS

This booklet contains a detailed description and outline of your ADVANCE HOME TRAINING COURSE. Keep it and your Course Progress Record in a handy place where you can refer to them as you complete your training program.

HOW YOUR COURSE WILL OPERATE

The lessons and educational aids described in this booklet have been programmed to provide you with the very finest home study training. You will not receive all of the training materials at one time. Your training materials will be mailed as you progress successfully through your ASI course.

Our automatic mailing system operates upon completion of tests and lessons. Send your tests in sequence. Do not skip tests. Your course is planned so that you may learn the most from your training and always have on hand a complete and adequate supply of study materials when you are ready to progress further in your course. REFER TO THE SHIPPING SCHEDULE AT THE BACK OF THIS BOOKLET.

WRITING TO ADVANCE

Use a Consultation Service Blank to send in questions about your training and educational materials.

1. On all correspondence, indicate your STUDENT NO. and COURSE NO. If possible — give the CODE NO. of the item which your question is about.
2. For questions involving counseling or your understanding of the course subject matter, etc. ☐ CHECK THE BOX MARKED EDUCATIONAL SERVICES.
3. For questions involving tuition, financing, missing or damaged materials, etc. ☐ CHECK BOX MARKED Administrative Services.

KEEP A RECORD OF YOUR PROGRESS

A separate Course Progress Record has been provided so that you may keep a record of your own progress and achievement. Enter your test grades and the dates that you receive each shipment of training materials.

ALL TRAINING MATERIALS BECOME YOUR PROPERTY

The Advance Home Study Training Materials included in this course become YOUR property. They are not loaned to you. We pay shipping charges on all of your course materials. Materials cannot be requested ahead of time. They cannot be exchanged or left out.

E141

Reprinted March 1974

LESSON OUTLINE

RADIO AND TELEVISION SERVICE AND REPAIR

COURSE OBJECTIVE: Completion of this course will enable the ASI graduate to trouble shoot and repair, Radios, Tape Recorders, Record players, Hi Fi Systems and B & W TV's or be employed by industry as an analyzer, repairman, phaser, quality control, etc.

●

LESSON NO. 1 (code 52-001)
ELECTRONICS TODAY AND TOMORROW

History and development of electronics, electronic industry opportunities, electric devices in the home, electronic devices in industry, your future in electronics, importance of theory, course material, importance of studying lessons in sequence.

●

LESSON NO. 2 (code 52-002)
ELECTRICAL FUNDAMENTALS

Electric age, static electricity, matter and molecules, ions, electric current, electric pressure or volts, voltage drop, current and amperes.

●

LESSON NO. 3 (code 52-003)
OHM'S LAW AND KIRCHOFF'S LAW

Importance of Ohm's Law, rule of thumb, calculating current, voltage and resistance, resistance symbols, equations.

●

LESSON NO. 4 (code 52-004)
MAGNETISM

Natural magnets, artificial magnets, magnetic polarity, attraction and repulsion, theory of magnetism, magnetomotive force, electro magnetism.

●

LESSON NO. 5 (code 52-005)
REVIEW FILM LESSON 1 THROUGH 4

YOU RECEIVE:

A 35mm projector, 33 1/3 r.p.m. records, and a 35mm colored filmstrip.

YOU REVIEW:

Electrical fundamentals, Ohm's Law, magnetism, voltage and resistance.

●

LESSON NO. 6 (code 52-006)
CELLS AND BATTERIES

The primary cell, secondary cell, nickel cadmium cell, output voltage, rating of cells, current capacity of cells, construction of cells.

●

LESSON NO. 7 (code 52-007)
DIRECT CURRENT

Direct current flow, direct current force, electromotive force, calculating current flow, calculating voltage in circuits, adding voltages, voltage drop.

●

LESSON NO. 8 (code 52-008)
RESISTANCE AND RESISTORS

Resistance, units of resistance, DC resistance of voltage sources, ratings and color codes, wire sizes, resistor types and design, and circuit protection.

●

LESSON NO. 9 (code 52-009)
ALTERNATING CURRENT

Alternating current, AC vs DC, energy level of the electron, AC wave forms, the cycle sine waves, quadrants and degrees, RMS (effective valves).

●

LESSON NO. 10 (code 52-010)
REVIEW FILM OF LESSONS 6 THROUGH 9

YOU RECEIVE:

A 35mm colored review film with audio recordings,

YOU REVIEW:

How cells and batteries are built and operate, capacity of cells, output voltage and rating of cells.

•

LESSON NO. 11 (code 52-011)
CAPACITANCE AND CAPACITORS

Review of electrostatics, electrostatic fields, basic capacitors, charging the capacitors, discharging the capacitor, farads, microfarads and picafarads.

•

LESSON NO. 12 (code 52-012)
INDUCTANCE AND INDUCTORS

Coils, inductors, Henries, inductance, calculating time constants, inductor current and voltage, self induction induced EMF.

•

LESSON NO. 13 (code 52-013)
WIRING AND SOLDERING

Mechanical connections, splices, correct type of solder, oxidation, soldering procedures, soldering irons.

•

LESSON NO. 14 (code 52-014)
AUDIO AND RADIO FREQUENCY

Wave length, frequency, velocity, usuable frequencies, AF distortion, RF harmonics.

•

LESSON NO. 15 (code 52-015)
REVIEW FILM OF LESSONS 11 THROUGH 14
YOUR RECEIVE:

Another colored review filmstrip with recordings.

YOU REVIEW:

Capacitors, inductors, proper wiring and soldering, audio and radio frequency.

•

LESSON NO. 16 (code 52-016)
MODULATION AND DEMODULATION

RF carriers, audio modulation, sideband generator, modulation percentage, linearity modulation, wave forms.

•

LESSON NO. 17 (code 52-017)
REACTANCE AND IMPEDANCE

Coil and capacitor reactance, reactance effect, reactance calculation, impedance calculation.

•

LESSON NO. 18 (code 52-018)
YOUR HOME WORKSHOP

Work area, lighting, tools and equipment, power, cleanliness.

•

LESSON NO. 19 (code 52-019)
STARTING YOUR OWN BUSINESS

Newspaper ads, door to door leaflets, itemized receipts, work orders, guarantees, discounts, parts, suppliers, pick up and delivery of units.

•

LESSON NO. 20 (code 52-020)
REVIEW FILM OF LESSONS 16 THROUGH 19
YOU RECEIVE:

A colored review filmstrip with recordings.

YOU REVIEW:

Modulation and demodulation, reactance and impedance, your home workshop and business.

•

LESSON NO. 21 (code 52-021)
TRANSISTORS AND THEIR USES

Solid state devices, diodes, FETS, SCRS, thermo stabilization, limitations, circuit configurations, NPN and PNP transistors

•

LESSON NO. 22 (code 52-022)
VACUUM TUBES

Principles, construction, applications diode, triode, pentode and power rectifier types.

•

LESSON NO. 23 (code 52-023)
SYMBOLS AND SCHEMATIC DRAWINGS

Component symbols, use of symbols, reading and understanding schematics, why used.

•

LESSON NO. 24 (code 52-024)
REVIEW FILM OF LESSONS 21 THROUGH 23
YOU RECEIVE:

Your fifth colored review filmstrip with recordings.

YOU REVIEW:

Transistors, vacuum tubes, construction, applications, types, schematics, reading component symbols.

•

LESSON NO. 25 (code 52-025)
AF and RF INDUCTORS

RF choke coils, AF choke coils, multi-layer coils, single layer coils, core materials, variable inductors, slug toned inductors.

•

LESSON NO. 26 (code 52-026)
POWER AND AUDIO TRANSFORMERS

Transformer turns ratio, step up and step down ratios, impedance, secondary types, audio interstage flyback transformers.

•

LESSON NO. 27 (code 52-027)
RF and IF TRANSFORMERS

Tuned and untuned transformers, series and parallel tuning, broadband IF systems, impedance matching, balanced loops, ferrite loops.

•

LESSON NO. 28 (code 52-028)
SPEAKERS AND MICROPHONES

Crystal microphones, dynamic microphones, tweeter and woofers, multiple speaker circuits, impedance matching.

•

LESSON NO. 29 (code 52-029)
REVIEW FILM OF LESSONS 25 THROUGH 28

YOU RECEIVE:
A colored review filmstrip with recordings.
YOU REVIEW:
AF and RF inductors, power and audio transformers, RF and IF transformers, speakers and microphones.

•

LESSON NO. 30 (code 52-030)
TUNED CIRCUITS

Tank circuits, parallel tuned circuits, IF transformers, filter net works, Q factors.

•

LESSON NO. 31 (code 52-031)
MULTIVIBRATORS

Free running, bi-stable, monostable, Schmitt trigger, differential amplifiers, solid state switches.

•

LESSON NO. 32 (code 52-032)
OSCILLATORS

Frequency generators, oscillatory circuits, Armstrong-Hartley and Colpitts oscillators, electron coupled oscillators, frequency-stabilization, crystal controlled oscillators.

•

LESSON NO. 33 (code 52-033)
ANTENNAS AND RADIO WAVES

AM antennas, FM antennas, TV antennas-VHF and UHF, antenna sensitivity, mobile type antennas.

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LESSON NO. 34 (code 52-034)
REVIEW FILM OF LESSONS 30 THROUGH 33

YOU RECEIVE:
Your colored review filmstrip with recordings.
YOU REVIEW:
Tuned circuits, tank circuits, multivibrators, oscillators, frequency stabilization, antennas stationary and mobil types.

•

LESSON NO. 35 (code 52-035)
AMPLITUDE MODULATION

AM broadcasting, plate modulation, alternate methods, audio amplifiers, studio sound equipment

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LESSON NO. 36 (code 52-036)
FREQUENCY MODULATION

FM broadcasting, reactance tube modulation, phase shift, studio sound equipment.

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LESSON NO. 37 (code 52-037)
COMPOSITE SIGNALS AND MULTIPLEXING

Signal syncronization, video information, sound frequency, chroma information.

•

LESSON NO. 38 (code 52-038)
FREQUENCY CONVERSIONS

Hetrodyne principle, oscillator mixer, converters, transistor use, vacuum tube use, stereo signals.

•

LESSON NO. 39 (code 52-039)
REVIEW FILM OF LESSONS 35 THROUGH 38
YOU RECEIVE:
Another colored review filmstrip with recordings.
YOU REVIEW:
Amplitude modulation, frequency modulation, composite signals, multiplexing and frequency conversion.

•

LESSON NO. 40 (code 52-040)
AUDIO FREQUENCY AMPLIFIERS

Transformer coupling, RC coupling, direct coupling, ratings, sound amplifiers, interstage amplifiers.

•

LESSON NO. 41 (code 52-041)
RADIO FREQUENCY AMPLIFIERS

Triode amplifiers, multi-element tubes, grounded grid transistor circuits, coupling methods, frequency selection IF amplifiers, super hetrodyne principle.

•

LESSON NO. 42 (code 52-042)
POWER AMPLIFIERS

Amplifier classes, distortion, linearity, amplifier types, stereo amplifiers, ratings, frequency response.

•

LESSON NO. 43 (code 52-043)
POWER SUPPLIERS

Rectifier circuits, wave forms, tube rectifiers, solid state rectifiers, transformer ratings, voltage regulation.

•

LESSON NO. 44 (code 52-044)
REVIEW FILM OF LESSONS 40 THROUGH 43
YOU RECEIVE:
A colored review filmstrip and audio recordings.
YOU REVIEW:
Audio frequency amplifiers, radio frequency amplifiers, power amplifiers, and power supplies.

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LESSON NO. 45 (code 52-045)
SWITCHES AND RELAYS

Rotary switches, multipoint switches snap action, multideck switches, push button types, electromagnetic relays, circuit breakers, reed relays.

•

LESSON NO. 46 (code 52-046)
PRINTED CIRCUITS

PC Board materials, etching methods, fabrication methods, soldering techniques, PC components, plug-in modules.

•

LESSON NO. 47 (code 52-047)
CIRCUIT DIAGRAMS FOR SERVICING

Block-type diagrams using diagrams isolating the trouble, understanding circuit diagrams, locating components, audio and video paths.

•

LESSON NO. 48 (code 52-048)
REVIEW FILM OF LESSONS 45 THROUGH 47
YOU RECEIVE:
Another colored review filmstrip with recordings.
YOU REVIEW:
Switches and relays, printed circuits, circuit diagrams, servicing and the assembly and operation of kits K-102 through K-112.

•

LESSON NO. 49 (code 52-049)
WORKING WITH TRANSISTORS

Type selection, proper application, heat sinks, soldering, substitution testing for defective transistors, transistor shapes and sizes.

•

LESSON NO. 50 (code 52-050
CONNECTING THE COMPONENTS

Location of components, workmanship, mechanical attachment, heat sinks.

•

LESSON NO. 51 (code 52-051)
TEST EQUIPMENT

Why needed, how to use, what they do, repair and maintenance, basic principles, interpretation of readings.

•

LESSON NO. 52 (code 52-052)
VOM and VTVM

Basic circuits, AC measurements, DC measurements, resistance measurements, proper applications.

•

LESSON NO. 53 (code 52-053)
REVIEW FILM OF LESSONS 49 THROUGH 52

YOU RECEIVE:
A colored review filmstrip and audio recordings.

YOU REVIEW:
Working with transistors, connecting components, test equipment, VOMS and VTVM's.

•

LESSON NO. 54 (code 52-054)
SIGNAL TRACER

Locating defects, signal injection, attenuation, modulated signals, what and where to check.

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LESSON NO. 55 (code 52-055)
SIGNAL GENERATORS

Frequency range, audio tone, harmonic generator, circuit tracing, injecting a signal, checking control voltages, visual indication.

•

LESSON NO. 56 (code 52-056)
TRANSISTOR TESTERS

Testing NPN and PNP transistors, determining beta, leakage current, in-circuit testing, tester circuits.

•

LESSON NO. 57 (code 52-057)
TUBE TESTER

Mutual conductance, short test, gassy tubes, loose elements, tube replacement, tube tester charts.

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LESSON NO. 58 (code 52-058)
REVIEW FILM OF LESSONS 54 THROUGH 57

YOU RECEIVE:
A colored review filmstrip with recordings.

YOU REVIEW:
Signal tracers, signal generators, transistor testers and tube testers.

•

LESSON NO. 59 (code 52-059)
OSCILLOSCOPES

Scope types, applications and uses, wave shapes, as a measuring instrument, frequency measurements, signal tracing.

•

LESSON NO. 60 (code 52-060)
INTEGRATED CIRCUITS

Multi element devices, application, packaging, testing, replacing, types.

•

LESSON NO. 61 (code 52-061)
AM RADIO RECEIVERS PART 1

Power supplies, built in antennas, RF and IF circuits, converter stage, detector and A.V.C., audio circuits, tone and loudness system.

•

LESSON NO. 62 (code 52-062)
AM RADIO RECEIVERS PART 2

Voltage distributors, RF signal, frequency conversion, IF signals, detection and level control, audio signal.

•

LESSON NO. 63 (code 52-063)
REVIEW OF LESSONS 59 THROUGH 62

YOU RECEIVE:
A colored review filmstrip with recorderings.

YOU REVIEW:
Oscilloscopes, integrated circuits, AM radio receivers parts 1 and 2.

•

LESSON NO. 64 (code 52-064)
AM RADIO SERVICING

Inoperative receivers, distortion and hum, weak and noisy, checking voltages, stage isolation.

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LESSON NO. 65 (code 52-065)
FM RECEIVERS PART 1

Power supplies, RF and IF circuits, converter stage, amplitude limiter, FM detectors, AVC and AFC, sound section.

•

LESSON NO. 66 **(code 52-066)**
FM RECEIVERS PART 2

Voltage distributors, RF-signal, frequency conversion, IF signal, detectors and level controls, audio signal.

•

LESSON NO. 67 **(code 52-067)**
FM RADIO SERVICING

Inoperative receivers, distortion and hum, weak and noisy, checking voltages, stage isolation, pinpointing defects, selecting replacements, alignment.

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LESSON NO. 68 **(code 52-068)**
REVIEW FILM OF LESSONS 64 THROUGH 67
YOU RECEIVE:
Another colored review film strip with audio recordings.
YOU REVIEW:
AM radio servicing, inoperative receivers, hum, etc., also FM radio servicing on the inoperative receivers, hum, etc.

•

LESSON NO. 69 **(code 52-069)**
AUTO RADIOS TUBE TYPE

Power source, vibrator supply, auto antennas, RF, IF and detector, AFC and AVC systems, audio circuits, push button tuning.

•

LESSON NO. 70 **(code 52-070**
AUTO RADIOS TRANSISTOR TYPE

Power distribution, RF, IF and detector, AFC and AVC systems, audio circuits, bias control, signal seeking systems.

•

LESSON NO. 71 **(code 52-071)**
AUTO RADIOS SERVICING

Antenna troubles, ignition and static noise, push button tuning repair, defective installation.

•

LESSON NO. 72 **(code 52-072)**
REVIEW FILM OF LESSONS 69 THROUGH 71
YOU RECEIVE:
A colored review filmstrip with recordings.
YOU REVIEW:
Tube type auto radios, transistor type auto radios, servicing AM FM types and antennas.

•

LESSON NO. 73 **(code 52-073)**
RECORD PLAYERS

Cartridge and needles, tone arms, turn tables, motors, automatic record changers, amplifier, monaural records.

•

LESSON NO. 74 **(code 52-074)**
TAPE RECORDERS PART 1

Recording heads, erase heads, capstan drive, bias oscillator, multi track heads.

•

LESSON NO. 75 **(code 52-075)**
TAPE RECORDERS PART 2

Record and playback, tapereels, cartridge and cassette, multi track recording.

•

LESSON NO. 76 **(code 52-076)**
TAPE RECORDER REPAIR

Mechanical repairs, cleaning and lubricating, test tapes, electronic checks, frequency response, flutter and wow.

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LESSON NO. 77 **(code 52-077)**
REVIEW OF FILM OF LESSONS 73 THROUGH 76
YOU RECEIVE:
A colored review filmstrip with audio recordings.
YOU REVIEW:
Record players, cartridge and needles, tone arms, tape recorders, and tape recorder servicing.

•

LESSON NO. 78 **(code 52-078)**
STEREO HI-FI

Stereo phono cartridge, multiplex decoder, stereo records, speakers and enclosures, sound filters.

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LESSON NO. 79 (code 52-079)

CIRCUIT THEORY AND FUNDAMENTALS OF TV

Block diagrams, schematic, tuner and video system, synchronization circuits, IF and sound strips, CRT circuits, location charts.

•

LESSON NO. 80 (code 52-080)

ANALYSIS OF TV CIRCUITS

Integrating circuits, clipping and clipper circuits, differentiating circuits, fly-back actions, separator circuits, level clamping.

•

LESSON NO. 81 (code 52-081)

RECEIVING ANTENNAS

Installation, feed lines, distribution systems, multi set amplifiers, FM antennas, UHF/VHF antennas.

•

LESSON NO. 82 (code 52-082)

REVIEW FILM OF LESSONS 78 THROUGH 81

YOU RECEIVE:

A colored review filmstrip with recordings.

YOU REVIEW:

Stereo hi-fi operation and theory, analysis of TV circuits, receiving antennas, separator circuits, flyback action.

•

LESSON NO. 83 (code 52-083)

TELEVISION TUNERS

Channel width, antenna couplers, RF stage, mixer stage, oscillator, tuning systems, tuner adjustment.

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LESSON NO. 84 (code 52-084)

TELEVISION IF SYSTEMS

IF frequencies, bandwidth adjustment, spot frequencies, IF gain, sync clipping, sound take off, video detector, sync separating.

•

LESSON NO. 85 (code 52-085)

TELEVISION AUDIO SYSTEMS

Audio circuits, sound detectors, amplitude limiting, tone and volume circuits, sound take off, speakers.

•

LESSON NO. 86 (code 52-086)

TELEVISION VIDEO SYSTEMS PART 1

Video wave form, system response, DC restoration, video peaking, video amplifier, video detector.

•

LESSON NO. 87 (code 52-087)

REVIEW FILM OF LESSONS 83 THROUGH 86

YOU RECEIVE:

Another colored review filmstrip and recordings.

YOU REVIEW:

Television tuners, audio and intermediate frequencys and part 1 of TV video systems.

•

LESSON NO. 88 (code 52-088)

TELEVISION VIDEO SYSTEMS PART 2

RC coupling, DC coupling, RL coupling, pulse shaping, developing AGC, sync separator control.

•

LESSON NO. 89 (code 52-089)

CATHODE RAY TUBES & SYNC CIRCUITS

Sweep systems, flyback transformers, yoke coils, anode circuit, focus control, ion deflection, interlaced scanning.

•

LESSON NO. 90 (code 52-090)

TELEVISION CIRCUIT TRACING

Mechanical layout, uniform circuit layout, service literature, component placement, standard wave forms, oscillator patterns.

•

LESSON NO. 91 (code 52-091)

TELEVISION TROUBLESHOOTING PART 1

Power section, vertical section, horizontal output, horizontal AFC, sync clipper, sync separator.

•

LESSON NO. 92 (code 52-092)
REVIEW FILM OF LESSONS 88 THROUGH 91
YOU RECEIVE:
A colored review filmstrip and audio recordings.
YOU REVIEW:
TV video systems, cathode ray tubes, TV circuit tracing and TV troubleshooting part 1.

•

LESSON NO. 93 (code 52-093)
TELEVISION TROUBLESHOOTING PART 2

Hi voltage section, damper, IF section, tuners, video amp., CRT circuit.

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LESSON NO. 94 (code 52-094)
ADVANCED TV SERVICING PART 1

CRT defects, manufacturers bulletins, vertical instability, horizontal instability, sync interference, linearity problems, video circuits.

•

LESSON NO. 95 (code 52-095)
ADVANCED TV SERVICING PART 2

Remote controls, damper circuits, clip in test components.

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LESSON NO. 96 (code 52-096)
REVIEW FILM OF LESSONS 1 THROUGH 95
YOU RECEIVE:
The last colored review filmstrip.
YOU REVIEW:
TV troubleshooting, advanced TV servicing, a final over all review, and the assembly and operation of kits K-113 through K-120.

HOME LABORATORY KITS

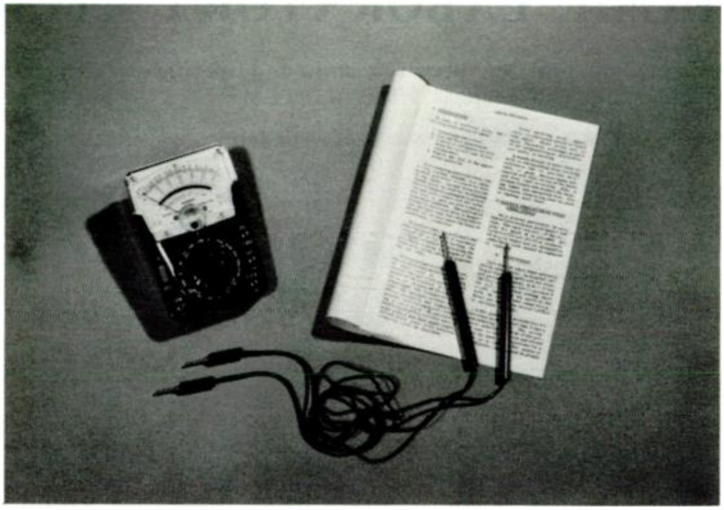
19 quality kits including tool set, prewired units and specifically engineered electronic kits for you to use, build and keep.

KIT NO. 1

code K-102

YOU RECEIVE: Hand tools, soldering irons, solder, shop apron and a tool use and care manual.

YOU PRACTICE: Correct use of your tools and how to keep them in working condition.

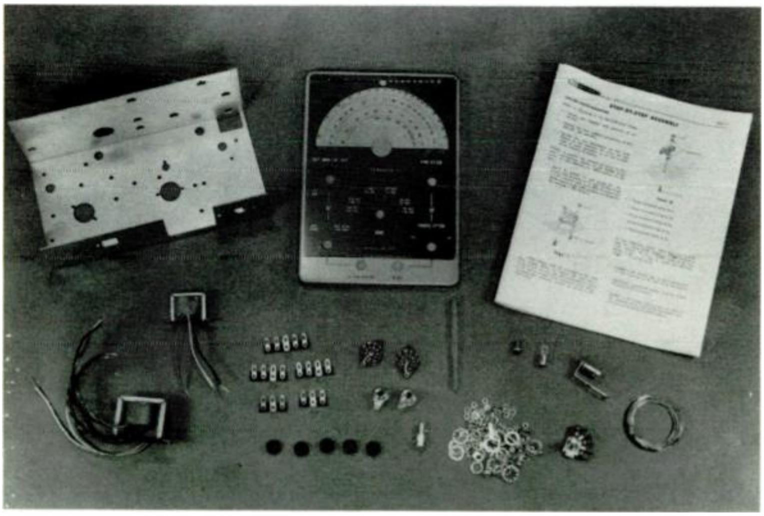


KIT NO. 2

code K-103

YOU RECEIVE: A prewired multitester and operation manual with lab experiments.

YOU PRACTICE: Reading the meter scales and how to set your meter for resistance, direct current and alternating current.

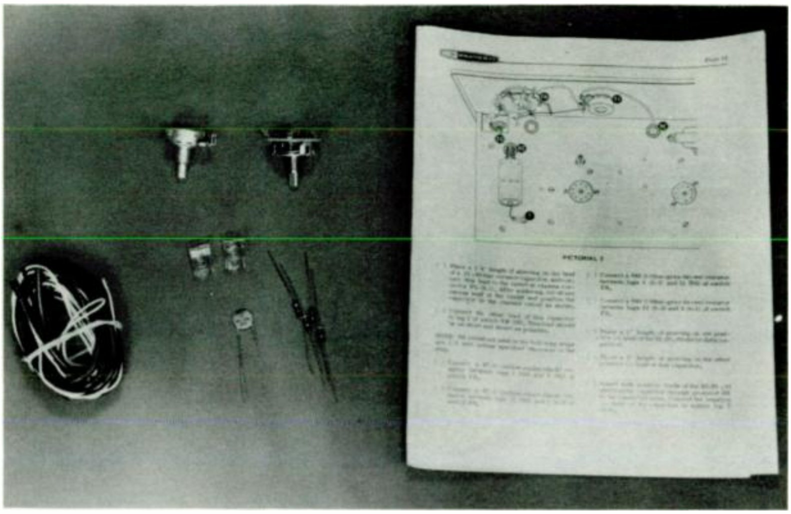


KIT NO. 3

code K-104

YOU RECEIVE: Kit A of your signal generator, with assembly instructions and lab experiments.

YOU BUILD: The first section of your signal generator and also check values of the various kit components with your multitester.
Caution: save all extra wire, etc., it will be needed later.

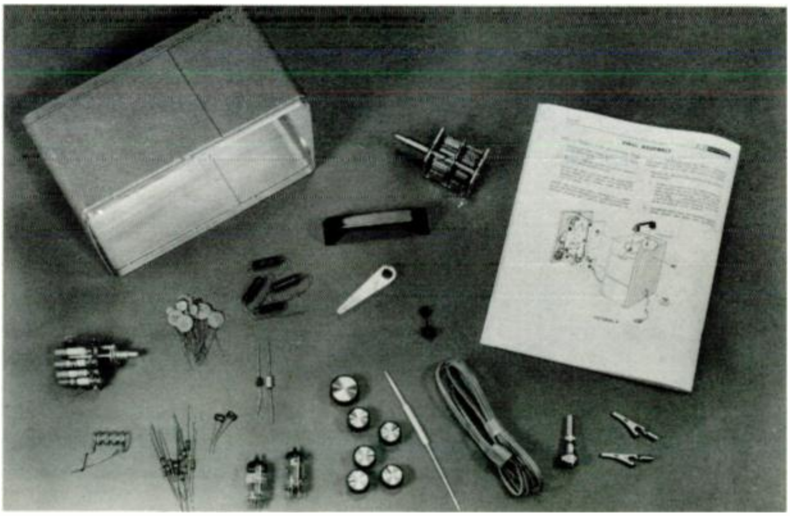


KIT NO. 4

code K-105

YOU RECEIVE: The second section of your signal generator, assembly manual and lab experiments.

YOU BUILD: The second part of your generator after checking the component values as with the preceding kit.



KIT NO. 5

code K-106

YOU RECEIVE: The third and final kit of your signal generator, assembly manual, operation instructions and lab experiments.

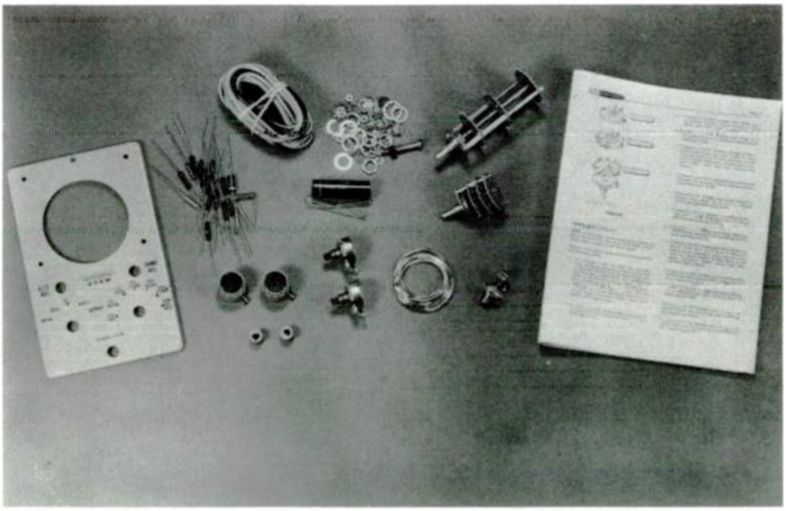
YOU BUILD: The final stage of the generator and test it out as per instructions.

KIT NO. 6

code K-107

YOU RECEIVE: Your prewired signal tracer, operating instructions, and lab experiments manual.

YOU PRACTICE: Signal tracing on any table model radio and later on through the portable AM radio which you will build.

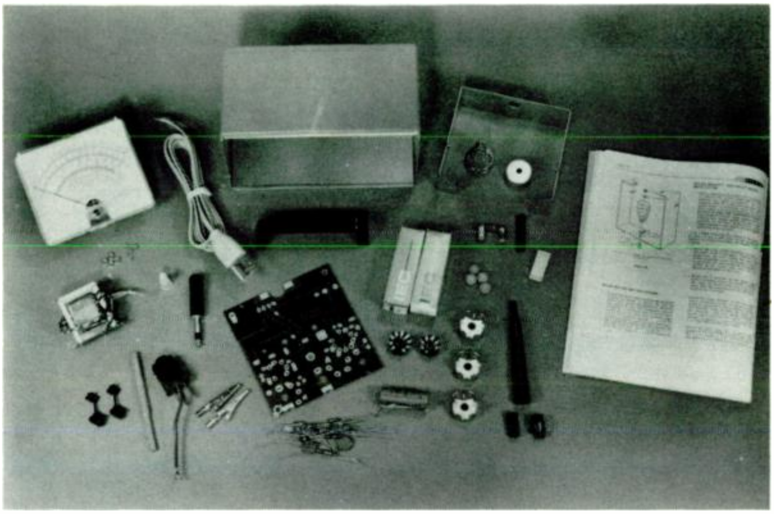


KIT NO. 7

code K-108

YOU RECEIVE: The first kit of your vacuum tube volt meter, assembly manual with lab experiments.

YOU BUILD: The first section of your V.T.V.M. kit, and check components with your multitester for correct values.

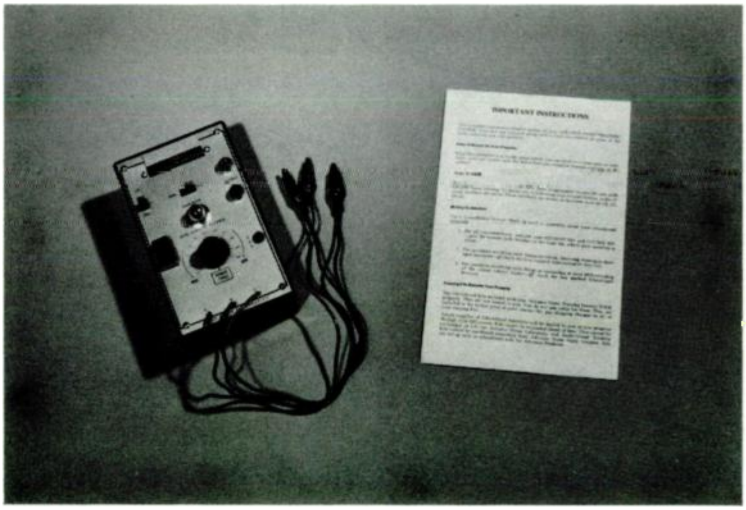


KIT NO. 8

code K-109

YOU RECEIVE: Your second V.T.V.M. kit with which you will finish assembling the unit. This includes assembly manual with lab experiments.

YOU BUILD: The final stages of the vacuum tube volt meter and then check it out per instructions.

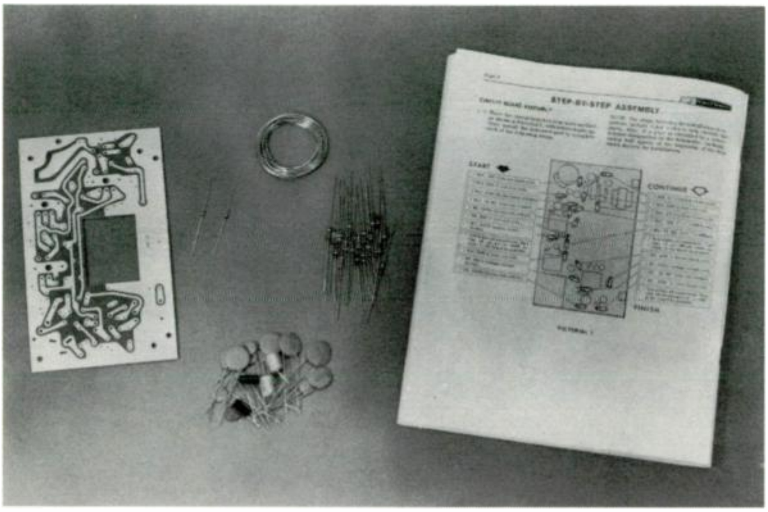


KIT NO. 9

code K-110

YOU RECEIVE: A transistor checker and operating instruction manual with lab experiments.

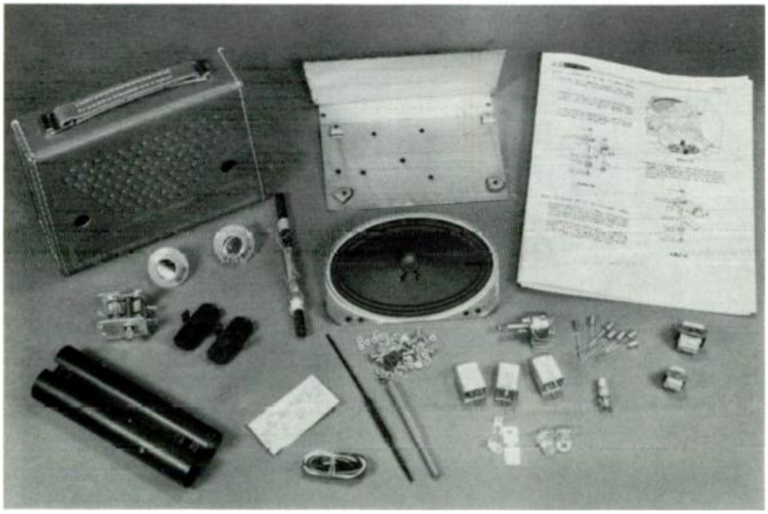
YOU PRACTICE: Checking NPN and PNP type transistors in circuit and out of circuit.



KIT NO. 10 code K-111

YOU RECEIVE: The first half of your portable 6 transistor AM radio kit and assembly manual with lab experiments.

YOU BUILD: The first section of the transistor radio and check out the components with both your multitester and V.T.V.M. plus practicing with your signal tracer.



KIT NO. 11 code K-112

YOU RECEIVE: The final half of your transistor radio with assembly instructions and lab experiments.

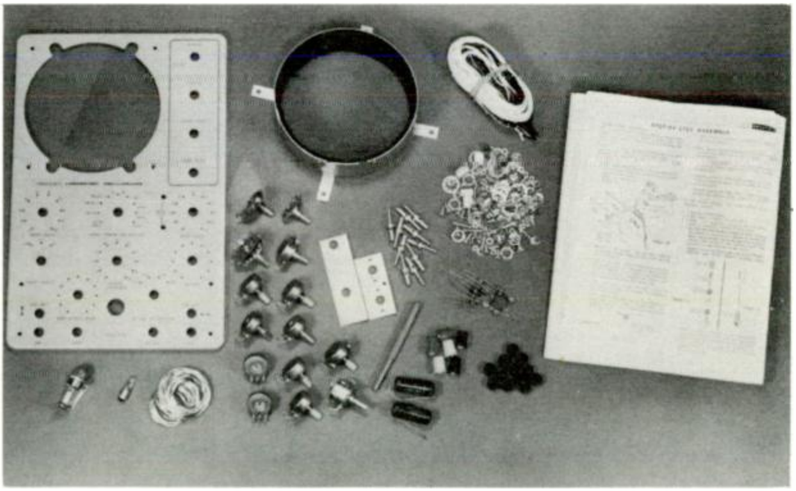
YOU BUILD: The last section, align it and experiment with your multitester, V.T.V.M. signal tracer and signal generator.

KIT NO. 12

code K-113

YOU RECEIVE: Your prewired DC power supply, operating instructions and lab experiments.

YOU PRACTICE: Connecting the power supply leads to AM battery operated radios. Also practice checking the four different voltage outputs with your multitester and V.T.V.M.

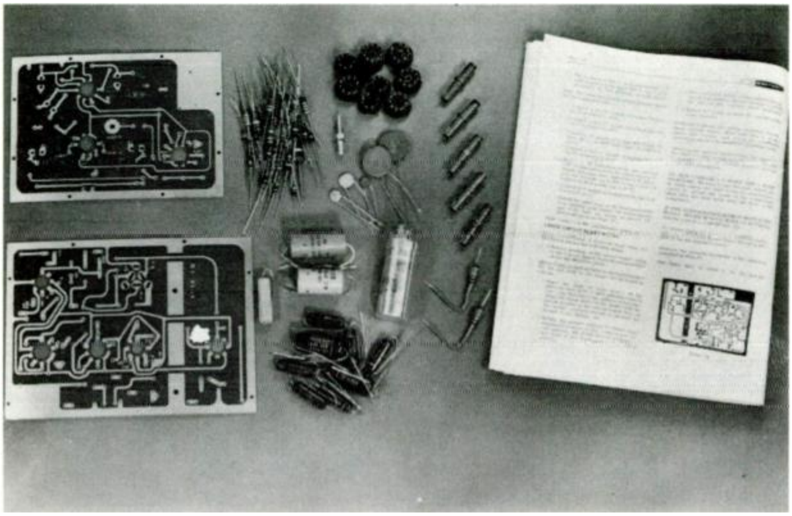


KIT NO. 13

code K-114

YOU RECEIVE: Kit "A" of your oscilloscope plus assembly manual with lab experiments.

YOU BUILD: The first section of the scope and test the various electronic components with both your multitester and V.T.V.M.



KIT NO. 14 code K-115

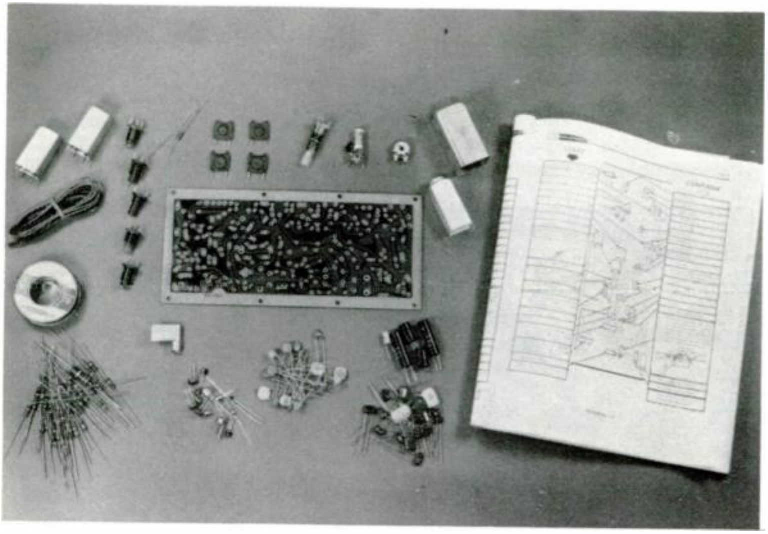
YOU RECEIVE: Kit "B" of your 5" broad band oscilloscope with assembly manual and lab experiments.

YOU BUILD: The second section of your scope and perform tests as outlined in the manual.

KIT NO. 15 code K-116

YOU RECEIVE: Your third and final oscilloscope kit with assembly manual and lab experiments.

YOU BUILD: This last section of your scope and test it out according to the instructions in the manual and perform experiments as directed.

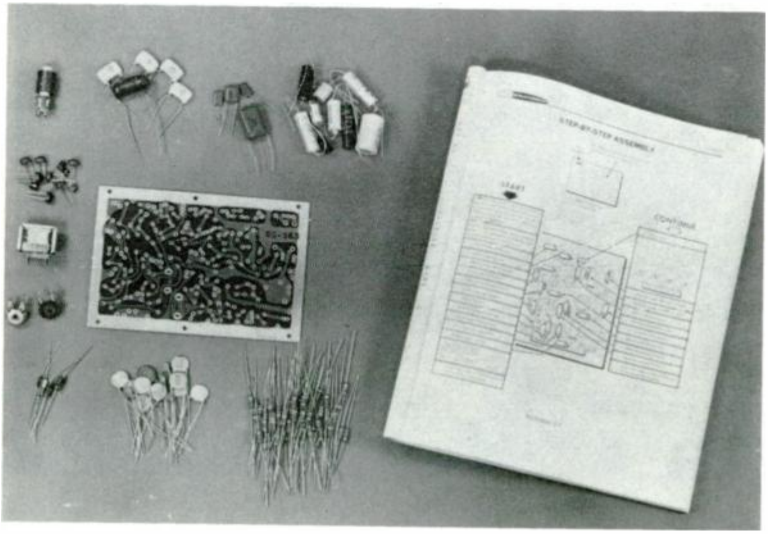


KIT NO. 16

code K-117

YOU RECEIVE: Section one of your black and white T.V. plus assembly manual and lab experiments.

YOU BUILD: The first part of your B and W TV and practice testing components with the equipment you have already received.

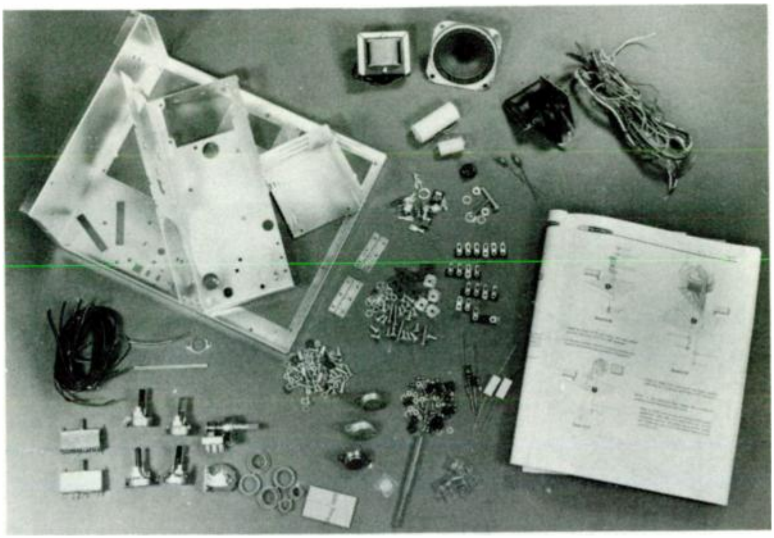


KIT NO. 17

code K-118

YOU RECEIVE: Section two of your Black and White T.V. assembly manual and lab experiments.

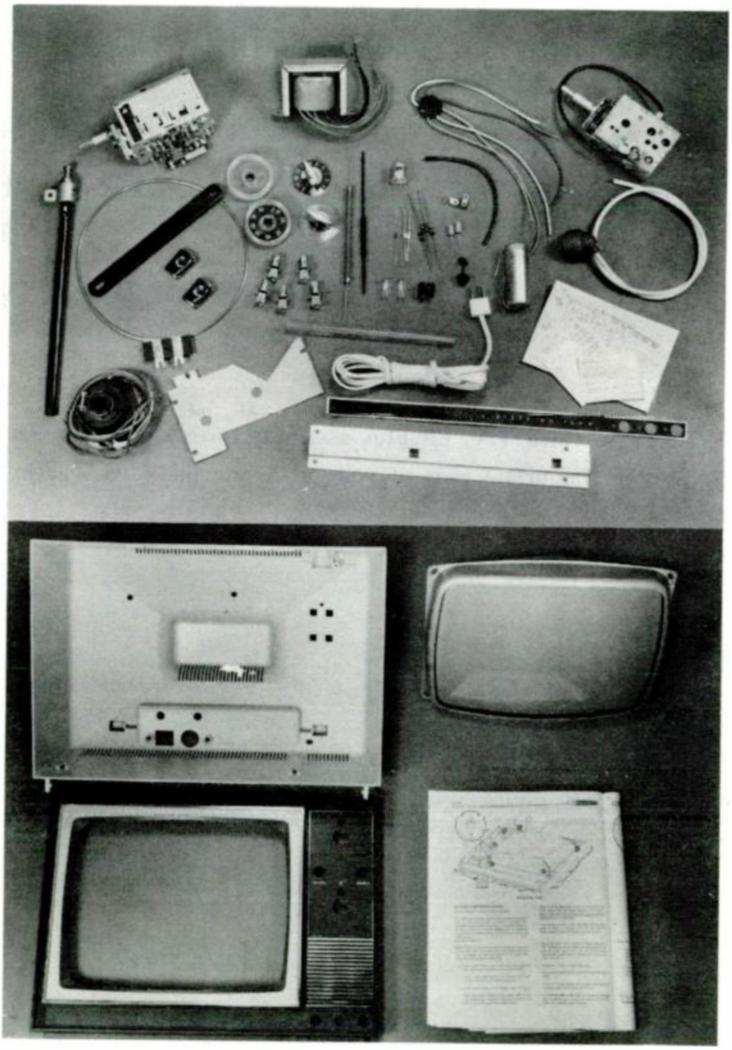
YOU BUILD: Part two of the T.V. and perform more tests.



KIT NO. 18 code K-119

YOU RECEIVE: Your third T.V. kit plus assembly instructions and lab experiments.

YOU BUILD: A very important part of your T.V. and make tests as instructed.



KIT NO. 19

code K-120

YOU RECEIVE: Your final black and white T.V. kit and assembly manual with alignment instructions and lab experiments.

YOU BUILD: The final stage of your B and W T.V. and check it out to complete your kits.

LESSON PACKAGE 1
(code No. P-108)

LESSON PACKAGE 2
(code No. P-109)

LESSON PACKAGE 3
(code No. P-110)

LESSON PACKAGE 4
(code No. P-111)

SHIPPING SCHEDULE

Each Package and Kit of training materials will be shipped as you satisfactorily complete tests. All preceding tests must be completed before the next shipment. Refer to your Course Progress Record.

When you reach and complete the test identified in the left column below, the Package or Kit in the right column will be shipped.

TEST FOR LESSON NO.	LESSON PACKAGE	KIT
UPON ENROLLMENT	P-108	
7		K-102
11		K-103
14	P-109	
16		K-104
20		K-105
25		K-106
27		K-107
30		K-108
35		K-109
38	P-110	
40		K-110
42		K-111
46		K-112
50		K-113
55		K-114
61		K-115
62	P-111	
67		K-116
74		K-117
81		K-118
87		K-119
91		K-120

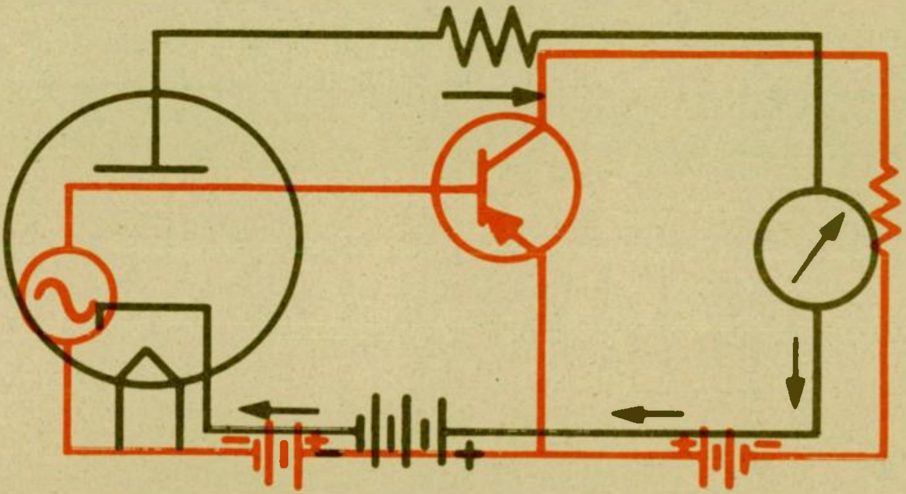
"School Without Walls"
"Serving America's Needs for Modern Vocational Training"

This training program is one of several Home Study Training courses offered by Advance Schools, Inc. Descriptive material and course specifications of other Home Study Training Programs offered are also available. The Advance Trades School Division offers courses in Mobile Engine Service and Vehicle Maintenance and also in Refrigeration and Air Conditioning. Secretarial, Shorthand, Records Management and Typing subjects are offered by the School of Secretarial Sciences Division. The School of Business Division offers Bookkeeping and Elementary Accounting. The School of Drafting and Design Division offers Home Study training in all phases of Drafting. The School of Electricity and Electronics Division includes a wide choice of courses in Electrical Service and Appliance Repair. Advance Schools, Inc. is fully accredited by the National Home Study Council Accrediting Commission.

SCHOOL OF ELECTRICITY AND ELECTRONICS

LESSON NO. 1

ELECTRONICS TODAY AND TOMORROW



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-001

406

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

Revised 6/73

Reprinted June 1974

Contents

ELECTRONICS TODAY AND TOMORROW

INTRODUCTION

Welcome to ASI's School of Electricity and Electronics. You have now entered a new phase of your life which, if you apply yourself well, will upgrade your way of living in a manner that you never thought possible. When you look at the opportunities available today for the man who will take advantage of them, you will realize that now is the time to move ahead.

Within the last half century, electronics has made many changes in our lives. Such developments as AM-FM radio, television, communications, and industrial electronics have actually improved our way of living. Our medical, military and industrial complexes have received valuable contributions from electronic discoveries.

The rapid advancement of radio and television broadcasting has affected each of us. With the availability of such mass media, a tremendous new field has opened up for both sales and service.

When automation was first introduced, everyone was talking about the vast unemployment that would result when the so-called machine took over. It has been proven that as automation progressed, thousands upon thousands of new jobs opened up. Naturally these were not common labor jobs but were positions that had to be filled by skilled tech-

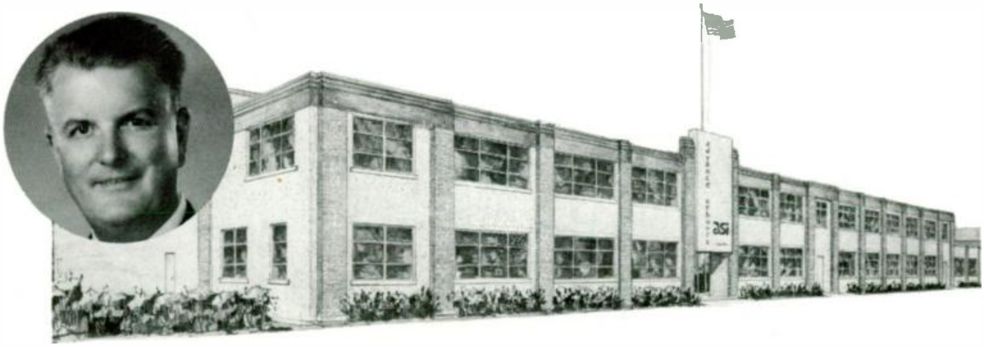


Figure 1 — Mr. Sherman Christensen, President of A.S.I. and home office.

nicians. How did these men become skilled technicians? – the same way you are going to become a skilled technician. You will be able to apply yourself to a well-planned, well-written course with quality kits which, when built by you, will last many years in your shop and on the job. Your home projects will lead you step by step into a clear understanding of the field you have chosen.

As you prepare to start your studies, please remember this: Study this training course thoughtfully and deliberately with pencil and paper available, making sure that all important points on each page are jotted down. DO NOT skim through the lessons. We hope that the rhyme "This is the day of the half read page" does not apply to you.

Whether you are interested in a hobby or a well-paying life-time job, this Electronics course will give you the *how* and the *way*. It is designed to give you a good solid background in basic electronics, radio, record players, tape recorders, and black and white television. Once you have completed this course, you will have the opportunity to take and understand more advanced courses such as computers, industrial electronics, color television, and communications. Most important of all, you will be earning money repairing radios, televisions, and other types of equipment while studying.

Figure 2 – An improvised work table.

HISTORY AND DEVELOPMENT OF ELECTRONICS

The world we live in can truly be called an Electronics World. The spark that appears when a person walks across a thick rug and then touches a doorknob, the bright flash of light that is caused by lightning, the voice that we hear on the telephone, the brilliant light that is produced by an electric bulb or flourescent lamp, the music that you hear on your AM-FM radio, or the picture that you see on your television screen is possible because of the phenomena known as electricity.

The adjective "electronic" was not generally used before 1939, and the noun "electronics" was probably first employed as recently as 1942. The word "electronic" is derived from the Greek word for amber, "elektron." Although it has been known since ancient times that amber had the peculiar property of attracting light bodies when it was rubbed, the Greek philosophers would be amazed at the developments that have taken place since that time.

What is electronics? It is the study of the behavior of electrons. Behavior of these electrons could be studied in solids, gas, and even under near-vacuum conditions. This leads to the control of these particles and their use in our day-to-day lives. Thus, electronics is not a fundamental science such as chemistry, physics, biology, astronomy, etc. It can be classified as a method or technique of precise engineering. Electrons are infinite in nature, extremely fast and sound in movement, and a recent ar-

Figure 3 – Electronic kit company.

rival on the scene of human knowledge.

Since the earliest times, mankind has often boasted of having made some of the biggest things in the world. Recent innovations in electronics, such as transistorized and integrated circuitry, are some of the smallest things which man has succeeded in engineering. Some of these integrated circuits are smaller than the smallest nutshell. These integrated circuits are used on some of the electrical appliances listed below. Therefore, you can see how closely related electricity and electronics are.

In general, the field of electricity deals with power generation and transmission, generators, motors, lighting equipment, and appliances commonly used in the home. Some of the special lamps used are the ultraviolet type which can bring the effects of sunshine into the home and also destroy harmful germs. Another type of lamp would be the infrared lamp which can provide radiant heat for various purposes.

Electric motors in the average home perform diverse functions, such as running the clothes washer and dryer, electric razor, clock, furnace blower, refrigerator, garbage disposal, fan, and various types of workshop equipment. Electric heaters provide heating for the home and also run appliances, such as the range, water

Figure 4 — Design and drafting area.

heater, coffee maker, toaster, heating pad, clothes iron, clothes dryer, and electric blankets. All these devices lessen the burdens placed upon the average housewife. Electricity also plays an important part in rural areas where many functions on the farm are possible with the help of electric motors.

In industry, electricity is used in every stage of development. For example, in the mining industry, electric shovels are used to dig out the ore, and electric cranes are used for loading and unloading purposes.

Many of these devices are electronically operated and can even be operated from a distance.

ELECTRONIC INDUSTRIAL OPPORTUNITIES

The vast amount of jobs available in the electronics industry is visible evidence of our progress in technology. Most products on the market today have been touched by electronic discoveries. They have been made faster and, thus, more economically. Industry has made use of electronic machine control in the inspection of products in all stages of production, thus assuring better quality control. Only a few years ago the number of hand-operations required to finish a product was excessive. With the discovery of new methods, a few highly skilled technicians today can do the work faster and easier. The average

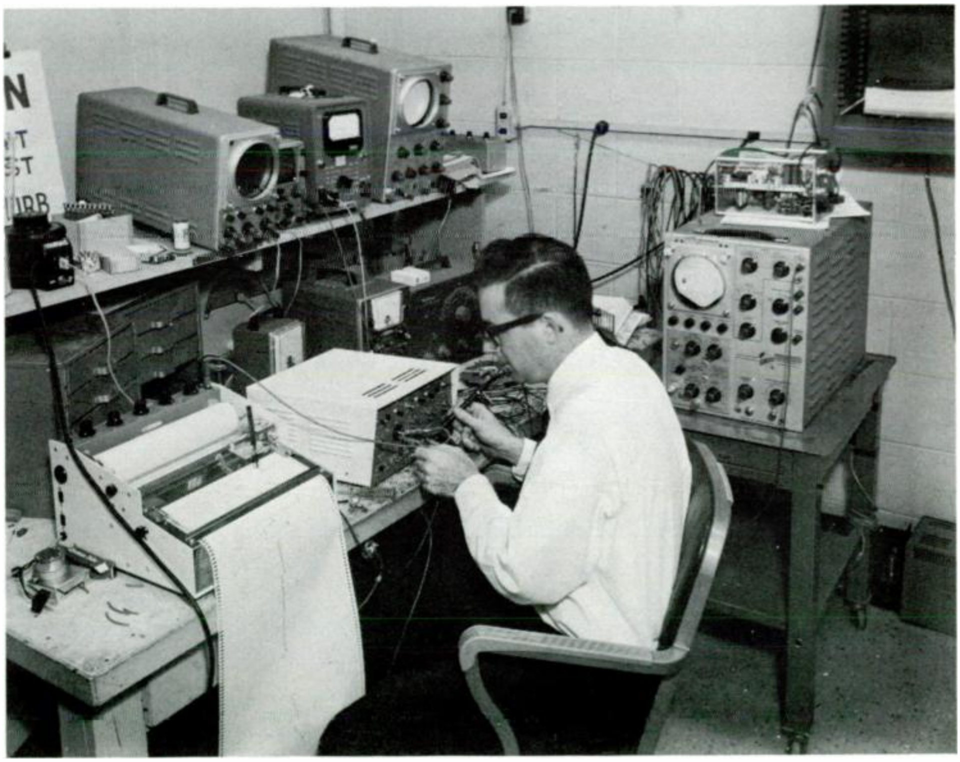


Figure 5 – Kit-engineering laboratory.

citizen does not realize how much his life is related to the electronic industry.

If you do not want to go into business for yourself after learning electronics the Advance way, you need only to apply at any number of the large electronic manufacturing plants and make an application for employment. During your interview with one of the department heads, you will impress him with your working knowledge of electronics. You will be qualified to enter any of several departments, such as troubleshooting, analyzing, alignment, quality control line inspection, and others.

There are many small factories which have contracts to build components for the industry. All of these can use your services. Some of them are engaged in manufacturing resistors, capacitors, IF and RF coils, transformers, audio and power transistors, tubes, cathode ray tubes, and tuning condensers.

The wage scale will vary, of course, in different areas of the country, but in most cases it will be higher than the average salary. These positions would also allow you to work in a clean atmosphere.

ELECTRONIC DEVICES IN THE HOME

There are many electronic devices now available for use in the home. Some, such as the radio, are several decades old. Others are fairly new,

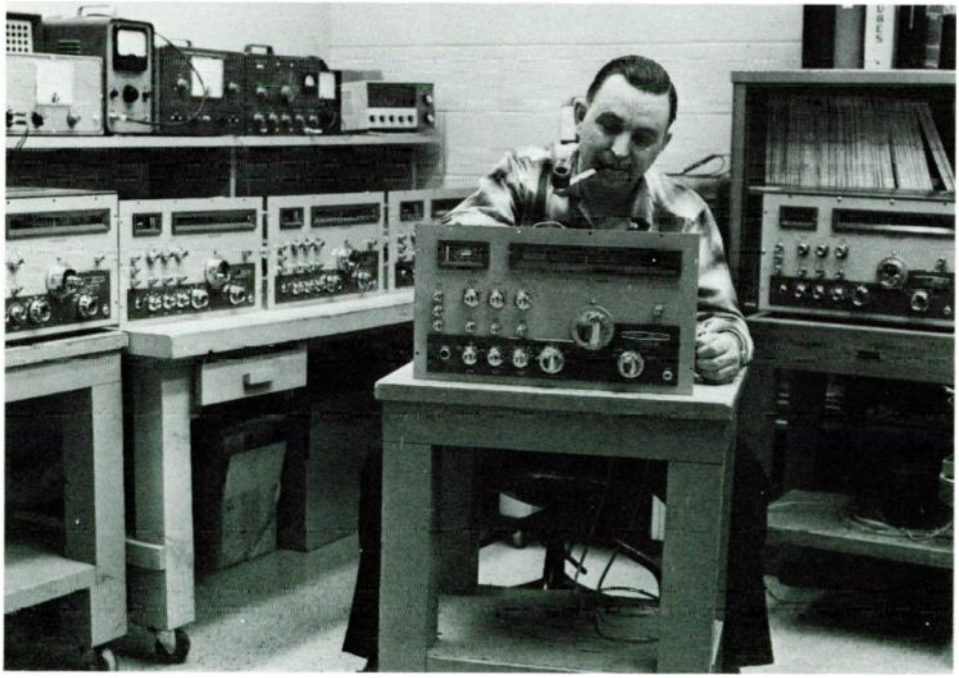


Figure 6 — Testing laboratory.

Figure 7 – Electronic kit packaging department.

and there are new inventions coming on the market every day.

Radio and television are by far the most common items found in the American household. There are over 300 million radios and about 100 million televisions in use.

Almost every home has one or more radios that need repair. There are also hundreds of inoperative television sets and sets that need tubes or components replaced because they are weak.

ELECTRONIC DEVICES IN INDUSTRY

One of the most important inventions that affects industry is the computer. Industries' highly complex computers can turn out in just minutes the work that previously took many men weeks and months to complete.

Automation has progressed to the point that many machine operations can be programmed through the computer. At the end of the operation, the machine has turned out a completed component or product.

Space exploration would be impossible without the aid of electronics. The spaceship is equipped with electronic gear, much of which has been miniaturized through the use of transistors and printed circuits.

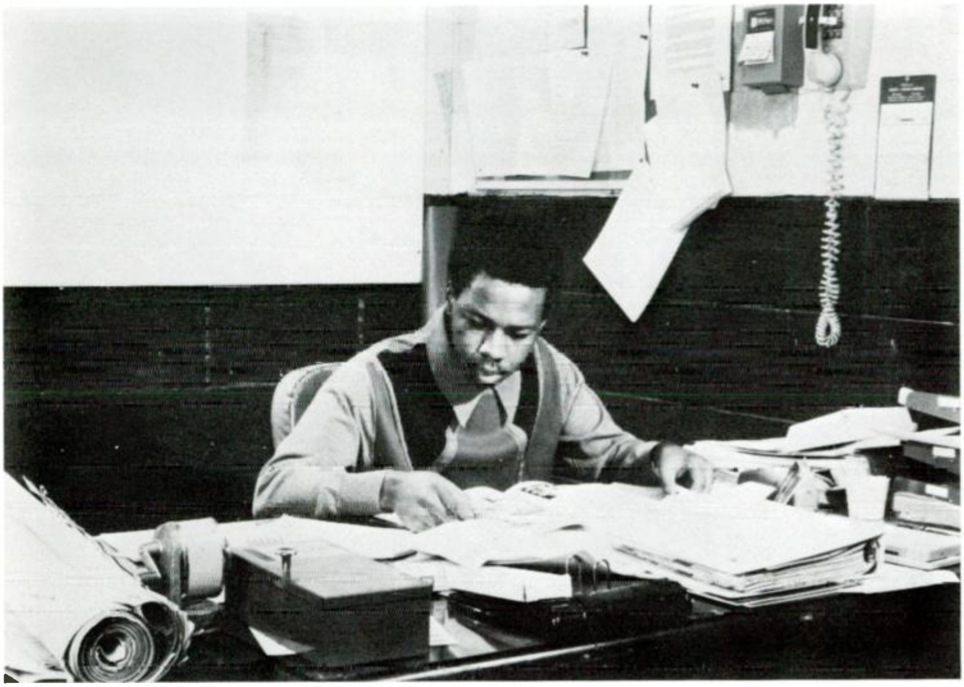


Figure 8 — Lunch hour study.

YOUR FUTURE IN ELECTRONICS

Part-Time Work

As you progress in this course, you will reach a point at which time you will feel confident enough to tackle your first paying repair job. At this point, I would suggest that it be a tube-type table radio. How much you charge for this repair job is not as important as the satisfaction you will receive in knowing that it was accomplished by putting what you learned in your Electronics course to work.

However, a word of advice at this point. You still have valuable things to learn, so do not rush out and load yourself down with dozens of units to repair. Make sure that you stick to your schedule, otherwise, you will not reach the goal you have set for yourself. Far more money may be made with an all around knowledge of Electronics, so look ahead.

Full-Time Work

For full-time work you will have to make a decision as to whether you want to become self-employed or work for someone else. It is a good idea to work for some industry or television repair shop while building up more practical knowledge. Later you could consider opening a full-time repair business.

There have been graduates of Electronic courses who have opened their own service and repair shops immediately after graduation and have become successful. It all depends on you and what you want to do.

Figure 9 — Kit building.

How to Locate Work in the Electronics Field

Locating work is fairly simple once you have become a graduate. Step one is to read the help-wanted columns in your local newspapers; step two, contact all of the local industries manufacturing for the electronics industry; step three, contact your local State Employment office; and four, write a short, to the point, "Position Wanted" ad and enter it in your local newspaper.

THE IMPORTANCE OF THEORY

In this service-oriented course, the practical aspect will be stressed, but you will also learn enough to understand electronics.

In Lesson Two, you will study the fundamentals of electricity. You will learn what matter is and what chemical elements are in the various compounds.

Once you understand what an atom is and how atoms form the chemical elements, and how chemical elements, singly or in combination, make up everything else, your foundation will be built. This foundation will enable you to master any phase of electronics you desire.

YOUR COURSE MATERIAL

Your course will consist of 96 lessons, of which 20 are review training films, a film projector with records, and a tool kit with soldering irons. Your kits will include an AM radio, all the necessary test equipment, and a portable black and white television kit. With the exception of the film projector, tools, radio and TV,

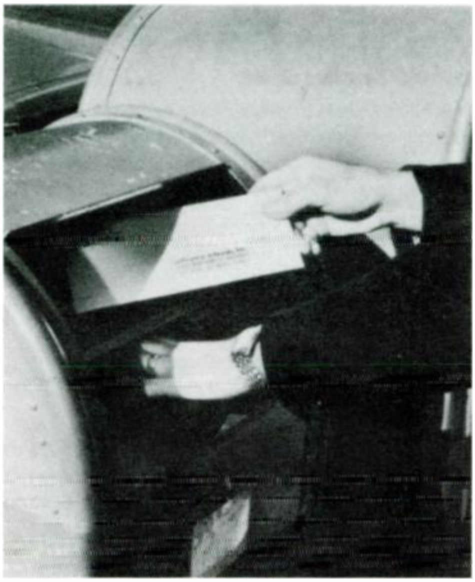


Figure 10A — Student mailing consultation sheet.

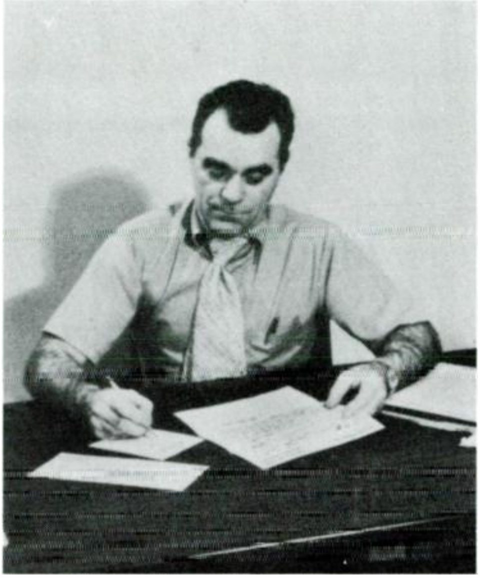


Figure 10B — Instructor answering students questions.

the above will be equipment for your home projects. When you have finished the course, you will not only be a qualified service man, but you will have built most of your own test equipment. This will give you an understanding of the equipment that will be used in all of your experiments and laboratory work.

All the above materials have been selected with your needs in mind; they include quality kits with step by step building directions and enclosed lab equipment for your home projects.

The training films, complete with projector and audio records, are used by you each time you complete certain lessons, as shown in your course outline booklet. First you will study your lessons, and then you will review visually on film what you have studied.

THE IMPORTANCE OF STUDYING LESSONS IN SEQUENCE

From our years of experience, we know that the student who studies his lessons in proper sequence and immediately submits his tests in order is the successful student. This course was designed to be studied one lesson at a time, beginning with Lesson One, Lesson Two, and so on.

If a restudy card is received from the school grading department, you must restudy that particular lesson and resubmit the test card immediately before proceeding with any more lessons.

Your lessons and kits will be mailed to you after certain key lesson grades are posted. **The school MUST receive all test cards in the proper sequence. Materials cannot be shipped until missing test cards are received.**

Figure 11 – ASI student picking up defective TV.

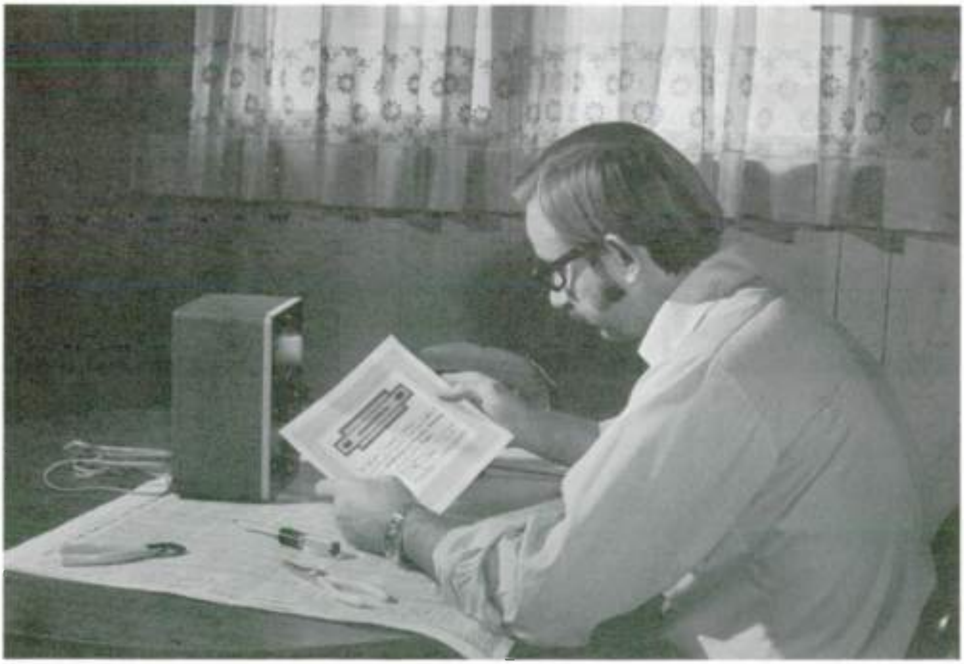


Figure 12 – Graduation day.

Figure 13 – Basement radio and TV work shop.

YOU AND YOUR INSTRUCTOR

At the time you were accepted as a student, you were assigned an instructor whose primary duty is to assist you with any problem you may encounter. We at ASI are fully aware that any student may run into an obstacle in his studies.

No matter what your problem is, we know that for you to become a successful graduate, you must understand all phases of the course. Remember, we are as close as your mail box. Please do not skip any portion of the lessons you do not understand. Use the Consultation Service Blanks furnished, making sure that you fill in all of the information at the top each time. Incomplete information leads to routing your questions to the incorrect department.

After the graded lesson card is returned to you, check every question that you have answered incorrectly, and then find the correct answer in your lesson book; this is very important. If you cannot come up with the correct answer, write to your Chief Instructor immediately stating the lesson number and question number. We want you to learn as much as possible from this course.

TEST

Lesson Number 1

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-001-1.

1. **As automation progressed, what happened to the job opportunities?**
   A. They became fewer.
   B. They stayed the same.
   [✓ C. They multiplied many times.]
   D. They ceased to exist.

2. **Electronics is a study of**
   A. observing the flow of electrons.
   B. counting the electrons.
   [✓ C. the behavior of electrons.]
   D. electrical appliances.

3. **After graduating, you will be qualified to**
   A. design short wave radios.
   B. service TV stations.
   [✓ C. repair radios, tape recorders, phonos, and black and white TV's.]
   D. electronically tune engines.

4. **Most homes have one or more**
   A. sweepers to repair.
   B. defective toasters.
   [✓ C. inoperative radios.]
   D. broken phonographs.

5. **The most important recent invention that affects industry is the**
   A. color television.
   B. turbine engine.
   C. highspeed lathe.
   [✓ D. computer.]

6. **The first paying repair job you take should be**
   A. a console black and white TV set.
   B. a stereo Hi-Fi phono.
   C. a short wave 4-band radio.
   [✓ D. a tube-type table radio.]

7. After graduation, you should
   A. rent a large building and buy lots of equipment.
   B. wait a year before using your knowledge.
   [✓ C. apply for a position in an industry or a TV Repair Shop.]
   D. take a course in some other subject.

8. The best way to get a job in electronics is to
   A. ask your friends to look.
   [✓ B. follow the steps outlined in the lesson.]
   C. wait for someone to call you.
   D. go on vacation.

9. The most successful way to study is to
   A. study the most interesting lessons first.
   B. skip the lessons that you do not like.
   C. not make notes.
   [✓ D. set up a study program and study lessons in sequence.]

10. If you run into a problem in the course, you should
   A. ignore it.
   B. ask for help at the end of the course.
   [✓ C. write your Instructor.]
   D. quit studying.

Figures 3 through 7
are Courtesy of
Heath Company

asi

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"Serving America's Needs for Modern Vocational Training"

You Make It Happen

Hop to it! Everyone strives to be a winner and individual success is possible if you make it happen. Setting a goal is a serious matter and it requires action. The decision must come from you. How? Prepare by good, solid training in a field which needs qualified men. Generally these areas are paying top salaries and the opportunities are unlimited.

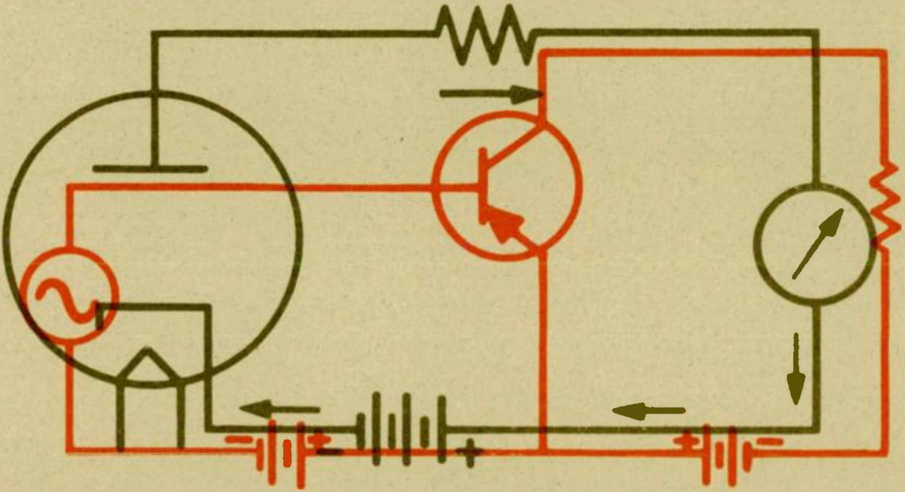
ASI is proud to help you by providing specialized lesson material, kits, shop procedures, student services, and individual counseling.

We offer you the professional preparation you need in the field of electronics today and tomorrow.

S. T. Christensen

LESSON NO. 2

ELECTRICAL FUNDAMENTALS



RADIO and TELEVISION SERVICE and REPAIR

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ELECTRICAL FUNDAMENTALS

ELECTRIC AGE

Many historians define our present era as the Atomic Age; other perhaps more astute individuals regard it in terms of electric power and electronic technology. The two are now inseparable, interrelated companions. Electricity produces power for complex electronic networks for communication, control and data processing. Electric power, in turn, is generated under the watchful eyes of intricate electronic devices. It has become so vital to our existence that near panic results when extended interruptions of service occur. Visualize a community from which electric power has been removed. Radio and television networks cease to provide entertainment. Heating and lighting of homes reverts to primitive means, and air conditioning does not exist. Storage of food, even for brief periods, becomes impractical, and preparation of food is a drudge. Neighborhood gossip is even affected; without electricity, the telephone is a mere conglomeration of associated junk.

Most leisure time is possible because of labor and time saving applications of electricity. In a modern home, cooking, dishwashing, and the washing and drying of clothes may be done almost automatically. While the work is being done the "household engineer" has ample time to do her nails, fix her hair, or chat on the phone.

Figure 1 - Electrically powered conveniences save time which may be devoted to leisure.

STATIC ELECTRICITY

"Electricity" and "electron" are words which were derived from ancient Greek. "Elektron" means amber, a substance first used experimentally to produce static electricity. Later it was discovered that other substances could be statically charged by rubbing them with some dissimilar material.

What happens on a cool clear morning when you shuffle across the rug and reach for the door knob? Snap! A spark springs from your fingertips and your fingers smart. Had you slowly approached the knob with the back of your hand, you would have felt a tugging sensation as the hair on your hand attempted to rise. This sensation is caused by electrostatic force (voltage). The tingle you felt earlier in your fingers was due to currents of electricity. Effects such as these amazed the ancients; they regarded them with mystery.

ELECTRICITY—FLUID OR CHARGE

Gradually electrical phenomena came to be regarded as natural forces which conformed to fixed patterns. This philosophy gained acceptance with each successive experiment. Ben Franklin incorrectly supposed that two types of electrical fluid (positive and negative) existed, but this concept has since been modified. The Fluid Flow theory of electricity surrendered to a force or charge concept as successive studies unveiled atomic structures and the electron theory.

Currently scientists prefer the dual charge idea of electricity. Two particles exist which have unlike charges, the positive proton and the negative electron. The positive charge (attracting force) of the proton equals exactly the negative charge of the electron.

Electric current consists of electron particles moving through a conductor, but it is more common to consider the movement of their charges, not the movement of the particles themselves.

MATTER—THE MOLECULE

Before exploring these theories, we must identify and define matter. Matter has weight, occupies space, and can be contained. Matter has three states: gaseous, liquid, and solid. Examples of these distinctive states are air, water, and wood. Heat, light, and electricity are not matter. These are forms of energy which exert force; they cannot be contained or weighed. A battery does

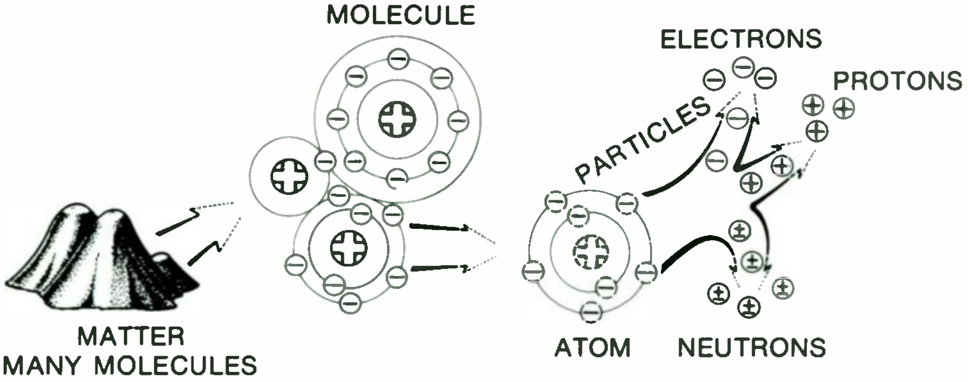

Figure 2 - Division of matter.

not hold electricity; it is filled with forms of matter which undergo chemical change as the battery is charged. Electric current from a battery is produced when the chemicals revert to original form.

All matter is formed from molecules much as a structure is built from bricks. A molecule is the smallest part into which a material compound can be divided, without undergoing change in some of its properties. Molecules are not just in matter — molecules *are* matter. Learn to think in terms of molecules of matter, as you do quarts of milk and gallons of gasoline. Molecules are in turn composed of atoms, as bricks are composed of bits of clay and sand.

ATOMS—ATOMIC STRUCTURE

If you divide a drop of water into smaller and smaller parts, you will eventually arrive at a molecule (Fig. 3). It will be wet and can be transformed into ice or steam by application of cold or heat. Reduce it even further, and you have atoms of two elements which drift away into the atmosphere. These are atoms of elements (hydrogen and oxygen) which cannot be further divided and still be matter (Fig. 3). Hydrogen and oxygen are two of the basic elements or building blocks from which all material compounds are formed. Ninety-two natural elements are known to exist. At least eleven more have been produced artifically.

Atoms also have building blocks. Two of these are charged particles, the third, the neutron is neutral. Positively charged protons structure the central portion or nucleus of atoms. Neutrons are present in most elements. Negatively charged electrons are attracted by the protons and scurry around the nucleus some-

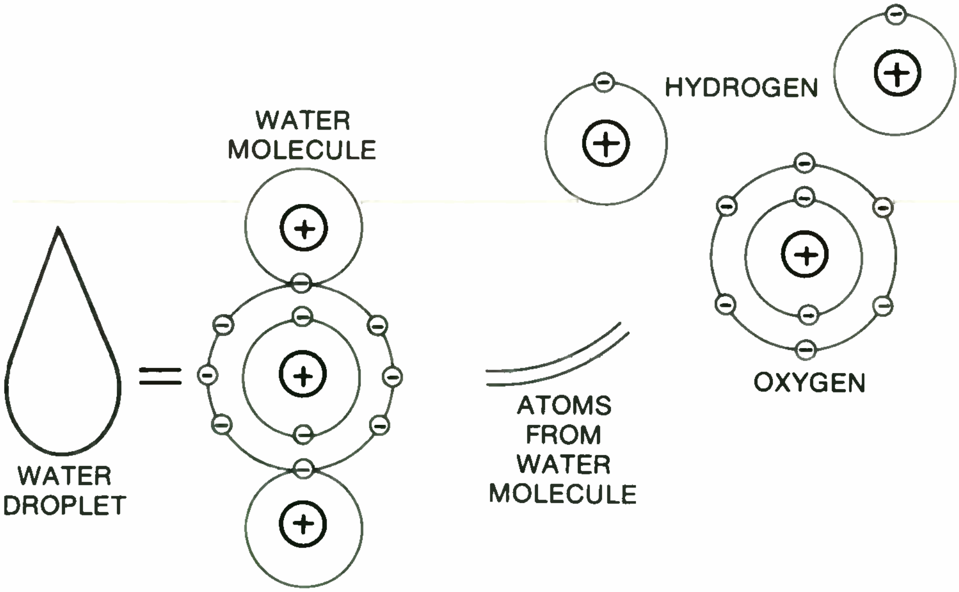

Figure 3 - Decomposition of water.

what like the planets revolve around the sun (Fig. 4). Each electron is identical to the others and every proton is alike. Likewise all neutrons are the same.

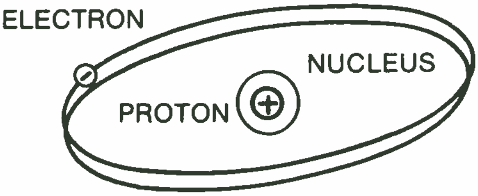

Figure 4 - Hydrogen atom.

Atoms of all elements have protons and electrons as a basic structure, but atoms of different elements have differing amounts. All atoms of any one element, however, are identical. Hydrogen is composed of one proton and one electron. Copper, which is also an element, has 29 protons and 29 electrons. The copper atom also contains 35 neutrons in its structure.

Neutrons (as was previously stated) have no charge and, like innocent bystanders, have no effect on the relationship between positive protons and negative electrons. They are currently believed to be formed by a proton and electron which have united; that is, the negative charge of the electron cancels the proton's positive charge and results in a no charge particle.

An atom's electrons revolve around the nucleus in discrete groups in an orderly fashion. Each group occupies a layer, and each layer becomes progressively farther removed from the nucleus. Only a limited number of electrons can occupy any one layer.

Picture a hollow ball as a compartment for the nucleus of an atom. Place a proton in this nucleus and it will demand the presence of an electron nearby to neutralize its positive charge. The companion electron will assume a position at some distance from the nucleus and sprint around it on a circular track.

It may be helpful to visualize this track enclosed by walls. The inside wall (call it centrifugal force) isolates the electron from the nucleus. The outer wall (attraction from the proton) prevents our electron from flying off into space. The electron is trapped in those narrow confines and can only race round and round.

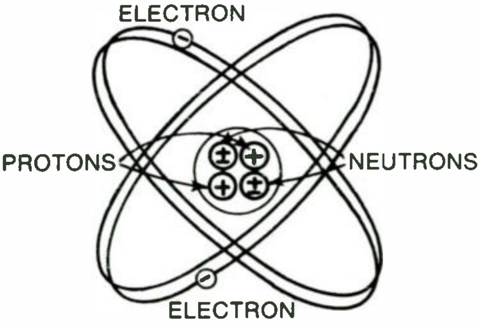

Figure 5 - Helium atom.

The atom we have constructed is the smallest divisible portion of the chemical element Hydrogen (Fig. 4). Add one more proton to the nucleus, and another electron will join it. Two neutrons will move into the nucleus as the element helium is formed (Fig. 5). The two electrons present cannot share a track because both are negative and inclined to reject each other. The second electron will locate at a distance similar to the first, but on a track which is

Element	Electrons per shell						
	1	2	3	4	5	6	7
Hydrogen	1						
Helium	2						
Lithium	2	1					
Beryllium	2	2					
Boron	2	3					
Carbon	2	4					
Nitrogen	2	5					
Oxygen	2	6					
Fluorine	2	7					
Neon	2	8					
Sodium	2	8	1				
Magnesium	2	8	2				
Aluminum	2	8	3				
Silicon	2	8	4				
Phosphorus	2	8	5				
Sulfur	2	8	6				
Chlorine	2	8	7				
Argon	2	8	8				
Potassium	2	8	8	1			
Calcium	2	8	8	2			
Scandium	2	8	9	2			
Titanium	2	8	10	2			
Vanadium	2	8	11	2			
Chromium	2	8	13	1			
Manganese	2	8	13	2			
Iron	2	8	14	2			
Cobalt	2	8	15	2			
Nickel	2	8	16	2			
Copper	2	8	18	1			
Zinc	2	8	18	2			
Gallium	2	8	18	3			
Germanium	2	8	18	4			
Arsenic	2	8	18	5			
Selenium	2	8	18	6			
Bromine	2	8	18	7			
Krypton	2	8	18	8			
Rubidium	2	8	18	8	1		
Strontium	2	8	18	8	2		
Yttrium	2	8	18	9	2		
Zirconium	2	8	18	10	2		
Niobium	2	8	18	12	1		
Molybdenum	2	8	18	13	1		
Technetium	2	8	18	14	1		
Ruthenium	2	8	18	15	1		
Rhodium	2	8	18	16	1		
Palladium	2	8	18	18	0		
Silver	2	8	18	18	1		
Cadmium	2	8	18	18	2		
Indium	2	8	18	18	3		
Tin	2	8	18	18	4		
Antimony	2	8	18	18	5		
Tellurium	2	8	18	18	6		
Iodine	2	8	18	18	7		
Xenon	2	8	18	18	8		
Cesium	2	8	18	18	8	1	
Barium	2	8	18	18	8	2	
Lanthanum	2	8	18	18	9	2	
Cerium	2	8	18	19	9	2	
Praseodymium	2	8	18	20	9	2	
Neodymium	2	8	18	21	9	2	
Promethium	2	8	18	22	9	2	
Samarium	2	8	18	23	9	2	
Europium	2	8	18	24	9	2	
Gadolinium	2	8	18	25	9	2	
Terbium	2	8	18	26	9	2	
Dysprosium	2	8	18	27	9	2	
Holmium	2	8	18	28	9	2	
Erbium	2	8	18	29	9	2	
Thulium	2	8	18	30	9	2	
Ytterbium	2	8	18	31	9	2	
Lutecium	2	8	18	32	9	2	
Hafnium	2	8	18	32	10	2	
Tantalum	2	8	18	32	11	2	
Tungsten	2	8	18	32	12	2	
Rhenium	2	8	18	32	13	2	
Osmium	2	8	18	32	14	2	
Iridium	2	8	18	32	15	2	
Platinum	2	8	18	32	16	2	
Gold	2	8	18	32	18	1	
Mercury	2	8	18	32	18	2	
Thallium	2	8	18	32	18	3	
Lead	2	8	18	32	18	4	
Bismuth	2	8	18	32	18	5	
Polonium	2	8	18	32	18	6	
Astatine	2	8	18	32	18	7	
Radon	2	8	18	32	18	8	
Francium	2	8	18	32	18	8	1
Radium	2	8	18	32	18	8	2
Actinium	2	8	18	32	18	9	2
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Americium	2	8	18	32	24	9	2
Curium	2	8	18	32	25	9	2
Berkelium	2	8	18	32	26	9	2
Californium	2	8	18	32	27	9	2
Einsteinium	2	8	18	32	28	9	2
Fermium	2	8	18	32	29	9	2
Mendelevium	2	8	18	32	30	9	2
Nobelium	2	8	18	32	31	9	2
Lawrencium	2	8	18	32	32	9	2

Figure 6 - Shell structure of atoms.

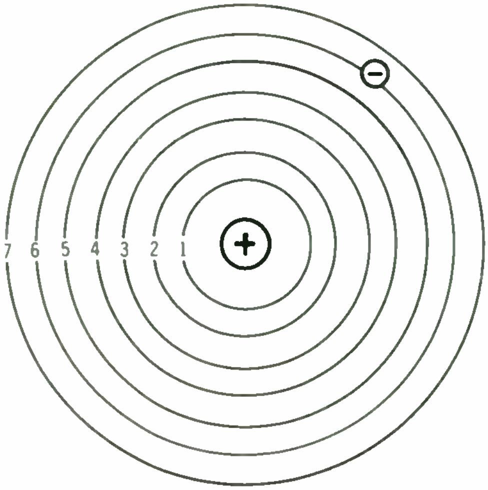

Figure 7 - Seven layers surround an atom which electrons can occupy.

inclined from that of the first (Fig. 5). For example, visualize two hoops or rings. Place one flat on a table, then stand the other upright in its center. Raise the first, being very careful to keep it level with the table top. When the two rings contact, they will describe the paths which our two electrons take.

Atoms like an orderly pattern and will object strenously when any one attempts to intrude. Should another electron attempt to occupy a track in the first layer, the two present electrons will propel it away. Only two electrons can occupy space in the first layer. Additional electrons must enter layers or shells farther removed from the center.

Seven shells (layers) exist which may be inhabited by electrons (Fig. 7). Each can hold a certain number of electrons, but the fringe layers may not necessarily be filled. A chart (Fig. 6) is included to show how many electrons are present by layer for each known element.

As we have demonstrated, the first shell can contain no more than 2 electrons. The second can hold 8, the third 18; the fourth, 32; etc.

ELECTROSTATIC FORCE

Earlier we stated that static electricity was discovered thousands of years ago. When ancients rubbed amber with fur, bits of shavings or dried leaves were attracted. Unfortunately, they lacked most of our present day knowledge and could only marvel at these effects. Ancients were unaware that atoms gained or lost electrons leaving them negatively or positively charged. They were also unaware that friction between certain unlike materials cause electrons to leave one in preference to the other, and actually cause opposite charges to appear on both substances.

Should two rods composed of rubber be freely suspended together and stroked with fur, they will physically move apart, substantiating claims that like charges repel each other (Fig. 8). Negative (-) electrostatic charges were deposited on both rods by the fur. This example also illustrates that physical force is exerted on materials when electrostatic charges are present.

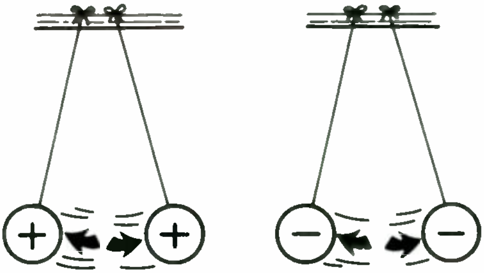

Figure 8 - Like charges repel.

Should the charges have been opposite on the two rods, they would attract (Fig. 9).

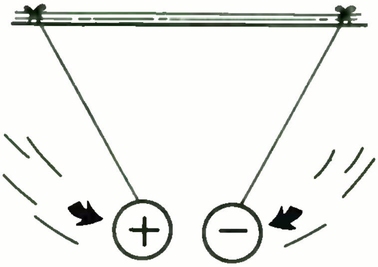

Figure 9 - Unlike charges attract.

CHARGING BY FRICTION

Friction between certain unlike substances excites surface atoms or molecules on both, causing electrons to stir violently. In the case of rubber stroked with fur, electrons are released from the fur and received by the rod (Fig. 10). The rubber gains a (-) charge as the fur becomes (+). Should the fur be brought into momentary contact with the rubber after charging, electrons will return to the fur and both materials become neutral. If the electrostatic charge is great enough, a spark or miniature lightning bolt will flash between them.

CHARGING BY CONTACT

When a statically charged body contacts a neutral object, transference takes place. The initial body deposits a portion of its charge on the neutral object and both are now electrostatically charged (Fig. 11). The two would repel, proving that they have like charges.

CHARGING BY INDUCTION

Should a neutral object be approached by a negatively charged body, electrons will drift to the opposite end. Conversely, a positive charge causes electrons to be attracted. The end towards which the electrons crowd becomes negative; the opposite end, positive. Remove the charged body, and electrons redistribute and neutrality is restored. Again approach a neutral object with a negatively charged body. This time touch the opposite end with a moistened fingertip. Electrons escape onto finger, leaving a positive charge behind (Fig. 12). Our formerly neutral object is opposite the charging source. Since the object was only approached, the indication is that electrostatic force bridges the sepa-

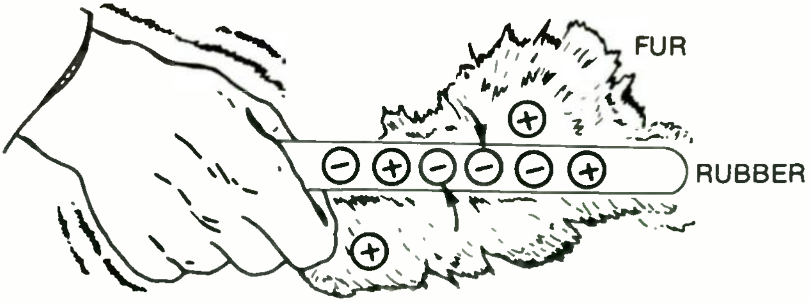

Figure 10 - Rubber rod stroked with fur gains electrons and a negative charge. The fur loses electrons and is charged positive.

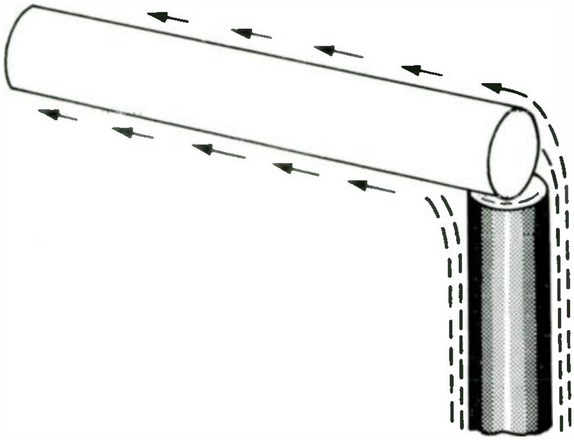

Figure 11 - A neutral body assumes a charge when contacted by a charged body.

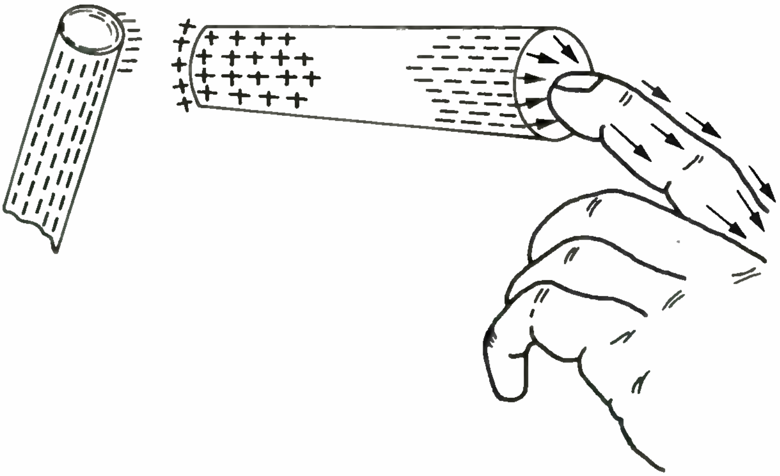

Figure 12 - Charge affects particles across a gap. Finger provides path for affected particles which causes the body to be charged when they depart.

ration and influences particles across a gap. It is theorized that an electrostatic force field produces invisible shafts which dart through space and material (Fig. 13). The number of shafts or lines of force increases as the charge and force field increases.

ELECTRON DRIFT

When atoms combine to hold an element or material together, electrons do not necessarily continue to revolve around the parent atom. Fringe electrons may skip to the outer layer of adjacent atoms where they dislodge another electron and allow it to move on (Fig. 14). It is in this fashion that electrons (electric current) flow from end to end in a copper wire. These somewhat free electrons in outer shells are called valence electrons. Metallic elements which have only one valence electron make excellent conductors of electricity. Copper, gold, and silver are good examples.

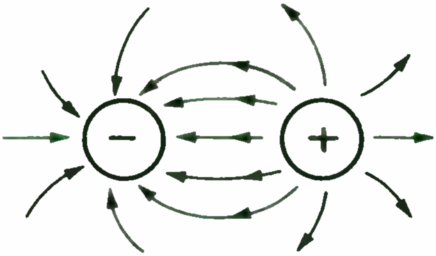

Figure 13 - Electrostatic lines of force bridge a gap between charges.

IONS

In general, atoms which have few electrons in the fringe shell contain spaces into which electrons may flow from adjacent atoms. When an electron moves within these substances two things happen:

1. The atom which loses an electron has a surplus proton with a positive charge. This atom becomes positive, and we call it a positive (+) Ion.
2. Atoms which gain an electron have a surplus negative charge. We call these negative (-) Ions.

You may wonder why we have not discussed proton movement. Protons are extremely small particles compared to electrons, but they are more than 1800 times heavier. In addition, they are cemented securely into the nucleus, making them almost impossible to dislodge.

CHARGE DISTRIBUTION IN A CONDUCTOR

It was previously stated that copper with one valence electron is an excellent conductor of electricity. It has only one electron in its fringe orbit and many spaces which electrons may use or drift through. (See ELECTRON DRIFT). Electrons in copper ordinarily shuffle about in a somewhat random fashion (Fig. 14). Where space exists, electrons move in; when overcrowding occurs, electrons move on. Considerable scurrying about occurs as atoms borrow and give up electrons, randomly changing from positive ions to neutral atoms or negative ions. Temperature affects this action. Cool the copper, and action decreases; heat it, and action becomes furious. Conversely, subject copper to a changing electrostatic field; electron activity increases, and heat will be generated.

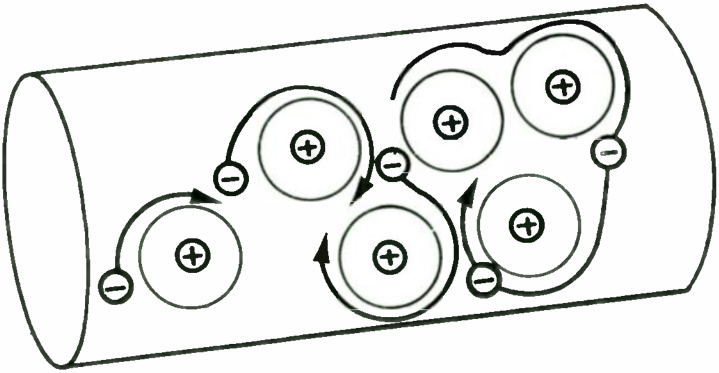

Figure 14 - Valence electron movement is somewhat random in a non-charged conductor, such as: copper, gold or silver.

Electrons must overcome friction when they move and, therefore, generate heat.

ELECTRIC CURRENT

Electrons *do not* fire straight through a conductor like a bullet, as many people think. As they travel, electrons are delayed, held back or forced aside by like-negative charges from other electrons.

Provide a negative force field at one end of a copper wire. Electrons will rapidly loop their way through the fringe layer of atoms toward the opposite end (Fig. 15). Attach a positive source, and they will stream toward it. With the negative end of a battery attached to one end of our wire and a positive to the other, electric current will begin to flow. Electrons move from the negative post of the battery into the wire and pass on to the positive terminal. From the positive terminal they drift through the battery's chemicals and return to the negative post (Fig. 16). The electrons continue a circular movement until either the wire is disconnected or our battery depletes its charge.

Although electrons are slowed considerably in their progress, their effects are felt long before they arrive. When they are pushed around by fellow electrons they naturally push back. As an electron attempts to move, it pushes on its neighbor. The neighbor gives a little and presses on those next in line. This pressure is felt almost immediately throughout the conductor. Its effect is similar to poking your finger into a sponge and seeing the opposite side instantly pop out.

RESISTANCE

Form a mental picture of resistance. When you encounter it instantly, visualize a choking action which reduces electric current to a trickle. Picture a partially open gate

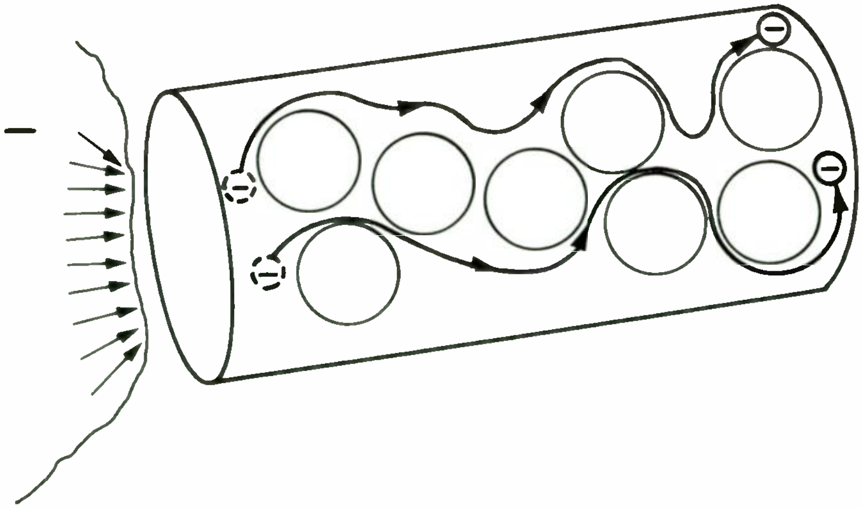

Figure 15 - Electron movement becomes directional when influenced by a charge.

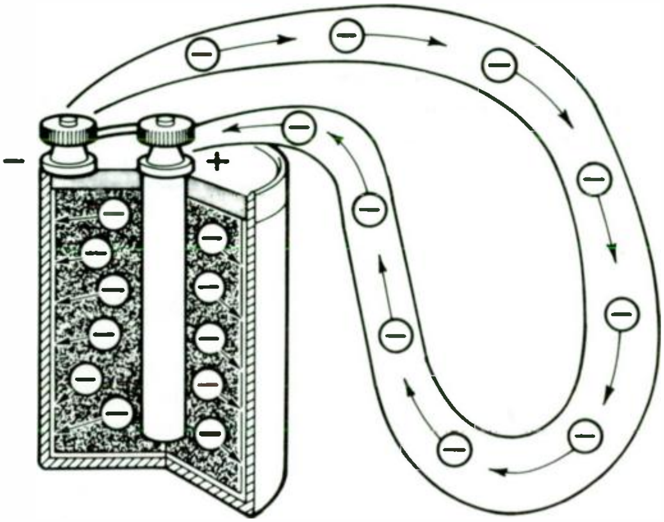

Figure 16 - Illustrates complete electrical circuit. Current flows from the battery (source) through the conductor and returns. Electric current continues to flow as long as a complete path exists.

with groups of electrons milling around before it. Individuals continue to join the group as other individuals sneak through the narrow opening. The hold back effect of resistance is measurable. The unit of measurement of resistance is the *ohm*.

VOLTAGE DROP

As the group of electrons mill about and crowd toward the opening, they press against each other. Those near the opening lean on the structure, and as long as the structure stands, pressure from this mob will not be felt beyond the exit. In comparing exit and entrance sides of the gate, we may say that a pressure drop exists. In electrical terms, we would refer to it as a voltage drop. Wherever current is impeded or held back, electrons group to form pressure points. These voltage drops are measurable or can be calculated, as you will later learn.

CURRENT—AMPERE

The rate at which electrons flow is defined by the term *ampere* (amp). When one amp of current flows, many electrons pass a given point each second, precisely 6.28 *billion billion.* Doubling this amount per second would amount to two amps of current; halving it results in .5 or half an amp.

ELECTRICAL WORK—JOULE

When current flows, it expends energy and does work. We have a term for the amount of work done by electricity; that is, the *Joule*. This tiny Joule lacks a sense of time relationship. It describes only how much work may be done by a quantity of electrical energy, not how long it takes to do this work. If 6.28 billion billion electrons flow through a restriction (resistance) in one second and produce a voltage drop of one volt, one Joule of work is done.

POWER—WATT

Watt is the term used to designate the rate at which electrical energy is being used to perform work. One Joule of work would require one watt of energy or power. Should the work be accomplished in a second, one Watt-Second of energy has been used.

It might be useful to note that the work accomplished may not be useful work. A yard light left on in bright daylight is wasted. Likewise, a motor which runs with nothing attached to the shaft is wasting watts of power.

ELECTRICAL PRESSURE—VOLT

The unit of electrical pressure which causes things to move, electrically speaking, is the *volt*. Volt is not related to time. It means only the amount of electrical force across a source such as a battery's terminals, or the amount of voltage drop across a resistance or electrical restriction. When one joule of work is done by 6.28 billion billion electrons, the electrical pressure required to move them is one volt. Voltage is not a moving thing which does work; it moves things and forces them to get the job done.

Another way of expressing volt would be to state: If one amp of current flows through one *ohm* of resistance, it was forced to do so by one volt of electrical pressure.

COULOMB

The number of electrons gained or lost by an object determines the electrical charge which the object has. The number of electrons which move is a fantastic figure; therefore, a term is used to represent this vast amount. To avoid saying 6.28 billion billion electrons, we simply state this amount as one *coulomb* of charge.

SUMMARY

Literally thousands of terms and abbreviations are used in electrical and electronic technologies. Fortunately, most apply only to specialized fields or products. It is advantageous to recognize many of these when you encounter them, but in most cases you will need to memorize only a few.

Three terms should stand out in your mind in all phases of electronics, and you will encounter them constantly. They are VOLT, OHM, and AMPERE (amp).

Equipment with this course is designed to give accurate readings of their values. Measuring and comparing their values is frequently all that is required to isolate a problem. Memorize their symbols and learn something of the actions they define. Be particularly attentive to portions of your course where VOLTS, OHMS, or AMPS are discussed, illustrated, or defined.

Remember:

E is Volts (electromotive force)
R is Ohms (resistance)
I is Amps (current)

TEST

Lesson Number 2

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-002-1.

1. **Matter is composed of**
   A. electricity.
   B. resistance.
   C. friction.
   [✓ D. molecules.]

2. **A molecule**
   A. is smaller than an atom.
   B. is larger than a brick.
   C. is larger than a drop of water.
   [✓ D. consists of more than one atom.]

3. **An electron has**
   A. a positive charge.
   [✓ B. a negative charge.]
   C. no charge.
   D. a positive and a negative charge.

4. **A proton has**
   [✓ A. a positive charge.]
   B. a negative charge.
   C. a positive and a negative charge.
   D. neutrons and electrons.

5. **A neutron has**
   A. a positive charge.
   B. a negative charge.
   [✓ C. a neutral charge.]
   D. atoms in its structure.

6. **Unlike charges**
   A. repel each other.
   B. do nothing.
   C. move apart from each other.
   [✓ D. attract each other.]

7. **When electric current flows, electrons**
   A. stand still.
   B. move only in circles.
   C. move only in straight lines.
   [✓ D. force electrons in their path to move.]

8. **The unit of measure of resistance is the**
   A. volt.
   [✓ B. ohm.]
   C. ampere.
   D. coulomb.

9. **Resistance**
   [✓ A. holds back electrons.]
   B. has no effect on electrons.
   C. attracts electrons.
   D. produces power.

10. **The Ampere (Amp) is used as a measurement for**
   A. electrical work.
   B. electric power.
   C. electrostatic force.
   [✓ D. electric current.]

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Vocational Awareness

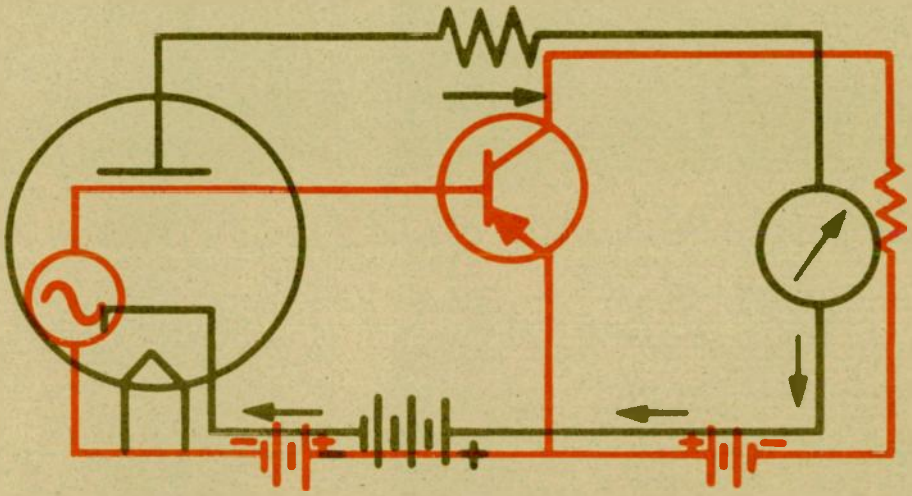
In the course of your studies with ASI, past experience has shown that additional reading material can be extremely helpful in strengthening your vocational awareness.

It is strongly recommended that a subscription to any of several Electronics Publications be initiated. This action will serve to deepen your ever growing knowledge of the Electronics field and open new avenues of challenge.

S. T. Christensen

LESSON NO. 3

OHM'S LAW
KIRCHOFF'S LAWS



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CONTENTS

OHM'S LAW - KIRCHOFF'S LAWS

BEGINNING OF ELECTRONICS

Electricity evolved from the desire to make it a useful tool as rules, laws, and principles were associated with its behavior. Serious students of science devoted their attentions to study and experimentation. As fact followed fact, definite patterns emerged. Distinguished pioneers in electricity—Westinghouse, Edison, Steinmetz, Telsa, and others—worked within these patterns to extend electric power into the most remote areas.

Electronics also began and evolved as a curiosity. Edison toyed with electric current through a vacuum prior to 1900, but failed to explain or realize its true significance.

Lee Deforest, another American, launched the Electronic Age early in the 20th century. He developed a vacuum tube which could boost feeble currents or voltages to usable signals. Radio broadcasting was then possible, and rapid audible communication to the masses became a reality.

Old scientific laws supported new principles as electronics matured into a technology. Foremost among these laws were those established by Ohm and Kirchoff. Together they describe basically how electric currents or voltages behave in nearly every type of electronic component or circuit.

This lesson will explain how Ohm's formulas may be simply applied and will introduce you to Kirchoff's Laws for voltage and current in series or parallel circuits.

IMPORTANCE OF OHM'S LAW

Rare, indeed, is the person who has not experienced a burned-out light bulb. After removing it from the lamp, many people shake the bulb and listen for the tell-tale rattle of a detached filament. Examine it closely; you will probably see the loose element. Minute scratch marks may be present on the inside coating where hot curls of wire have contacted the surface. Replacing the bulb with a known good one restores light to a darkened corner of the room.

Most troubleshooting is done in this fashion. A *problem* occurs; in this case, *no light*. A frequent offender is suspect—*the bulb.* It is examined visibly and/or audibly and is determined to be defective. *Replacement* corrects the problem.

Suppose that the bulb had not been defective. You would probably have suspected the fuse, plug, cord, switch or socket—in that order. All could be easily examined, and the problem would not have eluded you for long.

Some of the work in electronics which you will be doing is nearly that simple, but much of it will require additional troubleshooting steps to isolate a defective part.

Electronic products of today contain many multi-component packs and integrated circuits or IC's (Fig. 1). Several component parts—transistors, diodes, resistors, and capacitors—may be enclosed in each of these little Blobs. Wires from individual parts may not always extend from the pack. Several components frequently share a common wire coming from this component block.

It appears that we have no way of testing or identifying a bad component within. To further complicate troubleshooting, wires from these components connect to wires from other parts or groups of parts. It is not uncommon to have a hundred or more parts associated in this fashion. A failure of any one part within this group (a shorted capacitor, a burned out resistor or transistor, etc.) changes current or voltage present at many other points.

By studying the schematic drawing of a circuit, technicians quickly determine the current paths and where voltages, currents, and resistances may be measured. Where values of current, voltage, or resistance are not specified, these can

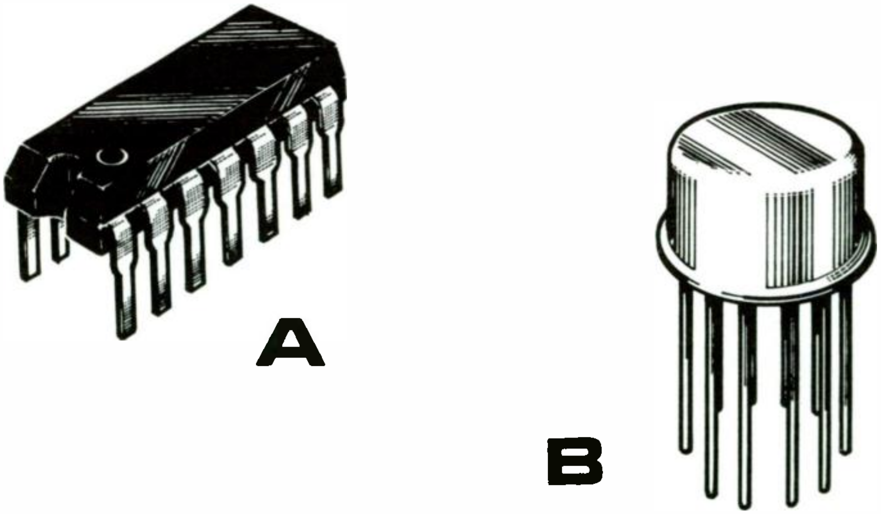


Figure 1 — Multi-component packs: A) Dual incline IC pack B) T.O. type IC pack.

generally be determined through Ohm's Law. Ohm's Law describes how much current flows through an amount of resistance when a known voltage is present. It may also be used to determine how much resistance there should be, or the value of the voltage which should be present.

Once you have mastered Ohm's Law and understand how electronic circuits and devices operate, you will be able to logically troubleshoot electronic products. By referring to schematic drawings and making a few simple tests with your equipment, the defective part will soon be revealed.

OHM'S LAW

More than 100 years ago a German scientist, George S. Ohm, explored the behavior of electric current. He demonstrated that the amount of current flowing in a circuit is dependent upon the strength of the applied force or voltage and the amount of resistance in the current's path. From his findings, Ohm established the most important law governing the conduct of electricity. His three simple formulas will enable you to quickly determine voltage, current, and resistance without actually measuring each. By using the appropriate Ohm's formula, current, voltage, or resistance can be found by simple calculation (Fig. 2). These formulas are appropriately called Ohm's Law, and resistance is expressed as a certain number of Ohms.

Before you can use this valuable tool, you must first know what the designations "I", "E", and "R" symbolize. "I" represents electron flow, which is *current* in amperes. "E" designates electromotive force in volts. "R", or resistance, is the opposition which electrons encounter as they flow. Simply stated,

"E" is in volts
"I" is in amperes
"R" is in ohms.

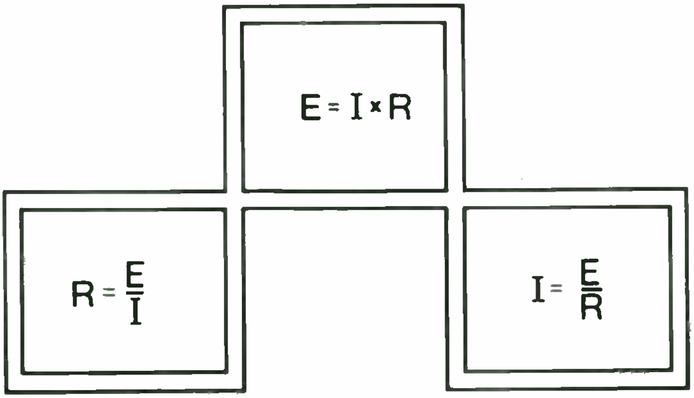


Figure 2 — The three Ohm's formulas.

RESISTANCE SYMBOL

In addition to the designations "E", "I", and "R", you should become familiar with a most important symbol for resistance (Fig. 3). You will encounter it constantly as you troubleshoot electronic products from schematic drawings. It is used to represent resistance rather than confusing pictures of intricate devices.

Figure 3 — Symbol for resistance.

Figure 4 shows how the resistance in the heating elements of a toaster appear when represented by symbols. This method of representation is much simpler than cutaway views or exploded drawings. Electronics has a distinct advantage over most technologies. Mechanics is such a small part that an entire television set may be represented intelligently through symbols in a page or two or drawings.

120 VOLTS

Perhaps we should at this time clarify "120 volts." You may be acquainted with tradesmen or other knowledgeable people who call it 110 or 115 volts. More recently it has been popularly known as 117 volts.

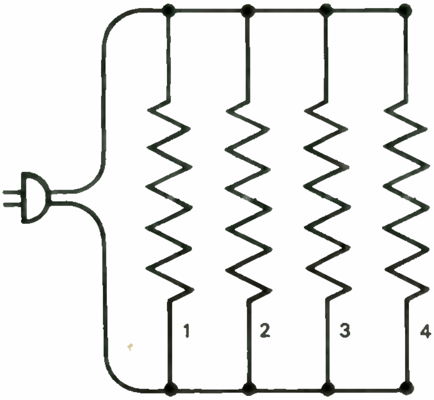


Figure 4 — Schematic representation of a toaster's heating elements using resistance symbols.

Electric power is distributed to a point near your home by high voltage lines in several thousand volts. It is reduced by a transformer and routed to your home at approximately 120 volts. Two sources of 120 are available which may be combined to provide 240 volts to power electric ranges, water heaters, electric heating systems or air conditioners.

NOTE: *Older homes in some areas may have only one source of 120.*

You would rarely measure precisely 120 volts at an outlet. Over a period of time, it would probably range from a temporary low of 110 to a momentary high of 130 volts. The normal range is between 115 to 125 volts. Home appliances are rated for power demands at 120 volts but can generally operate satisfactorily at voltages as low as 110.

A voltage of 120 became standard only after numerous other values had been tried. Early power companies covered small areas and weren't concerned with what neighboring companies were doing. Much of the generating equipment was custom made; therefore, companies selected their facilities according to their own particular needs.

As people became dependent upon electricity, huge grids or systems for power distribution developed. A dozen or more companies now frequently tie into one line and together supply power to millions of people, their homes and their industries.

To make it possible for many generators to connect to the same distribution line, all must share common characteristics. When universal standards were adopted, 120 volts was agreed upon as the standard for homes and certain other applications, such as lighting in factories and public buildings.

OHM'S FORMULAS

Suppose in your home you have an electrical outlet protected by a 15 ampere fuse; 120 volts is available at this outlet. The manufacturer's tag on a certain toaster states that it draws 6 amperes of current when 120 volts is applied. What is the hot resistance of the toaster's element? If you divide 120 volts by 6 amperes, you will find that this resistance is 20 ohms. Simply stated, *Ohm's resistance formula is:*

$$R = \frac{E}{I}\text{. Thus,}$$

$$\frac{120}{6} = 20 \text{ ohms (R), or}$$

$$\begin{array}{r} 20 \text{ ohms (R).} \\ 6\overline{)\ 120} \end{array}$$

Assume that you did not know the toaster's current requirements, but have determined that its heating elements measure 20-ohms resistance when heated. To determine the current flowing when operated from a 120-volt outlet, simply divide 120 volts by 20 ohms. *Ohm's current formula is:*

$$I = \frac{E}{R}$$

You have determined that this toaster draws only 6 amps and is safe to operate from your 15 amp circuit.

Should you not know from what voltage this toaster operates, it can be easily determined by applying *Ohm's voltage formula:* $E = I \times R$.

E is equal to 20 ohms multiplied by 6 amps,

$$\begin{array}{r} 20 \\ \times\ 6 \\ \hline 120 \end{array} \text{ volts or,}$$

$$6 \times 20 = 120 \text{ volts.}$$

ELECTRICAL POWER

When current is forced by a voltage to flow through a resistance, it is opposed by that resistance. Electrical energy is used to overcome resistance and results in the generation of other forms of energy. This principle is used extensively to produce heat from toasters, stoves, or other devices from which heat is desired. In the case of electric motors, electricity is used to produce rotary motion. From a TV set it produces sounds and a picture. Energy or power is measured in watts (named after the English inventor, James Watt) and is designated by the letter "P". Power "P" is directly related to Ohm's Law. It is the product of voltage (E) and current (I):

$$P = E \times I$$

NOTE: *Power in watts can also be represented by the letter "W".*

We determined from our study of Ohm's Law that a certain toaster operates from 120 volts and draws 6 amperes of current through its elements.

How many watts of power (P) are required to operate our appliance?

Using the power formula, we find that 120 volts (E) multiplied by 6 amps (I) results in 720 watts of power (P).

$$\begin{array}{r} 120 \\ \times\quad 6 \\ \hline 720 \end{array} \text{ or } 6 \times 120 = 720 \text{ Watts.}$$

$P = E \times I$ is the power formula when voltage and current are known.

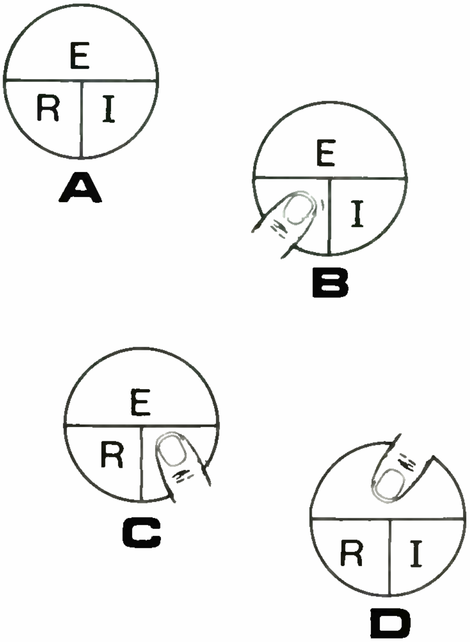


Figure 5 — A. Ohm's formula.
B. To find "R" cover "R" divide "E" by "I".
C. To find "I" cover "I" divide "E" by "R".
D. To find "E" cover "E" multiply "R" by "I".

It is possible to determine the current (I) through a device when voltage (E) and power (P) are known. In the case of our toaster, the manufacturer may state that it operates from 120 volts (E) and consumes 720 watts of power (P). To determine the current (I), we need only to divide 720 watts (P) by 120 volts (E):

I is equal to
$$\begin{array}{r} 6 \text{ amps} \\ 120\overline{)720} \end{array}$$

or

$$\frac{720}{120} = 6 \text{ amps.}$$

$I = \frac{P}{E}$ is the power formula for determining current when power (P) in watts and voltage (E) are known.

Test this formula. Use the power requirements stated on appliances or light bulbs in your home. You will find that a 75-watt 120-volt bulb draws 0.625 amps of current.

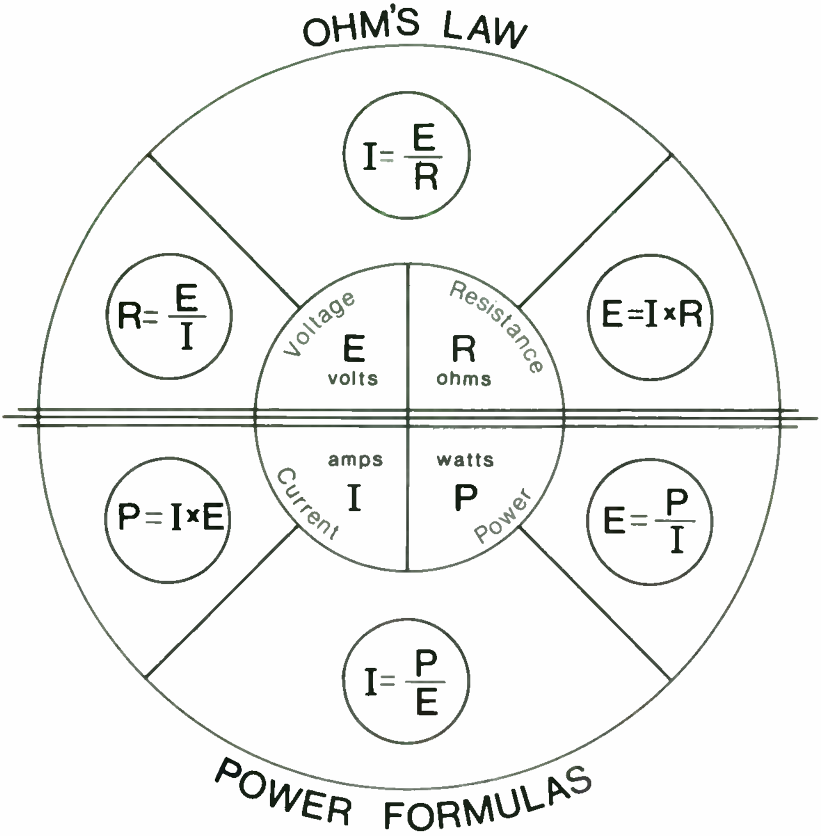


Figure 6 — Handy formula chart.

How much current does a 60-watt 120-volt bulb require? How much current does a 120-volt radio or TV set require? Divide watts (P) by volts (E) to find current (I).

Suppose you did not know the correct voltage from which your toaster should operate. If you learn that it uses 720 watts of power with 6 amps of current flowing, the correct voltage can be readily determined.

E is equal to 720 watts divided by 6, or

$$6\overline{)720}\quad \text{120 volts}$$

or

$$\frac{720}{6} = 120 \text{ volts.}$$

$E = \frac{P}{I}$ is the power formula for voltage when power (P) and current (I) are known.

KIRCHOFF'S VOLTAGE LAW

Ohm's Law is practical for solving simple circuits, but as circuits

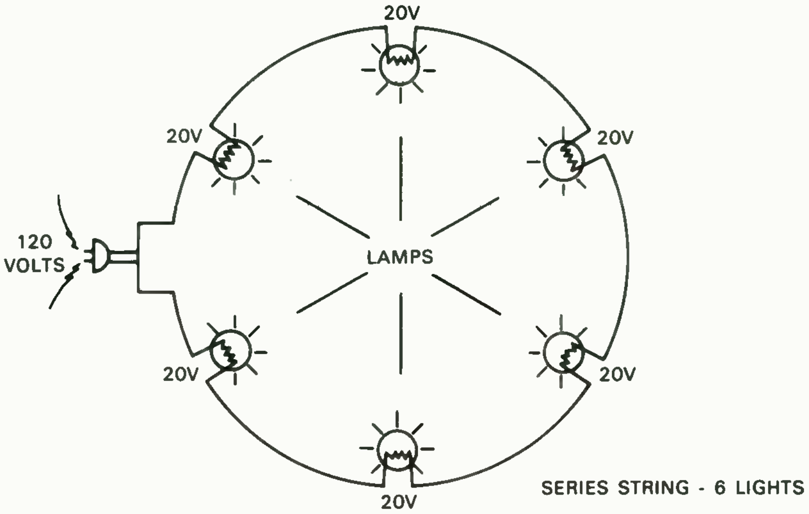


Figure 7 — Total voltage drops around a closed loop are equal to the applied voltage.

branch out, other formulas become necessary or more applicable. The 19th century scientist, Gustav Kirchoff, thoroughly explored the actions of voltage and current in electrical circuits. He established two laws which bear his name.

KIRCHOFF'S VOLTAGE LAW

The sum of all the voltage drops around any closed loop must be equal to the total voltage applied.

We shall now define a closed loop. As an example, visualize the fan belt of an automobile engine on which has been painted a large white mark. Idle the engine very slowly. Observe from this splotch how the belt travels as it leaves the crank pulley, moves around the alternator or generator pulley. Notice, too, how it then moves to and around the fan pulley and back to the source or crank pulley. Each part and particle of the belt has circled the entire system of pulleys. If we were able to tag and sufficiently enlarge a particle of electric current, and if we could see it trace through a series string of lights, we would notice how the action is similar to the mark on the belt (Fig. 7). Current flows from the power source, the wall receptacle, to and through the first bulb, the second, third, and so on until it eventually exits from the last lamp. From there it returns to the wall receptacle. In electronics this closed loop concept is called a series circuit. All of the current which enters the string leaves the circuit. The current that flows through the first bulb flows through each bulb in turn and arrives back at the outlet.

As current flows through our 120-volt series string of lights, the total voltage divides; therefore, a portion appears across each bulb which is called a voltage drop. If we

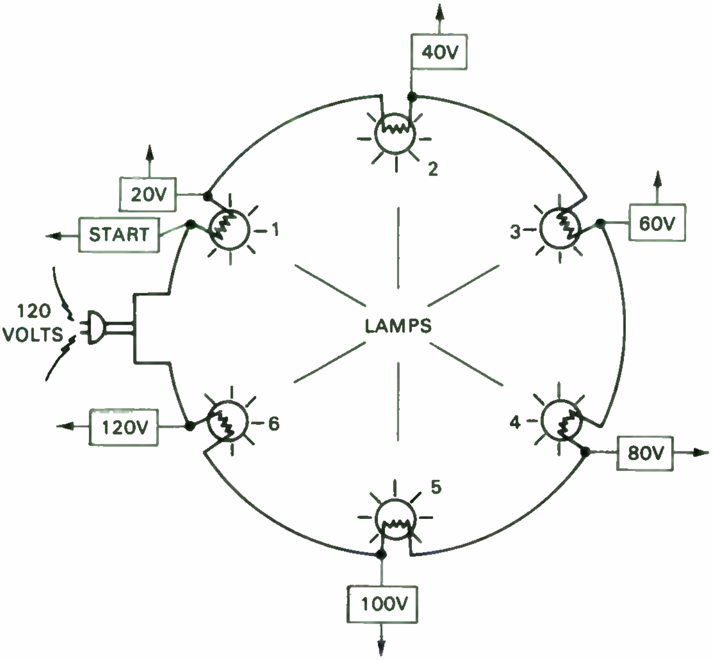


Figure 8 — Accumulation of voltage drops around a closed loop.

have a string of six identical 20-volt bulbs, they must, according to Kirchoff, total 120 volts, our applied voltage. Do they? Add them. (Fig. 7).

Figure 8 shows the accumulation of voltages around a closed loop or series circuit. Assume a clockwise direction for voltages beginning at Start. From Start to the opposite side of bulb 1 measures 20 volts; from Start to bulb 2 is 40 volts. If we continue around the series, we find that 20 volts is dropped by each bulb. From Start to bulb 6 is 120 volts, which is the same as measuring directly across the prongs of the power plug. In later lessons it will be explained how to determine voltage drops in circuits which have unlike components with differing resistance values. This knowledge will help you find shorted, open, and off-value components when troubleshooting electronic gear.

If we install a short across lamp 6 in our series, we remove the influence of its resistance from the circuit (Fig. 9).

The lamp will not light, and in effect we have removed it from the current path. Current now bypasses lamp 6, and the 20 volts which was formerly across it distributes equally among the remaining five.

We now have 24 volts dropped across each remaining bulb (Fig. 9). If Kirchoff's voltage law is correct, the total across these five lamps

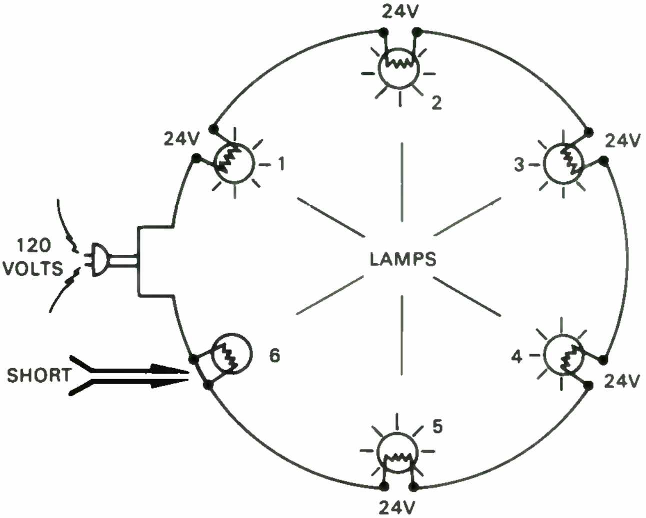


Figure 9 — Total voltage drops around a closed loop are equal to the applied voltage.

should be 120, the applied voltage. If you multiply 24 volts by 5 lamps, the product is 120 volts.

$$\begin{array}{r} 24 \\ \times\quad 5 \\ \hline 120 \end{array} \quad \text{or} \quad 5 \times 24 = 120 \text{ V.}$$

Since the resistance of one lamp has been replaced by a direct short, we have reduced the total amount of resistance in the loop. The applied voltage is still 120, but there is less opposition and more current will flow.

When for any reason the resistance in a series circuit becomes less, more current will flow, providing the applied voltage is not reduced.

Let us open the circuit and insert two additional lamps, 7 and 8 (Fig. 10). We have inserted additional resistance into the circuit. Less current will flow through the circuit due to the increased resistance. Less voltage will appear across each lamp, but the voltage drops still total 120 volts.

If for any reason resistance increases in a series circuit, less current will flow, providing the applied voltage is not increased.

In Figure 11 we have increased the source (applied voltage) to 240 volts, twice its previous value. Increasing the source voltage causes more electrons to flow. When a greater amount of current (electrons) flows, more voltage is dropped across each resistance in the circuit.

Doubling the voltage causes twice as much current to flow, which results in two times the voltage drop across each resistance.

NOTE: *This can be proven by Ohm's Law, but we will leave the calculations for a later lesson.*

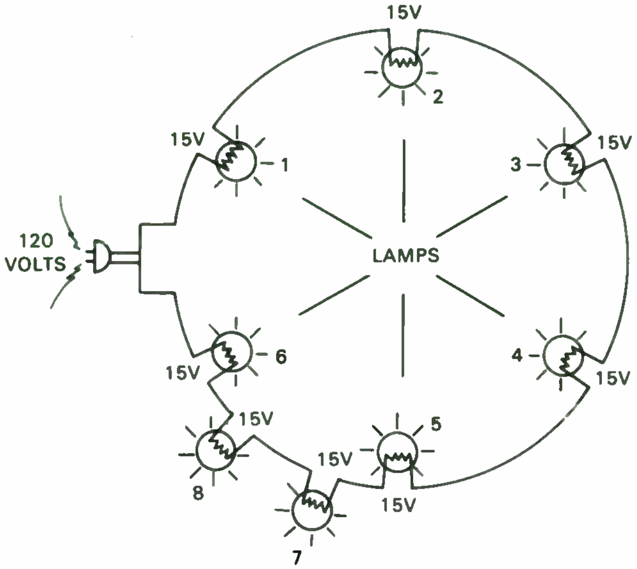


Figure 10 — Total voltage drops around a closed loop are equal to the applied voltage.

We now show 40 volts from Start to bulb 1, and as we progress clockwise (Fig. 11), an additional 40 volts is dropped across each lamp. Totaling the drops for six lamps results in 240 volts. This is correct according to Kirchoff's Law. The voltage drops equal the source, applied voltage.

When for any reason the source voltage to a series circuit is increased, current will increase and result in more voltage being

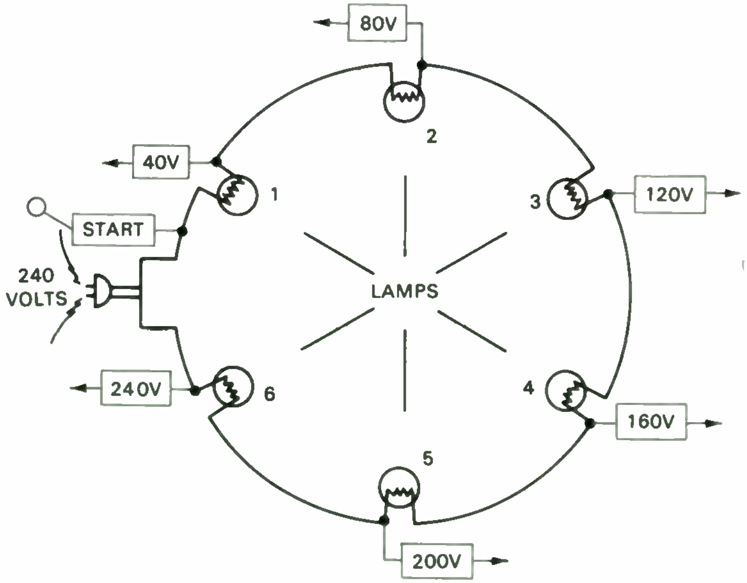


Figure 11 — Accumulation of voltage drops around a closed loop.

dropped across each resistance, providing the resistance is not increased.

KIRCHOFF'S CURRENT LAW

Kirchoff also proved that the same amount of current arrives at and leaves a junction or connecting point in a circuit. (Kirchoff's current law, unlike his voltage law, is not specified for a closed loop). Let us call our double wall outlet the junction point and plug into it two lamps, each of which has a 60-watt 120-volt bulb.

By using the power formula for current,

$$I = \frac{P}{E} = \quad \begin{array}{l} \quad\ .5 \text{ amps} \\ 120\overline{)60.0} \end{array} \quad \text{or}$$

$$\frac{60}{120} = .5 \text{ amps,}$$

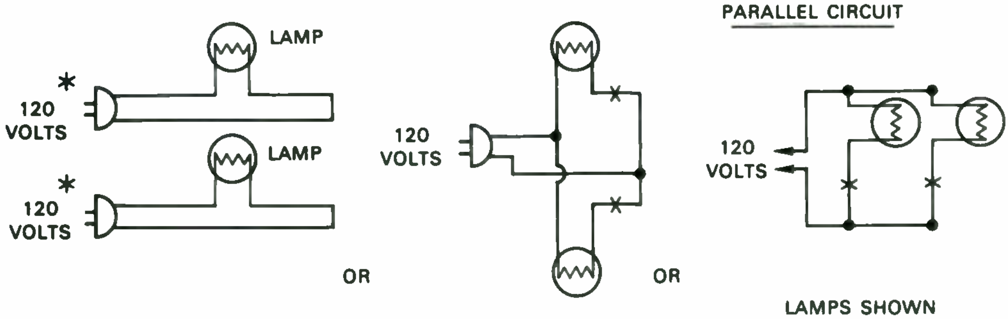
we discover that the current through each bulb is .5 or 1/2 amp. The two lamps are plugged in separately and operate independently. The same current does not flow through each lamp; therefore, the total current flowing from the outlet is .5 amps for one added to .5 amps for the other, or 1 amp. If you were to measure the current flowing into the outlet from the house wiring, you would find that it, too, equals 1 amp. This is correct according to Kirchoff's current law. The circuit described by the two lamps where each independently draws current from a source is called a parallel circuit (Fig. 12). Either lamp can be disconnected where indicated by an *(Fig. 12). The other will still burn. This is a general characteristic and requirement for parallel circuits.

The mathematics of Kirchoff's formulas will not be explored at this time. Although his laws are relatively simple, the formulas can be stated in many ways and would be of little value at this time.

SUMMARY

Because of their importance, we will repeat Ohm's formulas again before advancing to the next lesson.

$R = \frac{E}{I}$ is Ohm's formula for determining *ohms of resistance.*



TWO LAMPS - TWO PLUGS

TWO LAMPS - ONE PLUG

LAMPS SHOWN SCHEMATICALLY

Figure 12 — Representations of a parallel circuit.

$I = \frac{E}{R}$ is Ohm's formula for determining *amps of current.*

$E = I \times R$ is Ohm's formula for determining *volts of electromotive force.*

It is suggested that you return to this lesson and refresh your memory from time to time. Eventually, try to become so familiar with the formulas that you can recall them without effort.

TEST

Lesson Number 3

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-003-1.

1. Voltage (electromotive force) is designated by the letter
A. P.
B. R.
[✓ C. E.]
D. I.

2. Current in amperes is designated by the letter
A. P.
B. R.
C. E.
[✓ D. I.]

3. Resistance in ohms is designated by the letter
A. P.
[✓ B. R.]
C. E.
D. I.

4. Power in watts is designated by the letter
[✓ A. P.]
B. R.
C. E.
D. I.

5. When current flows, it is opposed by

A. power.
[✓ B. resistance.]
C. volts.
D. watts.

6. The electromotive force which causes current flow is measured in

A. ohms.
[✓ B. volts.]
C. amps.
D. watts.

7. The sum of all the voltage drops around any closed loop must be

A. greater than the applied voltage.
B. less than the total current.
[✓ C. equal to the total applied voltage.]
D. greater than the total current.

8. Power is consumed when electric current develops heat in a

[✓ A. resistance.]
B. voltage.
C. current.
D. power.

9. In a series circuit, if resistance remains the same and the applied voltage is increased,

A. voltage drops decrease.
B. less current flows.
C. current does not change.
[✓ D. more current flows.]

10. In a series circuit, if resistance remains the same but more current flows,

A. voltage drops decrease.
B. less power is used.
[✓ C. voltage drops increase.]
D. voltage drops remain the same.

Notes

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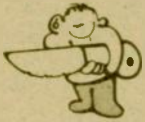


People Are Important

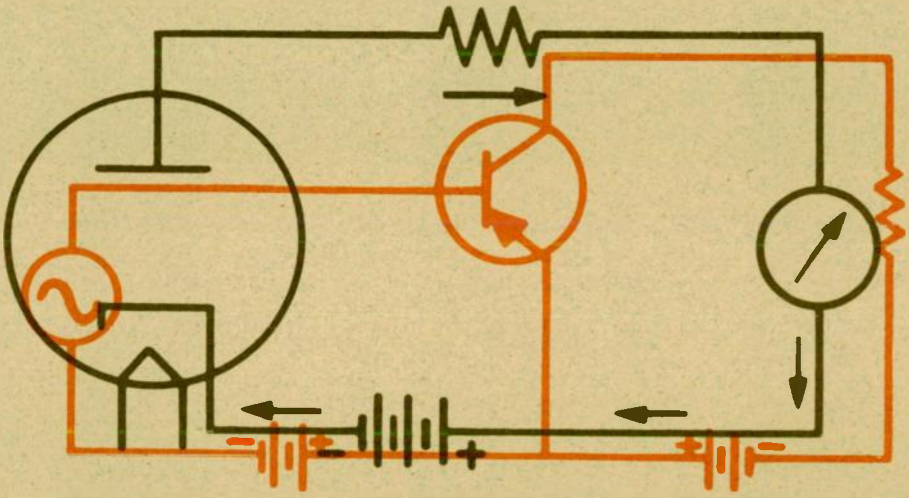
No matter how you slice it! In the business world of today it goes without saying that equality is the password of industry and commerce. Many people feel that they can treat their customers anyway they wish but these people are only hurting themselves and sometimes they unfortunately can hurt other people who have similar services to render to the public.

By and large, people want to be treated fairly and this feeling is only natural. It gives respect to their intelligence and it instills them with a sense of confidence. Yes, ASI hopes that through your course of studies you will learn your lesson material well but also we urge you to understand the importance of business ethics. Because no matter how you slice it, the customer comes first.

S. T. Christensen

LESSON NO. 4

MAGNETISM



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Contents

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MAGNETISM

INTRODUCTION TO MAGNETISM

Men have known about magnetism for many centuries, but little use was made of it for thousands of years. The only early practical use was its application to the operation of a crude compass.

Currently magnetic and electromagnetic devices have literally thousands of uses. *Relays* are switches which magnetically close or open when electric current flows. Operation of speakers in home entertainment devices, communications equipment and public address systems depend on the fields of fixed permanent magnets. An automatic washer drains because a powerful electromagnet pulls the plug. These are all direct applications of magnetic pulling power.

In addition, the principles of magnetism are used in many phases of electronics. Current or force fields in a solid-state semiconductor may be controlled by a magnetic field. Transformers and coils depend upon magnetic principles for their operation. Even radio waves are said to be forms of vibrating magnetic energy. In this lesson, we will explain magnetic theory according to the latest concepts and discuss its many forms.

NATURAL MAGNETS

The existence of magnetism has been known for more than 2000 years. Early Greeks discovered a stone now called magnetite which attracted iron. Later it was discovered that a piece of magnetite suspended from a string would align itself and point in a north-south direction. This was the first compass, and magnetite became known as lodestone, or translated, leading stone (Fig. 1).

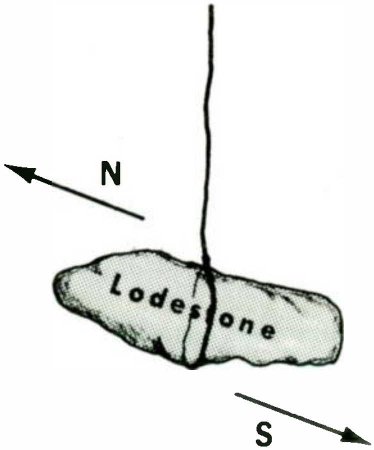


Figure 1 — Primitive Compass.

ARTIFICIAL MAGNETS

Figure 2A pictures a natural magnet which may be found in certain mineral deposits. These natural magnets contain natural magnetic elements. In their refined state, these metallic elements may be easily magnetized by artificial means. The magnet which results is called an artificial magnet (Fig. 2B). Iron is the most popular magnetic material from which artificial magnets are made. Cobalt and nickel may also be used.

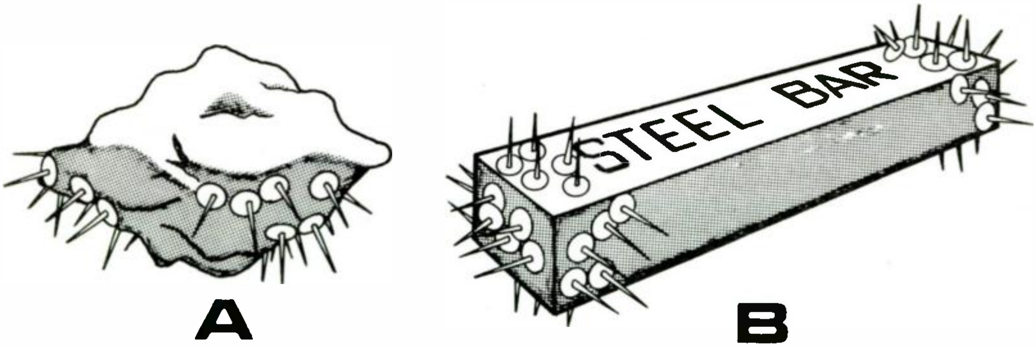


Figure 2 — A. Natural Magnet. B. Artificial Magnet.

Combinations of elements have been mixed to form even more powerful magnets. One of these compounds contains some aluminum, a non-magnetic material. For high speed work in communications and computers, powdered materials have become very popular. Minute particles of magnetic materials are held together by plastic materials or special adhesives and are molded into special shapes.

Magnetic fields can be easily induced into these materials and just as simply cancelled. Computers remember millions of bits of information by magnetizing cores constructed from this type material.

MAGNETIC POLARITY

The earth on which we live exhibits magnetic properties. Surrounding the earth is a magnetic field produced by the earth's magnetism. The magnetic polarities of the earth are indicated in Figure 3. Notice that the magnetic poles do not coincide with the geographic north and south. Early users of the magnetic compass regarded the end of the compass needle which pointed north as the north pole.

When it was discovered that the earth is a magnet and that opposite poles of magnets attract, it was necessary to call the geographic north pole the south magnetic pole. Likewise, the geographic south pole is called the north magnetic pole. Magnetic lines of force emanate from the magnetic north pole and return to magnetic south pole as closed loops (Fig. 3).

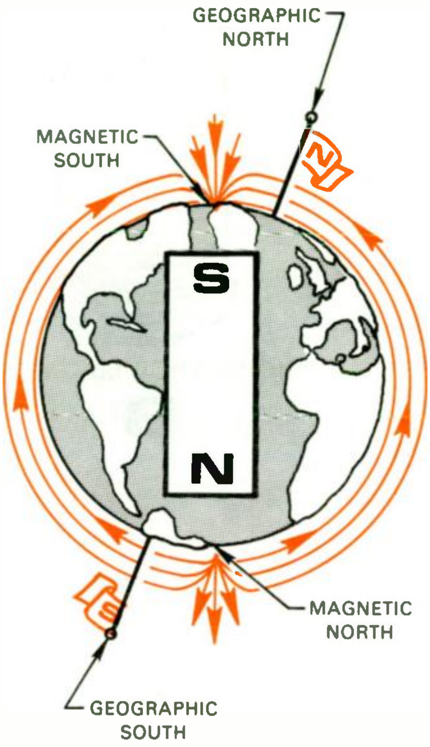


Figure 3 — The earth is a magnet.

NOTE: *To illustrate how magnets perform, we suggest that you purchase a pair of bar magnets. These may be obtained from most large department stores or your local variety store in the hardware, toy, or sewing departments.*

To understand how magnets affect each other, north-south polarities are assigned. Suspend a bar magnet from a string. The end which points north is called the north-seeking pole or north pole. The one which points south is the south-seeking pole or south pole. These are sometimes abbreviated "N" and "S" (Fig. 4).

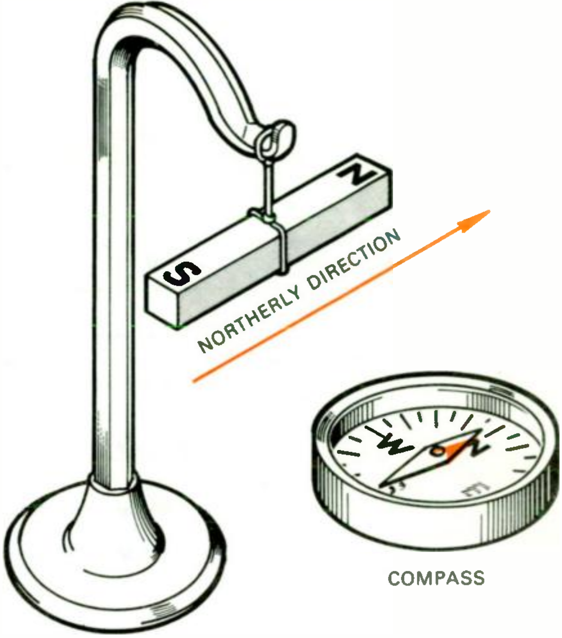
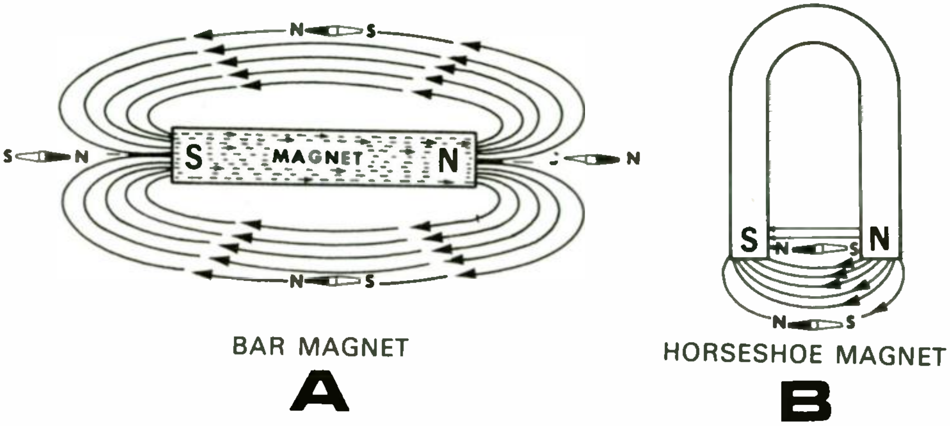


Figure 4 — A bar magnet acts as a compass.

MAGNETIC FIELDS AND LINES OF FORCE

Dip the ends of a bar magnet into a pile of iron filings. They will cling and form strings of iron particles end to end (Fig. 6).

Knowledgeable observers theorize that magnetic force is not solid or fluid, as early students thought. We now accept that the magnetic force is separated into invisible lines flowing from end to end and extending beyond the magnet's poles (Fig. 5A). If these lines were visible within the magnet, they would appear much like streams of fine sand drifting through a screen. From the ends of the magnet, they tend to curve toward the opposite pole (Fig. 5). These lines of force are called flux. The number of lines varies considerably with different magnets;



BAR MAGNET
A

HORSESHOE MAGNET
B

Figure 5 — Magnetic lines of force.

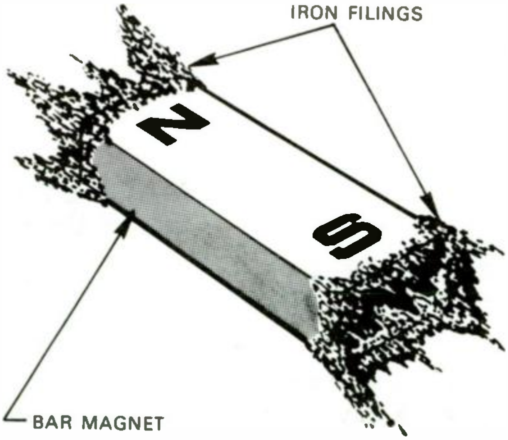


Figure 6 — Iron filings cling to the poles of a magnet.

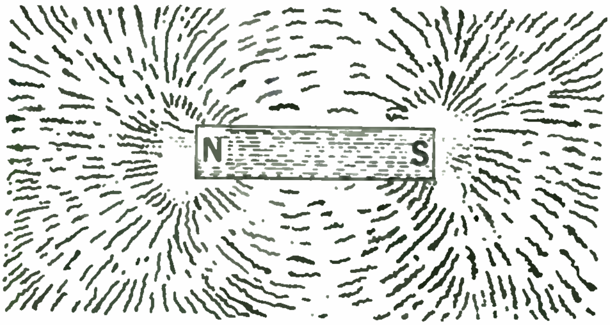
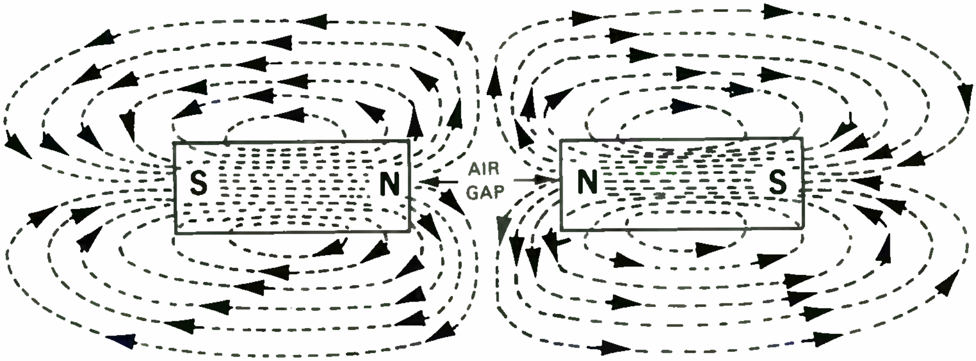


Figure 7 — Magnetic field pattern around a magnet.

fewer lines produce weaker magnets, more lines produce stronger ones. One line of force is called 1 *Maxwell* of force, and the strength of a magnetic field is measured in *Gausses.*

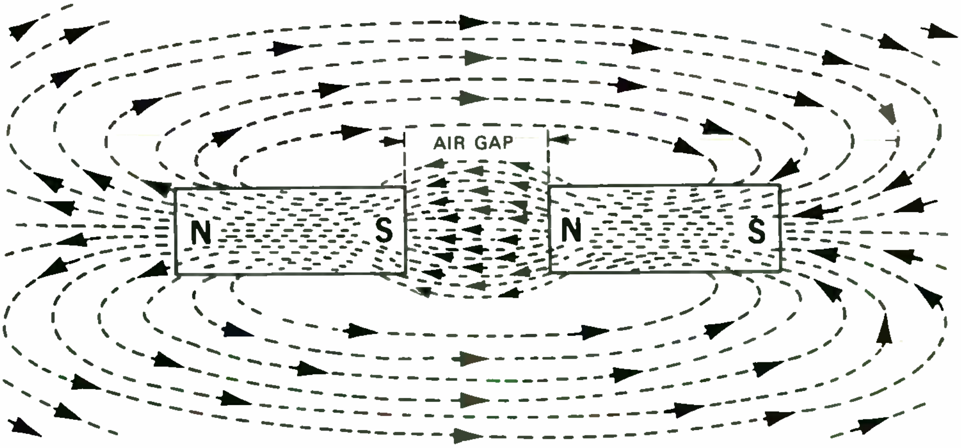
Individual magnetic lines of force cannot cross. When two lines from opposite poles meet, they combine and continue (Fig. 8B). If the two lines are from like poles, they reject each other and tend to curve away. Lines of the same polarity which reject each other exert a force against each other which is felt at the magnets (Fig. 8A). This is what we would feel should we attempt to press like poles of two magnets together. Lines from opposite poles which combine cause an attracting force to be felt on each magnet (Fig. 8B).



A

LINES OF FORCE

LIKE POLES REPEL



B

UNLIKE POLES ATTRACT

Figure 8 — Magnetic field interaction.

ATTRACTION AND REPULSION

When the ends of two magnets are in close proximity, they will either push away or attract each other (Fig. 8). If they push away or repel, reverse one magnet; they will now attract. Mark the pole on each magnet which attracts the other. Suspend the two magnets one at a time. One marked pole will point north, the other south. This illustrates the rule for magnetic interaction; that is, unlike poles attract —like poles repel.

THEORY OF MAGNETISM

Magnetism and electricity are related, but magnetic and electrostatic forces have no effect on each other when they are at rest. If either are in motion, interaction occurs. It is now believed that each electron is a sub-microscopic magnet (Fig. 9).

A magnetic field surrounds each electron (Fig. 9). This field consists of invisible lines of magnetic force which are strong near the electron and grow progressively weaker as they move away. As electrons revolve around the nucleus of an atom, they are constantly spinning. When two electrons close together spin in opposite directions, the magnetic fields repel and cancel each other (Fig. 10).

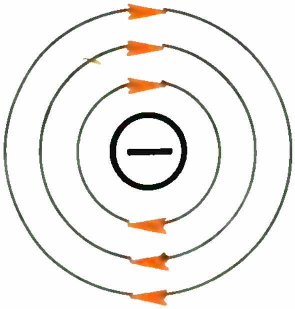


Figure 9 — A magnetic field surrounds an electron.

In a few metallic elements such as iron, cobalt, and nickel, adjacent electrons may spin in the same direction. In this case, the magnetic fields support each other and form larger, more powerful fields (Fig. 11).

In these metallic elements, many atoms combine to form individual molecular structures (Fig. 12A). The valence electrons which are shared by the atoms in this structure are believed to spin in the same direction. This causes their fields to combine throughout the molecule, and the entire molecule becomes surrounded by a magnetic field. These molecules have north and south poles and are actually magnets within the material, too small to be seen even with powerful microscopes (Fig. 12A). A bar of iron will be magnetic unless these magnetic molecules are haphazardly aligned (Fig. 12A). If they appear in random order (Fig. 12A-1), the bar will not be magnetic.

If you break a bar magnet into pieces, each piece will become a magnet (Fig. 12B). Each piece will have a north and a south pole. The polarities will be the same as the magnet from which they were broken (Fig. 12B).

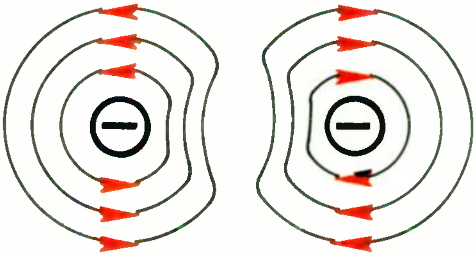


Figure 10 — Magnetic fields of electrons that spin in opposite directions repel.

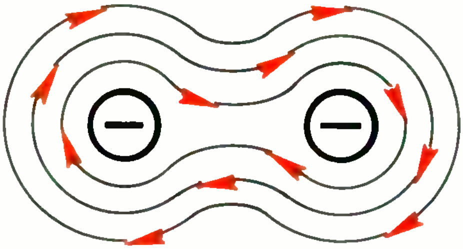


Figure 11 — Magnetic fields of electrons which spin in the same direction combine into a more powerful field.

TEMPORARY MAGNETS

In certain alloys of steel or other magnetic material, the molecules fail to remain pointed in one direction. This material can be magnetized but soon loses its properties. The molecules want to assume random directions. These are called temporary magnets and have numerous uses. One example is the huge electromagnets used by scrap yards to stack and load scrap iron. The magnetic properties remain as long as electric current is applied. To pick up a load, the crane operator closes a switch which sends electric current through the coils of wire surrounding a temporary magnetic core. Once he has the load positioned over a rail car or stack, he opens the switch. When the current ceases, the core loses its magnetism and the load drops; a magnet which depends on electricity to maintain its field is called an *electromagnet.*

RELUCTANCE

All material offers some opposition to the passing of magnetic lines of force (flux). The unit of measure for this property, reluctance, is the *rel.* If a high value of reluctance exists, few lines will flow, and the field will be weak. A low value of reluctance allows many lines to pass and results in a strong magnetic field. From this explanation of reluctance, it is evident that reluctance bears a resemblance to resistance in electrical circuits.

MAGNETOMOTIVE FORCE

There must be a force which causes flux lines to pass through a material. This force is called magnetomotive force and is measured in *gilberts* represented by "F". This force is similar to the electromotive force, voltage, which causes electric current to flow.

ELECTROMAGNETISM

A steel bar can be magnetized by stroking it in only one direction with a permanent magnet (Fig. 13B). Another method is to insert this steel bar into a coil of wire that is connected to a battery (Fig. 13A). Why? In 1819 Hans Oersted, a Danish physicist, discovered that a

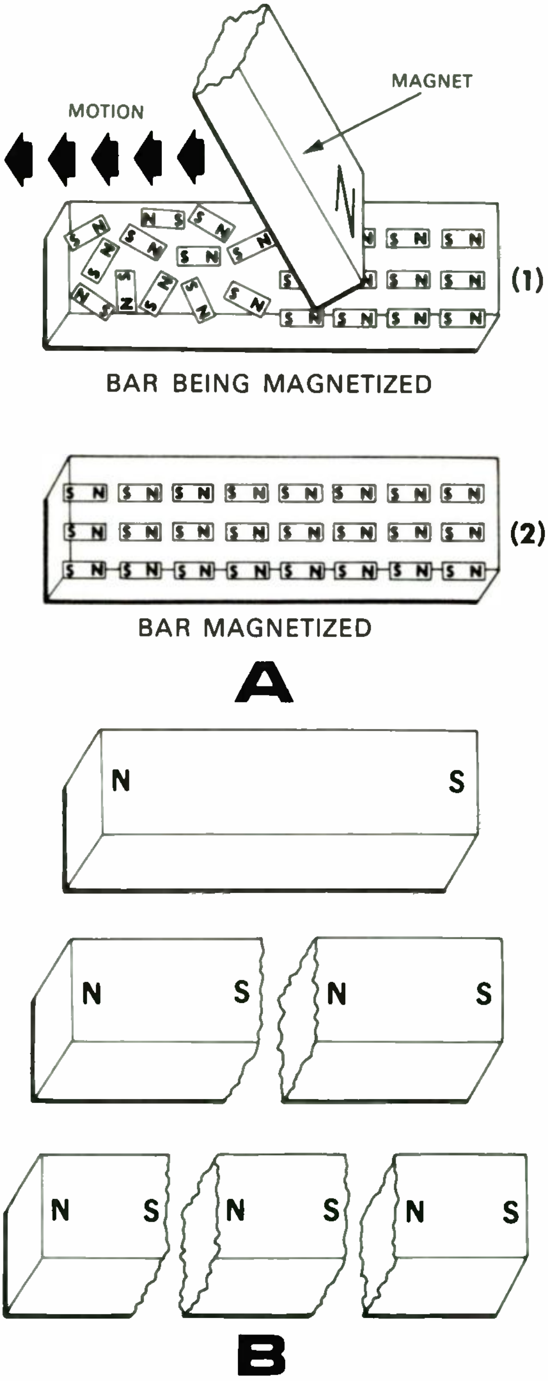
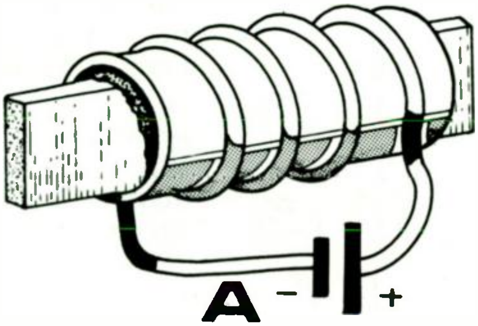
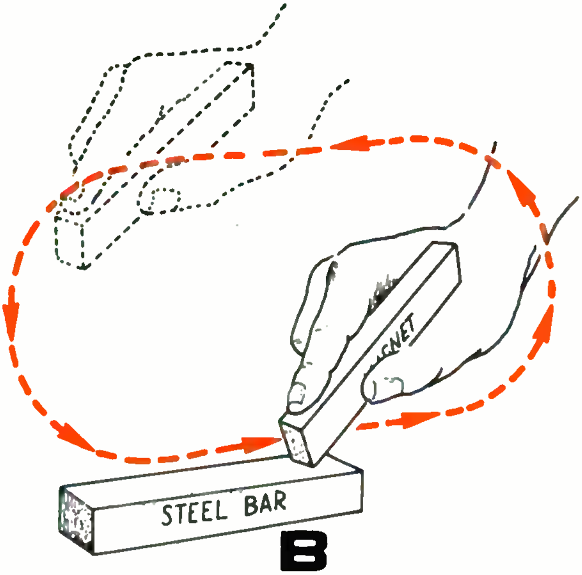


Figure 12 — A. Molecular magnets. B. Broken magnets.



A
COIL METHOD



B
STROKING METHOD

Figure 13 — Methods of producing artificial magnets.

definite relationship existed between magnetism and electricity. By experimenting, he discovered that a magnetic field existed around a current-carrying wire.

His conclusions were developed when he connected a battery to opposite ends of a wire and passed a compass completely around this wire. The needle of his compass always pointed in a direction which indicated the presence of a magnetic field around the wire (Fig. 14).

From his experiment he also detected a relationship which exists between direction of current flow and direction of magnetic lines of force. The direction these lines travel around the wire can be found by the "Left Hand Rule" (Fig. 15).

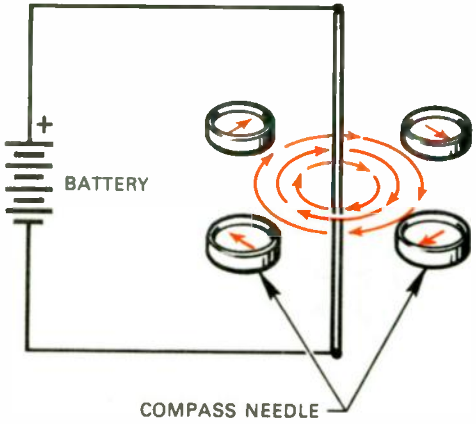


Figure 14 — Direction of a field around a current carrying wire.

The thumb points in the direction of the current flow, and the fingers point to the direction in which lines of flux travel.

Earlier in this lesson it was explained that valence electrons in non-magnetic materials normally pair off and spin in opposite directions. This is true for copper and many other conductors of electricity. You may wonder how copper can produce a magnetic field around it. When electric current flows, large quantities of free electrons move in the conductor. It is believed that when an electron moves from atom to atom, it is no longer paired with one spinning in the opposite direction. Instead it seems to rotate in the same direction. The lines of magnetic force from each electron are joined by lines from others and expand to encompass the wire.

If two current-carrying wires are placed side by side, the lines of flux interact and affect each other (Figs. 16 & 17). When the current flow is opposite, flux patterns oppose each other (Fig. 17). If one battery is reversed (Fig. 16), the lines combine to form a field which now encompasses both wires. Should

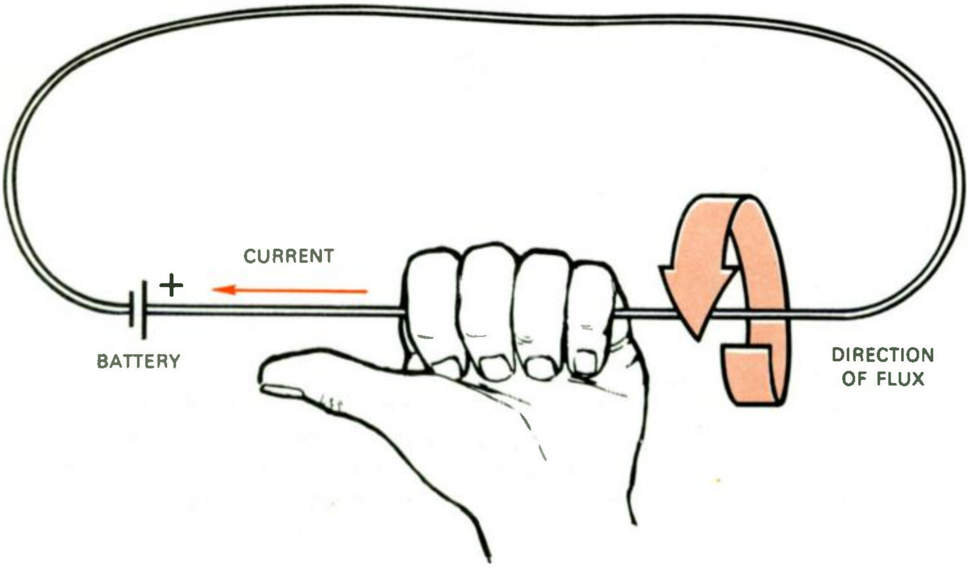


Figure 15 — Left hand rule for conductors.

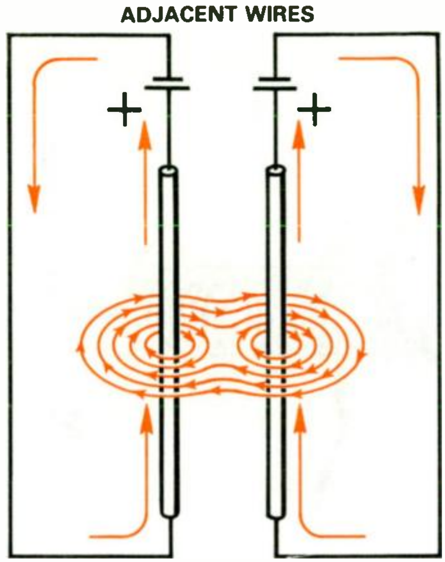


Figure 16 — A magnetic field around wires with currents flowing in the same direction.

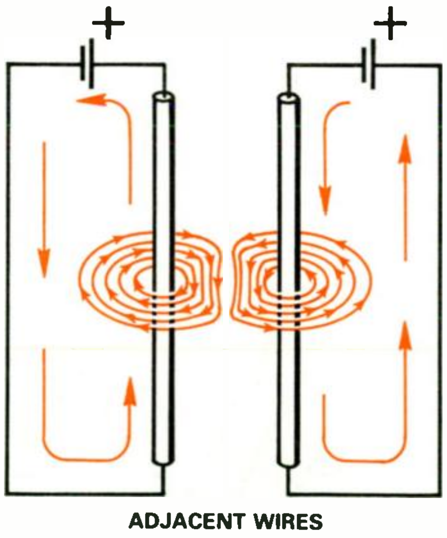


Figure 17 — The magnetic fields around wires with currents flowing in opposite directions.

you include additional conductors with the same polarity currents, the field will expand to encircle these also.

Compare the field produced from a coil of wire to that of a bar magnet (Fig. 18). Notice the similarity. Magnetically, the coil produces all the effects of the bar magnet. It can attract and hold other magnetic material, and when it is freely suspended, it will align in a north-south direction.

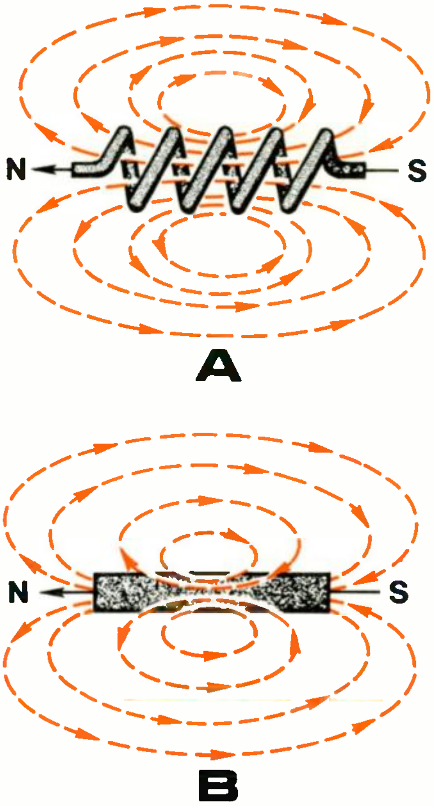


Figure 18 — A. Magnetic field around current conducting wire. B. Field surrounding a bar magnet.

The polarity of this magnetic field is related to the direction of current flow, again by a left hand rule (Fig. 19). This is known as the left hand rule for coils. If you know the direction of current flow

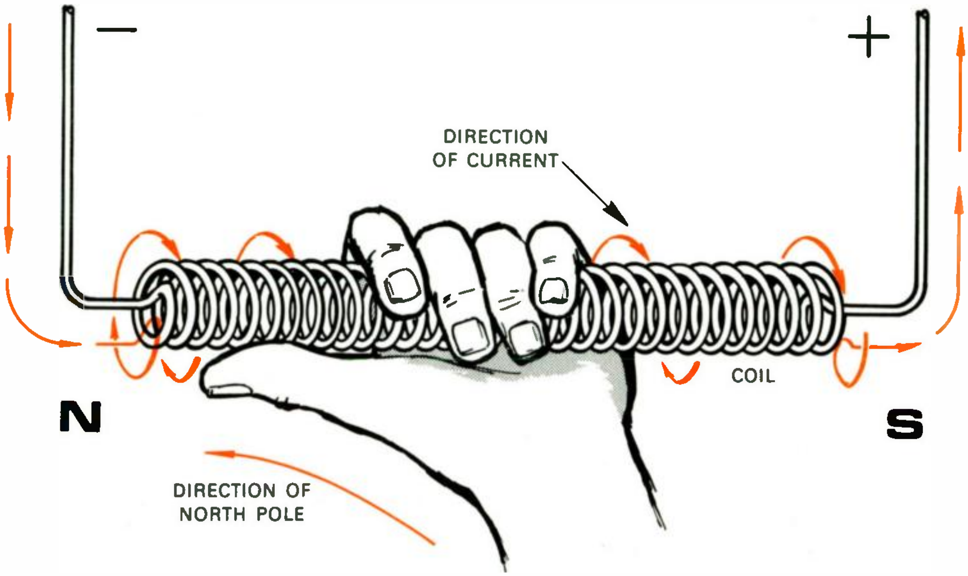


Figure 19 — Left hand rule for coils.

through a coil of wire, you can determine the polarity of the magnetic field. The left hand rule for coils states that if you wrap the fingers of your left hand around a coil so that the fingers point in the direction of current flow, the thumb will point to the north end of the magnetic field set up by the coil.

ELECTRIC CURRENT FROM MAGNETIC FIELDS

You have seen how magnetic fields are produced by electric current flowing through wire. We will now illustrate how current can be produced from a magnetic field. When a conductor of electricity is physically passed through a magnetic field, voltage is induced in the conductor, and current can be made to flow. Figure 20 illustrates the polarity of induced voltage and direction of current when a conductor is passed through the field of a magnet. Motion of the conductor through the magnetic field apparently causes the lines of force to

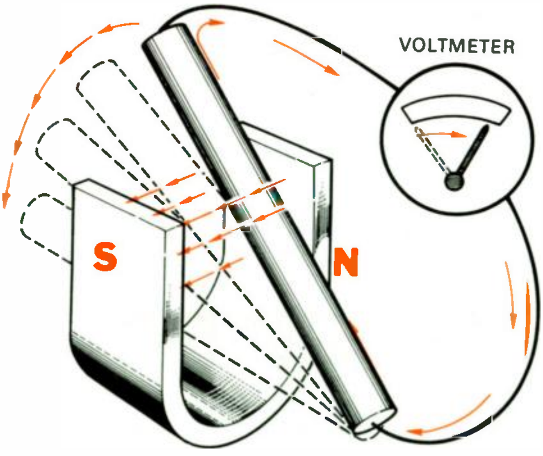


Figure 20 — The motion of conductor through a magnetic field induces a voltage.

react with lines surrounding free electrons. This interaction causes the electrons to spin in one direction and move toward one end of the conductor. The end toward which they move is determined by the direction which the conductor moves through the field. Reverse the direction, and current will flow in the opposite direction. This is the principle upon which generators and alternators operate.

Figure 21 pictures a basic DC generator. As the single loop (the armature) revolves between the poles (the stators), voltage is induced in the loop. Polarities of voltage and current reverse each half revolution as the loop changes its direction through the field.

A split ring commutator is included which also reverses after each half revolution. This keeps the current flowing from the generator in one direction.

Commercial and industrial generators are extremely complex devices. They are designed with many pole pairs and multi-pole armatures. Windings through which current flows are added to increase efficiency and provide control of output voltage, current, and power.

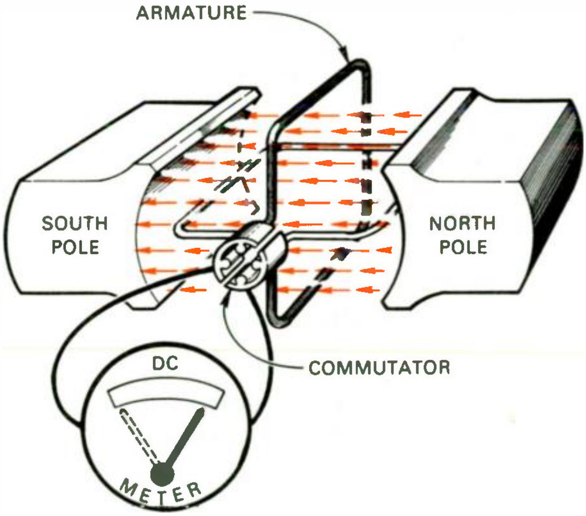


Figure 21 — A basic DC generator.

TEST

Lesson Number 4

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-004-1.

1. **A natural magnet**
   - A. is manufactured.
   - [✓ B. is found in nature.]
   - C. does not exist.
   - D. is composed of rubber.

2. **Three magnetic materials are**
   - A. copper, gold, and iron.
   - [✓ B. iron, nickel, and cobalt.]
   - C. rubber, steel, and glass.
   - D. silver, glass, and air.

3. **Pure aluminum**
   - A. is magnetic.
   - [✓ B. is non-magnetic.]
   - C. is magnetic when hot.
   - D. is magnetic when cold.

4. **The earth**
   - A. is not magnetic.
   - B. can be magnetic.
   - [✓ C. is magnetic.]
   - D. is sometimes magnetic.

5. The pole of a magnet which points north is called the
[✓ A.] north-seeking pole.
B. south-seeking pole.
C. neutral pole.
D. repelling pole.

6. A magnetic force field
A. is solid.
B. is fluid.
[✓ C.] can not be seen.
D. can be seen.

7. The strength of a magnetic field is measured in
A. volts.
B. ohms.
[✓ C.] gausses.
D. amperes.

8. The electron is
A. non-magnetic.
[✓ B.] magnetic.
C. neutral.
D. stationary.

9. If you break a bar magnet into pieces,
[✓ A.] each will be magnetic.
B. only one will be magnetic.
C. none will be magnetic.
D. both will be stronger.

10. Electromagnetism can be produced by
A. friction.
[✓ B.] electric current.
C. mechanical motion.
D. resistance.

Notes

Notes

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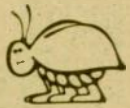


What Price Success

We don't mean to bug you, but...Do you want to be successful in your chosen field of endeavor? Hoping that the answer to this question is yes, how do you propose to reach that unreachable star?

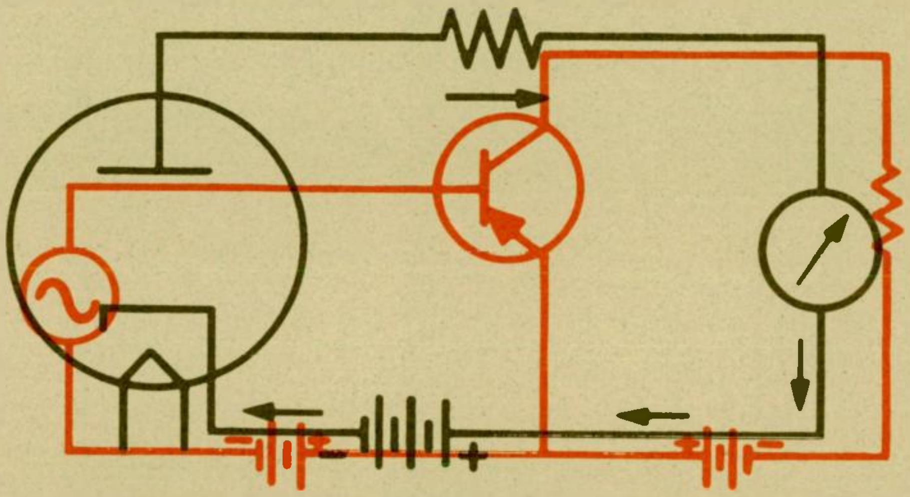
Everyone in the world has the potential for unlimited growth and the highest level of success. The challenge is to have the desire to attack this challenge and utilize this capacity to its fullest extent. Do not let your abilities go to waste.

As you continue with your ASI courses try to approach them as your newest and toughest opponent in your quest for success. Never lose your lust for knowledge; you and you alone hold the key to your success. Get started right now!

S. T. Christensen

LESSON NO. 5

REVIEW FILM OF LESSONS 1 THROUGH 4



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-005

406

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

Revised 6/73

Reprinted June 1974

REVIEW FILM TEST

Lesson Number 5

The ten questions enclosed are review questions of lessons 1, 2, 3, & 4 which you have just studied.

All ten are multiple choice questions, as in your regular lesson material.

Please rerun your Review Records and Film before answering these questions.

You will be graded on your answers, as in the written lessons.

REMEMBER: YOU MUST COMPLETE AND MAIL IN ALL TESTS IN THE PROPER SEQUENCE IN ORDER FOR US TO SHIP YOUR KITS.

REVIEW FILM TEST

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-005-1.

1. If two resin rods are rubbed with the same material, they will
   A. attract each other.
   [✓ B.] repel each other.
   C. always point north.
   D. become magnets.

2. An electron is
   A. a positive particle.
   [✓ B.] a negative particle.
   C. an atom.
   D. part of a nucleus.

3. A free electron is
   A. an electron without a charge.
   [✓ B.] an electron that drifts from atom to atom.
   C. a liquid.
   D. a material discovered by Greeks.

4. When electrons are moved through a wire in only one direction, we have
   A. a positive charge.
   B. a negative charge.
   C. a lodestone.
   [✓ D.] an electric current.

5. In Ohm's Law, the letter used to represent voltage is
A. I.
B. V.
C. R.
[✓ D. E.]

6. In Ohm's Law, the letter used to designate current is
[✓ A. I.]
B. C.
C. R.
D. E.

7. In Ohm's Law, the letter used to designate resistance is
A. E.
B. V.
[✓ C. R.]
D. I.

8. Power is generally expressed in
A. amperes.
B. ohms.
[✓ C. watts.]
D. volts.

9. Lodestones
A. are electrons.
[✓ B. act like magnets.]
C. are battery operated.
D. were discovered by Ben Franklin.

10. Magnets always point
[✓ A. North/South.]
B. East/West.
C. up/down.
D. to the center of the earth.

Notes

Test 1-5 12/29/74

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Organize Your Efforts (Stop, Look, and Perform)

We'd like to light your fire! So listen. In order for anyone to be effective in their work it is of the utmost importance to have what we like to refer to as "our game plan".

Before tackling your problem allow yourself to step back, take a deep breath and find the logical starting point. In relation to your position as a home study student you, more than we, must show a strong ability toward organization.

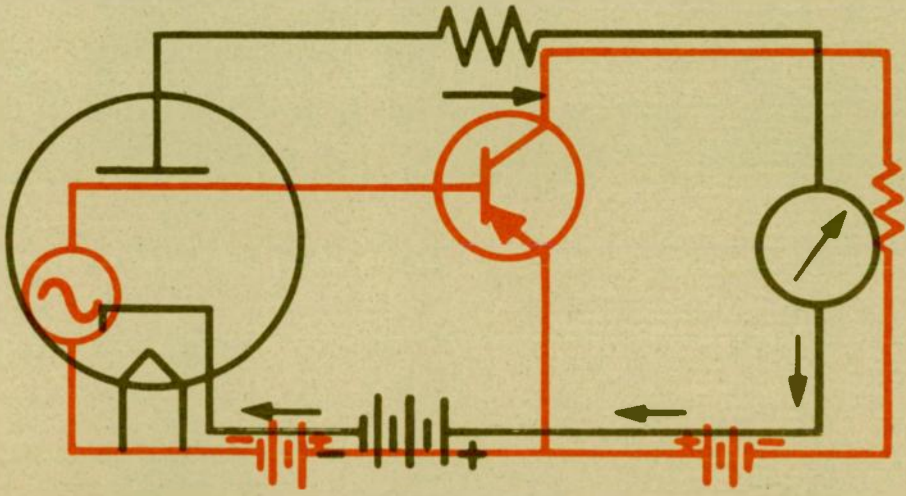
As you begin your assignment try and use these three concepts to improve your academic performance: 1. seek important information, 2. organize this information into a logical and understandable structure, and 3. use this information to answer your questions.

Constant review with this procedure will definitely help you improve your position in the home study field; and also serve as a guideline for future understanding of electronics today and tomorrow.

S. T. Christensen

LESSON NO. 6

CELLS AND BATTERIES



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-006
406

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Contents

52-006

CELLS AND BATTERIES

INTRODUCTION

An electric cell is broadly defined as a device which produces electrical energy from something other than mechanical motion. The most common type of electric cell uses chemical action, but heat, light and pressure can also provoke electrons and cause them to move.

A cell is one single source of voltage and electric current. Batteries contain more than one cell arranged to produce higher voltages or greater amounts of current. Several dry cells and dry cell batteries are shown in Figure 1.

The development and use of batteries somewhat parallels the rapid growth of electronics~~,~~ excluding a period of time shortly after electronics had its beginning. Early radios were powered mostly from lead-acid storage batteries with the higher voltage potentials coming from dry cell batteries.

When electric power became commonly available, power packs replaced batteries and new radios were designed to operate from ordinary house current. Battery operated portable radios existed, but they contained vacuum tubes which required considerable current to operate their filaments. Because of this high power requirement, battery life was short and they were not exceptionally popular.

In 1948 Bell Telephone Laboratories announced the results of studies and experiments by a special research group. The product of this research, the transistor, was soon to revolutionize the entire electronics field.

Soon afterwards in about 1953, battery powered portable radios were available from leading radio manufacturers. Completely portable record players, tape recorders and TVs followed. With the sudden increase in demand for batteries to power these devices, manufacturers were pressured to fulfill this need. Battery makers then began earnestly to update their products for this fast changing technology.

Longlasting mercury batteries were soon available, followed by other long life types. As more versatile batteries became available, electronics manufactuers designed, developed, and marketed whole

Figure 1 — Various types of dry cells. At the bottom are shown three Mercury Cells of different sizes. Mercury cells are dry cells in which the energizer consists of mercury.

new generations of compact portable equipment.

In addition to entertainment, battery powered products now serve thousands of seriously afflicted persons. Subminiature hearing aids bring sounds to partially deaf people, and some day it will be possible for blind persons to regain sight. A device which is currently in the laboratory stage traces images on patches of sensitive skin. A blind person need only be trained to respond in order to gain a second sight. Thousands of heart patients owe their life to a tiny battery powered device. It develops signals which are routed to an impaired heart to keep it beating. Some of these devices (battery included) are buried deep in the human body; the battery is recharged inductively without direct connection to the charging source.

Little of this is possible without the use of the transistor. Nor could it some day be a reality without modern batteries.

ELECTRIC CELL ELEMENTS

Chemical electric cells consist of three basic parts.

1. **Electrodes** are in the form of carbon or metal strips, blocks, plates or rods. These electrodes, also called plates, gather positive and negative charges and make them available at terminals. Each cell consists of a positive terminal connected to one or more positive electrodes and a negative terminal connected to one or more negative electrodes.

2. **Electrolyte** is a solution in which the electrodes (plates) are immersed. Two common forms of electrolyte are a liquid and a moist paste. Active chemicals are salt, acid or alkaline solutions. Two distinct types of cells exist with two different chemical actions. In one type of cell, chemicals corrode or etch a material which releases large quantities of electrons that gather at the negative terminal. The electrolyte serves two purposes; it is both an active agent and a conductive path within the cell. The second type of cell confines all chemical action to the electrodes. The solution does not act on the plates; it serves only as a conductor of electric current within the cell.

In the familiar automobile storage battery, electrolyte is a liquid solution of water with acid. Popular dry cells (Leclanche) contain an alkaline electrolyte in the form of a wet paste (Fig. 2).

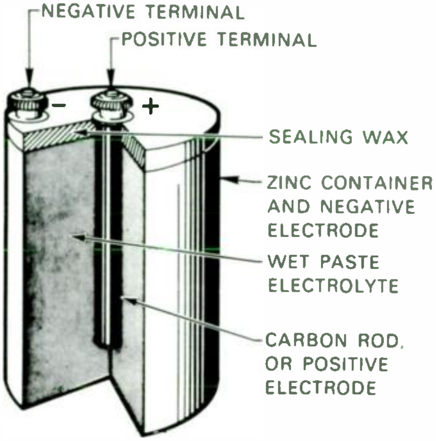


Figure 2 — Internal arrangement of a Leclanche dry cell.

3. **A container** is used to house the chemicals and other parts of a cell. Case forms vary widely among different manufacturers and for different type cells. They are made from many substances such as glass, metal, plastic, etc. In the popular Leclanche dry cell, a zinc container also serves as the negative electrode (Fig. 2).

CHEMICAL ELECTRIC CELLS

Figure 3 pictures a simple voltaic or galvanic cell. An acid etches or corrodes the surface of a material and releases large quantities of electrons which are free to flow. They tend to congregate at the negative electrode which is the plate. This particular cell consists of a sheet or block of metallic zinc and one of carbon; both are immersed in a liquid solution of water with sulphuric acid. The water-acid solution is the electrolyte; the zinc and carbon pieces are the electrodes (plates). A surplus of electrons becomes available at the zinc electrode, charging it negative. The carbon with an absence of electrons is charged positive. This results in a voltage or a difference of potential between the positive and the negative electrodes.

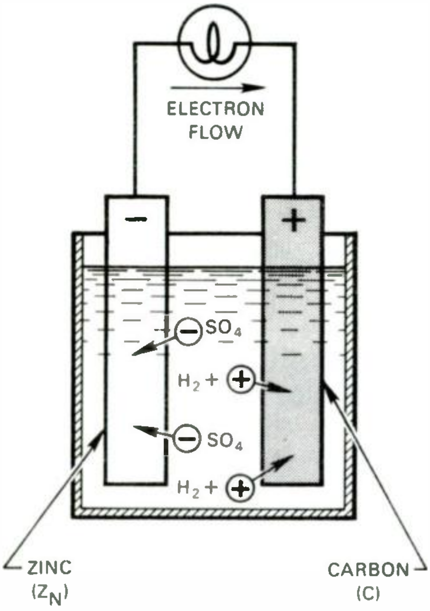


Figure 3 — A simple voltaic cell.

THE BATTERY CIRCUIT

A battery circuit includes some type of battery or cell and a load which is external to the battery.

NOTE: Electrically speaking, a load is anything which takes current from a power source.

Figure 3 pictures a battery circuit consisting of a single voltaic cell and an externally connected lamp. This circuit is shown schematically in Figure 4 using symbols. Switches and parallel or series connected resistances are often included in battery circuits.

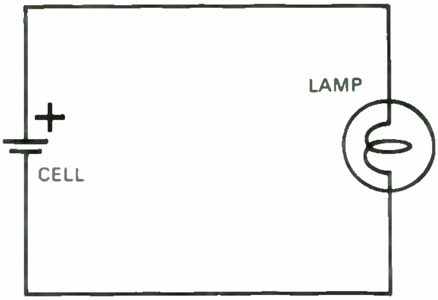


Figure 4 — A complete circuit shown schematically.

With a light bulb connected between the two electrodes of a voltaic cell (Fig. 3), current will flow from the negative(−) zinc electrode through the bulb to the positive (+) carbon electrode. From the positive (+) electrode, they enter the electrolyte and drift back to the zinc electrode. Zinc is etched by the electrolyte causing atoms of zinc to enter the solution. Hydrogen gas escapes to make room for them, and new chemical compounds are formed in the electrolyte when sulphur, zinc, oxygen, and hydrogen combine. Eventually the negative electrode is either completely dissolved, or the solution contains all the zinc compounds it can hold. At this time chemical action ceases, as does the current. To restore action, the zinc electrode and the electrolyte must be replaced.

The cell described, voltaic or galvanic, has little practical value beyond the laboratory. It is used to describe basically how electrical energy may be generated from chemical action.

INTERNAL RESISTANCE

When new, galvanic cells develop approximately 1.5 volts with small amounts of current flowing. Increase the current, and portions of the 1.5 volts appears across resistance within the electrodes and electrolyte. As more current flows, progressively more voltage is wasted within the cell, and less is available across the terminals. These voltage drops within the cell are due to internal resistance, which limits the amount of current that any cell can deliver to a load.

PRIMARY CELLS

The voltaic cell described (Fig. 3) may be identified with a group called primary cells. Common flashlight and transistor radio batteries belong in this group. Primary cells depend on chemical destruction of an electrode for their operation and are not normally rechargeable. They are considered to be disposable and require replacement when electrode material is exhausted.

SECONDARY CELLS

Secondary cells are those which are rechargeable; auto storage batteries are an example. Electrodes in secondary storage cells are grid-like structures of chemically stable metals. These are coated with chemicals which either react with each other or are transferred through the electrolyte to the opposite plate.

Secondary cells can be repeatedly recharged by forcing current through them in a reverse direction. These cells or batteries have been particularly useful for powering mobile gear where a generator or alternator is available to keep them charged. Smaller sealed versions of some types are frequently used to power portable equipment, lights, shavers, radios, TVs, etc. They can be easily rejuvenated from ordinary house current in simple low cost chargers.

BATTERY CHEMISTRY

If a conductor is connected externally to the electrodes of a voltaic cell, electrons are forced to flow because of the difference in potential between plates. Current will flow from the negative plate through the external conductor to the positive plate, returning within the solution to the negative electrode. After a short period of time, a burning-like action begins to occur. Chemicals actually burn electrode material much like oxygen consumes fuel. A chemical cell is similar to a furnace, but the energy released is electrical instead of heat.

The voltage across the electrodes depends upon the materials from which the electrodes are made and the type of electrolyte used. For example, the difference of potential between carbon and zinc electrodes in a diluted solution of sulfuric acid and water is about 1.5 volts.

The current that a cell delivers is dependent upon the resistance of the entire circuit, including the resistance within the cells elements. Internal resistance is determined by the size of the electrodes, the distance between them in the solution, and their resistance. The larger the electrodes and the closer together they are, the lower the internal resistance and the more current the cell can deliver.

When current flows in a galvanic cell (Fig. 3), zinc gradually dissolves into the solution causing acid to be neutralized. A chemical equation is sometimes used to show the action that takes place. Symbols represent the different materials that are used (C for carbon, Zn for Zinc, etc.). As stated previously in Lesson 2, all matter is composed of atoms and molecules, with the atom being the smallest divisible part of an element and the molecule the smallest divisible part of a compound.

A compound is a chemical combination of two or more elements in which the physical properties of the compound are different from those of each element. For instance, a molecule of water (H_2O) is composed of two atoms of hydrogen (H_2) and one atom of oxygen (O). Ordinarily, hydrogen and oxygen are gases, but when combined, they form water which is normally a liquid. Sulfuric acid (H_2SO_4) and water (H_2O) form a mixture, not a compound. The identity of both liquids is preserved; they are merely mixed, not chemically combined. The acid molecules fill spaces between water molecules.

Current flow from a primary cell of carbon and zinc electrodes (in a diluted solution of sulfuric acid) results in a chemical reaction that can be expressed as:

$$Zn + H_2SO_4 + H_2O \xrightarrow[\text{discharge}]{} ZnSO_4 + H_2O + H_2\uparrow$$

NOTE: A gas is designated by an arrow pointing upward.

The expression indicates that as current flows, a molecule of zinc combines with a molecule of sulfuric acid to form zinc sulfate ($ZnSO_4$) and hydrogen (H_2). The zinc sulfate dissolves in the solution, and hydrogen gas appears as bubbles around the carbon electrode. As current continues to flow, zinc is gradually consumed, and the solution changes to zinc sulfate and water. The carbon electrode does not enter into the chemical changes, but simply provides a continuous path for the current.

In the process, positive and negative ions form in the solution and move in opposite directions. Positive ions are hydrogen atoms that are minus an electron. These positive ions attach themselves to the positive electrode, attracted by the negative charge of returning electrons. The negative ions are SO_4 which form zinc sulfate ($ZnSO_4$), a grayish-white substance that dissolves in water. While positive and negative ions are moving in opposite directions (through the electrolyte) electrons are moving from the negative zinc terminal through the load and back to the positive carbon terminal. When the zinc is used up, the voltage of the cell becomes almost zero.

POLARIZATION

The chemical action that occurs in a primary cell while current is flowing causes hydrogen bubbles to form. A few of these bubbles rise to the surface and escape, but most surround the positive electrode. This action is called polarization, and soon the entire surface of the positive electrode is covered with bubbles of hydrogen.

Hydrogen tends to set up an opposing force which acts against the cell's voltage to reduce the output current. A cell that is heavily polarized has no useful output. There are several ways, however, to prevent or overcome polarization after it has occurred. The accepted method is to combine a substance with the hydrogen which neutralizes its effect.

A commercial form of voltaic cell (the dry cell) employs a depolarizing substance rich in oxygen. Excess oxygen from this substance combines chemically with the hydrogen to form water (H_2O). A common depolarizing chemical used in dry cells is manganese dioxide (MnO_2). It supplies enough free oxygen to keep the cell virtually free from polarization. Thus, the reverse voltage of polarization does not exist, and the voltage and output current are reasonably constant.

LOCAL ACTION

When the load is disconnected from a cell or battery, current ceases to flow, and theoretically, all chemical action within the cell stops. In practice, this is not quite true, because commercial zinc contains many impurities, such as iron, carbon, lead, or arsenic. Impurities react within the zinc electrode to form minute batteries in which current flows between them and the zinc. Thus, the zinc is being consumed even though the cell itself is not in use. This wasting away of the zinc without useful current flowing is called local action. For example, a small local cell exists on a zinc plate containing impurities of iron, as shown in Figure 5. Electrons flow between the zinc and iron through the solution around the impurity. The negative SO_4 ions combine with the positive Zn ions to form $ZnSO_4$. Thus, the acid in the electrolyte becomes inactive and the zinc is consumed.

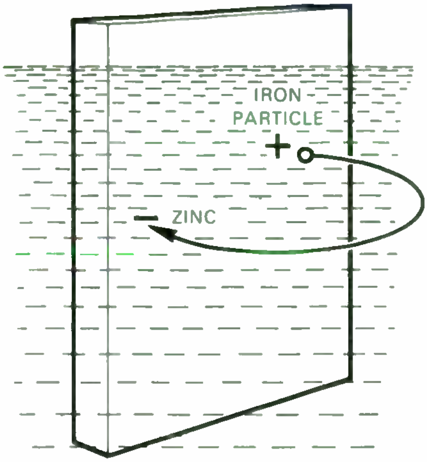


Figure 5 — Illustrates local action.

Local action may be prevented by using pure zinc (which is not practical), by coating the zinc with mercury, or by adding small amounts of mercury to the zinc during manufacture. Treating the zinc with mercury is called amalgamating or mixing. Since mercury is much heavier than water, small particles of light weight impurities float to the surface of the mercury. Removal of these impurities from the zinc prevents local action. The mercury is not readily acted upon by the acid; even when the cell is delivering current to a load, the mercury contributes a neutralizing effect on the impurities. This process greatly increases the life of a primary cell.

TYPES OF BATTERIES

The development of new batteries since the 1950's has been so rapid that it is virtually impossible to have a complete knowledge of all of the various types. A few recent types are silver-zinc, nickel-zinc, silver-cadmium, magnesium-magnesium perchlorate, mercury, thermal, and water-activated batteries.

The lead-acid battery has been in service for a relatively long period of time, but there are various alterations still being made to improve it. Although it does not include all types of batteries, this lesson provides the reader with a knowledge of various kinds.

DRY (PRIMARY) CELLS

The dry cell is so called, because its electrolyte is not in a liquid state. Actually, the electrolyte is in the form of a moist paste. If it should become dry, it would no longer be able to transform chemical energy into electrical energy. The name dry cell, therefore, is somewhat misleading and not entirely correct in a technical sense.

CONSTRUCTION OF THE DRY CELL

The construction of a common type of Leclanche dry cell is shown in Figure 6. The internal parts of the cell are located in a zinc container which also serves as the negative electrode. The container is lined with blotting paper which separates the zinc from the paste. A carbon electrode, located in the center, serves as the positive terminal. The paste is a mixture which may vary in composition between manufacturers. Generally, however, the paste contains some combination of the following substances: ammonium chloride (sal ammoniac), powdered coke, ground carbon, manganese dioxide, zinc chloride, graphite, and water.

This electrolyte is packed in the space between the carbon electrode and the container. Terminal posts are attached to the electrodes and project from the cell which permits easy attachment of wires. Prior to sealing with a disc of asphalt-saturated cardboard, a small expansion space is provided.

Since the zinc container is one of the electrodes, it must be protected with an insulating material. It is common practice for manufacturers to enclose these cells in cardboard containers. Some manufacturers use steel jackets insulated from the zinc as final enclosures.

CHEMICAL ACTION OF THE CELL

The dry cell (Fig. 6) is fundamentally the same as the simple voltaic cell (in this case, wet cell) described earlier, in relation to its internal chemical action. The action of water and ammonium chloride in the paste, together with the zinc and carbon electrodes, pro-

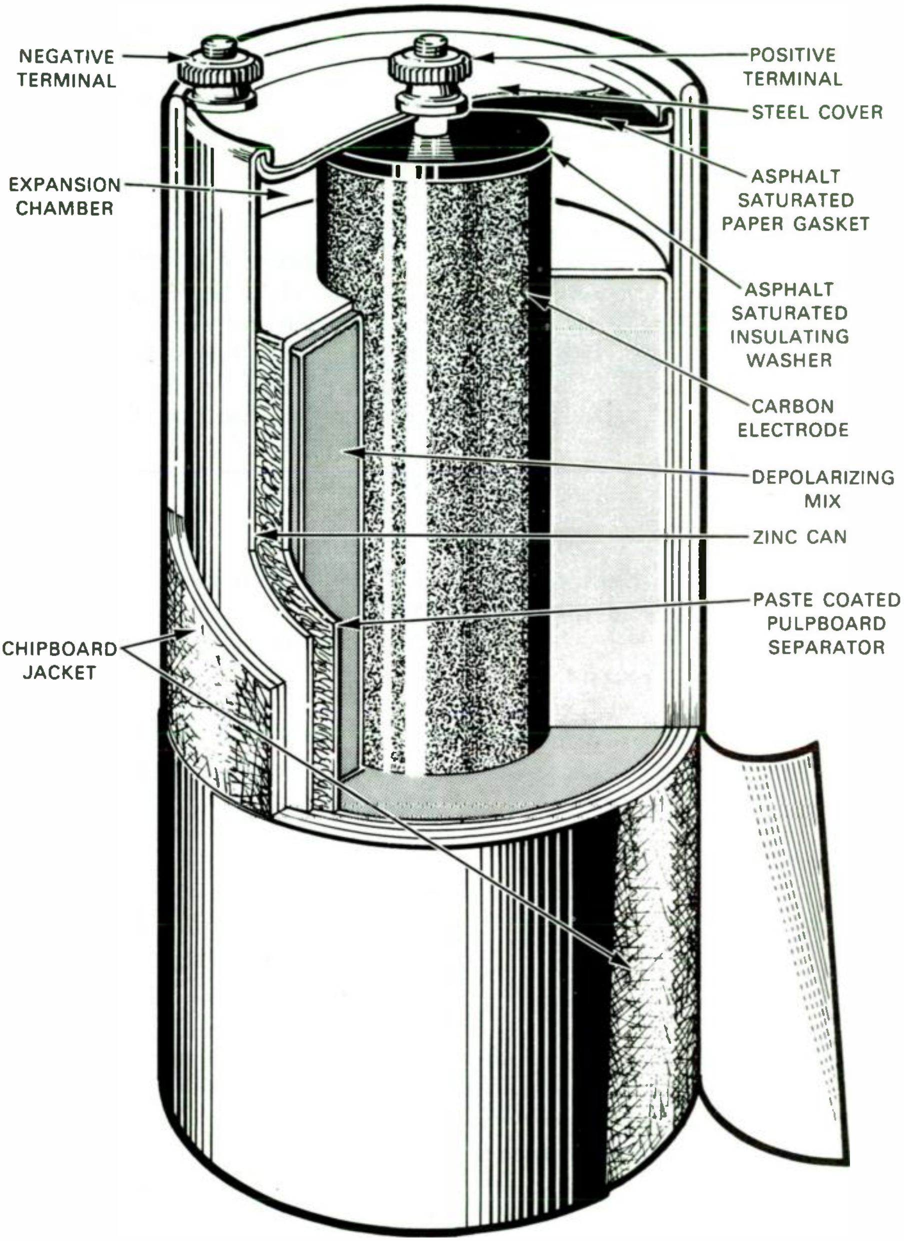


Figure 6 — Internal construction of a Leclanche dry cell.

duces voltage. Manganese dioxide is added to reduce polarization when current flows, and zinc chloride reduces local action when the cell is idle. The blotting paper, a paste-coated pulpboard separator, serves two purposes, one being to keep the paste from making contact with the zinc container, and the other being to permit moisture to slowly filter through the separator and act on the zinc. This type of cell is sealed at the top to prevent air from entering and drying the electrolyte.

Zinc chloride-Leclanche type dry cells have a number of detracting features:

1. Output voltage becomes lower through their life cycle due to increasing internal resistance.
2. They deteriorate somewhat during storage.
3. High temperatures reduce their useful life span.
4. They can supply only moderate amounts of current.

Despite these drawbacks, they still enjoy considerable popularity due to their low cost.

MERCURY CELLS

With the advent of the space program and the development of miniaturized equipment and small transceivers an appropriate power source was needed. Such equipment requires a small battery which is capable of delivering maximum electrical capacity while operating in varying temperatures, and at a constant voltage. The mercury battery, which is one of the smallest, meets these requirements.

Mercury batteries are manufactured in three basic structures. The wound anode mercury cell (Fig. 7A) has one plate composed of corrugated zinc faced with absorbent paper. The zinc is mixed with mercury, and the paper is soaked with the electrolyte causing it to swell and produce a contact pressure.

In the pressed powder cells (Figs. 7B and 7C), the zinc powder is mixed with mercury prior to being pressed into shape. Its sponge-like structure allows electrolyte to be absorbed so that it will act on large quantities of electrode surface when current is discharged.

Double can structures are generally used in larger cells. The space between the inner and outer containers provide passage for any gas generated by improper chemical balance or impurities present within the cell. Construction is such that, if excessive gas pressures are experienced, the compression of the upper part of the grommet by internal pressure allows gas to escape into the space between these two cans. A paper tube surrounds the inner can so that any liquid carried by discharging gas will be absorbed, maintaining a leak resistant structure. Release of unusually large amounts of gas automatically reseals the cell.

NOTE: Mercury batteries have been known to explode with considerable force when shorted. Caution should be exercised to prevent this from happening. **Do not** short the terminals of a mercury cell or battery.

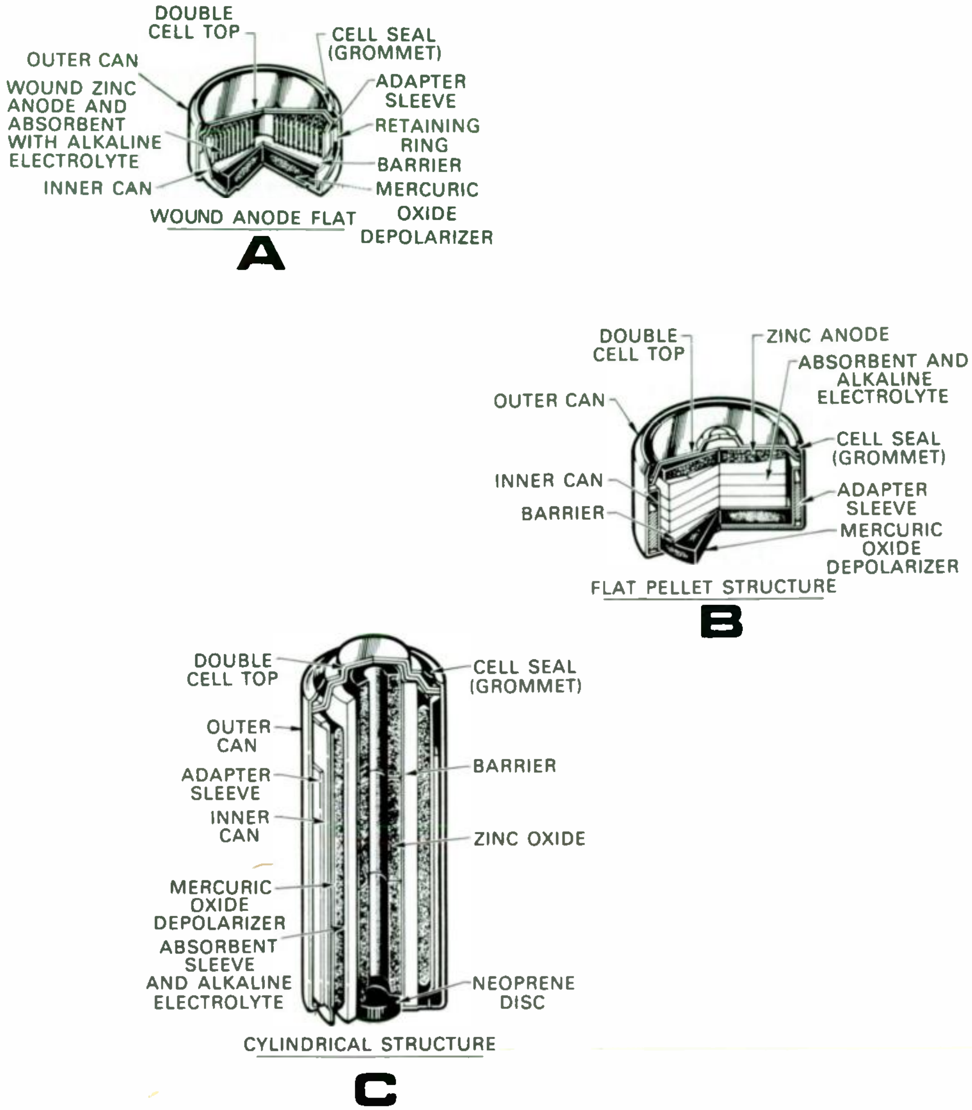


Figure 7 — Three types of mercury cells: A) wound anode type; B) flat pellet structure; C) cylindrical structure.

The overall chemical action by which mercury cells produce electricity is given by the following chemical formula:

$$Zn + H_2O + HgO \longrightarrow ZnO + H_2O + Hg$$

This action, the same as in other type cells, is a process whereby chemicals combine with oxygen. The alkaline electrolyte is in contact with the zinc electrode. Zinc oxidizes (Zn changes to ZnO), thus taking oxygen from water molecules in the electrolyte. This leaves positive hydrogen ions, which move toward the mercuric oxide pellet, causing polarization. These hydrogen ions take oxygen from the mercuric oxide, thus forming water. Where one molecule of water is destroyed at the negative electrode, one molecule is produced at the positive electrode, maintaining the net amount constant. By absorbing oxygen, the zinc electrode gathers excess electrons, making it negative. By giving up oxygen, the mercuric oxide electrode loses electrons, making it positive. When discharged, the negative electrode becomes zinc oxide, and the positive electrode becomes ordinary mercury.

COMBINING CELLS

In many cases, battery powered devices may require more power than one cell can provide. The device may require either a higher voltage or more current, and in some cases both. Under such conditions, it is necessary to combine or interconnect a number of cells to meet the power demands. Cells connected in series provide a higher voltage, while cells connected in parallel provide a greater current capacity. To provide adequate power when both voltage and current needs are greater than any one cell can provide, a series-parallel combination of cells must be used.

SERIES CONNECTED CELLS

Assume that a load requires a 6-volt power supply with a current capacity of $^{1}/_{8}$ amp. Assume that a single cell normally supplies a potential of only 1.5 volts. More than one cell is obviously needed. To obtain the required higher potential, cells are connected in series as shown in Figure 8A.

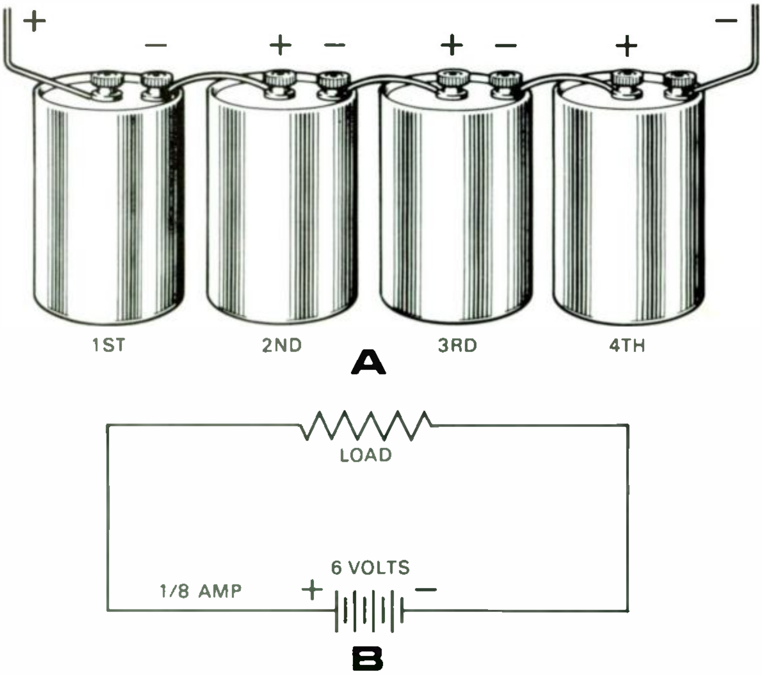


Figure 8 — A) Series connected cells; B) Series circuit represented schematically.

In a series hookup, the negative terminal of the first cell connects to the positive terminal of the second, the negative terminal of the second to the positive of the third, etc. The positive terminal of the first cell and negative terminal for the last cell are connected to the load. In this way, voltage is boosted 1.5 volts for each cell. There are four cells; therefore, the output terminal voltage is 1.5 × 4 =6 volts. When connected to the load, 1/8 amp flows through the load and each cell in the battery. Each cell can deliver this amount, so only four are needed. These four can be properly called a battery of cells.

PARALLEL CONNECTED CELLS

In this case, assume an electrical load requires only 1.5 volts but will draw 1/2 ampere of current. Also assume that one cell can supply 1/8 ampere. To meet the requirement, cells are arranged in parallel, as shown in Figure 9A. In a parallel connection, all positive terminals are connected to one line, and all negative terminals tie to the other. The potential difference between the lines is the same as that of one cell (1.5 volts); however, each cell may contribute its maximum allowable current of 1/8 amp to the line. There are four cells; therefore, the total line current is 1/8 + 1/8 + 1/8 + 1/8 = 4/8 which is 1/2 amp. In this example, four cells have enough capacity to supply a load requiring 1/2 amp at 1.5 volts.

SECONDARY (WET) CELLS

Secondary cells function on the same basic chemical principles as

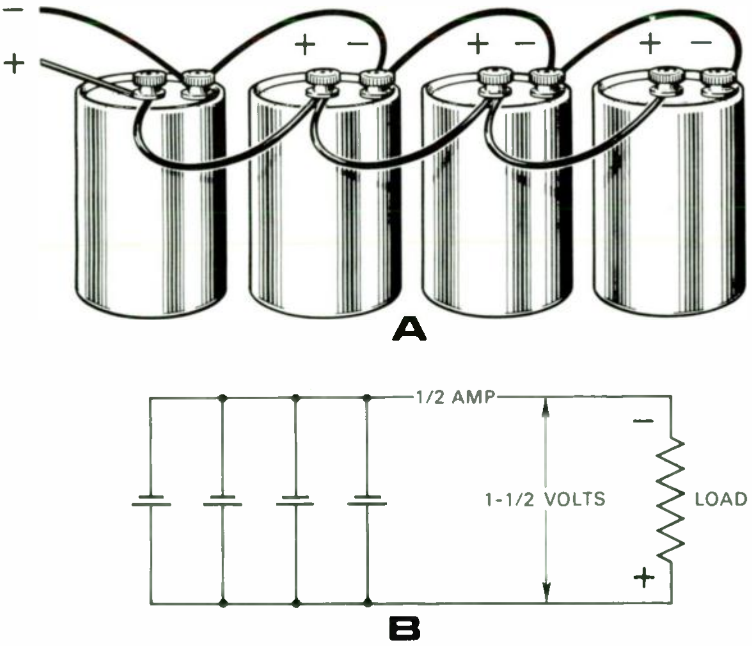


Figure 9 — A) Parallel connected cells; B) Parallel circuit shown schematically.

primary cells. They differ mainly in that they may be recharged, whereas the primary cells cannot. Some of the materials in a primary cell are consumed when chemical energy is changed to electrical energy. In the secondary cell, materials are usually transformed into other chemical compounds as the cell discharges. Discharged secondary cells may be restored or charged to their orginal state by forcing electric current through them in an opposite direction.

The storage battery consists of a number of secondary cells connected in series. Technically, this battery does not store electrical energy but is a source of chemical action which produces electrical energy. There are various types of storage cells: the lead-acid type which has an EMF of 2.2 volts per cell; the nickel-iron alkali type which has an EMF of 1.2 volts per cell; the nickel-cadmium alkali type with an EMF of 1.2 volts per cell; and the silver-zinc type which has an EMF of 1.5 volts per cell. Of these storage cells, the lead-acid is most widely used and will be described first.

LEAD-ACID BATTERIES

The lead-acid battery is an electrochemical device for storing chemical energy until it is released as electrical energy. Active materials within the battery react to produce a flow of direct current whenever a load is connected to the terminals. Current is produced because of chemical action between material on the plates or electrodes and the electrolyte. Lead-acid batteries are used extensively throughout the world. The parts of a lead-acid battery are illustrated in Figure 10 and are discussed in the following paragraphs.

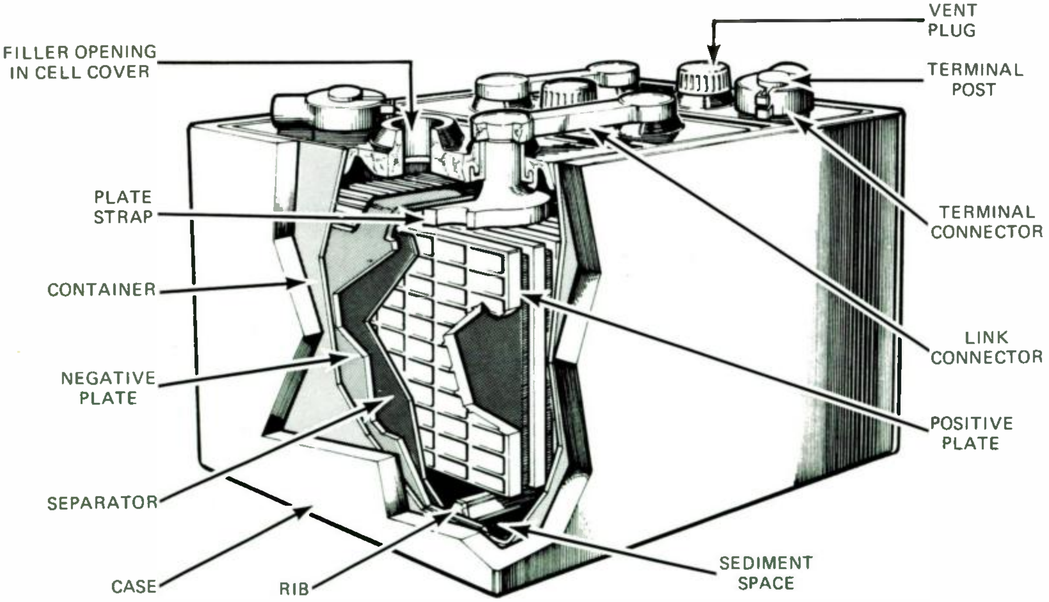


Figure 10 — A typical lead-acid storage battery.

LEAD-ACID BATTERY CONSTRUCTION

A lead-acid battery consists of a number of cells connected together; the number needed depends upon the voltage desired. Each cell produces approximately 2 volts.

A cell consists of a hard rubber, plastic, or bituminous material compartment into which is placed the cell element. This cell consists of two types of lead plates, positive and negative (Fig. 11). These plates are insulated from each other by suitable separators which are usually made of plastic, rubber, or glass. They are submerged in a sulfuric acid-water solution, the electrolyte.

There are a variety of plates used in the lead-acid battery, each of which is designed to fulfill a specific purpose. Most commonly used are pasted plates. These are formed by applying lead-oxide paste to a grid (Fig. 12) which is made from a lead-antimony alloy. The grid is designed to give the plates mechanical strength, to hold the active material in place, and to provide a conductive path for electric current. The lead oxide is applied to the grids in paste form and then allowed to dry. These plates are then put through a process that converts active material on the positive plates into lead peroxide, and the negative plates into sponge lead. This is done by immersing the plates in an electrolyte and passing current through them in the proper direction. These types of plates are light in weight compared to other plates that are more rugged and durable in construction.

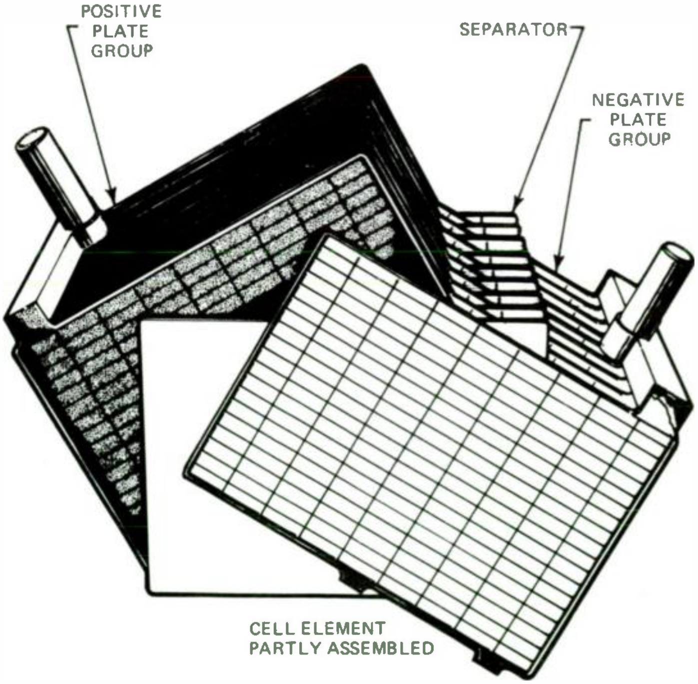


Figure 11 — Internal parts from a cell of a lead-acid storage battery.

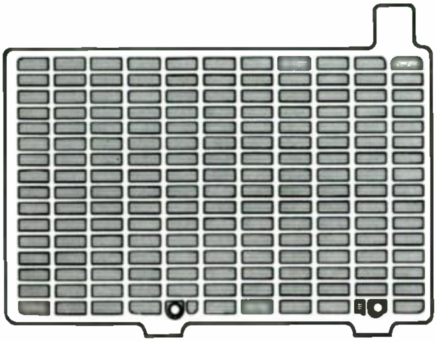


Figure 12 — Grid like structure of a plate from a lead-acid storage battery.

After the plates have been formed, they are built into positive and negative groups. The negative group always has one more plate than the positive group. This keeps the expansion and contraction that takes place in the positive plates the same on both sides, and prevents buckling. The groups are asembled with separators between them to form cell elements (Fig. 11). Separators are grooved on one side and smooth on the other. The grooved side is placed next to the positive plate to permit free circulation of the electrolyte around the active material.

Chemicals on the positive and the negative plates are referred to as the active material; however, alone in a container, they will cause no chemical action. There must be a current path between plates. It is the electrolyte which provides this current path within a cell.

A battery's container is the case into which the cells that make up the battery are placed. Most containers are hard rubber, plastic, or bituminous composition. They are resistant to mechanical shock and are able to withstand extreme weather conditions. Most batteries are assembled in a one-piece container with compartments for each individual cell The bottom of the container has ribs molded into it to provide both support for the elements and a sediment space for flakes of active material which drop off the plates.

The battery's container and the covers which enclose it are usually made from identical material. There are three openings in the cell covers. These holes are provided for the positive terminal, the negative terminal, and the vent plug.

Cell connectors are used to tie the cells of a battery together electrically. Each cell is constructed so that the negative terminal of one is physically located next to the positive terminal of the next. Cells are connected both physically and electrically by a metal connector of sufficient size to carry the current demands of the battery without over heating.

Vent plugs are designed to permit the escape of gases that form within the cells while preventing leakage or loss of the electrolyte. Many batteries utilize a non-spill type of vent plug which makes it possible to place the battery in any position without loss of the electrolyte (Fig. 13).

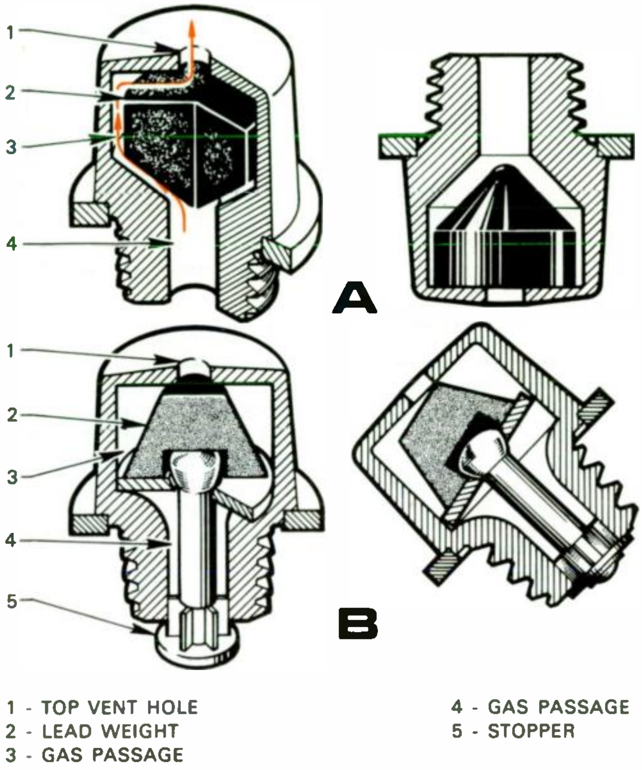


Figure 13 — Cell vent caps from a lead-acid storage battery.

Sealing compound, which is generally made of a bituminous substance, is used to attach the cell cover to the container. The compound is acid resistant and must withstand intense vibration and heat. Sealing compounds neither melt at summer temperatures nor crack when frozen.

The positive and negative terminals of a lead-acid battery are distinguished from one another by their physical size and markings. The positive terminal (marked +) is larger than the negative terminal (marked −). A storage battery's terminals are commonly called **posts.**

LEAD-ACID BATTERY OPERATION

In its charged condition, the active materials in the lead-acid battery are lead peroxide, which is the positive plate, and sponge lead, which is the negative plate (Fig. 14). The electrolyte is a mixture of sulfuric acid and water. The strength or acidity of the electrolyte is measured in terms of its weight.

In a fully charged battery, all acid is in the electrolyte, so that the weight is at its highest value. The active materials of both the positive and negative plates are porous

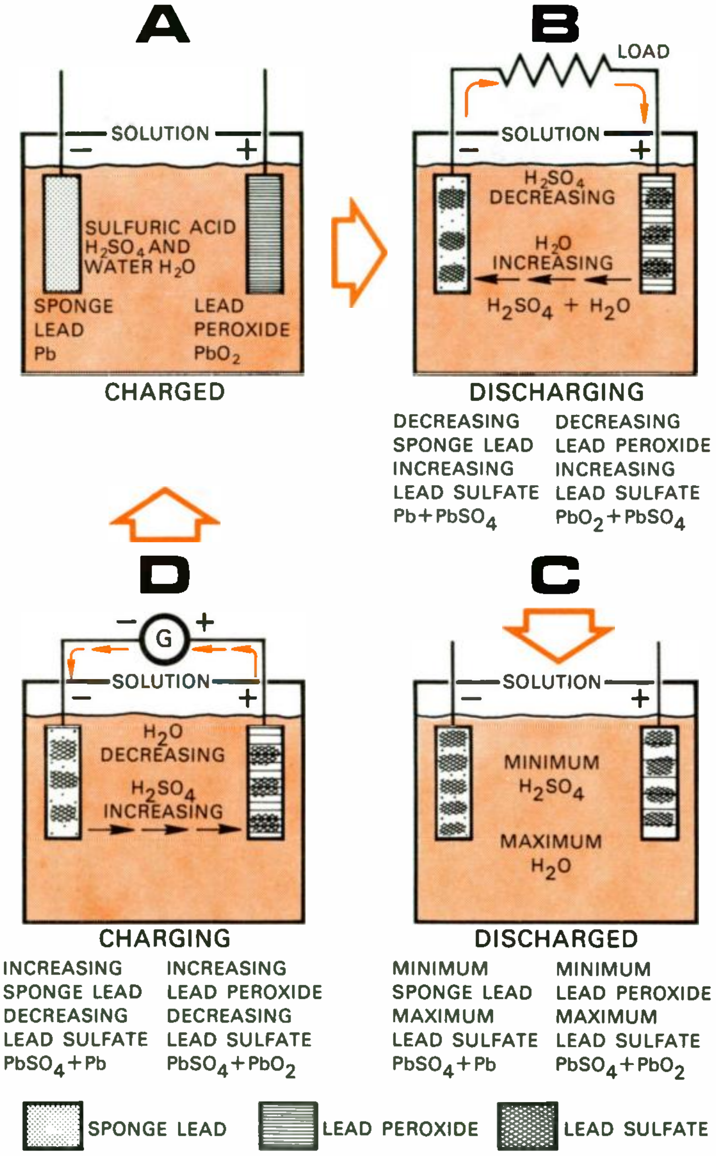


Figure 14 — Conditions within a lead-acid cell in various stages: A) charged; B) discharging; C) discharged; D) charging.

or similar to a sponge. The pores soak up the solution, or electrolyte, in which they are immersed. As the battery discharges, acid (in contact with the plates) separates from the electrolyte. It forms a chemical combination with active materials on the plates, changing them to different compounds. As the discharge continues, lead sulfate forms on the plates and more acid is taken from the solution, causing the electrolyte to become nearly pure water. The weight of a cell's electrolyte decreases as it loses acid.

When the battery is being charged, a reverse action takes place; acid held by the plate material is driven back into the electrolyte. When fully charged, the material on both sets of plates returns to its original form.

Electrical energy is derived from a cell when the plate materials react with the electrolyte. As a molecule of sulfuric acid separates, part of it combines with sponge lead on the negative plates. It contains extra electrons, which make the sponge lead plates negative and at the same time forms lead sulfate. The remainder of the sulfuric acid molecule, lacking electrons and making it a positive ion, filters through the electrolyte to the opposite plates and takes electrons from them. This action neutralizes the positive ions, forming ordinary water. It also makes the lead peroxide plates positive by extracting electrons from them. Again, lead sulfate is formed in the process.

The action just described can be represented by the following chemical equation:

discharging charging

$$Pb + PbO_2 + 2H_2SO_4 \rightleftarrows 2PbSO_4 + 2H_2O$$

The left side of the expression (left of the double arrows) represents the cell in the charged condition; the right side represents it in a discharged state.

If the discharged cell is properly connected to a direct current charging source (whose voltage is slightly higher than that of the cell), current will flow through the cell in the opposite direction. The cell is then said to be charging. The effect of the current will be to change lead sulfate on both the positive and negative plates back to its original active form of lead peroxide and sponge lead, respectively. At the same time, sulfate is restored to the electrolyte which results in increased weight of the electrolyte. When all the sulfate has been restored to the electrolyte, its weight will be maximum. The cell is then fully charged and is ready to again produce electric current.

It should always be remembered that the addition of sulfuric acid to a discharged lead-acid cell does not recharge it. Adding acid increases the specific gravity or weight of the electrolyte but does not convert the plates back to a charged form. Consequently this does not bring the cell back to a charged condition. A charging current must be passed through the cell to do this.

As a cell's charge nears completion, hydrogen gas (H_2) is released at the negative plate, and oxygen gas (O_2) is released at the positive plate. This action occurs because incoming current is greater than that required to complete the charge. Excess current causes water in the electrolyte to decompose into its elements, hydrogen and oxygen. This action is necessary for a short time to completely charge a cell.

DETERMINING CHARGE

Since electrolyte becomes lighter as a lead-acid battery discharges, the weight of this solution can be used to indicate the amount of charge. Instruments called hydrometers are used for this purpose (Fig. 15). These consist of a glass envelope with a rubber squeeze bulb attached. With the tip inserted into a cell's electrolyte, the bulb is squeezed and released. Solution is drawn up into the envelope where it floats a numbered glass scale. The heavier the electrolyte, the higher it floats and the larger the number showing at the surface of the liquid. The larger the number, the greater the charge. Numbers on these scales are those used to indicate specific gravity, a chemical quantity for relative weight.

TREATMENT OF ACID BURNS

If acid or electrolyte from a lead-acid battery comes into contact with the skin, the affected area should be washed immediately with large quantities of fresh water. A salve such as petrolatum, boric acid, or zinc ointment should be applied. If none of these solutions are available, clean lubricating oil will suffice. When washing, large amounts of water should be used, since a small amount might do more harm than good by spreading the acid burn.

Acid spilled on clothing may be neutralized with diluted ammonia or a solution of baking soda and water.

RATING OF STORAGE BATTERIES

Storage batteries are rated according to discharge time and ampere-hour capacity. Most batteries, except aircraft and some used for radio and sound systems, are rated according to a 20-hour rate of discharge. If a battery can deliver 20 amperes continuously for 20 hours, the battery has a rating of 20 × 20, or 400 ampere-hours. The 20-hour rating indicates the average current that a battery is capable of supplying for 20 hours without interruption.

All standard batteries deliver 100 percent of their available capacity if discharged in 20 hours or more, but they will deliver less than their available capacity if discharged at a faster rate. The faster they discharge, the less capacity they have.

TYPES OF CHARGES

The following types of charges may be given to a storage battery, depending upon its condition.

1. Initial charge.
2. Normal charge.
3. Equalizing charge.
4. Floating charge.
5. Fast charge.

Initial Charge

When a new battery is shipped dry, the plates are in an uncharged condition. After the electrolyte has been added, it is necessary to convert the plates into the charged condition. This is accomplished by giving the battery a long low-rate initial charge. The charge is given in accordance with manufacturer's instruction, which are shipped with each battery.

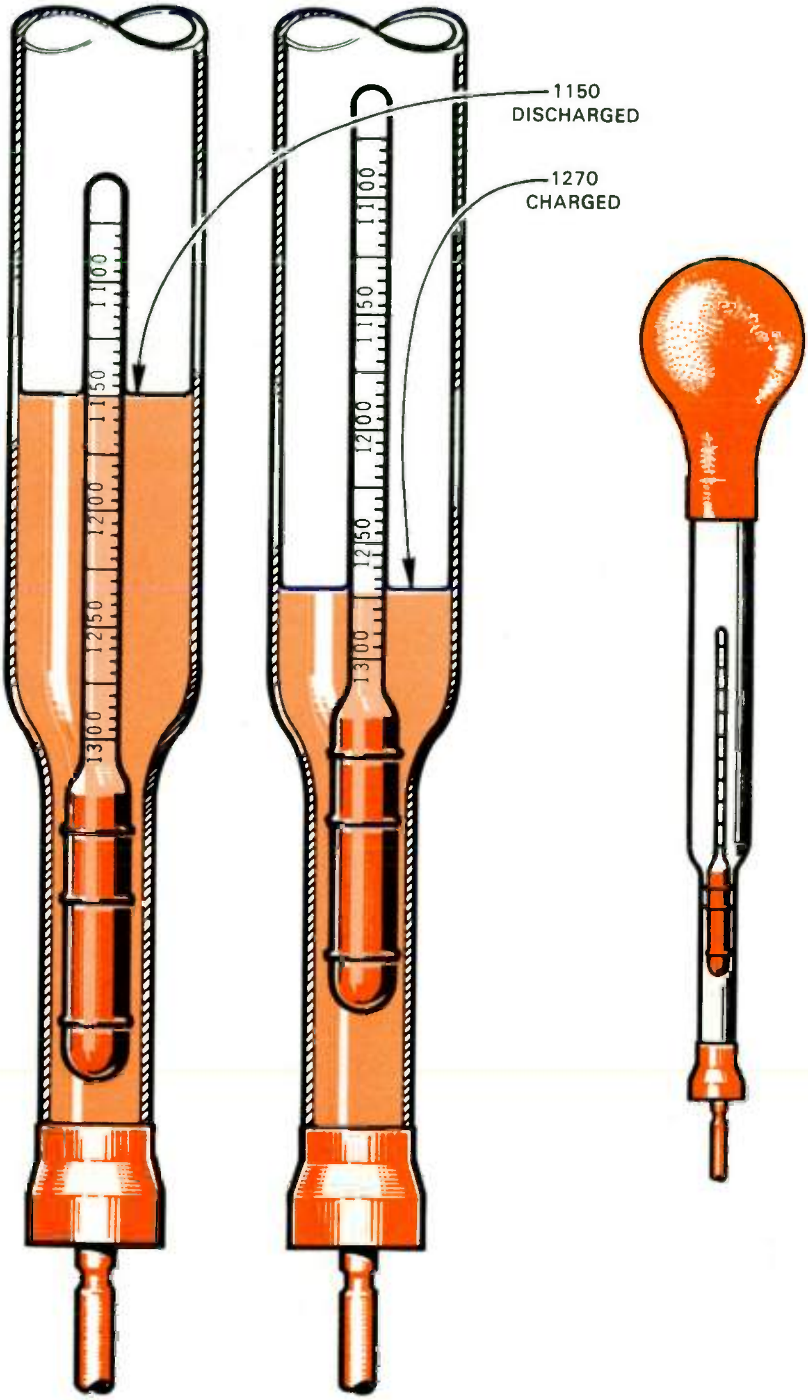


Figure 15 — Hydrometer used to check state of charge in a lead-acid storage cell.

Equalizing Charge

An equalizing charge is a longer than normal charge. It is given to insure that all sulfate is driven from the plates, and that all the cells are restored to maximum charge. The equalizing charge is continued until the specifc gravity of all cells shows no change for a 4-hour period.

Floating Charge

A battery may be maintained at full charge by connecting it across a charging source that has a voltage maintained within the limits of 2.13 to 2.17 volts per cell. In a floating charge, the rate is determined by battery voltage rather than by a charge current value. The voltage is maintained between 2.13 and 2.17 volts per cell with an average as close to 2.15 volts as possible. An automobile alternator supplies this type of charge, except when the battery's charge is seriously depleted.

Fast Charge

A fast charge is used when a battery must be restored in the shortest possible time. This kind of charge starts at a much higher rate than is normally used and should be used only in an emergency as it may be harmful to the battery.

NICKEL-CADMIUM BATTERIES (NICAD)

Nickel-cadmium batteries are far superior to lead-acid types. Some are physically and electrically interchangeable with lead-acid types, while others are sealed units which use plug and receptacle connections (Fig. 16). These batteries require less maintenance than lead-acid types, in regard to the adding of electrolyte.

Nickel-cadmium and lead-acid batteries have similar capacities at normal discharge rates, but at high discharge rates the nickel-cadmium battery can

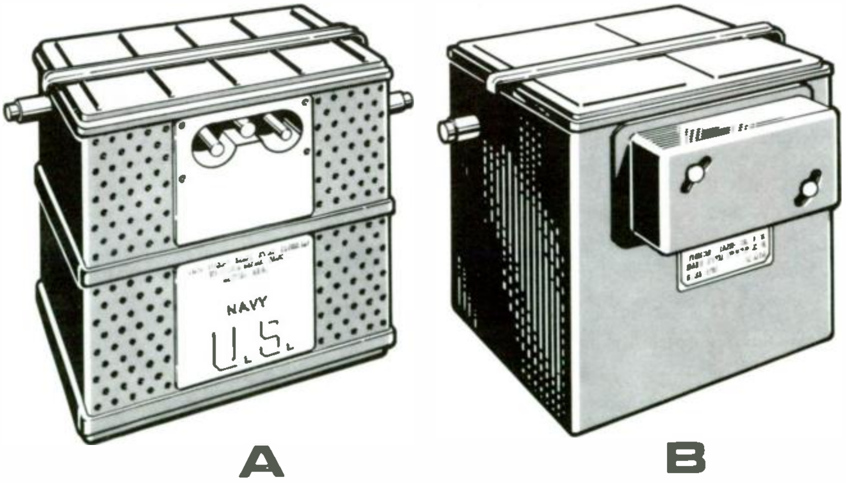


Figure 16 — A nickel-cadmium storage battery.

1. be charged in a short time,
2. deliver a large amount of power,
3. stay idle in any state of charge and keep a full charge when stored for a long time,
4. be charged and discharged any number of times without any appreciable damage, and
5. individual cells may be replaced if a cell becomes defective; that is, all cells need not be replaced.

Due to their superior capabilities, nickel-cadmium batteries are being used extensively in applications that require a battery with a high discharge rate. A prime example is the aircraft storage battery.

The NI-CAD battery's plates are constructed of nickel-powder attached to a nickel wire screen. Active materials are nickel-salts on the positive plate and cadmium salts on the negative plate. The separators are constructed of plastic, nylon cloth, or a special type of cellophane (Fig. 17).

Construction of a sintered-plate cell is accomplished by a powdered metal process. Special nickel powder is pressed onto the plates then subjected either to a temperature of about 1,600° in a sintering furnace or to a sudden heavy electric current. Either process causes individual grains of nickel to weld at their points of contact, producing a porous plaque which is approximately 80 percent open holes and 20 percent solid nickel. The plaques are then forcefully filled with active materials. The positive plate is then soaked in a solution of nickel salts, and the negative plate in a solution of cadmium salts. This bath is repeated until each plate contains the necessary amount of active material.

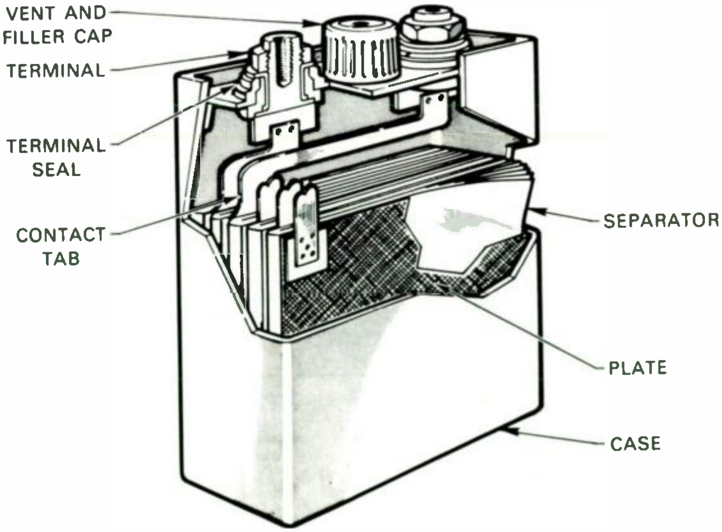


Figure 17 — A cell from a nickel-cadmium battery.

The electrolyte used in nickel-cadmium batteries is a solution of potassium hydroxide and distilled water. As with lead-acid batteries, there are limitations on the amount of active chemicals that can be used in the solution.

The electrolyte used in a nickel-cadmium battery does not chemically act on its plates as in the lead battery. It serves only as a conductor of current between plates, therefore, no flaking or shredding of active material occurs. Consequently, the plates do not deteriorate, nor does the weight of the electrolyte appreciably change. For this reason, it is not possible to determine the charge state of a nickel-cadmium battery by checking the electrolyte with a hydrometer; neither can the charge be determined by a voltage test, because voltage remains nearly constant during 90 percent of the discharge cycle.

Since little gassing occurs, the cell could be securely sealed. As a safety precaution, however, relief valves are installed in the fill hole cap of each cell (Fig. 18) to release gas that is formed should the battery be overcharged.

SAFETY PRECAUTIONS

The electrolyte used in nickel-cadmium batteries is potassium hydroxide (KOH). This is a highly corrosive alkaline solution and should be handled with the same degree of caution as sulfuric acid (H_2SO_4). If it is spilled on the skin or clothing, the exposed area should be rinsed immediately with water or, if available, vinegar, lemon juice, or boric acid solution. If the face or eyes are affected, treat as above. Then see your doctor.

SILVER-ZINC BATTERIES

Silver-zinc batteries are used in some military and industrial applications. Their unique characteristics in these situations justify their high cost.

The silver-zinc battery was developed for one major and one secondary purpose. The major purpose was to secure large quantities of electric power for emergency operations. The secondary purpose was to

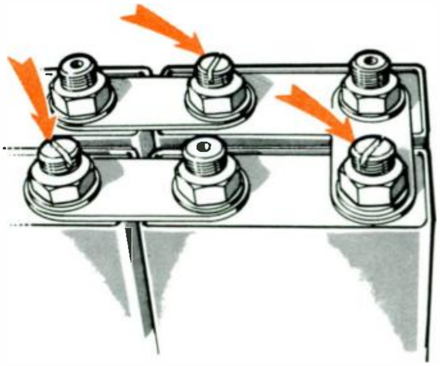


Figure 18 — Relief caps in negative post of cells of a nickel-cadmium battery.

permit a weight saving. A lightweight, silver-zinc battery produces as much electrical energy as the much larger lead-acid or nickel-cadmium type.

Silver-zinc batteries normally operate at 24 volts. They contain sixteen 1.5 volt cells connected in series. Due to its extremely low internal resistance, the silver-zinc battery is capable of discharge rates of up to 30 times its ampere-hour rating. The low internal resistance (as low as 0.0003 ohms per cell) is due primarily to the excellent current conducting properties of the plates, the close plate spacing (possible because small amounts of electrolyte are used), and the fact that the composition (and therefore, conductivity) of the electrolyte does not change during use. They actually conduct better during discharge, because the positive plates change from oxides of silver, (fair conductors) to metallic silver, an excellent conductor.

The high electrical capacity is a result of close plate spacing and the large degree to which active plate materials are used. Silver-zinc batteries are capable of producing six times the energy of other equal size and weight types. They have been built with capacities ranging from tenths to thousands of ampere-hours.

Good voltage regulation is provided because of the constant voltage characteristic. Terminal voltage is essentially constant throughout most of a discharge cycle. Silver-zinc batteries have a maximum service cycle life which is less than that of other types, but their life expectancy compares favorably with that of other batteries.

The construction and electrochemical reactions of the silver-zinc battery are somewhat similar to those of the nickel-cadmium type. When the battery is fully charged, the positive plates are silver oxide, and the negative plates are pure zinc. As the battery discharges, the positive plates are reduced to metallic silver, and the negative plates are oxidized. Thus, when the battery is discharging, electrons are flowing out of the cathode or negative plates and into the anode (positive plates) through the external circuit. The electrolyte, potassium hydroxide, exists as potassium (K) and hydroxide (OH) ions, which serve only to conduct electric charges between the plates.

As with other types of alkaline cells and unlike lead-acid cells, the electrolyte does not take part in the chemical transformations. Therefore, its specific gravity or weight does not change with the state of charge. As long as the plates are covered, the electrical capacity of the battery is independent of the amount of electrolyte present.

SILVER-CADMIUM BATTERIES

A recent development in storage batteries is the silver-cadmium battery. Generally, the most important requirements of a battery are for high energy density, good voltage regulation, long shelf life, a repeatable number of cycles, and long service life expectancy. The silver-cadmium battery is designed to offer overall maximum performance in all of these expectations.

The silver-cadmium battery has more than twice the shelf life of the silver-zinc battery. A long shelf life and good voltage regulation make the silver-cadmium battery a highly desirable addition to the family of storage batteries. Limitations include lower voltage and higher cost.

ELECTRICITY FROM LIGHT

A device which produces electric current from light is called a photo voltaic cell. Light is directed onto a junction of two dissimilar materials and causes electrons to be released. These free electrons gather at one side of the junction and cause it to act as a negative plate. The opposite material is depleted of electrons and is charged positive. They develop low voltage potentials and minute amounts of current, but are nevertheless useful when several are combined to produce greater amounts of power. Sunlight can be used to power communication equipment and low power systems for control and data processing. Space probes send back much more information than they did when primary batteries with short life spans were used.

Photo-voltaic cells should not be confused with photo-emission or photo-resistive devices. In these, light does not cause electrons to be released. It only controls how many flow in circuits which contain additional power sources.

ELECTRICITY FROM HEAT

Thermo-voltaic devices convert heat directly into electrical energy in a fashion similar to photo-voltaic devices. Instead of light striking a junction, the junction is subjected to a concentrated flame or heat. One common type, much used as signal sources in industrial monitoring equipment is the thermocouple. It develops a voltage proportional to the temperature applied; the hotter it becomes the greater the voltage. By measuring this voltage, we are able to determine the temperature of steam, bearing surfaces, cooling water etc., in a power-generating plant.

Wires several hundred feet long connect to a central computer which has the ability to detect a temperature change and determine if a problem is about to occur. Control room engineers are frequently able to correct a problem before it happens, without stopping the generator. Speedy correction is essential in the power industry because a day's down time can easily cost the company over $100,000.

Thermocouples are also used as safety devices, to control the main gas valve on home furnaces and hot water heaters. If the pilot flame fails for any reason they prevent gas from being discharged into a room and endangering the life of its occupants.

TEST

Lesson Number 6

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-006-1.

1. A chemical electric cell develops electricity from
A. magnetic action.
B. electrostatic action.
[✓ C. chemical action.]
D. electronic action.

2. The corrosive chemical used in cells is either
A. water or oil.
B. mercury or iron.
[✓ C. acid or alkali.]
D. liquid or gas.

3. A dry cell has
A. liquid electrolyte.
[✓ B. moist paste electrolyte.]
C. dry electrolyte.
D. no electrolyte.

4. A load, electrically speaking
A. generates power.
B. is always heavy.
C. is always light.
[✓ D. draws current from a power source.]

5. If a load is connected directly across a battery's terminals
[✓ A. current flows.]
B. only voltage is present.
C. the battery charges.
D. 12 volts is always present.

6. The voltage of a battery
A. is always 12 volts.
[✓ B. depends on the number and type of cells.]
C. is always greater when more current flows.
D. is less than one cell.

7. To determine the amount of charge stored in a lead-acid battery

A. measure the battery voltage.
B. weigh the battery on a scale.
[✓ C. use a hydrometer and measure the specific gravity.]
D. check the size of the battery plates.

8. A cell which generates electricity from light is called

[✓ A. photo-voltaic.]
B. nickel-cadmium.
C. chemical-electric.
D. alkaline.

9. Parallel-connected cells produce

[✓ A. more current than 1 cell.]
B. less voltage than 1 cell.
C. higher voltages than 1 cell.
D. less current and voltage than 1 cell.

10. Series connected cells produce

A. more current than 1 cell.
B. less current than 1 cell.
C. less voltage and current than 1 cell.
[✓ D. more voltage than 1 cell.]

Notes

Notes

"School Without Walls"
"Serving America's Needs for Modern Vocational Training"

Finish What You Start

It is our belief at ASI that the success-oriented person is the individual who completes what was originally begun.

In order to attain a specific end there must be some time and energy put forth if you are to reach completion. The first positive step you made was enrolling with ASI in the Electronics course. Your task is now at hand and it is going to require hard work and the willingness to sacrifice certain things more entertaining than completing a test or reading your lesson material.

Some people will accept this challenge and pursue it with great desire. These are the people who will succeed in any walk of life. It is our hope that you are that type of person. Exercise a thorough follow-up system and you cannot go wrong. Always allow yourself enough time to complete what you have started. Organize your thoughts and plan the correct means to achieve your end.

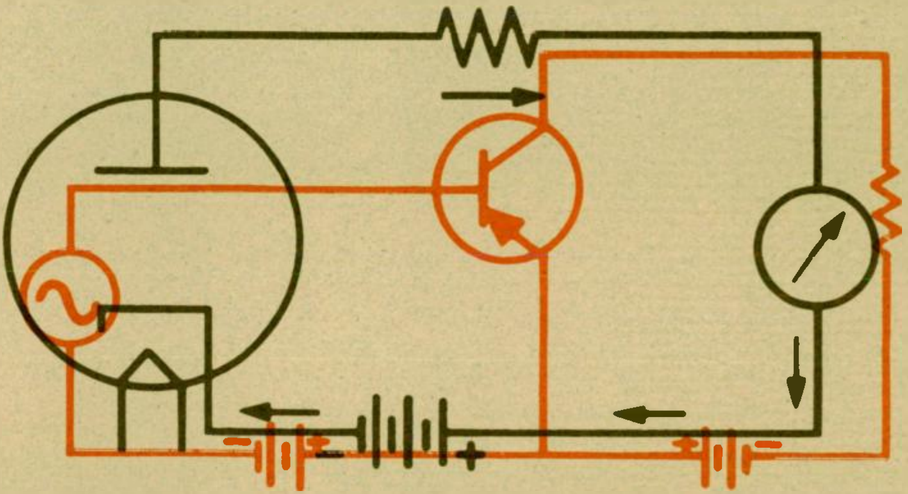
Finally, do not try to take on too much too soon.

As mentioned previously, plan effectively and work at a pace which is equal to your abilities. Coordinate your efforts efficiently and I am sure quality will become your byword: Charge!

S. T. Christensen

LESSON NO. 7

DIRECT CURRENT



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LESSON SEVEN

DIRECT CURRENT

Contents

Revised 1973

INTRODUCTION TO DIRECT CURRENT

Direct Current is the name that is used to identify electricity that flows in only one direction in an electrical circuit.

In this DC circuit (DC is the abbreviation for Direct Current), the current flows from the negative terminal of the power supply through the remainder of the circuit and returns to the positive terminal of the power source (Fig. 1).

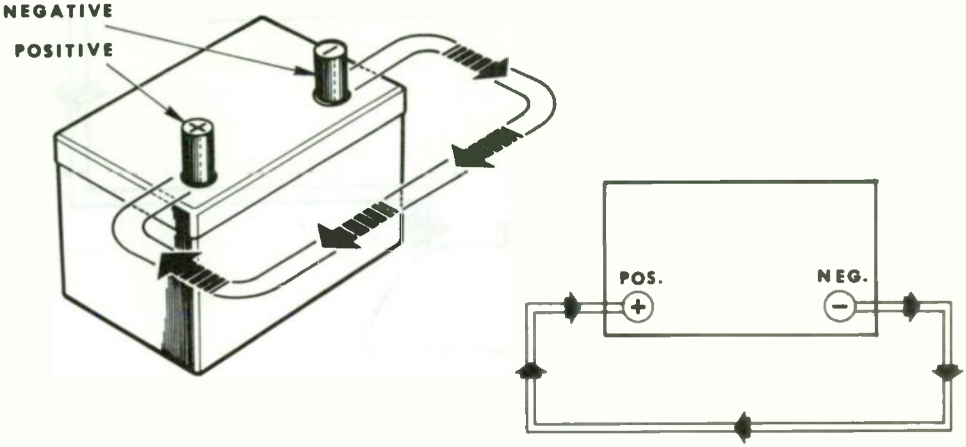


Figure 1 – Current flow is always in one direction and always from the negative to the positive terminal

This power source might be a battery, or it might be the DC voltage available in a TV or a hi-fi phonograph.

The amount of current flow is determined by the voltage available from the power source (shown as a battery in the illustration) and by the resistance of the external circuit. The external circuit is comprised of the wires used to conduct the current FROM the battery and TO the battery, plus the device that uses the power of the battery.

A practical example of the use of a conventional battery is its use as a power supply for an automobile headlight (Fig. 2). The current flows through the wire from the negative terminal of the battery in the direction of the arrow through the filament in the headlight and back through the return wire to the positive terminal of the battery.

CONDUCTORS AND INSULATORS

Before we can properly handle and direct the flow of current in a safe and proper manner, an understanding of the difference between electrical conductors and electrical insulators will be helpful.

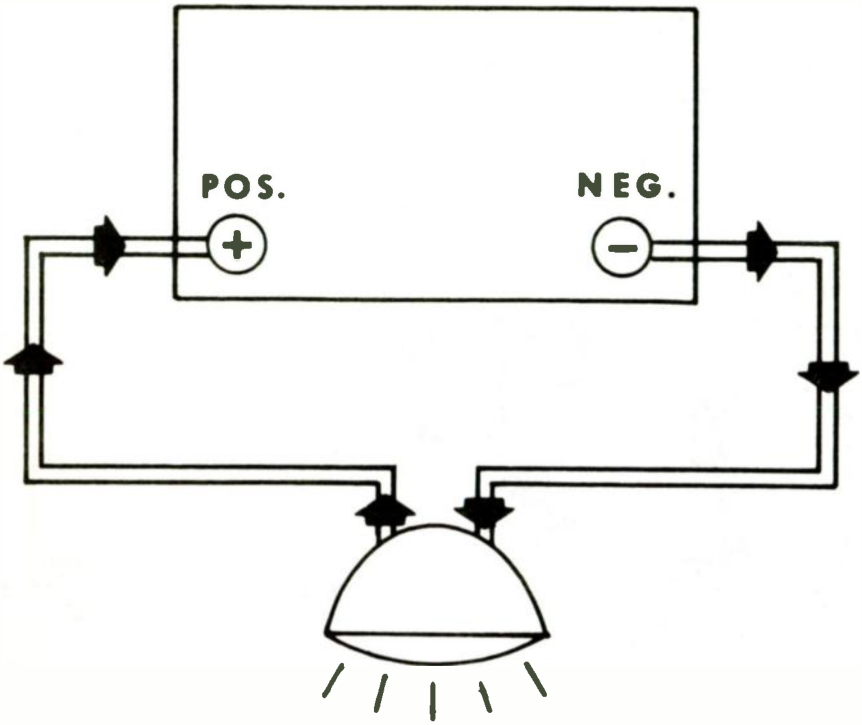


Figure 2 — Current flow is from the negative terminal through the headlight and returns to the positive terminal of the battery

Conductors

The dictionary definition of a conductor is "a material which permits free motion of a large number of electrons." The definition does not state that a conductor is a material that has a certain number of electrons that can move freely, but simply states that it is a material containing electrons that can move freely.

All metals conduct electricity; that is, they permit all electrons to move freely through their molecular structure. But all of them do not conduct with the same degree of freedom. This fact led to rating metals according to their conductivity.

Insulators

Opposite in nature to an electrical conductor is an electrical insulator, which is defined as "a material which offers a tremendously high resistance to the passage of electricity." Insulating materials are substances that contain very few free electrons and require large amounts of energy to break electrons free from the holding force of the nucleus of the atom.

The table in Fig. 3 lists some of the more common materials used as insulators. In a future discussion we will learn the exact values for these materials and how this information can be applied.

Fig. 3 TABLE OF INSULATORS AND CONDUCTORS

Good Conductors	Good Insulators (high resistance)
Silver	Porcelain
Copper	Glass
Aluminum	Rubber
Zinc	Marble
Tin	Dry Air
Steel – Iron	Dry Cotton
Nichrome	Dry Wood
Water	

IMPORTANT: This Table lists the best conductors and the best insulators at the top. As we go down each column, the conductors and insulators become inferior in the order shown.

DIRECT CURRENT: FLOW

Electric Current in a Circuit

Direct current always flows from the negative terminal to the positive terminal of a battery, because the free electrons, which have a negative polarity, are attracted to the positive terminal which, having the opposite polarity, attracts them.

This flow of electrons from negative to positive is true of any power source, whether the power source is a battery or a power supply in an electronic device.

Because every electronic device requires a different amount of current to operate properly, we must have some definite unit of measurement to indicate how much current is actually flowing. We need a unit of measurement and an instrument to measure it.

Measurement of Electric Current

The electrical unit of measurement that indicates the amount of current flowing through a device is the *ampere* (or *amp*). Electron flow is determined by the number of electrons that pass a given point in an electrical conductor in one second of time. Because a single electron has such a small charge, a larger quantity of these electrons has been given the name "coulomb".

A coulomb is a quantity consisting of 6.28×10^{18} electrons. This number is a mathematical shorthand method to express the number 6,280,000,000,000,000,000. It simply states that there are eighteen zeros and numbers to the right of the decimal point. When this *one* coulomb passes *one* point in the electrical conductor during *one* second of time, *one* ampere of current is flowing. Thus, an ampere is the convenient unit of measurement to indicate how much current is flowing (Fig. 4).

DIRECT CURRENT: FORCE

When we previously discussed the flow of electricity, we called this electrical flow by its proper name, *current.* It is easy to understand why the flow of electricity is called current, because it is similar to the flow of current in a river. When we use the expressions "a fast current" or "a slow current" in talking about a river, we are indicating that a large

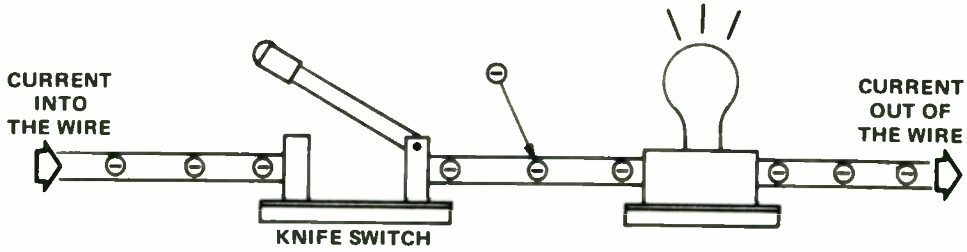


Figure 4 – If we could close the knife switch for one second and could count the electrons, we could determine how much current is flowing. If 6.28 x 10^{18} electrons passed through the switch in one second, 1 amp of current was flowing.

quantity of water is flowing (a fast current), or a small quantity of water is flowing (a slow current). Webster's dictionary confirms this in some of the definitions given for CURRENT:

1. A body of water flowing in a definite direction;
2. A running or flowing;
3. The flow or rate of flow of electricity in a conductor from a point of higher potential to a point of lower potential.

The definition given under 3, above, indicates that there must be a potential or a force that pushes these electrons through the conductor – "from a point of higher potential to a point of lower potential".

Electromotive Force

The electric force is correctly known as electromotive force, abbreviated as EMF, and generally spoken of as "EMF". This is the force that pushes the electrons from the negative terminal to the positive terminal of the power supply. The negative terminal is what Webster's definition called "a point of higher potential;" the positive terminal is "a point of lower potential".

Another way of looking at this concept is to consider that our storage battery has been turned on its side while it was lighting the headlight (Fig. 5). The current can then flow from the point of high potential through the headlight and to the point of low potential.

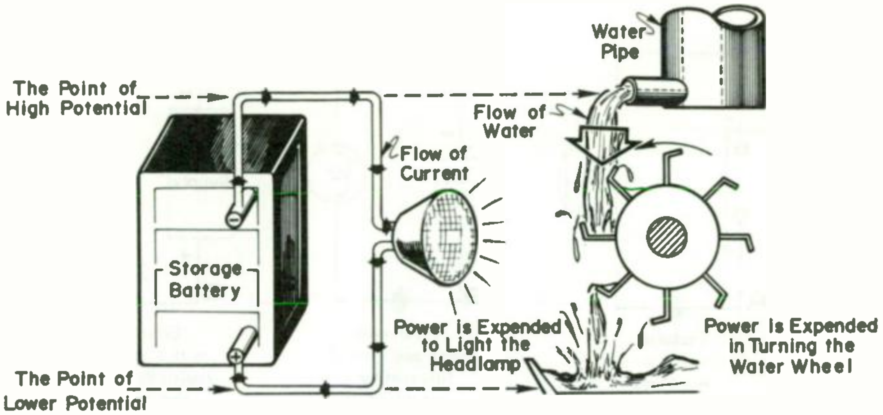
The illustration also shows a water wheel turning and producing power by the action of water falling from a potentially higher level to a lower potential level. Power of some kind has previously been used to

(a) charge the storage battery and (b) lift the water into the pipe.

This power that was made available to

(a) light the headlight and also to (b) turn the water wheel.

is "potential energy" as it is "potentially available" and, in the case of the water wheel, the water fell from a higher potential level to a lower potential level.



Illustrating the Flow of Current from a High Potential to a Low Potential

Illustrating the Flow of water from a point of High Potential to a point of Lower Potential

Figure 5 — Energy flows from a high potential to a low potential

Voltage

It is necessary to have a unit of measurement for this electrical force, properly called the electromotive force or EMF, and this force or pressure that "pushes the current" is measured in *volts.* A force of any kind cannot do work without having something to push, and the quantity that is pushed is the current. This is the current that we previously described as flowing through the circuit. A baseball batter uses a great deal of force when he swings the bat, but unless he actually hits the ball, he cannot demonstrate his power.

CALCULATING CURRENT FLOW IN A CIRCUIT

A DC circuit consists of at least three major elements:

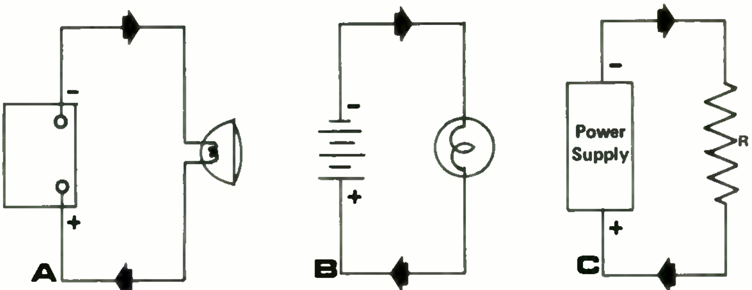
- a power source,
- a set of connecting wires, and
- the device that consumes the electrical energy.

The device might convert the electrical energy into light if it is a lamp, into rotary motion if it is an electric drill, or into both picture and sound if it is a TV receiver.

Series Circuits

These three elements in the DC circuit always establish the relationship between voltage, current and resistance. We have not discussed resistance in detail, but all electrical devices that use electrical energy resist the flow of current in one way or another, and the amount of this resistance is measured in *ohms.* An investigation of a simple series circuit will help to eliminate the mystery of how these three units of electrical measurement are used.

The illustration used to show how the automobile headlight was connected to the battery (Fig. 5) was a simple series circuit. This circuit has been redrawn (Fig. 6), beginning with the pictorial diagram at A and converting it to a conventional diagram using electrical symbols at B. The drawing at B shows the conventional symbols for a battery and for any filament-type lamp.



Pictorial with a Headlamp and a battery

Schematic with any type of filament lamp and a battery

Schematic with a resistance replacing the lamp and any type of Power Supply

Figure 6 — Three methods of representing the same circuit

Identifying Resistors

The drawing at C is a further simplification of a series circuit and illustrates any type of power source. Any device – a lamp, a drill, or a TV – may be represented by the resistance symbol, the letter "R". We can give values to this circuit and learn how the current changes with different values of resistance and voltage.

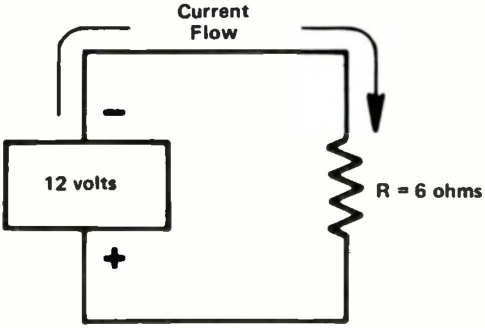


Figure 7 — A simple series circuit

Applying Ohm's Law to Determine Current Flow

Fig. 7 illustrates a power source that supplies 12 volts of energy to resistance "R" of 6 ohms. To determine how much current is flowing, we will use the formula from Ohm's law that allows us to calculate the current flow. It is:

$$\frac{\text{Voltage}}{\text{Resistance}} = \text{Current, or in symbols } \frac{E}{R} = I.$$

When we put numbers into the formula, we find that

$$\frac{E}{R} = I \text{ or } \frac{12 \text{ volts}}{6 \text{ ohms}} =$$ 2 amps of current are flowing in this series circuit.

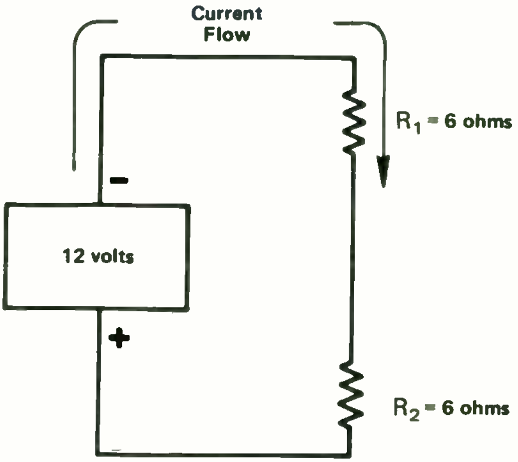


Figure 8 – This is still a series circuit

Now we will put two resistors in series in this circuit, each resistor having 6 ohms of resistance, to determine how much current is flowing. The same formula is used to determine the current despite the number of individual resistors involved; however, we must use the total resistance in the formula (Fig. 8).

$$\frac{\text{Voltage}}{\text{Resistance}} = \text{Current or}$$

$$\frac{E}{R} = I \text{ or } \frac{12 \text{ volts}}{12 \text{ ohms}} = 1 \text{ amp.}$$

Two important points are demonstrated here:

A. the larger the resistance, the lower the current; and
B. resistors in series are added together.

A future lesson will deal with resistance in greater detail, but for the present, all we need to remember is that resistance values are added together when they are used in series.

You will also see that is is customary to identify each resistor by giving it a subscript number, and we do this by referring to them as R_1, R_2, R_3,. . . on the wiring diagram (Fig. 8). Then we would list the actual resistance values in a separate table.

Using An Ammeter

We could verify our calculated value of current by inserting an ammeter in the circuit. An ammeter is a meter to measure the number of amperes flowing in a circuit. Remember that the current has the same value in every part of a series circuit. This principle allows us to open the circuit anywhere and put the ammeter in series with the entire circuit.

Fig. 9 shows the ammeter inserted in the circuit. The pointer of an actual meter would indicate 1 on the scale. Schematic diagrams that include meters do not generally have a current value indicated.

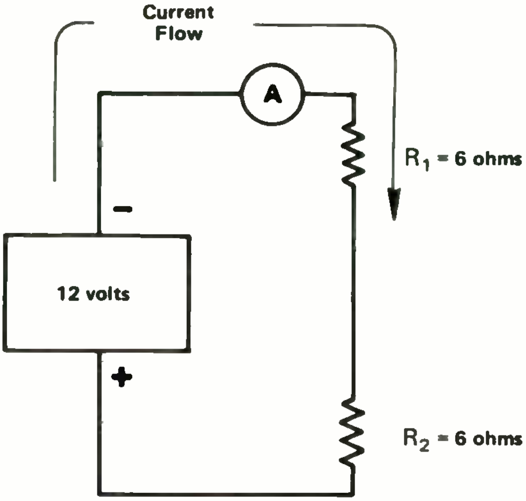


Figure 9 – This ammeter would indicate that 1.0 ampere was flowing throughout this circuit

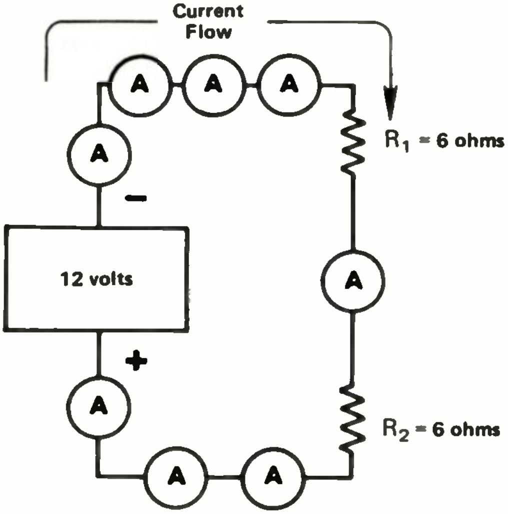


Figure 10 – Every ammeter indicates that 1 amp of current is flowing in this circuit

Fig. 10 illustrates a number of ammeters in this series circuit and, if we connected a number of ammeters, we would find that they all would "read" the same and indicate that 1 amp was flowing throughout this series circuit.

Applying Different Voltages in a Circuit

We have previously dealt with a constant voltage power supply of 12 volts. By putting in different values of resistors, we have varied the current flowing throughout the series circuit. We will now increase the power supply to 24 volts and compute the current flowing in this series circuit. Fig. 11 is the schematic representation of a 24 volt power supply with a 6 ohm resistance in the circuit.

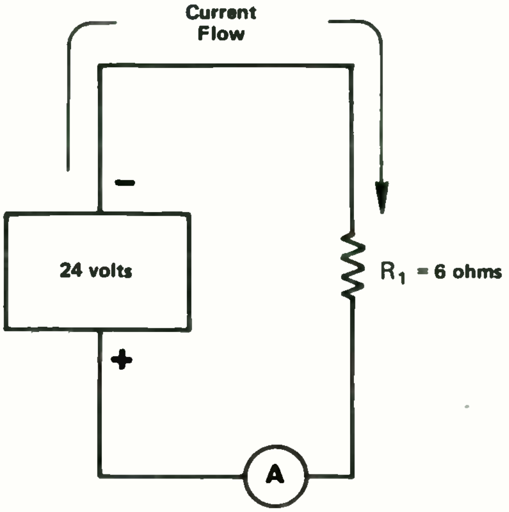


Figure 11 – A series circuit with a 24 volt power supply

$$\frac{\text{Voltage}}{\text{Resistance}} = \text{Current or}$$

$$\frac{E}{R} = I, \text{ and } \frac{24 \text{ volts}}{6 \text{ ohms}} = 4 \text{ amps}$$

If we increase the resistance to 12 ohms and feed it from a 24 volt supply, the current will be

$$\frac{E}{R} = I \text{ or } \frac{24 \text{ volts}}{12 \text{ ohms}} = 2 \text{ amps}$$

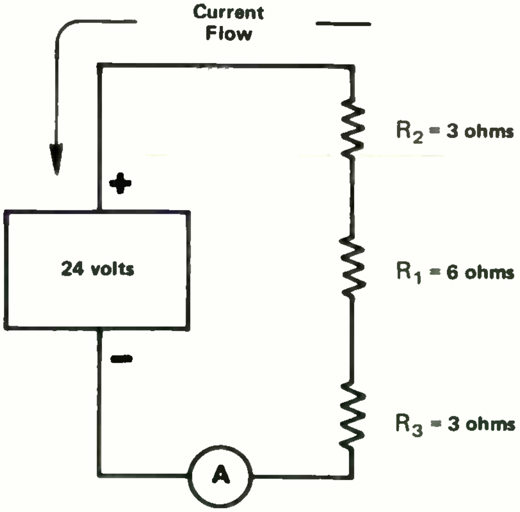


Figure 12 – A series circuit with 3 separate resistors

Fig. 12 shows how we increased the resistance to 12 ohms. The original 6 ohm resistor remains, and then 2 resistors of 3 ohms each are added to make the total 12 ohms. Remember that the resistance value of all the resistors in a circuit should simply be added to obtain the total resistance value used in the formula to calculate current flow.

Notice also that an arbitrary system was used to identify the three resistors. We retained R_1 for the 6 ohm resistor (Fig. 11) and simply used the next subscript numerals and assigned them as R_2 and R_3.

One other important change has been made in this schematic diagram. The same power supply was used, but the wires from the resistors have been connected to the opposite polarity. The only physical change made to this circuit was reversal of the positive polarity (+) and the negative polarity (—) on the schematic diagram. The effect of this change was reversal of the flow of the direct current, as shown by the arrow.

The direction of the current flow has no effect on a resistor, but the direction of current flow does have an effect on some other electrical devices.

CALCULATING VOLTAGES IN A CIRCUIT

In the section CALCULATING CURRENT FLOW, it was explained how to calculate with Ohm's law the actual value of the current flowing in a series circuit. In this section, we will learn how to determine the value of the voltages present throughout the various parts of a circuit. Let us first analyze some simple circuits using dry cells and flash light bulbs.

Adding Voltages

A number PR-112 flange-type flashlight bulb operates on four dry cells and is used in large, heavy duty flashlights. Four dry cells must be slipped into the flashlight case in the same way, or the bulb will not light up. The reason for this failure to "light-up" when the dry cells are not put into the proper order is explained in the following examples.

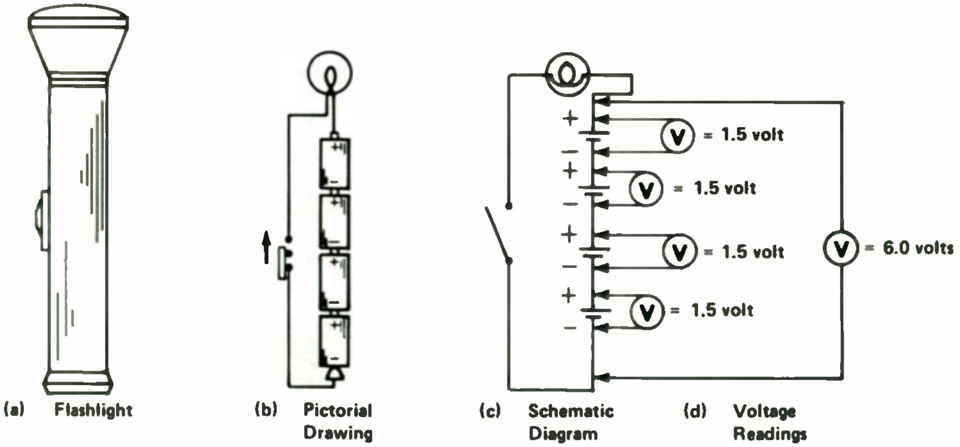


Figure 13 — Adding the voltages in a flashlight battery

Each dry cell develops a voltage of 1.5 volts, and with four dry cells in series, a total of 6 volts is developed (4 dry cells × 1.5 volts for each cell equals 6 volts).

Fig. 13 shows

- A. the flashlight,
- B. the pictorial representation,
- C. the schematic diagram of this flashlight circuit, and
- D. the voltage reading of each dry cell.

This diagram also illustrates the proper connection of each dry cell to its neighbor in this series connection to develop a total voltage of 6 volts. Voltmeters have been connected across each dry cell, and as its name implies, a DC voltmeter indicates the voltage in the circuit.

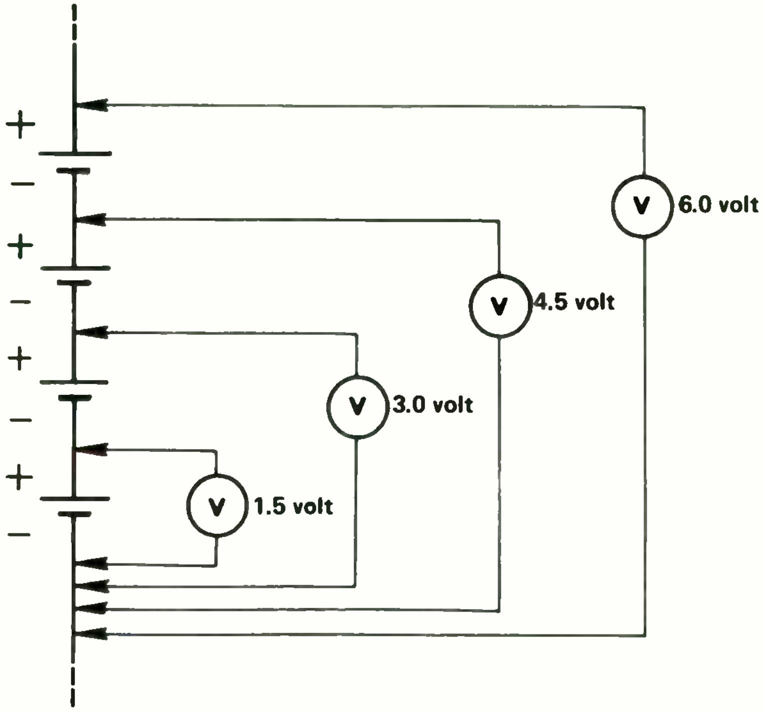
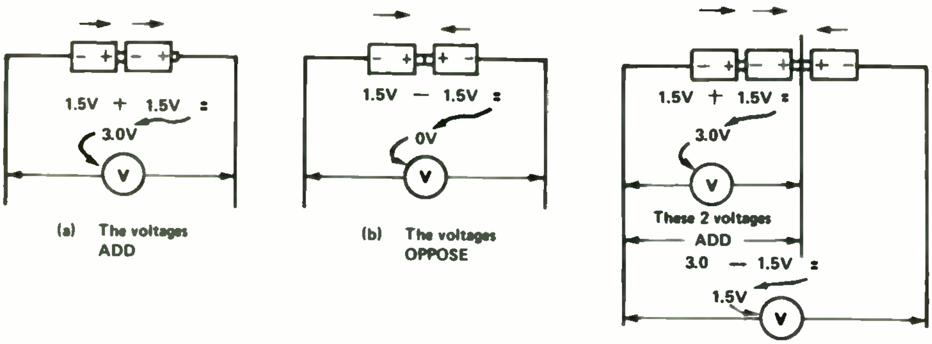


Figure 14 — Illustrating how voltages add

Adding and Subtracting Voltages

In Fig. 14 we have drawn again the four dry cells in the same relationship as in Fig. 13. We can now connect the four voltmeters to read the four voltages. The cells are properly connected in series, and as we progress from one to four dry cells, it can be seen that the voltages increase as they should. But, let us reconnect these dry cells in a number of different ways (Fig. 15).

Diagram (a) illustrates that the voltages add, because the arrows are in the same direction. Diagram (b) shows how the voltages oppose, because the arrows are in opposite direction, while diagram (c) shows a combination of both the addition of voltages and the opposition of voltages, as indicated by the arrows.



(a) The voltages ADD

(b) The voltages OPPOSE

(c) and finally the voltages OPPOSE

Figure 15 – Voltages may be added or subtracted, depending upon how they are connected in series

There are many other ways that we could group dry cells to illustrate how voltages may be added or subtracted, but the one important fact demonstrated here is the simplicity in which voltages may be added or subtracted. If we use a schematic representation of what we illustrated pictorially with the dry cells, we can determine additional facts about an electrical circuit.

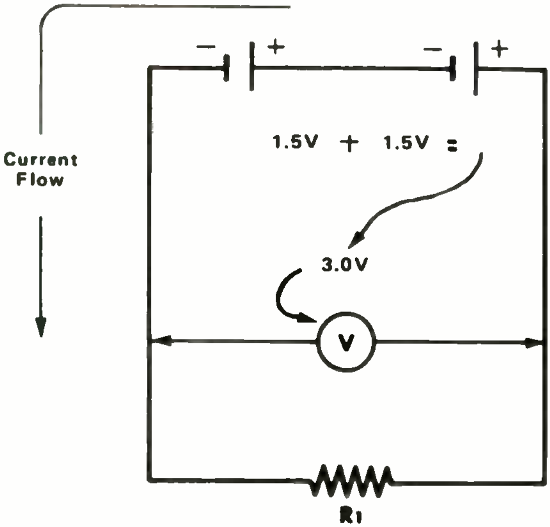


Figure 16 – The voltage drop in the circuit is always equal to the supply voltage

Voltage Drop

Fig. 16 shows two dry cells in series totaling a supply voltage of 3 volts. We have added a resistor and "closed" the circuit electrically, and by completing the circuit, we have allowed current to flow.

> **NOTE:** Because we do not know the value of the resistor, we cannot calculate the current flow. It is always necessary when applying Ohm's law to have two known values to determine the remaining one that is unknown.

The voltmeter indicates 3 volts are available from the power supply, from the two dry cells. It is important to realize that we also have 3 volts *across* the resistor. The 3 volts from the dry cells equal the 3 volts of "voltage drop" across the resistor. The term "voltage drop" means that the force of the voltage across the actual physical length of the resistor is dropping in value. As an electron moves around a circuit, it gradually loses the energy with which it started. When it arrives at the positive terminal, it is at a zero energy level. The original "force" is gradually dropping in value, and the total loss is called the total "voltage drop". Because the total energy delivered by the power source is always used in the remainder of the circuit, such as in a resistor or in a light bulb, the total "voltage drop" around a circuit is always equal to the supply voltage.

This concept of voltage drop is important to understand. A good way to visualize the decreased voltage along a resistance is to replace the resistor R_1 (Fig. 16) with a length of resistance wire having the same value. The resistance wire is supported between two insulators, and a number of voltmeters have been used to indicate the actual value of voltage that exists along the length of resistance wire (Fig. 17).

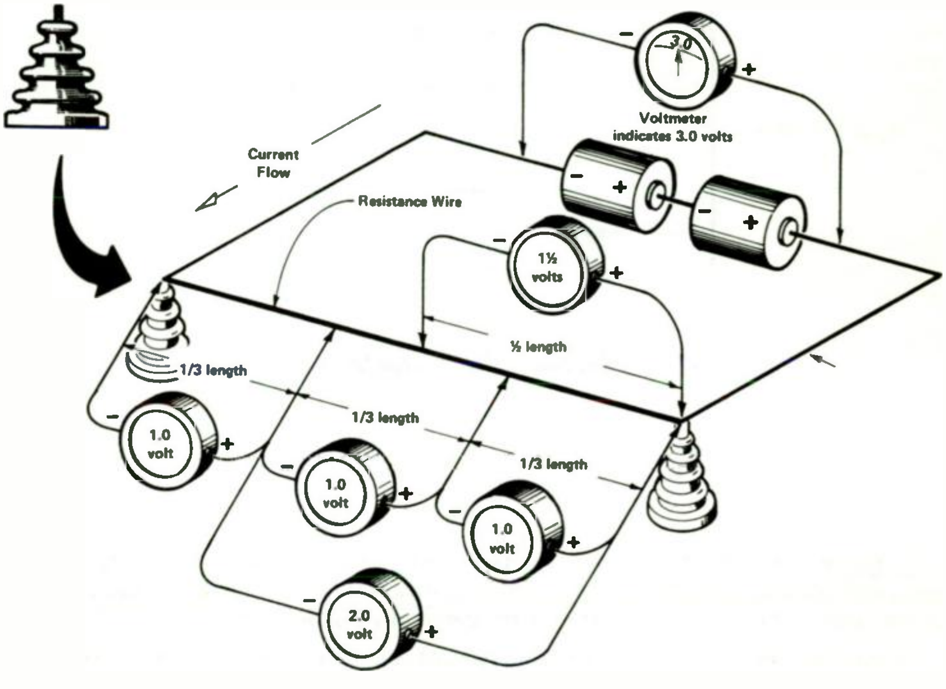


Figure 17 — Illustrates the use of a length of resistance wire to show how voltage drop exists along a resistance. The same values of voltage drop exist along the wire no matter what the actual resistance of the wire is.

Using a Voltmeter

Notice the polarity signs at each voltmeter. These polarity signs are important because the positive (+) terminal of the voltmeter must be connected to the positive (+) terminal of the power supply, or the needle of the meter will be forced backward to the left of the "zero" mark on the meter. If the voltage of the power source is "high" enough, it could bend the needle, damage the meter and necessitate its repair.

Adding Voltage Drops

The voltage drops indicated by the voltmeters total 3 volts equaling the 3 volts supplied by the two dry cells. If the three voltmeters that indicate 1 volt are totalled, the result is 3 volts. If the voltmeter that indicates 2 volts is added to the voltmeter on the left, indicating 1 volt, the result is also 3 volts of voltage drop. If you divide the total length of resistance wire into ten equal parts, you would discover that any one of these short equal lengths would indicate 0.3 volts on the voltmeter. We would again total 3 volts when we added all ten of the individual voltmeter readings of 0.3 volts each.

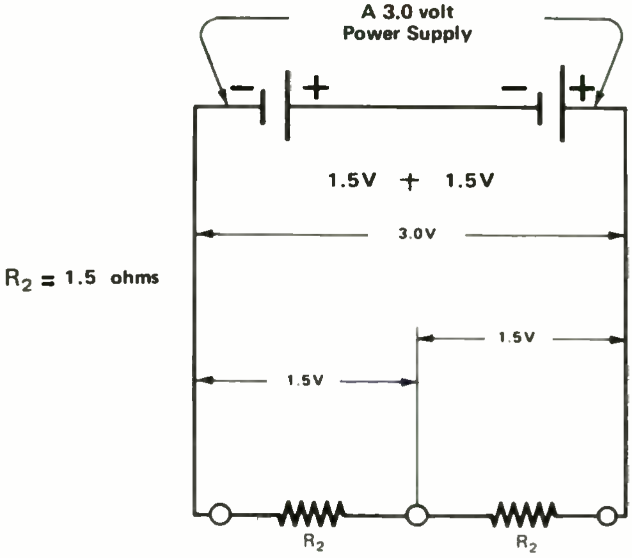


Figure 18 – The sum of the voltage drops equals the supply voltage

In Figure 18 we have drawn Figure 16 again. This time we have used two resistors that are equal in resistance. Both resistors are identified as R_2 because they are equal in value and have a total resistance of 3 ohms, but an individual resistance of 1.5 ohms each.

Again the 3 volts from the power supply must equal the 3 volts that exist across the two resistors. We no longer need to use the voltmeter symbol, since we only need to indicate the actual voltages by the numbers.

Applying Ohm's law to this circuit will enable us to determine the current flow through the circuit.

$$\frac{E}{R} = \frac{3 \text{ volts}}{3 \text{ ohms}} = 1 \text{ amp in the circuit.}$$

We must use the total resistance in the circuit to calculate the total current. Knowing the current, however, we can determine the voltage *across* each resistor again using Ohm's law.

$E = IR$ or Electromotive Force = Current x Resistance, or

Current x Resistance = Voltage, or

1 amp. of current	x	3 ohms of resistance	=	3 volts of EMF

This calculated value of 3 volts is the voltage drop across the total resistance, R_2 and R_2, which is a total of 3 ohms.

Ohm's law provides a powerful means of obtaining a great deal of information about what is occurring in an electrical circuit. Previously we have used it simply to determine *current* and *voltage drop,* but there are many other ways to apply it.

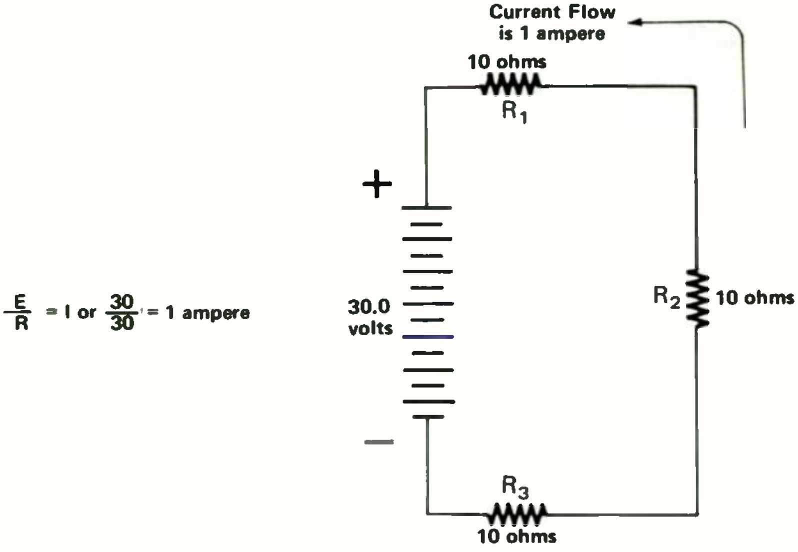


Figure 19 – Calculation of current flow in the circuit

Fig. 19 is a drawing of a circuit containing a source of voltage and three resistors. To determine current, we use

$$\frac{E}{R} = I \quad \text{or} \quad \frac{30 \text{ volts}}{30 \text{ ohms}} = 1 \text{ amp.}$$

Since the current value is known the voltage drop for each resistor can be calculated by using

$E = IR$ or 1 amp x 10 ohms = 10 volts.

Because each resistor has the same value of resistance, only one calculation is needed for the voltage drop across any one of the resistors (Fig. 20).

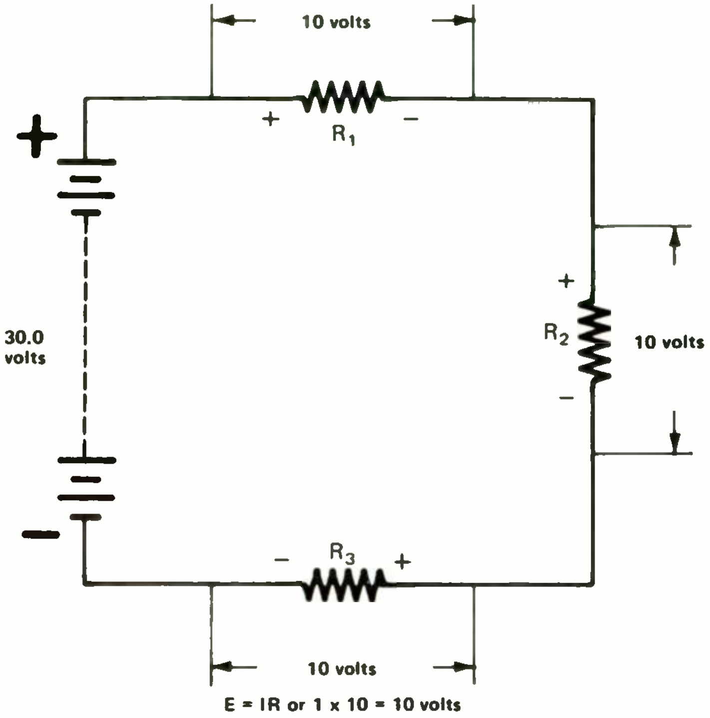


Figure 20 — Calculation of voltage drop across each resistor

Also shown is the polarity that exists at each end of each of the three resistors. It might appear that this drawing is in error, because it appears that the connecting wire between each resistor has both a + and a − polarity assigned to it. Notice, however, that the polarities on each end of each resistor have a + and a − polarity, and it is this pair of polarities that relate to each other. A polarity by itself has no meaning since a positive polarity (+) can be assigned to a voltage only when it is positive (+) with respect to a negative(−) potential.

Relationship of Polarities

High potential was discussed at the beginning of this lesson. It was explained that this high potential existed only with respect to a lower potential. We can illustrate this "difference of potential" between a high and a low potential by redrawing Fig. 20. The negative terminal of the battery is placed on the top of a desk and the positive terminal on the floor. The resistors are spaced from the desk top to the floor (Fig. 21). The polarities were also reversed from their positions in Fig. 20. This reversal shows that there is nothing fixed about the manner in which polarities must be shown. Notice, however, that the *relationship* of *all* of the polarities in this circuit have not changed. They bear the same inter-relationship that they did in Fig. 20.

The current flows from a high potential to a low potential as if the current were water flowing down the incline formed by the resistors. If it were water flowing downhill, each of the three resistors must be replaced by small diameter pipes that would offer

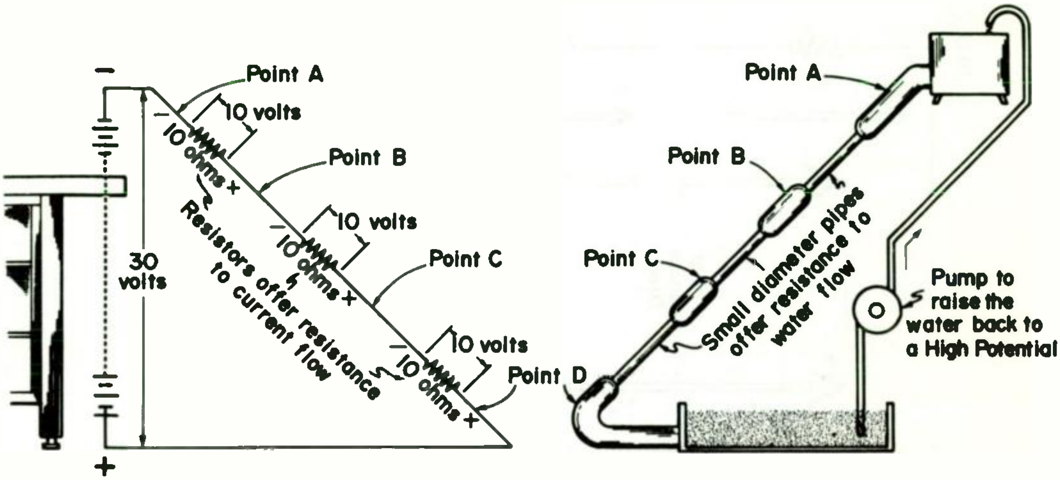


Figure 21 — Illustrates voltage drop across resistors and shows its similarity to a drop in water pressure

resistance to the flow of the water. The right side of the illustration shows a piping system built with large and small diameter pipes. The large diameter pipes represent the copper conductors having low resistance, and the small diameter pipes represent high resistance. The force of the water is greatest at point A and decreases to a zero value at point D.

On the left side of the drawing,

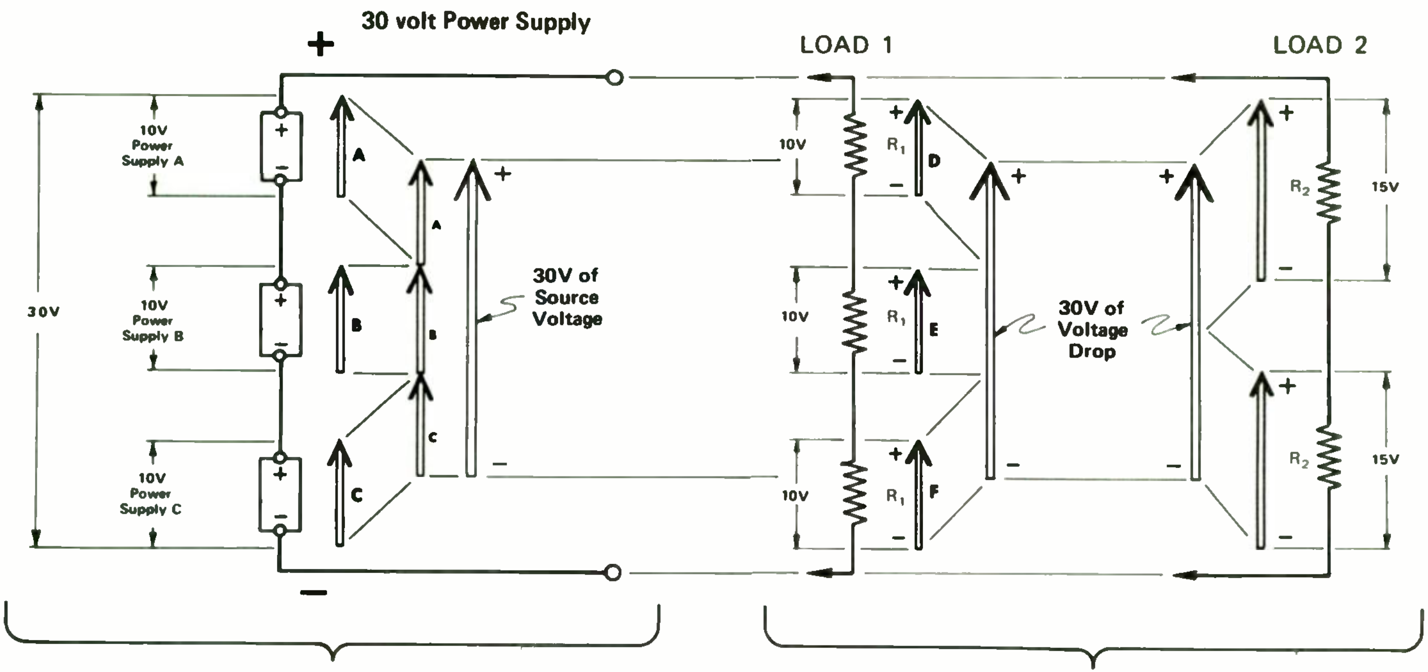
Point A is 10 volts *different* than Point B;
Point B is 10 volts *different* than Point C; and
Point C is 10 volts *different* than Point D.

The proper way to state this would be to say that there is a "difference of potential" between Points A and B, between Points B and C, and between Points C and D. This "difference of potential" is 10 volts *across* each resistor. These three voltages total 30 volts which is in opposition to the supply voltage of 30 volts.

Electrical Loads

Fig. 22 is a method of illustrating how voltages may be totalled by using arrows to represent voltages. The arrow is used to represent the value of the source voltage and is pointed in a direction from negative to positive. The three arrows drawn beside each of the three power supplies, under the section headed "30 Volt Power Supply," have the same length. In Fig. 22 this length is arbitrarily equivalent to 10 volts. Each arrow points in the same direction to signify that the three power supplies are wired in series to combine their three voltages to produce the 30 volt source voltage.

These three arrows, marked A, B, and C beside the power supplies, were moved, so the tip of each arrow would touch the tail of the arrow in front of it. They were then replaced by the single long arrow to represent the source voltage of 30 volts.



Individual voltages may be represented by arrows A, B, & C, which may be added to form a new long arrow equal to the sum of the three smaller ones.

Individual voltage drops across each resistor in both Load 1 and Load 2 may also be represented by arrows. These arrows add also, and "buck" the arrows from the voltage source, when either load is connected.

Figure 22 — A representation of electrical loads

To the right of this 30 volt power supply are two loads that could be connected to the power supply. LOAD 1 is a representation of the same three resistors that are used in the circuits (Figs. 19, 20 and 21) with the addition of three arrows to represent the three voltage drops across them. These three arrows, D, E and F have been combined into the single long arrow representing the total voltage drop that exists *in opposition* to the single long arrow representing the source voltage.

If LOAD 1 is replaced by LOAD 2, the 30 volts from the voltage source is now applied to the two equal-valued resistors R_2. Since the input voltage must be opposed by 30 volts of voltage drop and LOAD 2 is composed of two equal resistors, the 30 volts is divided between the two resistors. This can be determined without a need to calculate the actual voltage drop.

LOAD 1 was drawn with three resistors to show that each 1 volt from a power source must have a corresponding 1 volt of voltage drop. In LOAD 1, this equality was illustrated by three power supplies of 10 volts each and three resistors of equal resistance to provide the three required 10 volts of voltage drop. In LOAD 2, there are only two resistors of equal value, which means that the 30 volts of voltage drop are distributed equally, or 15 volts is "dropped" across each resistor.

No matter what the load might be, it will absorb the product of the voltage (E) that is impressed on it and the current (I) that flows through it. The voltage and current supplied to a load, whether the load is a radio, a washing machine or a TV receiver, is consumed as power.

CALCULATING POWER IN A LOAD

Power Dissipation

When the voltage that exists across a resistor and the current that flows through it are known, the power that is dispersed in the resistor can be calculated.

The power consumed in a resistor is used as heat. A good example of this conversion of electrical energy into heat is the electric toaster. The resistance wire used in the toaster is designed to reach a visible red heat, while the resistors used in electronics are generally used to reduce supply voltages to the values required in various parts of the electrical circuit.

The resistors used in radio and TV circuits are small molded, carbon resistors that handle small amounts of current. Consequently, they develop small amounts of power that must be turned into heat. But they exert this energy or force as electrical power. Such an example would be a 100 watt lamp or any electrical device that requires 100 watts of power to operate properly.

Webster's dictionary defines power that deals with electrical action as

1. the capability of producing . . . power;
2. the force, strength;
3. the physical force or energy, as electric power; and
4. the capacity to exert physical force or energy, usually in terms of the rate or results of its use, as 60 watt power.

Definition of Electrical Power

The unit of electrical power is the watt, and the numerical value is defined as

1 Watt	=	1 Ampere	x	1 Volt
of		of current		of pressure
power		flowing		applied

The components in electronic circuits are small and generally do not consume much power. These components are not devices that convert energy into power, like an electric drill; but all electrical components consume power and generate some heat, which requires a calculation of their power handling capability.

Calculation of Total Wattage

A circuit with a number of resistors as the load is shown in Figure 23. This circuit is similar to Fig. 19, except the values have been changed. The first step is to calculate the current flow.

$$I = \frac{E}{R} = \frac{30 \text{ volts}}{10 \text{ ohms}} = 3 \text{ amperes of current.}$$

The total wattage consumed in this circuit is

Watts = Volts x Current or $W = EI$ or $30 \times 3 = 90$ watts.

The wattage for each resistor is determined by the same formula. Before we can do this, however, we must determine the voltage that exists across each resistor, using Ohm's law, $E = IR$. We can put this information in the form of a table of data:

I Current in Amperes	Times	R Resistance in Ohms	Equals	E Voltage Drop in Volts
3	x	4	=	12
3	x	1	=	3
3	x	5	=	15
				30

If the last column of voltages are added, they will total 30 volts which is the voltage drop across the entire circuit, and is the identical 30 volts used to calculate the total wattage developed in the circuit.

The easiest formula to determine wattage is $W = E \times I$, which we used to calculate the 90 watts of power in Fig. 23. Other wattage formulas can also be obtained from Ohm's law. We can substitute either

(a) $E = IR$

or

(b) $I = \frac{E}{R}.$

Starting with $W = EI$, we can replace the E with (a) above and obtain

$W = E \times I$; and since $E = IR$, we can obtain

$W = IR \times I = I^2R.$

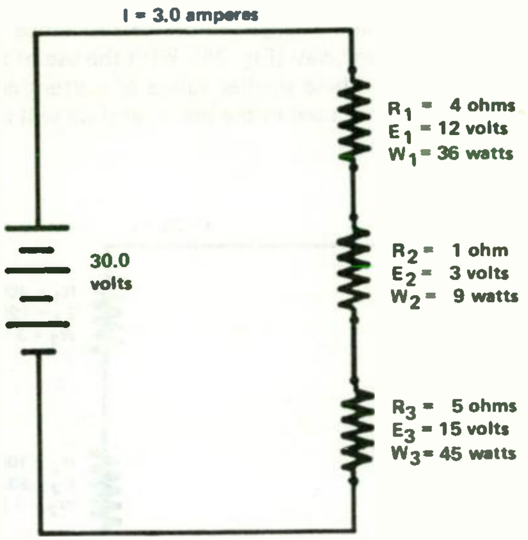


Figure 23 — All important information about this circuit is listed on the circuit diagram

Another form may be developed by substituting (b) above for the I in the formula for watts. Thus,

$W = E \times I$; and since $I = \frac{E}{R,}$ we can obtain

$$W = E \times \frac{E}{R} = \frac{E^2}{R.}$$

Using the data from Figure 23, we can verify all three formulas.

$W = EI$	$W = I^2R$	$W = \frac{E^2}{R}$
$W = 30 \times 3$	$W = 3 \times 3 \times 10$	$W = \frac{30 \times 30}{10}$
$W = 90$ watts	$W = 90$ watts	$W = 90$ watts

With these three formulas, wattage can be computed if any two of the values of E, I or R are known.

Calculations of Wattage for Each Component

The wattage of each individual resistor may now be calculated and listed in the following table:

Formula	E Voltage Drop in Volts	Times	I Current in Amperes	Equals	W Power in Watts
$E_1I = W$	12	x	3	=	36
$E_2I = W$	3	x	3	=	9
$E_3I = W$	15	x	3	=	45
					90

An electronic circuit containing larger values of resistance and a higher voltage power supply is analyzed in the same way (Fig. 24). With the use of such large resistances, the current will be much smaller. These smaller values of current are similar in range to those found in electronic equipment used in the home, and we will be using similar values of current and voltage in future study.

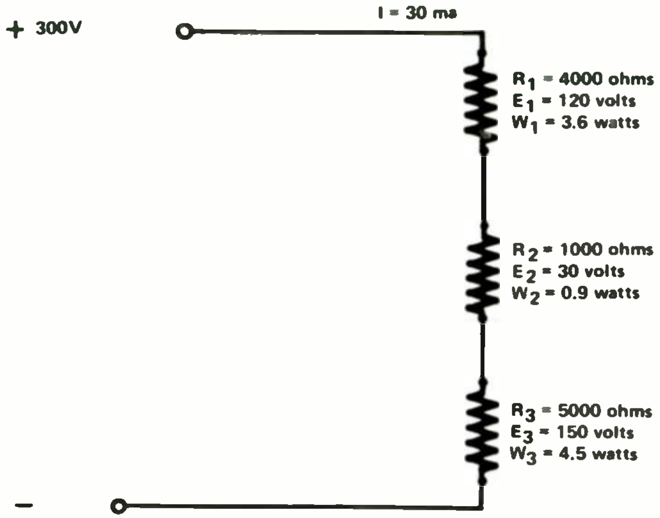


Figure 24 — A representative electronic circuit

The power supply on this drawing has not been sketched, but simply indicated as an input voltage of 300 volts. This voltage will provide power and eventually return to the power supply through the negative connection (—). All computations to determine current (I), voltage (E) and wattage (W) are solved below.

$$\text{Current}\quad I = \frac{E}{R} = \frac{300\text{ volts}}{10{,}000\text{ ohms}} = ?\ \text{current}$$

To solve this, we write

$$\begin{array}{r} .03 \\ 10{,}000\,\overline{)\,300.00} \\ \underline{300.00} \\ \text{no remainder} \end{array}$$

NOTE: Put as many places here as there are in the divisor.

The correct answer is

$$I = \frac{E}{R} = \frac{300}{10{,}000} = .03\text{ amperes} = 30\ \text{milliamperes.}$$

Definition of a Milliampere

Milliamperes is a simpler form of expressing the flowrate than 0.03 amps (read as "three-hundredths of an ampere"). The relationship of an amp to a milliampere is the same relationship that a ten dollar bill has to one penny.

1 Ten Dollar Bill	=	1000 pennies.
1 Ampere	=	1000 milliamperes.

This relationship shows that a milliampere is one one-thousandth of an amp. A few milliamperes frequently represents the amount of current used in an electronic circuit. The term milliamperes is generally spoken of as milliamps, and many times is simply called "mils." On diagrams that list the current, this value of 30 milliamps, which is equivalent to the 0.03 amperes, would be written as "30 ma."

The use of milliamps rather than amps will become easier as we investigate additional circuits. In the present circuit, use the value of 30 ma to calculate the voltage drop. For the first resistor R_1, we calculate voltage drop as

$E_1 = IR_1$ or 30 ma x 4000 ohms =

0.030 amperes x 4000 ohms = 120 volts.

To solve this we write

$$\begin{array}{r} 4000 \\ \underline{.03} \\ 120.00 \end{array}$$

NOTE: To locate the decimal point we must

1. Add the total number of figures and zeros above the line that are located to the right of the decimal points, and
2. count off the same number of "places" below the line from right to left.

The two other voltage drops are figured in a similar manner. To solve for E_2 and E_3,

$E_{R_2} = IR_2 =$ 30 ma x 1000 ohms =

= 0.030 amperes x 1000 ohms = 30 volts.

$E_{R_3} = IR_3 =$ 30 ma x 5000 ohms =

= 0.030 amperes x 5000 ohms = 150 volts.

Since the voltage drops across each resistor have been determined, the wattage ratings may be calculated. Setting up a table will be an easy way to list all of the data.

		E Voltage Drop in Volts	x	I Current in Amperes	=	W Power in Watts
E_{R_1}	=	120	x	0.030	=	3.6
E_{R_2}	=	30	x	0.030	=	0.9
E_{R_3}	=	150	x	0.030	=	4.5
						9.0

A verification of the total wattage in the circuit can be made by using the value of the total voltage drop and the total resistance. This is

W = EI = 300 volts x 0.030 amp = ? watts.

We solve this by multiplying and obtaining

$$\begin{array}{rl} & 300 \text{ volts} \\ \times & .03 \text{ amperes} \\ \hline & 9.00 \text{ watts,} \end{array}$$

by placing the decimal point two places to the left of the last zero. Thus, the calculation of the total wattage of 9 watts for the total load of the three resistors equals the sum of the individual wattages.

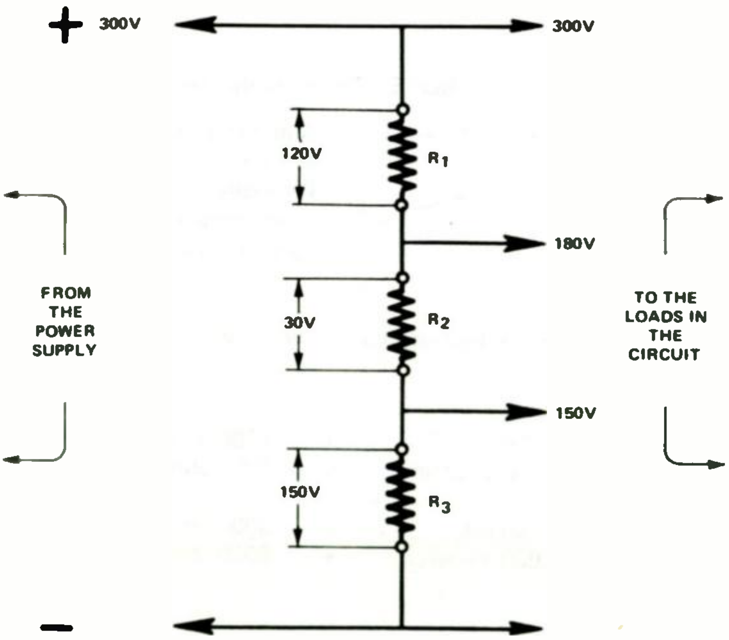


Figure 25 — A voltage dividing network

Voltage Dividing Network

The electronic circuit that has just been analyzed is drawn again (Fig. 25). It is a circuit from an electronic device that required three different values of DC voltage, namely 150 volts, 180 volts and 300 volts. With the use of the "voltage dropping resistors", R_1, R_2, and R_3, the three required voltages have been obtained.

This arrangement of resistors is called a "voltage dividing network", because

(a) the voltage is "divided" as required, and
(b) the voltage is divided by a network of resistors.

A single voltage source can be used to supply any number of different voltages necessary for the proper operation of vacuum tubes and transistors, which by their design and use in circuits require different operating voltages.

SUMMARY

Direct current is the name of the electrical energy that flows only in one direction in a circuit. The electrons flow from the negative terminal through the load and to the positive terminal of the power source. The power source may be a single cell, a battery or an electronic power supply, but the theory of operation of the circuit is the same.

An electrical circuit consists of (a) a power supply, (b) a device or a load to consume the electrical energy from the power supply and (c) the wires that connect all units together. The load may be any component that converts the electrical energy into another useful form, such as conversion into light, heat, or power.

Voltage is the pressure or force that pushes the current through an electrical circuit, while current is the quantity of energy that is pushed. The higher the voltage, the greater the current flow through a fixed load. The lower the resistance of the load, the greater the current flow.

Both conductors and insulators are important in electrical work. Metals that have low resistance are considered to be good conductors, and materials that resist electron flow are called insulators.

LESSON SEVEN
DIRECT CURRENT

TEST

1. The power required to operate an electrical device is measured in

A. volts.
B. amperes.
C. current.
[✓ D.] watts.

2. Direct current can be obtained from

A. only a dry cell.
B. only a battery.
C. only a DC power source.
[✓ D.] all of the above.

3. The amount of current that flows in a DC circuit is established exactly by

A. the total resistance of the circuit.
B. The polarity connected to the resistor.
C. knowing the value of the voltage.
[✓ D.] knowing the value of the voltage source and the resistance.

4. An electric toaster converts electricity into

[✓ A.] heat.
B. current.
C. voltage drop.
D. wattage.

5. Ohm's law is a tool to calculate

A. current only.
B. voltage only.
C. wattage only.
[✓ D.] any one of the above quantities if the two other quantities are known.

6. If 200 volts are applied across the two equal resistors in series, the voltage drop across each resistor

[✓ A.] is one-half of the applied voltage.
B. is equal to the applied voltage.
[✓ C.] cannot be determined without knowing the value of current flowing in the circuit.
D. is 200 volts.

7. Doubling the voltage applied to a load will

[✓ A.] double the current.
B. lower the power.
C. halve the current.
D. increase the resistance.

8. A watt is determined by

[✓ A.] E x I
B. I x R
C. E + I
D. I + R

9. The resistance of a 100 watt lamp used on a 115 volt house circuit can be determined by using these relationships of Ohm's law.

[✓ A.] W = EI and $\frac{E}{I} = R$
B. E + I = W and E + R = I.
C. only W and E
D. it is impossible to determine.

10. An ampere is an indication of

A. how fast electrons are moving.
B. the number of electrons that are moving.
[✓ C.] the number of electrons that flow past a point in one second.
D. none of the above.

$\frac{P}{E} = I$ $\frac{100\ W}{115\ V}$ 0.87 amp

$R = \frac{E}{I}$ $\frac{115}{.87} = 132$ ohm

NOTES

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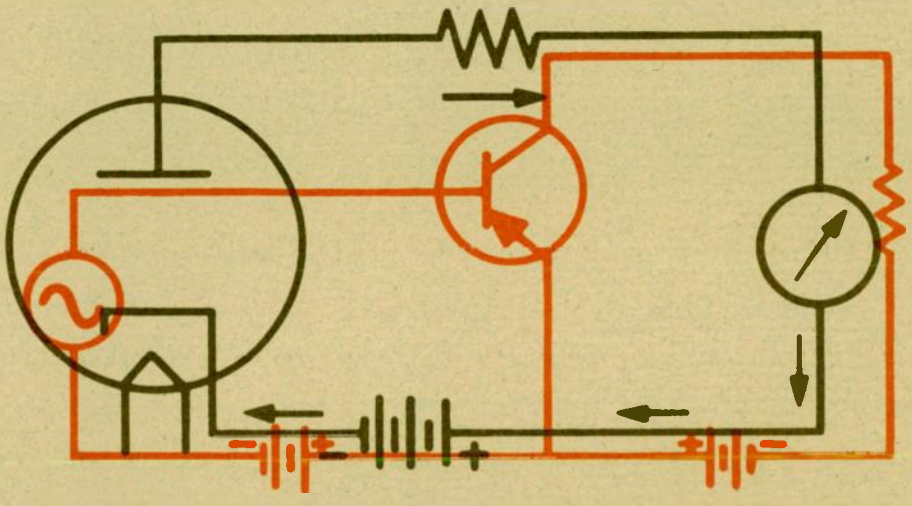
LESSON NO. 8

RESISTORS AND RESISTANCE



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Contents

RESISTORS AND RESISTANCE

INTRODUCTION

Every material offers some resistance or opposition to the flow of electric current. Good conductors, such as copper, silver and aluminum, offer little resistance. Poor conductors or insulators, such as glass, wood and paper, offer a high resistance to current flow.

DEFINITION OF RESISTANCE

Webster defines "resistance" as

(a) the property of opposing the passage of a current, causing electrical energy to be transformed into heat;

(b) any device, such as a coil or length of wire, that offers such resistance;

(c) a resistor.

The size and type of material of the wires in an electric circuit are chosen to keep the electrical resistance as low as possible. Current can thus flow easily through the conductors, just as water flows freely through a large diameter pipe. The smaller the diameter of the pipe, the smaller the flow of the water in gallons per second.

In the electric circuit, the larger the diameter of the wires, the lower their electrical resistance or opposition to the flow of current through them. In the water analogy, pipe friction opposes the flow of water through the pipe. This friction is similar to electrical resistance. A comparison of the factors that determine both kinds of resistance are listed here to show their similarity.

The resistance of the pipe to the flow of water through it depends upon

(1) the length of the pipe,

(2) the diameter of the pipe,

(3) the nature of the inside walls (rough or smooth).

The electrical resistance of the conductor depends upon

(1) the length of the wire,

(2) the diameter of the wire,

(3) the material of the wire, (copper, aluminum, etc.).

This relationship is shown in Figure 1.

Temperature also affects the resistance of electrical conductors to some extent. In most conductors, such as copper, aluminum and iron, the resistance increases with temperature. Carbon is an excep-

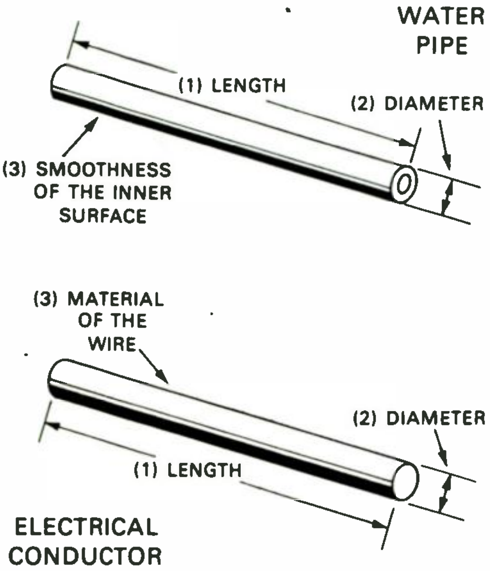


Figure 1—Resistance to flow of water and current.

tion. In carbon the resistance decreases as temperature increases. Certain alloys of metals (manganin and constantan) have resistance that does not change appreciably with temperature.

Specific Resistance of Metals

The relative resistance of several conductors of the same length and cross section is given in the following list, with silver as a standard of 1.0 and the remaining metals arranged in an order of ascending resistance.

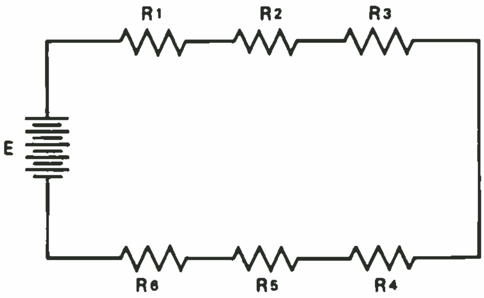
Silver	1.0
Copper	1.08
Gold	1.4
Aluminum	1.8
Platinum	7.0
Lead	13.5

The resistance in an electrical circuit is expressed by the symbol R. Manufactured circuit parts containing definite amounts of resistance are called *resistors*. Resistance (R), as we reviewed previously, is measured in ohms. One ohm is the resistance of a circuit element or circuit that permits a steady current of 1 amp (1 coulomb per second) to flow when a steady EMF of 1 volt is applied to the circuit.

RESISTORS IN SERIES

In a previous lesson it was stated that resistances in series are added to determine the total resistance in the circuit, and we solved problems using resistors in series. We identified each one of the resistors on the circuit diagram by an R_1 R_2 and R_3 . . . . But we have shown the concept of adding these resistors to make up the total resistance (R_T) for identification (Fig. 2). This relationship can be shown by a formula.

When a battery nears the end of its useful life, its internal resistance rises rapidly which decreases its output voltage. Consequently, this internal resistance must be considered and must be added to



$$R_T = R_1 + R_2 + R_3 + R_4 + R_5 + R_6$$

Figure 2—Adding resistors in series.

the other resistors in the circuit to calculate the true current flow. For example, R_1 (Fig. 2) might be the internal resistance of battery E and the internal resistance is simply added to the other resistors.

USING K FOR 1000

This formula for adding resistors is a convenient way of expressing what we have learned in the lesson, DIRECT CURRENT. It holds for all values of resistors, no matter how large or small they may be. In a number of previous examples, we used resistors of 4000 ohms and 5000 ohms and placed these large numbers on the circuit diagram. Since we will use resistors much larger than these when we are inspecting electronic circuits, we will begin using the simpler way of writing large values of resistors. The accepted practice is to let the letter "K" stand for 1000; thus, 4000 ohms would be written 4K.

The use of K for 1000 comes from the word "kilo" which stands for 1000 in the metric system. Kilo is in everyday use by electric utilities who charge their customers for kilowatts of power (kw) and is used on some radio dials to indicate the frequency of transmitting stations. The AM Broadcast Band covers the frequency from 540 kHz to 1600 kHz, indicating that the frequency of the radio wave is from

540,000 hertz (540 kHz) to
1,600,000 hertz (1,600 kHz).

Until now we have used only two abbreviations for numbers:

milli (meaning one-thousandth of 1), and

kilo (meaning one thousand times 1).

From time to time, other abbreviations for small and large numbers will be introduced, and they will become familiar and easy to apply as we use them in practical applications.

NOTE: Within the last few years, the term "cycles per second" has been changed to "hertz", in honor of Hertz, a founder in the field of radio. The same honors have been given to Ampere, Volta, Maxwell, Ohm, Faraday and others.

RESISTORS IN PARALLEL

The application of one of Ohm's laws will enable us to calculate the resistance of light bulbs that we use in our home, without using either a voltmeter or an ammeter.

One of the power formulas that can be used is this relationship:

$$P = EI \text{ or } \frac{P}{E} = I.$$

Because the voltage in the United States is standardized at 120 volts, we need not measure it. This value of voltage is not constant and might vary from 110 volts during periods of heavy use to 120 volts when the current demand is light. The power companies try to maintain a constant voltage by regulating it, but this voltage does vary from time to time.

Calculating Resistance by Two Methods

If we assume that the voltage is 120 volts, and we are considering a 60 watt bulb, we would have

$$\frac{P}{E} = I \text{ or } \frac{60 \text{ watts}}{120 \text{ volts}} = 0.5 \text{ amps}$$

Knowing that the current is 0.5 amps, compute the resistance by substituting in the formula

$$R = \frac{E}{I} \text{ or } \frac{120 \text{ volts}}{0.5 \text{ amps}} = 240 \text{ ohms}$$

which is the resistance of a 60 watt bulb.

Two calculations were needed to determine the resistance with the previous method, but we could have calculated the resistance in one step, using another formula of Ohm's law. This formula states that

$P = \frac{E^2}{R}$, which after transposing or exchanging P and R, may be rewritten as

$$R = \frac{E^2}{P} \text{ or } R = \frac{E \times E}{P}$$

E^2 means that the value E is used in the formula as many times as the number indicates. If we substitute the only two values that we know, which are 120 volts and 60 watts, the result is

$$R = \frac{E \times E}{P} \text{ or } R = \frac{120 \times 120}{60}$$
$$= \frac{120 \times 2}{1} = 240 \text{ ohms}$$

This is the same answer we obtained using the previous two-step method rather than this single computation. Either formula results in the same answer. Use the computation that is easiest to apply.

In these computations, we have assumed that the 60-watt bulb was in use with the filament hot. The resistance of a hot lamp is many times higher than when it is cold.

Single Bulb Circuit

This 60-watt bulb could be one bulb in a table lamp connected to an electrical wall outlet (Fig. 3).

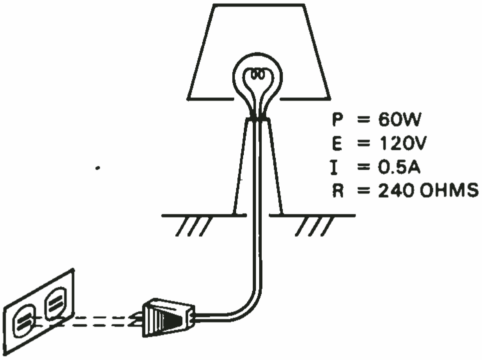


Figure 3—Electrical constants for a single lamp.

We know all of the important electrical constants of this lamp. In Figure 4, two lamps are connected to the same 120-volt supply by their individual cords and plugs, and the constants for each lamp are the same. The current flowing in each lamp cord is 0.5 amps, because the resistance of the 60-watt bulb is 240 ohms.

Double Bulb Circuit

Now investigate the electrical constants of a single table lamp

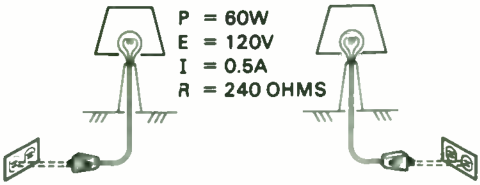


Figure 4—Electrical constants are the same for each lamp.

that combines two 60-watt bulbs (Fig. 5). The wattage in this lamp is twice as much, but the voltage from the power supply is the same.

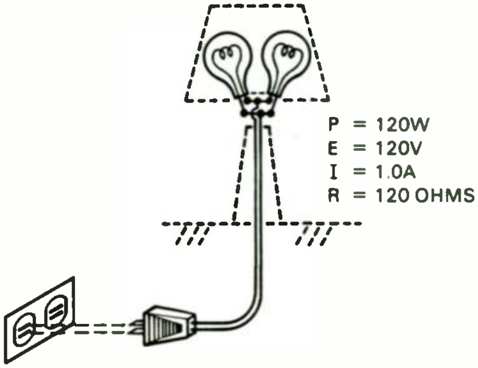


Figure 5—Electrical constants for two 60 watt lamps from a single cord.

The current through the electrical cord from the wall outlet is doubled, because two bulbs require twice as much current as one bulb. With the voltage the same but the current doubled, the resistance is

$$R = \frac{E}{I} \text{ or}$$

$$\frac{120 \text{ volts}}{1 \text{ amp}} = 120 \text{ ohms.}$$

If we drew this two bulb table lamp again, using electrical symbols, the circuit diagram could be as shown in Figure 6.

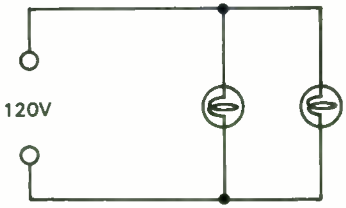


Figure 6—Representation of Figure 5, using electrical symbols.

However, a more basic circuit could be drawn (Fig. 7). The bulbs are shown as resistors R_1 and R_2. When we use basic electrical symbols in this manner, every electrical circuit is reduced to its simplest form. This simpler form makes it easy for us to analyze the electrical action of the circuit.

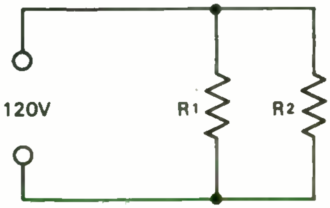


Figure 7—An equivalent representation of two lamp bulbs.

Division of Current

The 1 amp of current that is provided by the power supply must divide equally to supply 60 watts of power to each resistor. The resistance of both R_1 and R_2 is 240 ohms, which is the resistance of each bulb.

The amount of current that flows through each resistor is determined by

$$\frac{E}{R} = I \text{ or } \frac{120}{240} = 0.5 \text{ amp.}$$

This 0.5 amp of current is the same for each branch circuit, because each resistor has the same value of resistance. The important fact developed here is that current divides equally when the resistance in the two branch circuits is the same. The circuit in Figure 8 illustrates how currents divide, and we can indicate the relationship of the currents:

$$I_T = I_1 + I_2.$$

This is a convenient way of stating that the total current I_T is composed of the individual currents I_1 and I_2 in the two branches.

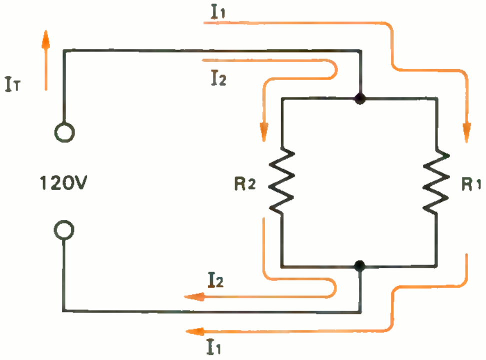


Figure 8—The sum of branch currents equals the total current.

PARALLEL CIRCUITS

We have introduced a number of new concepts in which we have developed some principles of parallel electrical circuits. A parallel circuit is one that has more than one path for current flow. The lamp with two bulbs is one of the simplest examples of a parallel circuit. Another example is the two headlights on an automobile that are connected in parallel.

One new method used to determine the amount of current that must be supplied by a power source to a circuit with resistors connected in parallel is to calculate each branch current individually. Then simply add the individual branch currents to obtain the total current. This is a cumbersome method that requires many individual calculations.

A simple method of determining the equivalent resistance has been developed through a combination of certain formulas. When the value of the equivalent resistance has been determined and the value of the applied voltage is known, a simple application of Ohm's law will allow computation of the value of the total current.

$$I_{total} = \frac{E_{total}}{R_{equivalent}}$$

Symbol for Ohms

Because we will be dealing with a number of examples using resistors, we will use the symbol for the word ohms that appears on a great number of electrical diagrams. The symbol for ohms comes from a letter in the Greek alphabet that is similar in shape to the first letter in the word ohm. The Greek letter is *omega,* and it is shaped and used like this:

$$300 \text{ ohms} = 300\ \Omega$$

With this symbol joining the others we have used, our list of abbreviations is:

P stands for power.

E	stands for voltage in Ohm's law.
V	is used on circuit diagrams after an indicated voltage, such as 120V.
I	stands for current.
R	stands for resistance.
W	stands for watts.
Ω	stands for ohms.

An understanding of electrical action in parallel circuits can be obtained by starting with a simple parallel circuit. Various methods used to determine the total resistance in parallel circuits will then be described.

Equal Resistors in Parallel

In Figure 9, two resistors with a resistance value of 10 ohms each are connected across a 5-volt battery. A complete circuit consisting of two parallel paths is formed, and current will flow as shown. The resistors are shown here as long, square-sided tubes for a reason that will become apparent later.

Computing the individual currents shows that there is 0.5 amps of current flowing through each resistor. Accordingly, the total current flowing from the battery to the junction of the resistors and returning from the resistors to the battery is equal to 1 amp.

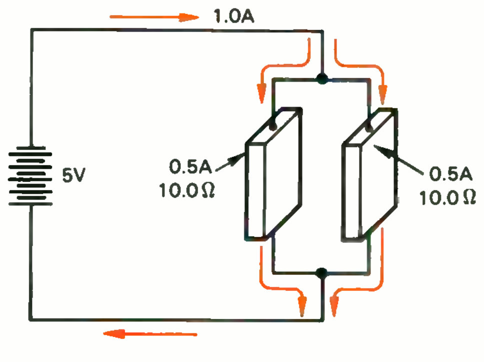


Figure 9—Two equal resistors connected in parallel.

The total resistance of the circuit can be determined by substituting total voltage and current into the following equation. This equation is derived from Ohm's law.

$$\text{Total Resistance} = R_t = \frac{E_t}{I_t}$$

$$= \frac{\text{Total voltage}}{\text{Total current}}$$

$$R_t = \frac{5}{1} = 5 \text{ ohms}$$

This computation shows the total resistance to be 5 ohms, one-half the value of either of the two resistors.

Since the total resistance of this parallel circuit is smaller than either of the two resistors, the term "total resistance" does not mean the sum of the individual resistor values in every case; the total resistors in parallel is also referred to as "equivalent resistance".

Equivalent Resistance

There are several methods to determine the equivalent resistance of parallel circuits. The most appropriate method for a particular circuit depends upon the number and the value of the resistors.

For the circuit described in Figure 9 with two equal value parallel resistors, the following simple equation is used:

Equivalent Parallel Resistance is

$$R_{eq} = \frac{R \quad \text{the ohmic value of one resistor}}{N \quad \text{the number of parallel resistors.}}$$

This equation is valid for any number of equal valued parallel resistors.

The equivalent resistance of two parallel resistors is smaller than the resistance of either of the two resistors. Examine Figure 9. The two 10-ohm resistors have fixed equal volumes. If the resistors were combined into one resistor (Fig. 10), the volume would double. If the same length is retained and the volume doubled, the cross-sectional area will double. When the cross-sectional *area* of a material is increased, the resistance is *decreased* proportionately.

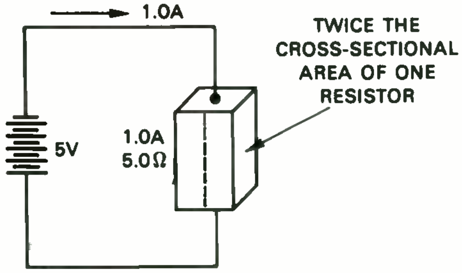


Figure 10—An equivalent parallel circuit.

Since, in this case, the cross-sectional area is twice the original area, the resistance is one-half the former value. Therefore, when two equal valued resistors are connected in parallel, they present a total resistance of one-half the value of either of the original resistors.

We can illustrate another example of the application of this simple formula for equal valued resistors. When four 40-ohm resistors are connected in parallel, their equivalent resistance is

$$R_{eq} = \frac{R}{N} = \frac{\text{40 ohms each}}{\text{4 resistors}}$$

$$= \text{10 ohms.}$$

Unequal Resistors in Parallel

Circuits containing parallel resistance of *unequal* value will now be considered (Fig. 11). All the information that is known about this circuit is shown on the circuit diagram.

As long as we know the
  total voltage applied to the
    load and the
  total current supplied to the
    load,
Ohm's law allows us to compute the
  total equivalent resistance of
    the load:

$$R_{eq} = \frac{E}{I} = \frac{30}{15} = 2 \text{ ohms.}$$

Notice that the equivalent resistance of 2 ohms is less than the value of either branch resistor. In parallel circuits, the equivalent resistance will always be smaller than the resistance of any branch.

Product Over the Sum Formula

There is a convenient formula for finding the equivalent resistance

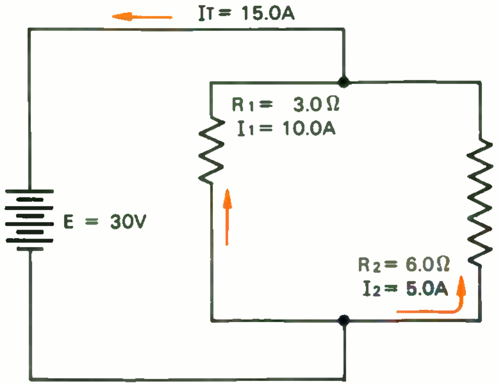


Figure 11—A circuit with unequal parallel resistors.

of two parallel resistors of unequal value. This formula is used so frequently that it can be easily remembered.

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$

Multiply the two values of resistance and then add them. Divide the sum into the product and obtain the answer.

With this formula we can determine the equivalent resistance of a 20-ohm and a 30-ohm resistor connected in parallel. The solution for the equivalent resistance R_{eq} is

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$

$$R_{eq} = \frac{20 \times 30}{20 + 30} = \frac{600}{50}$$

$$R_{eq} = 12 \text{ ohms}$$

Examples

Here are three examples of how to use this formula when two parallel resistors are of unequal value.

★*Example 1:*
2 resistors of 200 and 300 ohms.

Solution:
The product of
$200 \times 300 = 60{,}000$
The sum of
$200 + 300 = 500$
Dividing
60,000 by 500 = 120 ohms.

★*Example 2:*
2 resistors of 25 and 75 ohms.

Solution:
The product of
$25 \times 75 = 1{,}875$
The sum of
$25 + 75 = 100$
Dividing
1875 by 100 = 18.75 ohms.

★*Example 3:*
2 resistors of 40 and 60 ohms.

Solution:
The product of
$40 \times 60 = 2{,}400$
The sum of
$40 + 60 = 100$
Dividing
2400 by 100 = 24 ohms.

SERIES—PARALLEL CIRCUITS

In preceding discussions and lessons, series and parallel circuits have been considered separately, but seldom is a circuit encountered that consists of either type of circuit alone. Combinations of series and parallel circuits are easy to analyze when each of the elements in the circuit are handled separately, and

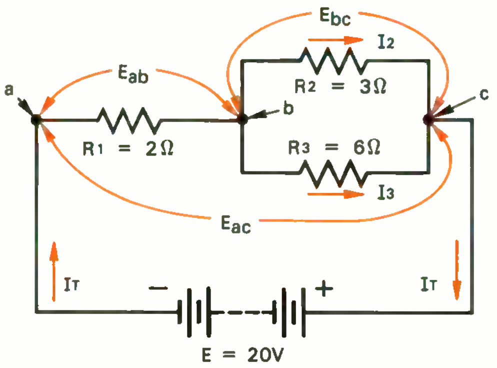


Figure 12—R_1 is in series with the parallel combination of R_2 and R_3.

the results are combined. A basic series-parallel circuit is shown in Figure 12.

The total resistance (R_t) (Fig. 12) is determined in two steps. First, the equivalent resistance of the parallel combination of R_2 and R_3 is determined as follows:

$$R_{2,3} = \frac{R_2 \times R_3}{R_2 + R_3} = \frac{3 \times 6}{3 + 6} = \frac{18}{9}$$
$$= 2 \text{ ohms.}$$

Second, the sum of $R_{2,3}$ and R_1, which is the total resistance R_t, is

$$R_t = R_{2,3} + R_1 = 2 + 2$$
$$= 4 \text{ ohms}$$

If the total resistance R_t and the source voltage E are known, the total current I_t may be determined by Ohm's law. Thus, in Figure 12

$$I_t = \frac{E_t}{R_t} = \frac{20}{4} = 5 \text{ amps.}$$

Voltages between Points

If the values of the various resistors and the current through them are known, the voltage drops across the resistors may be determined by Ohm's law.

$$E_{ab} = I_tR_1 \quad = 5 \times 2 = 10 \text{ volts, and}$$
$$E_{bc} = I_tR_{2,3} = 5 \times 2 = 10 \text{ volts.}$$

The term E_{ab} identifies the voltage E that exists between points a and b (Fig. 12), and E_{bc} identified the voltage that exists between points b and c. Again, terms E_{ab} and E_{bc} are shorter ways of expressing the voltage drops that exist between certain points in an electrical circuit.

KIRCHOFF'S VOLTAGE LAW

According to Kirchoff's voltage law, the sum of the voltage drops around the closed circuit is equal to the source voltage.

Thus,

$$E_{ab} + E_{bc} = E_{ac} \text{ or}$$
$$10 + 10 = 20 \text{ volts.}$$

If the voltage drop E_{bc} across the equivalent resistance $R_{2,3}$ is known (that is, the drop between points b and c), the current through the individual branches may be determined.

$$I_2 = \frac{E_{bc}}{R_2} = \frac{10}{3} = 3.333 \text{ amps}$$

and

$$I_3 = \frac{E_{bc}}{R_3} = \frac{10}{6} = 1.666 \text{ amps}$$

KIRCHOFF'S CURRENT LAW

Kirchoff's current law states that the sum of the currents flowing in the individual parallel branches is equal to the total current.

Thus,

$$I_2 + I_3 = I_t$$

or

$$3.333 + 1.666 = 5 \text{ amps}$$

The total current flows through R_1, and at point b, it divides between the two branches in inverse proportion to the resistance of each branch. Twice as much current goes through R_2 as through R_3, because R_2 has one-half the resistance of R_3. Therefore,

3.333 + or two-thirds of 5 amps flows through R_2, and

1.666 + or one-third of 5 amps flows through R_3, and the sum totals 5.000 amps.

Another type of series-parallel circuit is illustrated when R_1 is in parallel with the series combination of R_2 and R_3 (Fig. 13). $R_{2,3}$ is determined as follows:

$$R_{2,3} = R_2 + R_3 = 2 + 10$$
$$= 12 \text{ ohms (series circuit)}$$

The total resistance R_t is the result of combining $R_{2,3}$ in parallel with R_1, or

$$R_t = \frac{R_{2,3} \times R_1}{R_{2,3} + R_1} = \frac{12 \times 6}{12 + 6}$$
$$= 4 \text{ ohms.}$$

If the total resistance R_t and the source of voltage E are known, the total current I_t may be determined by Ohm's law (Fig. 13). Thus,

$$I_t = \frac{E_t}{R_t} = \frac{20}{4} = 5 \text{ amps.}$$

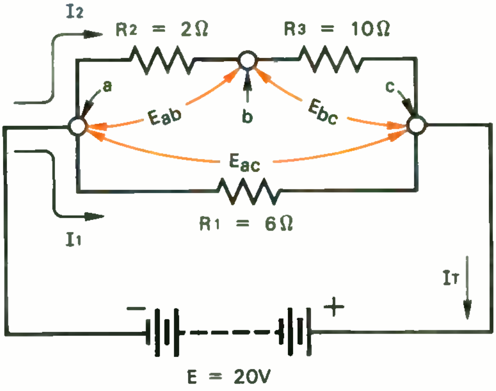


Figure 13—R_1 is in parallel with the series combination of R_2 and R_3.

Part of the total current flows through the series combination of R_2 and R_3, and the remainder flows through R_1. Because current varies inversely with the resistance, two-thirds of the total current flows through R_1, and one-third flows through the series combination of R_2 and R_3, because R_1 is one-half the resistance of $R_2 + R_3$.

The source voltage E is applied between points a and c, and therefore, the current I_1 through R_1 is

$$I_1 = \frac{E}{R_1} = \frac{20}{6} = 3.333 \text{ amps,}$$

and the current I_2 through $R_{2,3}$ is

$$I_2 = \frac{E}{R_{2,3}} = \frac{20}{12} = 1.666 \text{ amps.}$$

According to Kirchoff's current law, the sum of the individual branch currents is equal to the total current, or

$$I_t = I_1 + I_2$$
$$5 = 3.333 + 1.666$$

COMBINATION CIRCUITS

Combination circuits are composed of a number of resistors arranged in numerous series and parallel combinations. In more complicated circuits, special theorems, rules and formulas are used. These are based on Ohm's law and provide faster solutions for particular applications. Series formulas are applied to the series parts of the circuit, and parallel formulas are applied to the parallel parts. For example, the total resistance R_t (Fig. 14) may be obtained in three logical steps.

First, as R_3, R_4 and R_5 are in series (that is, only one path for current), they may be combined (Fig. 15) to determine the resistance R_s of the three resistors.

Thus,

$$\begin{aligned} R_s &= R_3 + R_4 + R_5 = 5 + 9 + 10 \\ &= 24 \text{ ohms,} \end{aligned}$$

and it is now in parallel with R_2, because they both receive the same voltage.

Second, the combined resistance R_s in parallel with R_2 (Fig. 16) is

$$\begin{aligned} R_{s,2} &= \frac{R_2 \times R_s}{R_2 + R_s} = \frac{8 \times 24}{8 + 24} = \frac{192}{32} \\ &= 6 \text{ ohms.} \end{aligned}$$

Third, the total resistance R_t is determined by combining resistors R_1 and R_6 with $R_{s,2}$ (Fig. 17):

$$\begin{aligned} R_t &= R_1 + R_6 + R_{s,2} \\ &= 2 + 12 + 6 = 20 \text{ ohms.} \end{aligned}$$

WIRE SIZES

Copper Wire

Wires are manufactured in sizes numbered according to a table known as the American Wire Gauge (AWG). The wire diameters become smaller as the gauge numbers become larger. The largest wire size shown in the table is Number 1, and the smallest is Number 40 (Fig. 18).

Circular Mil

The circular mil is the standard unit of wire cross-sectional area used in American and English wire tables. Because the diameters of round conductors or wires that conduct electricity may be only a small fraction of an inch, it is convenient to express these diameters in mils to avoid the use of decimals. For example, the diameter of a wire is expressed as 25 mils rather than 0.025 inch. A circular mil is the area of a circle having a diameter of 1 mil. The area in circular mils of a round conductor is obtained by squaring the diameter measured in mils. Thus, a wire having a diameter of 25 mils has an area of 25^2 or 625 circular mils.

The table (Fig. 18) gives relevant information about copper wire. Using this table, it is possible to estimate the resistance of a length of copper wire. For example, No. 22 wire is 25.3 mils in diameter (0.0253 inches) and has a nominal resistance of 16.5 ohms per 1000 feet. It is obvious that 100 feet of No. 22 wire has a resistance of 1.65 ohms.

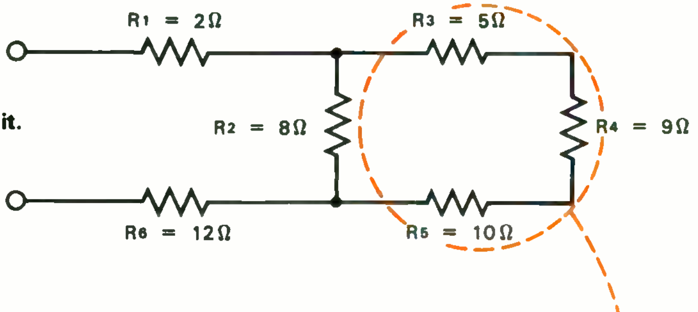


Figure 14—Original Circuit.

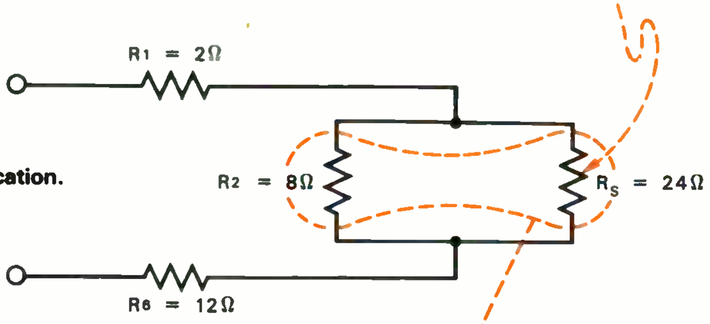


Figure 15—First Simplification.

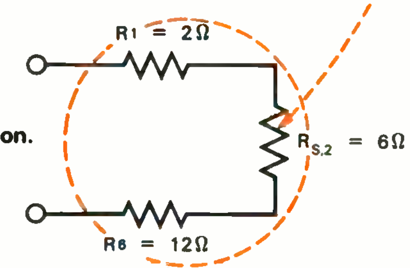


Figure 16—Second Simplification.

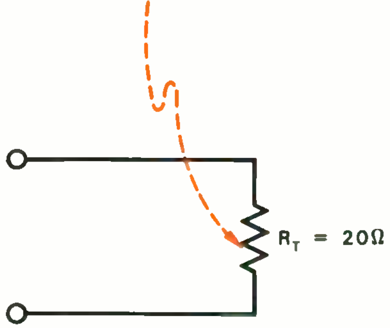


Figure 17—Equivalent Circuit.

Gage number	Diameter in mils	Cross section		Ohms per 1,000 ft.	Pounds per 1,000 ft.
		Circular mils	Square inches	At 25°C. (=77°F.)	
1	289.0	83,700.0	.0657	.126	253.0
2	258.0	66,400.0	.0521	.159	201.0
3	229.0	52,600.0	.0413	.201	159.0
4	204.0	41,700.0	.0328	.253	126.0
5	182.0	33,100.0	.0260	.319	100.0
6	162.0	26,300.0	.0206	.403	79.5
7	144.0	20.800.0	.0164	.508	63.0
8	128.0	16,500.0	.0130	.641	50.0
9	114.0	13,100.0	.0103	.808	39.6
10	102.0	10,400.0	.00815	1.02	31.4
11	91.0	8,230.0	.00647	1.28	24.9
12	81.0	6,530.0	.00513	1.62	19.8
13	72.0	5,180.0	.00407	2.04	15.7
14	64.0	4,110.0	.00323	2.58	12.4
15	57.0	3,260.0	.00256	3.25	9.86
16	51.0	2,580.0	.00203	4.09	7.82
17	45.0	2,050.0	.00161	5.16	6.20
18	40.0	1,620.0	.00128	6.51	4.92
19	36.0	1,290.0	.00101	8.21	3.90
20	32.0	1,020.0	.000802	10.4	3.09
21	28.5	810.0	.000636	13.1	2.45
22	25.3	642.0	.000505	16.5	1.94
23	22.6	509.0	.000400	20.8	1.54
24	20.1	404.0	.000317	26.2	1.22
25	17.9	320.0	.000252	33.0	0.970
26	15.9	254.0	.000200	41.6	0.769
27	14.2	202.0	.000158	52.5	0.610
28	12.6	160.0	.000126	66.2	0.484
29	11.3	127.0	.0000995	83.4	0.384
30	10.0	101.0	.0000789	105.0	0.304
31	8.9	79.7	.0000626	133.0	0.241
32	8.0	63.2	.0000496	167.0	0.191
33	7.1	50.1	.0000394	211.0	0.152
34	6.3	39.8	.0000312	266.0	0.120
35	5.6	31.5	.0000248	335.0	0.0954
36	5.0	25.0	.0000196	423.0	0.0757
37	4.5	19.8	.0000156	533.0	0.0600
38	4.0	15.7	.0000123	673.0	0.0476
39	3.5	12.5	.0000098	848.0	0.0377
40	3.1	9.9	.0000078	1,070.0	0.0299

Figure 18—Copper wire table.

RESISTORS

Resistor Types

The two general types of resistors are: the wire wound and the carbon type (Fig. 19). Resistors are rated according to their maximum power handling capacity rather than by their maximum safe voltage and current limits. Consequently, a resistor may be used in circuits with widely different operating voltages, depending upon the de-

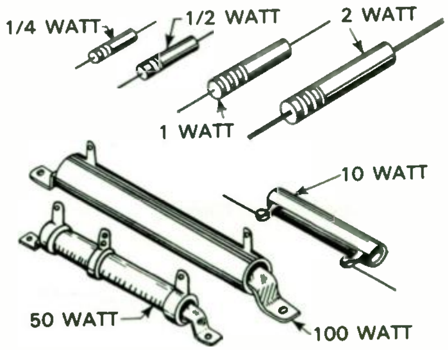


Figure 19—Resistors of different wattage ratings.

sired current. However, the resistor has a maximum current limitation to each voltage applied to it. The product of the resistor's voltage and current at any time must not exceed a certain wattage.

Thus, resistors are rated in watts, in addition to their ohmic resistance. Resistors of the same resistance value are available in different wattage values. Carbon resistors, for example, are commonly made in wattage ratings of ¼, ½, 1, and 2 watts (Fig. 19). The larger the physical size of a carbon resistor, the higher its wattage rating, because a larger amount of material will absorb and give up heat more easily.

Wire wound resistors are manufactured in ranges between 5 to 200 watts, with special types used for power in excess of 200 watts.

Resistor Tolerances

Resistors have a tolerance rating in addition to ohmic value and wattage rating. The tolerance rating of a resistor indicates the closeness to its stated value of resistance. The closer the actual value of the resistor to its stated resistance, the higher its cost. Carbon resistors are made on high speed, high volume production machinery, and each resistor is segregated according to its tolerance range. Both the diameter and the length of the individual resistors have a manufacturing tolerance, which accounts for this variation of resistance in production (Fig. 20).

Resistor Wattage Ratings

The selection of a safe wattage value is based on the working conditions of the resistor in the circuit. Consider the use of an 850 ohm resistor which has a tolerance of ±20 percent. Suppose the normal voltage across the resistor is 40 volts. Because of the 20 percent tolerance, the actual resistance of the replacement may be as much as 1,020 ohms or as little as 680 ohms. With the lesser value, which is the more unfavorable from a heat-producing standpoint, the power that may develop in the resistor under circuit conditions is found as follows:

$$P = \frac{E^2}{R}$$

$$P = \frac{40 \times 40}{680}$$

$P = 2.35$ watts, approximately

A resistor should be capable of dissipating from 1.5 to 2 times the power actually encountered to allow sufficient margin of safety. In this example, the value is less than 4.7 watts.

$$2 \times 2.35 = 4.7$$

Since a 5-watt resistor is the next standard size above the 4.7 watt value, this is a desirable rating for the replacement.

Resistor Color Code

The electronics industry has developed several identification systems for electronic components. Most of the systems use colors on the component to indicate its "elec-

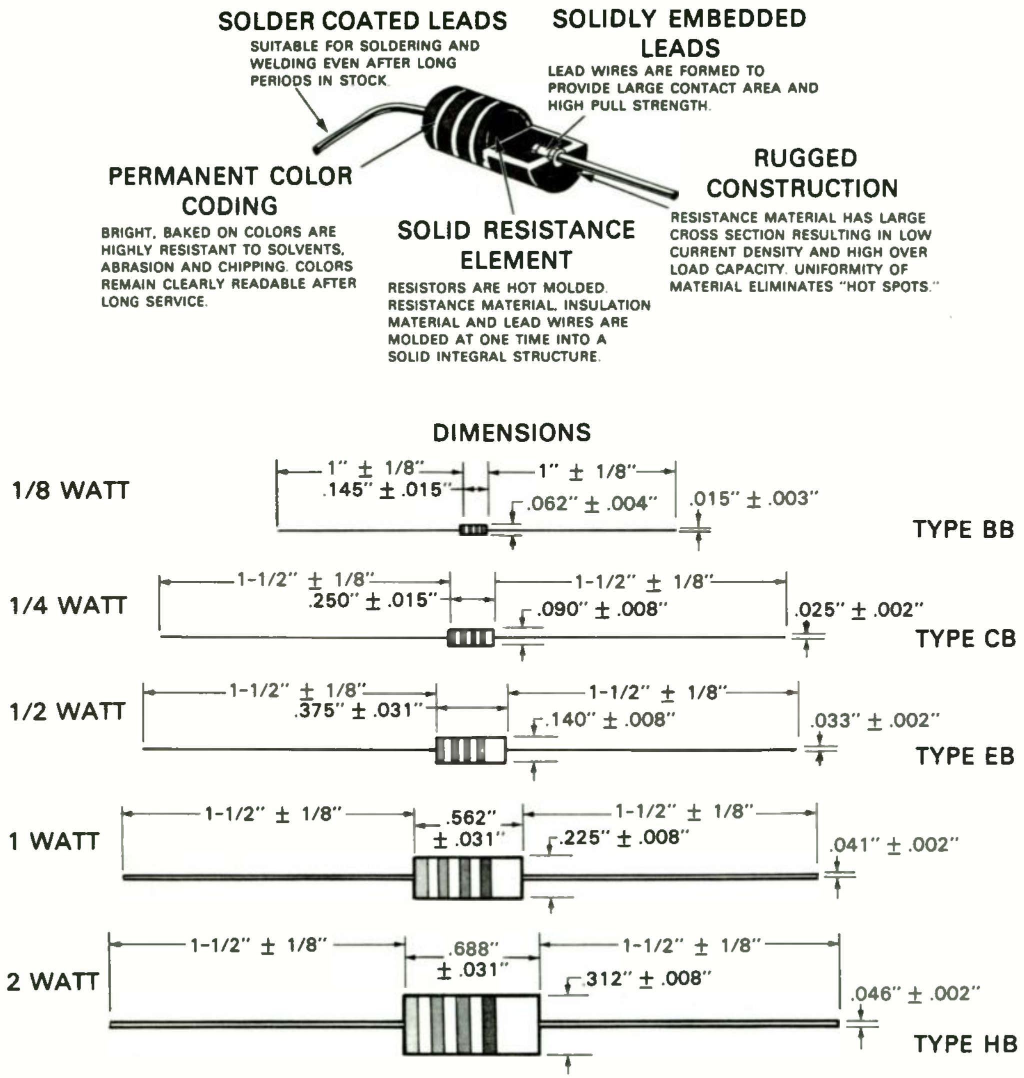


Figure 20—Typical hot molded, fixed resistors (Courtesy Allen-Bradley Company).

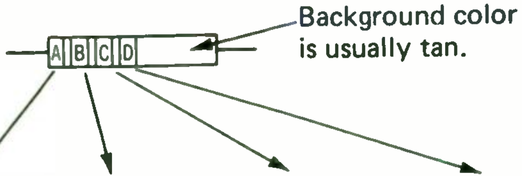
trical value". The resistor color code is shown in Figure 21, and the use of this system is shown in Figure 22.

RESISTOR DESIGN

In addition to classifying resistors as wirewound and composition types, they are further divided into (1) fixed and (2) the (a) adjustable and (b) the variable types.

Wirewound Resistors

Resistors of the wirewound types are made by winding resistance wire over a ceramic tube. It is then covered with an enamel glaze and baked in a high temperature oven.



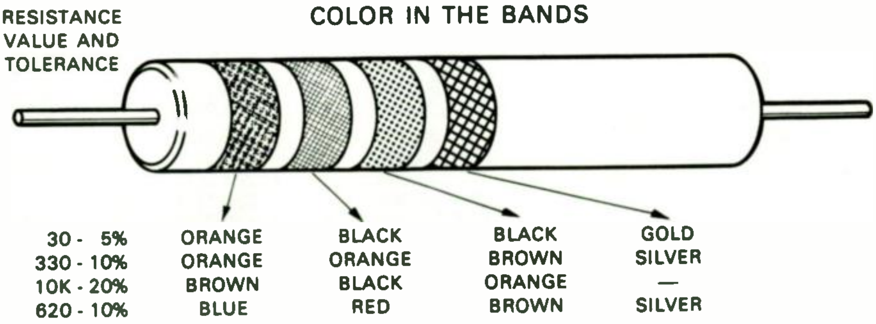
Color	1st Digit A	2nd Digit B	Multiplier C	Tolerance D
Black	0	0	1	—
Brown	1	1	10	± 1%
Red	2	2	100	± 2%
Orange	3	3	1,000	± 3%
Yellow	4	4	10,000	± 4%
Green	5	5	100,000	—
Blue	6	6	1,000,000	—
Violet	7	7	10,000,000	—
Gray	8	8	100,000,000	—
White	9	9	—	—
Gold	—	—	0.1	± 5%
Silver	—	—	0.01	± 10%
No Color	—	—	—	± 20%

-,300

Figure 21—Resistor color code.

As the wires are carefully and uniformly spaced along the entire length, any portion of the total resistance may be obtained by positioning an adjustable slider along the resistor. The use of a slider necessitates a bare area running the length of the resistor, which makes it the adjustable type. If, however, there is no bare strip, it is a fixed, wirewound type.

In addition to the straight line type of resistor, which is usually



RESISTANCE VALUE AND TOLERANCE	COLOR IN THE BANDS			
30 - 5%	ORANGE	BLACK	BLACK	GOLD
330 - 10%	ORANGE	ORANGE	BROWN	SILVER
10K - 20%	BROWN	BLACK	ORANGE	—
620 - 10%	BLUE	RED	BROWN	SILVER

Figure 22—Application of the resistor color code.

B & S	Dia. in Inches	Ohms Per Ft. at 68°F. (20°C.)	Ohms Per Pound Bare Wire	Feet Per Pound Bare Wire	Pounds Per M Feet
000	.410	.004015	.008507	2.119	472.0
00	.365	.005067	.01354	2.673	374.1
0	.325	.006391	.02155	3.372	296.6
1	.289	.008082	.03446	4.264	234.5
2	.258	.01014	.05425	5.350	186.9
3	.229	.01287	.08737	6.789	147.3
4	.204	.01622	.1387	8.554	116.9
5	.182	.02038	.2191	10.75	93.01
6	.162	.02572	.3490	13.57	73.69
7	.144	.03255	.5589	17.17	58.23
8	.128	.04120	.8957	21.74	46.00
9	.114	.05194	1.423	27.40	36.49
10	.102	.06488	2.221	34.23	29.21
11	.091	.08151	3.506	43.01	23.25
12	.081	.1029	5.586	54.29	18.42
13	.072	.1302	8.942	68.68	14.56
14	.064	.1648	14.33	86.96	11.50
15	.057	.2078	22.77	109.6	9.123
16	.051	.2595	35.53	136.9	7.304
17	.045	.3333	58.63	175.9	5.686
18	.040	.4219	93.91	222.6	4.493
19	.036	.5208	143.1	274.8	3.639
20	.032	.6592	229.3	347.8	2.875
21	.0285	.8310	364.3	438.4	2.281
22	.0253	1.055	587.1	556.5	1.797
23	.0226	1.322	921.9	697.4	1.434
24	.0201	1.671	1,473.	881.8	1.134
25	.0179	2.107	2,341.	1,111.	.8997
26	.0159	2.670	3,773.	1,413.	.7099
27	.0142	3.348	5,913.	1,766.	.5662
28	.0126	4.251	9,535.	2,243.	.4458
29	.0113	5.286	14,740.	2,789.	.3586
30	.010	6.750	24,040.	3,561.	.2808
31	.0089	8.523	38,320.	4,496.	.2224
32	.008	10.55	58,710.	5,565.	.1797
33	.0071	13.39	94,560.	7,062.	.1416
34	.0063	17.00	152,600.	8,977.	.1114
35	.0056	21.52	244,500.	11,360.	.08806
36	.005	27.00	384,800.	14,250.	.07020
37	.0045	33.33	586,300.	17,590.	.05686
38	.004	42.19	939,100.	22,260.	.04493
39	.0035	55.10	1,602,000.	29,070.	.03440
40	.0031	70.24	2,603,000.	37,060.	.02698
	.00275	89.29	4,204,000.	47,080.	.02124
	.0025	108.0	6,154,000.	56,980.	.01755
	.00225	133.4	9,381,000.	70,320.	.01422
	.002	168.8	15,030,000.	89,050.	.01123
	.00175	220.6	25,656,000.	116,300.	.00860
	.0015	300.0	47,490,000.	158,300.	.006318
	.0014	344.4	62,580,000.	181,700.	.005504
	.0013	399.4	84,150,000.	210,700.	.004746
	.0012	468.7	115,900,000.	247,300.	.004044
	.0011	557.8	164,200,000.	294,300.	.003398
	.001	675.0	240,400,000.	356,100.	.002808
	.0009	833.3	366,000,000.	439,000.	.002277
	.0008	1,054.6	587,000,000.	557,000.	.001796
	.0007	1,377.5	1,002,000,000.	727,000.	.001378

Figure 23—A representative table of resistance wire values.

adjusted only once for a particular value of resistance, there are continously variable types. These have the resistance wire wound on a doughnut-shaped ceramic. They also have a wiper arm that rotates and makes contact against the wire to provide a continously variable resistance. This latter device is called a rheostat if two electrical connections are used, and a potentiometer if three connections are used (Fig. 24).

Different sizes of resistance wires are used for various ranges of resistance and for different wattage ratings. Figure 23 shows the sizes and specifications of resistance wire that is an alloy of 60% nickel, 16% chromium with the balance iron. This particular alloy is used extensively in the manufacture of wirewound resistors.

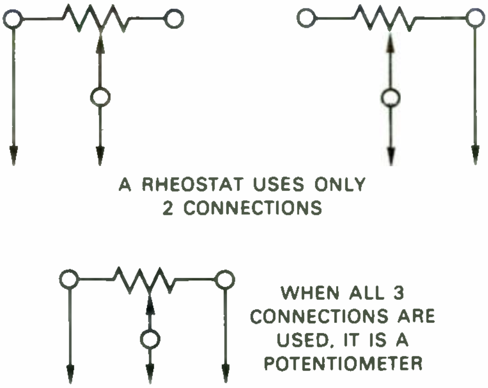


Figure 24—Potentiometers and rheostats.

Carbon or Composition Resistors

The hot molded, fixed resistor consists of a mixture of carbon to conduct the current, a filler material, and a plastic coating for protection. A wire at each end provides electrical contact. The length and diameter of the body determines the wattage rating while the ingredients, the carbon and the filler, determine its resistance.

Rheostat and Potentiometer

Variable resistances composed of a carbon disc and a rotary wiper arm are used in circuits that require a fairly high resistance, but less than one or two watts. This form of variable resistance is also known as a rheostat or a potentiometer. Most of them are used as potentiometers and are more commonly termed "pots" (Fig. 25).

A potentiometer provides a convenient means of obtaining a variable voltage. Figure 26 is the schematic representation of a potentiometer, with the rotary wiper arm at the middle or in the ½ turn position which will supply 50 volts of output voltage. At the ¾ turn position, ¾ of the input voltage is available at the output terminals.

The potentiometer in Figure 26 is known as a linear pot, because the percentage of output voltage is in direct proportion to the percentage of rotation. Other types of potentiometers are built with more resistance per degree of rotation at the beginning of each rotation. The resistance gradually decreases for an equal amount of rotation toward the other end. Still others start with a small amount of resistance per degree of rotation, and then increase in resistance at the end.

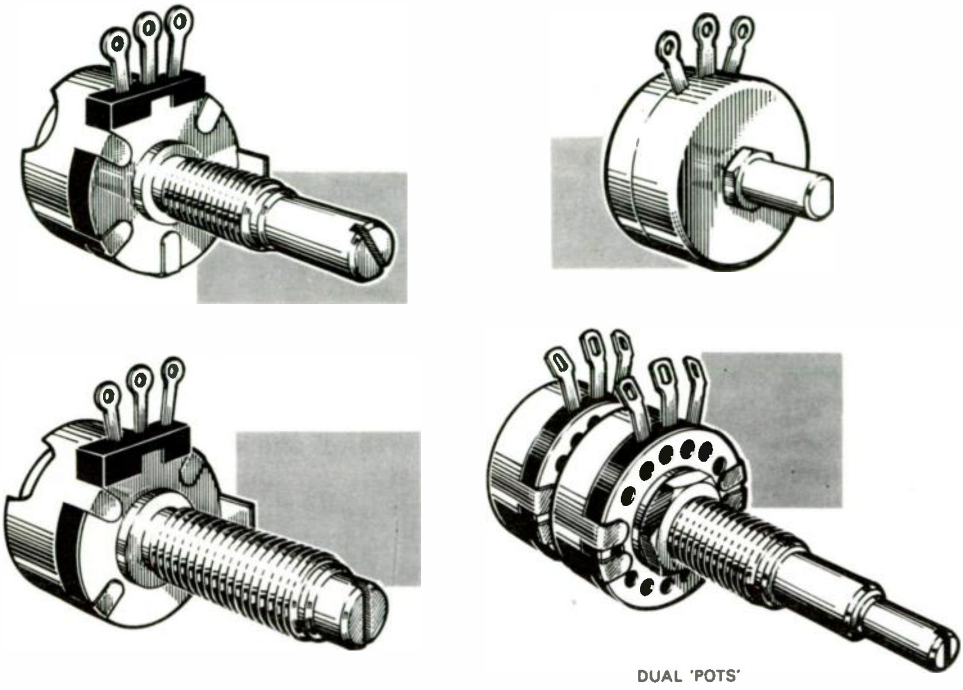


Figure 25—Representative potentiometers.

Other types of potentiometers have most of their resistance at the beginning and end with only a small amount of resistance in the center of rotation. Each specific use will determine the type of pot to be used.

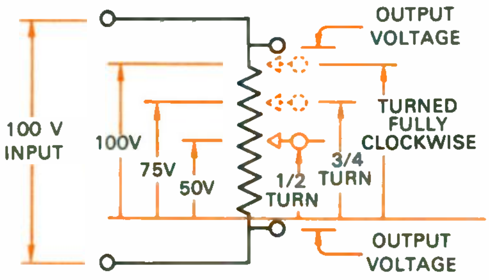


Figure 26—Obtaining variable voltage from a potentiometer.

CIRCUIT PROTECTION

Fuses

When current passes through a resistor, electric energy is transformed into heat which raises the temperature of the resistor. If the temperature becomes too high, the resistor may be damaged. The metal wire in a wound resistor may melt, opening the circuit and interrupting current flow. This effect is used to an advantage in fuses.

Fuses are actually metal resistors with very low resistance values. They are designed to "blow out", and thus open a circuit when current exceeds the fuse's rated value.

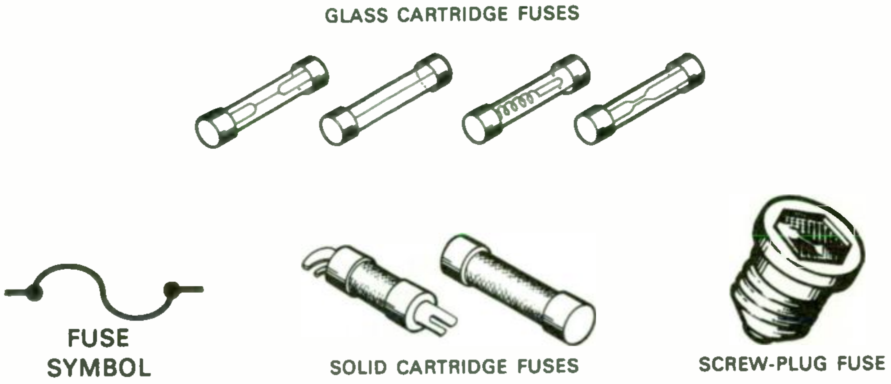


Figure 27—Fuse types.

There are a great number of different types and sizes of fuses presently in use (Fig. 27).

Circuit Breaker

Some newer electronic devices use small electric circuit breakers. Rather than breaking the circuit by permanently destroying itself, as a fuse does, a circuit breaker simply opens the circuit. It may be reactivated by being manually reset (Fig. 28).

ADDITIONAL INFORMATION

The Reciprocal of the Sum of the Reciprocals

The derivation of this "reciprocal" formula is given here for students who are interested. It is not necessary that it be studied or remembered, because the practical applications have previously been explained. The equation is derived as follows:

Given:

$$I_t = I_1 + I_2 + \ldots\ldots\ldots\ldots I_n$$

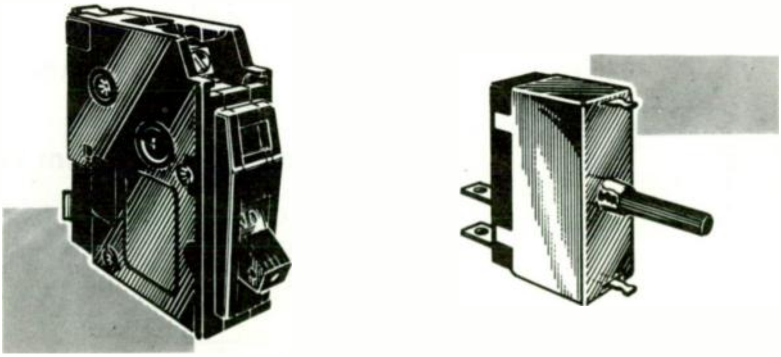


Figure 28—A representative type of circuit breaker.

Substituting $\frac{E}{R}$ for I gives

$$\frac{E_t}{R_t} = \frac{E_1}{R_1} + \frac{E_2}{R_2} + \cdots \cdots \frac{E_n}{R_n}$$

Since in a parallel circuit
$E_t = E_1 = E_2 = E_n$.

$$\frac{E}{R_t} = \frac{E}{R_1} + \frac{E}{R_2} + \cdots \cdots \frac{E}{R_n}$$

Dividing both sides by E

$$\frac{E}{ER_t} = \frac{E}{ER_1} + \frac{E}{ER_2} + \cdots \cdots \frac{E}{ER_n}$$

Therefore

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots \cdots \frac{1}{R_n}.$$

Taking the reciprocal of both sides

$$\frac{1}{\frac{1}{R_t}} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots \cdots \frac{1}{R_n}}$$

Can be simplified as

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots \cdots \frac{1}{R_n}}$$

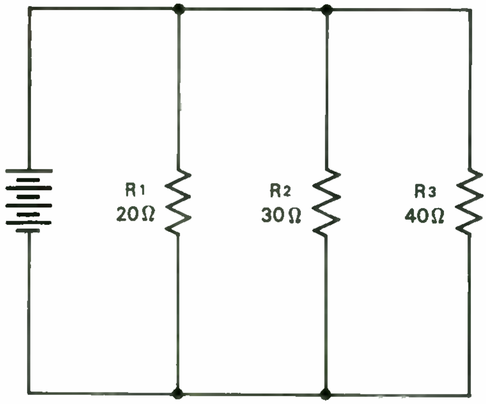


Figure 29—An example of a parallel circuit with unequal branch resistors.

This formula is called "the reciprocal of the sum of the reciprocals" and is normally used to solve for the equivalent resistance of a number of parallel resistors.

For example, if you are given three parallel resistors of 20 ohms, 30 ohms, and 40 ohms, find the equivalent resistance using the reciprocal equation (Fig. 29).

Solution:

Select the proper equation

$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots \frac{1}{R_3}}$$

Substitute

$$R_{eq} = \frac{1}{\frac{1}{20} + \frac{1}{30} + \frac{1}{40}}$$

Find the lowest common denominator.

$$R_{eq} = \frac{1}{\frac{6}{120} + \frac{4}{120} + \frac{3}{120}} = \frac{1}{\frac{13}{120}}$$

Invert

$$R_{eq} = \frac{120}{13}$$
$$= 9.23 \text{ ohms, Answer.}$$

Product Over the Sum Formula

The derivation of the formula for the special case of two resistors in parallel is as follows:

$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2}}$$

Find the lowest common denominator

$$R_{eq} = \frac{1}{\frac{R_1 + R_2}{R_1 \times R_2}}$$

The reciprocal is

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$

SUMMARY

Materials that limit the flow of current in a circuit are called resistors. The value of a resistance can be determined by Ohm's law, if the voltage E and the current I are known.

Resistances in series are added to determine the total resistance in a circuit. This total resistance in a series circuit determines the current flow which has the same value throughout a series circuit. The voltage drop across each series resistor equals the series current I times each resistance value R.

The equivalent resistance of two unequal parallel resistors is determined by using the Product/Sum method. When equal resistances are in parallel, the equivalent resistance is determined by dividing the value of one resistance by the number of resistances. The voltage is the same across parallel resistors whether they are equal or unequal in resistance value.

Series-parallel circuits should be reduced to their simplest form to calculate current flows and voltage drops around the circuit. The equivalent resistance of each parallel combination should be calculated and used to make up the equivalent series circuit. The resulting series resistance can be used to determine the total current flow. Then the branch currents can be determined.

Kirchoff's voltage law explains that the addition of all of the voltage drops across each series resistor will be equal to the supply voltage. Kirchoff's current law states that the total of the individual currents in parallel circuits always equals the current supplied by the power source.

Composition resistors are made with tolerances of 5, 10, and 20 percent.

Both wirewound and composition resistors are identified as fixed, adjustable or variable. They also must be specified by type, resistance value, tolerance, and wattage rating. Fuses are a form of resistor, made with a material that melts when its current rating is exceeded.

This lesson demonstrates the application of Ohm's law to series and parallel circuits. It also shows how the current is the same in a series circuit and is inversely proportional to the resistance in a parallel circuit.

TEST

Lesson Number 8

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-008-1.

1. The resistance of a length of wire is determined by

A. its cross sectional area.
B. the length of the wire.
C. the material from which it is constructed.
[✓ D. all of the above.]

2. Of the following gauges of wire, which has the largest resistance per 1,000 ft.

A. No. 1
[✓ B. No. 40]
C. No. 12
D. No. 8

3. A resistor with 10 ohms of resistance and a resistor with 20 ohms of resistance are connected in series. The total resistance of these two is

A. 6.6 ohms.
[✓ B. 30.0 ohms.]
C. 15.0 ohms.
D. 16.6 ohms.

4. Two resistors are connected in parallel, and each has a resistance of 100 ohms. The parallel connection gives a total resistance of

A. 200 ohms.
B. 150 ohms.
[✓ C. 50 ohms.]
D. 35 ohms.

10

5. The voltage across a resistance can be determined by using

- A. $E = IR$
- B. $R = EI$
- C. $E^2 = PR$
- D. $I = \frac{E}{R}$

9

6. If 5 resistors of 100 ohms each are connected in parallel, the resistance

- A. is $\frac{100}{5} = 20$ ohms.
- B. is $100 \times 5 = 500$ ohms.
- C. is $100 \times 5 \div 5 = 100$ ohms.
- D. cannot be determined. You must first know the voltage.

9

7. If a 30-ohm and a 20-ohm resistor are connected in parallel, the resistance is

- A. 12 ohms.
- B. 15 ohms.
- C. 50 ohms.
- D. 25 ohms.

8. Composition resistors are made in tolerances of

- A. 5%, 10% and 20%.
- B. 1%, 10% and 20%.
- C. 10% and 20%.
- D 5%, 10%, and 15%.

9. A composition resistor has the following color bands on it, from left to right: violet, green, red. This indicates that it has a resistance of

- A. 7.5 K.
- B. 750 Ω.
- C. 75,000 Ω.
- D. 6,500 Ω.

10. A resistor is color-banded from left to right with bands of red—yellow—red, indicating that it has a resistance of 2400 ohms. If the color is changed to red—red—red, the resistance is now

- A. 2,200 ohms.
- B. 2K ohms.
- C. 22,000 ohms.
- D. 2,000 ohms.

Notes

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Shoulder To The Wheel And Push For The Goal Line

Time passes rapidly and before you realize it you will be closing in on the completion of your Electronics course. In a short while you will be stepping out into the business world to make use of the knowledge you have gained. You are the one who must evaluate your ASI training and direct it toward the most practical end.

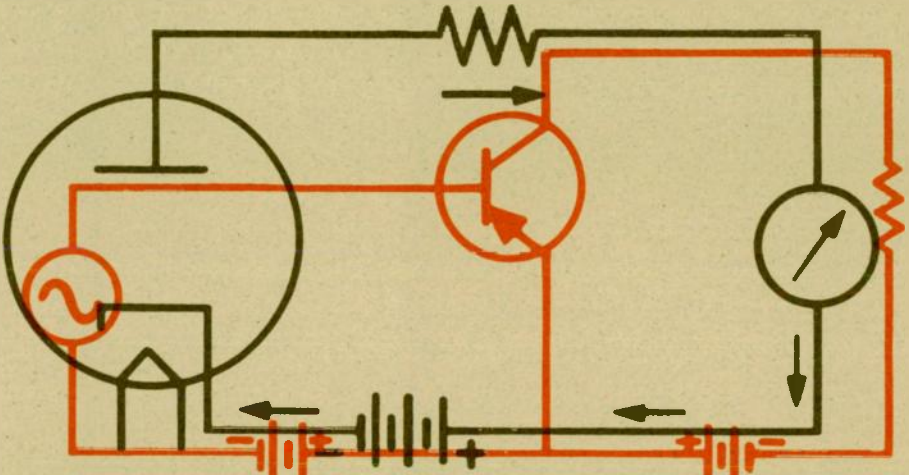
Whether or not you go into business for yourself or work for someone else you will make your own future. Your ASI training program is dedicated to training men who want to succeed. You will have the skills and know-how necessary for success in the Electronics field. Now is the time to reach for that little something extra which will make the difference between success and failure.

By putting this all to good use you will cross the goal line and soon be making your own opportunities for the future. Don't stop now!

S. T. Christensen

LESSON NO. 9

ALTERNATING CURRENT



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Contents

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52-009

ALTERNATING CURRENT

INTRODUCTION

Until now you have been introduced only to Direct Current (DC) which flows constantly in one direction. It is DC current that powers the circuits within electronic systems and devices. Circuit signals and information also are usually DC, but they occur as pulses or varying current.

Early power was distributed in direct current form, which soon proved to be impractical for mass distribution. It is economically impossible to conveniently raise and lower DC voltages. If DC were still used for power, monster-sized cables would be required to supply the immense current needed at voltages suitable for home or industry.

Electric power today is generated and then sent great distances over transmission lines; some of which extend for hundreds of miles. Even good conductors of electricity, copper or aluminum, have some resistance which results in generation of heat or wasted energy. Over short distances these losses are negligible, but when miles of wire are involved, power waste could become considerable. To keep losses at a minimum, high energy levels or voltages are used to propel smaller amounts of current. This is accomplished with **Alternating Current (AC).**

ENERGY LEVELS AND THE ELECTRON

At this point, let us explore electrical energy from another concept. Suppose that a free electron is being repelled by another electron, and that the electron which is doing the repelling is stationary. We might then say that the free electron is being repelled by the force of **one electron.** Include another stationary electron so that the free one will be propelled by forces from **two electrons.** Applied force has doubled, and the free electron can move through twice as much resistance; it has double the energy.

We could propel two free electrons, each with half the force. The total energy developed would be the same, but each must separately overcome the opposition to its movement or resistance in the conducting wires. The amount of wasted energy would be twice that for one electron.

The same concept for increasing an electron's energy applies when an atom loses two electrons. It would then attract a free electron with the force of two protons.

Greater positive voltages attract electrons more forcefully and cause them to do more work. Likewise, greater negative voltages repel electrons with increased force and cause them to do more work.

ALTERNATING CURRENT

Alternating current (AC) does not flow continually in one direction, like DC. AC moves first in one direction through a load, then reverses and flows for a time in the opposite direction. Its action is not unlike a stream of air breathed in and then out of the human lung.

How can this type current do useful work? It appears that work done in one direction is undone when current returns. Not so! Consider a simple light bulb. The bulb is not at all particular which way electrons move; in either direction, their movement is resisted, which results in the generation of heat. A bulb is purposely designed with enough resistance to allow the filament to get quite hot; that is, hot enough to glow radiantly when either type of current flows. Pure resistive devices will operate the same from either AC or DC power.

Alternating current power is transmitted on grids at EMFs of several hundred thousand volts. 345,000 volts is common but with better quality insulators, potentials up to 780,000 volts can be employed.

AC voltage can be easily increased or decreased through simple transformers, with very little loss of energy. High potentials from long distance lines are reduced in a switch yard for distribution through local lines, and again reduced near your home to the value required for appliances. In Figure 1, the symbol which is popularly used to represent an AC power source is shown.

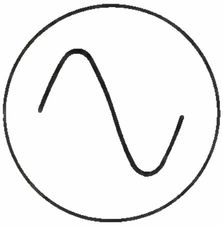

Figure 1 — Symbol for an AC power source.

THE CYCLE

AC does not rush instantly at full strength in one direction and then shut off abruptly and suddenly reverse. Instead, the current rapidly gains strength until it nears maximum. After the maximum current rush, it then begins to shut off. The shut off becomes increasingly more abrupt as current decreases toward zero.

We can visualize energy during one half cycle of alternating current (Fig. 2). The difference in level during the alternation is represented by different-sized circles of energy. The charge rolls from left to right, gaining strength until it peaks at the mid-position. After peaking the energy decreases toward zero.

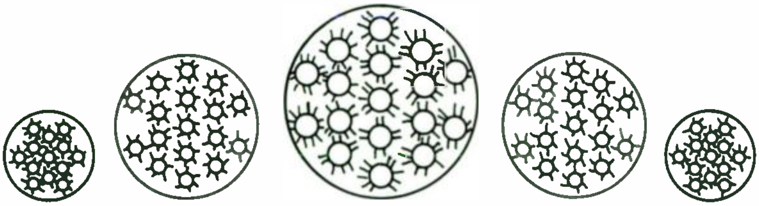

Figure 2 — Magnitude of an alternation of AC at different points.

A simple and useful method of picturing one alternation (1/2 cycle) would be to draw a curve from left to right, over the tops of these circles (Fig. 2). The magnitude of voltage or current is the distance to the curve from the base line.

If a pencil moved across a page controlled by the force of voltage or current in an AC cycle, it would mark a curve (Fig. 3). The trace would start at the left from a straight line (zeroline) drawn horizontally across the page. The pencil would move both to the right and upward as current and voltage increased in a forward direction. After completing a half cycle, the trace would loop below the line as the current and voltage reversed direction.

A loop or curve above the zero line indicates positive current or voltage in a forward direction. Negative current or voltage in a reverse direction is indicated by a curve drawn below the zero line (Fig. 3).

Figure 4 illustrates a very basic alternating current generator. A conductive loop revolves through lines of flux in a magnetic field. Current flow and voltage polarity are in one direction through half the revolution, then reverse when the edges of the loop begin to move through the field in the opposite direction. The curve shown is similar to swells or waves on water. We call this plot a **waveform.**

When the voltage and current reverse, they are described by an identical curve which is drawn below the zero base line. The two alternations (Fig. 5) total one complete cycle. We have divided this cycle into four parts to better illus-

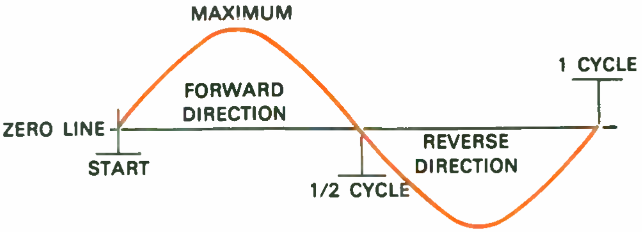

Figure 3 — The parts of an AC cycle.

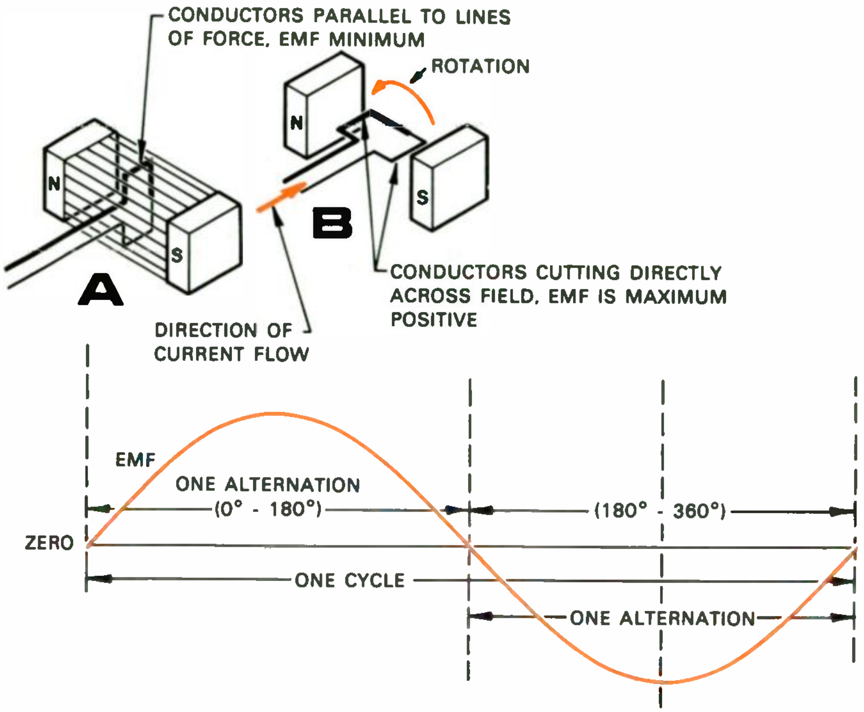

Figure 4 — A very basic AC generator and its waveform.

trate the relative amounts of voltage or current at specific times during a cycle.

From left to right, observe how it builds from zero to full strength during the first $^1/_4$ cycle (Fig. 5). At the end of $^1/_2$ cycle, the current and voltage have returned to zero. At the $^3/_4$ point they have, once again, reached maximum, but in a reverse direction. Again the current and voltage decrease in amplitude, until voltage is absent and current ceases to flow. At this point we have completed one cycle.

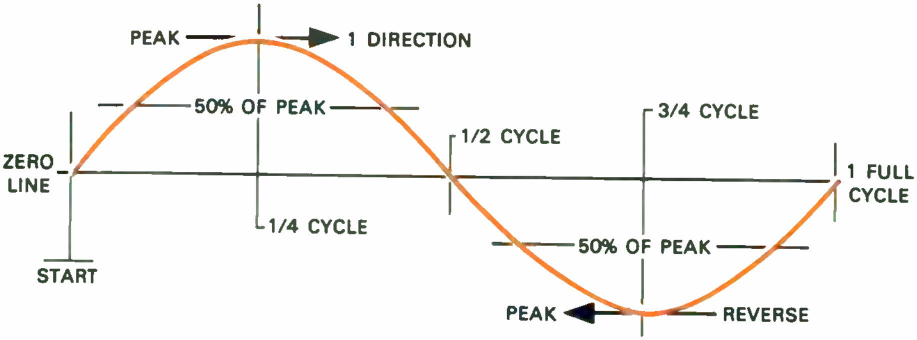

Figure 5 — Illustration of an AC cycle divided into quarter parts.

FREQUENCY

The frequency (f) of an alternating current or voltage is the number of complete cycles occurring in one second of time. The speed of rotation of the loop (Fig. 4) determines the output frequency. A frequency of 1 cycle-per-second will result if the loop makes 1 revolution in 1 second. If the loop makes 2 revolutions in 1 second the frequency is 2 cycles-per-second. It should be apparent that as the speed of rotation of the loop of wire in the generator increases, the frequency of the output increases. If the speed of the generator decreases, the frequency also decreases.

More than 90 percent of all power generated and distributed in the United States is AC with a frequency of 60 cycles-per-second. This means that voltage and current reverse direction 120 times each second. In the 1960s, a new term was adopted: rather than use cycles-per-second as the unit of frequency, "hertz" is now the accepted unit of measure of frequency. 60 cycles-per-second is now stated as 60 hertz.

PERIOD

An individual cycle of any sine wave represents a certain amount of time. Figure 6 shows two cycles of a sine wave which has a frequency of 2 hertz. Since two cycles occur in one second, 1 cycle must require $1/2$ second of time. The time required to complete 1 cycle of a waveform is called the *period* of the waveform. Each cycle of a waveform consists of two pulse shaped variations. The pulse that occurs in the positive direction is called the positive alternation (Fig. 6). The pulse that occurs in the negative direction is called the negative alternation.

The period of a waveform is inversely proportional to the frequency. In other words, if the frequency is increased the period becomes shorter. The equation for period is:

$$t = \frac{1}{f}$$

t = period in seconds

f = frequency in hertz

AMPLITUDE

Amplitude is a term used to designate the strength of AC current or voltage. Peak amplitude is the point of maximum voltage or current above or below the zero line (Fig. 6). Peak to peak amplitude is a measurement from maximum in one direction to maximum in the reverse direction (Fig. 6).

SINE WAVE

The curves (Figs. 5 & 6) follow the laws of mathematical sines and are called sine wave curves or **sine waves.** Sine waves for voltage and current are identical, but they may not always start and end at the same time. Time is a most important factor in alternating current or voltage; AC is constantly changing its amplitude or direction in relation to time.

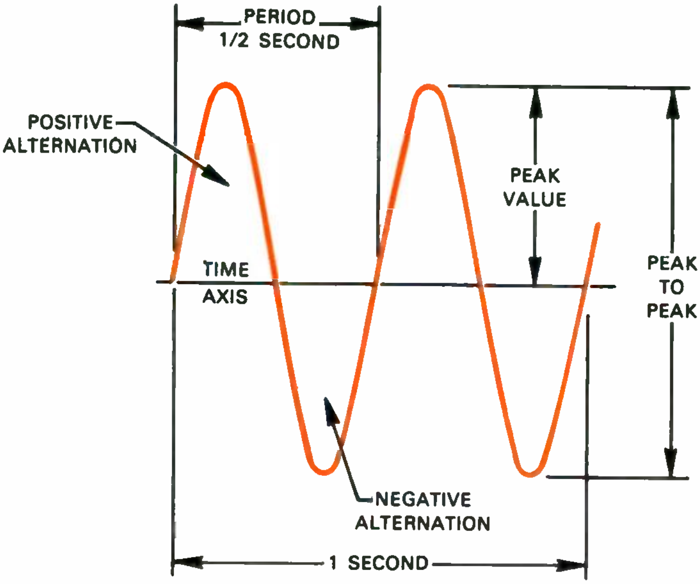

Figure 6 — Two cycles of an AC waveform.

You perhaps wonder why this particular waveform was adopted. Early developers of electric power were somewhat trapped by its natural occurrence, because this is the form more easily generated.

Figure 7 shows another basic AC generator. A loop revolves in a field between two magnetized pole pieces. If the ends of the loop are connected to a load, current will flow when the loop begins to turn (Fig. 7A). It is quite a distance from the pole pieces and will generate only a small amount of current. Initially, it is moving somewhat with the lines of force rather than across them. The greatest amount of voltage and current is produced when the loop cuts squarely across lines of flux.

Our loop moves toward position B (Fig. 7), and a greater amount of voltage is developed as it cuts more directly across magnetic lines of force. Next the loop rotates through point B toward the position indicated at C.

As it moves from B to C (Fig. 7) away from the position where it slices directly across lines of flux, voltage and available current decrease until they are zero at position C. After moving through position C, the loop begins to cross magnetic lines of force in the opposite direction. The voltage and current are now reversed.

At D we see the loop exactly opposite B. It is during this period that peak voltage and current are generated in the reverse direction. At E we have completed one revolution of the generator, and one complete cycle of current and voltage has been generated. The loop has in

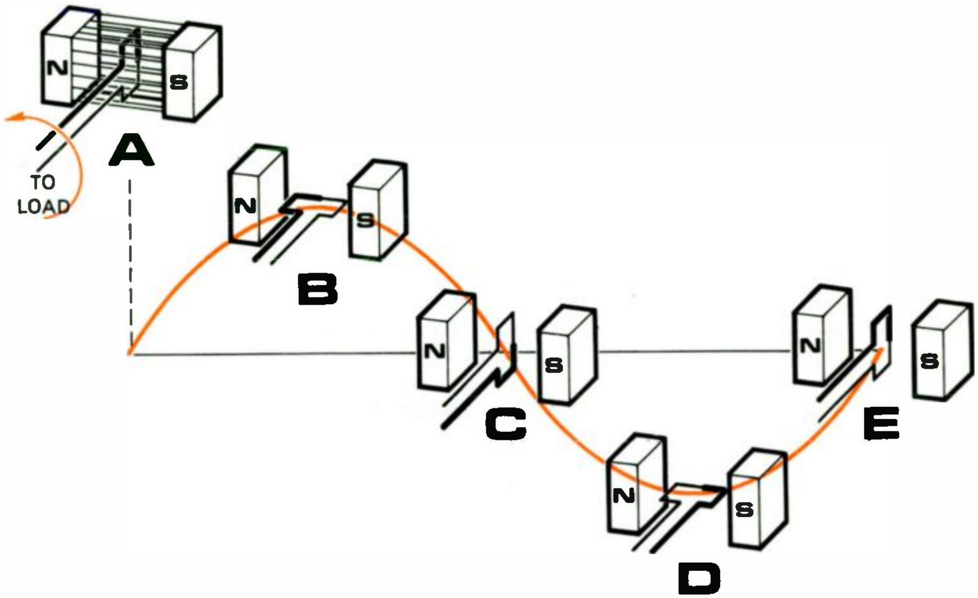

Figure 7 — Positions of the loop of a basic AC generator at different points of a cycle.

effect returned to its starting position and is ready to begin generating another cycle.

DEGREES AND QUADRANTS

Thousands of years ago, mathematicians divided the circle into 360 parts. Each of these parts is called a degree. The distance around any circle always contains 360°. (The small circle above and to the right of "360" is used instead of the word "degree".)

In electrical and electronic work, we frequently use circular motion to represent changing currents and voltages. The motion is in a counter-clockwise direction, (opposite the motion of the hands on a clock). The circle is divided into parts to illustrate what is happening during a given time period. Figure 8 pictures a circle divded into four parts, beginning at the right at zero degrees. Each part is called a quadrant, and each quadrant contains $^1/_4$ of 360° or there are

$$\frac{360°}{4} = 90° \text{ per quadrant}$$

Figure 9 shows a row of circles, each divided into four quadrants. Each quadrant indicates $^1/_4$ revolution of an AC generator. The curve above this row of circles shows the magnitude and direction of current or voltage as the generator completes its motion through each quadrant or quarter cycle.

EVALUATING THE SINE WAVE

With degrees, we can develop a picture of a sine wave relative to

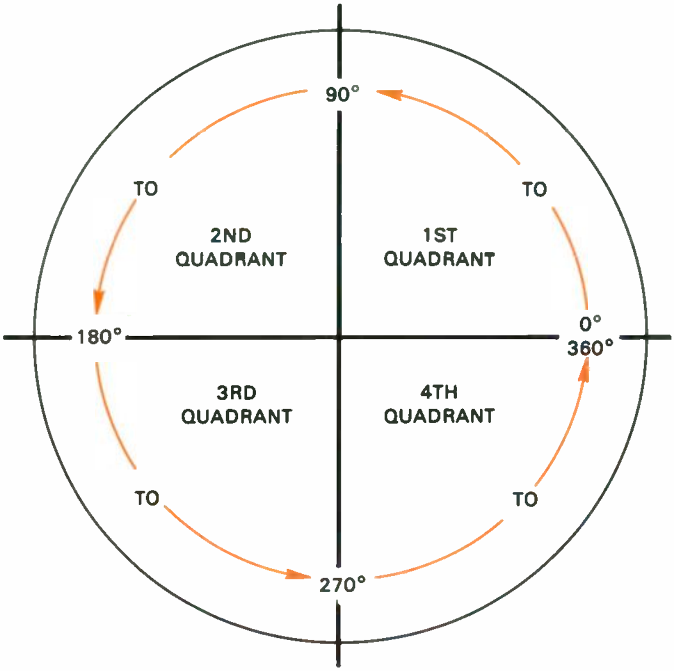

Figure 8 — A circle divided into quadrants.

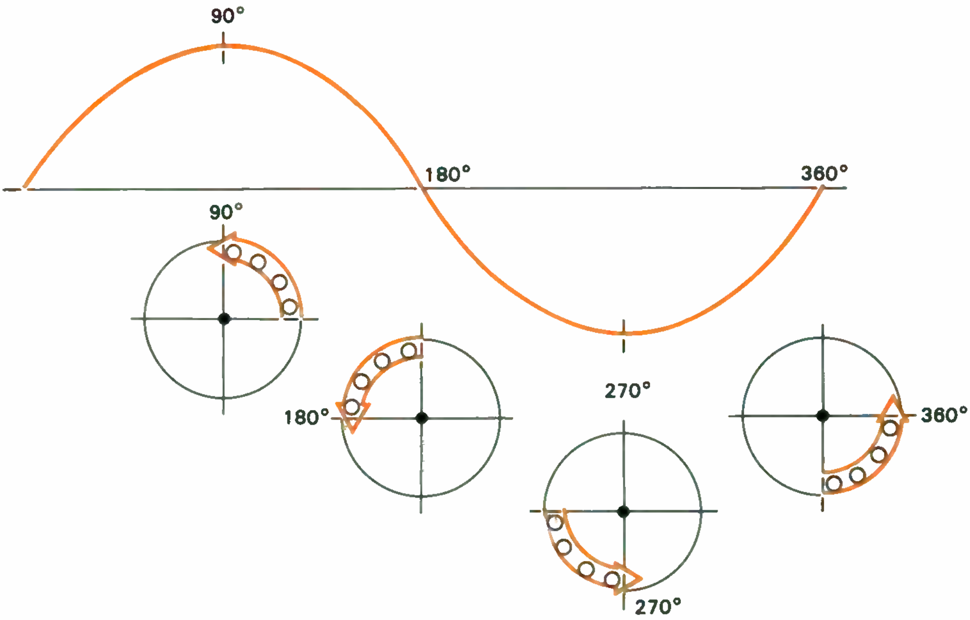

Figure 9 — The quadrants of a circle shown with the portions of a cycle they represent.

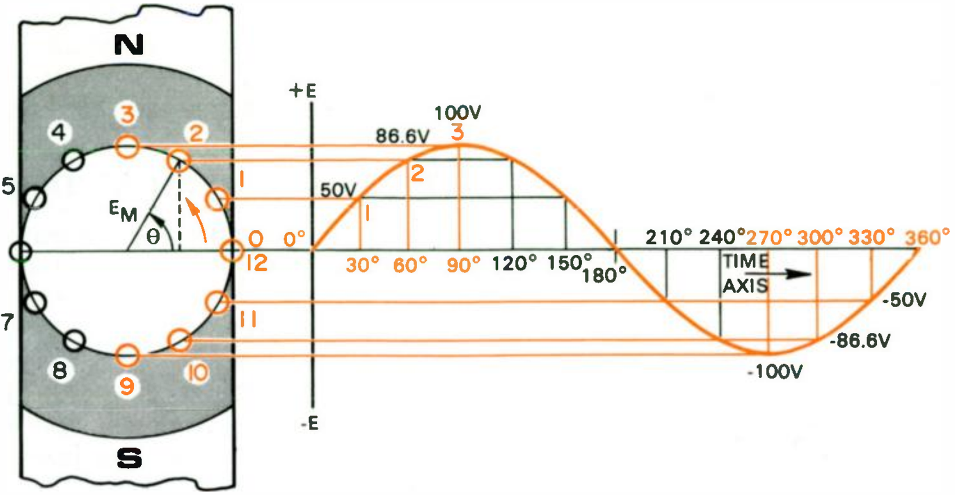

Figure 10 — Generation of a sine-wave voltage.

circular motion. Figure 10 shows such a projection with some voltages at different positions for a certain generator. The values measured at these points are called instantaneous values. In this diagram each quadrant is further divided; a numerical value for voltage is shown every 30°.

A 50-volt change occurs between 0° and 30° (Fig. 10). This is the area of rapid rise during the first alternation. Sixty degrees of rotation (twice the distance) is required for an additional 50-volt increase to 100 volts between 30° and 90°. This is followed by an area of a slow fall of 50 volts between 90° and 150°, (60° rotation). The period of rapid decline occurs during the 30° period between 150° and 180° when the EMF drops from 50 volts to zero. The negative alternation which follows is a precise duplicate of the preceding relationships.

EFFECTIVE VALUES

The effective voltage or current developed from a sine wave is not peak level as in DC. To better un-

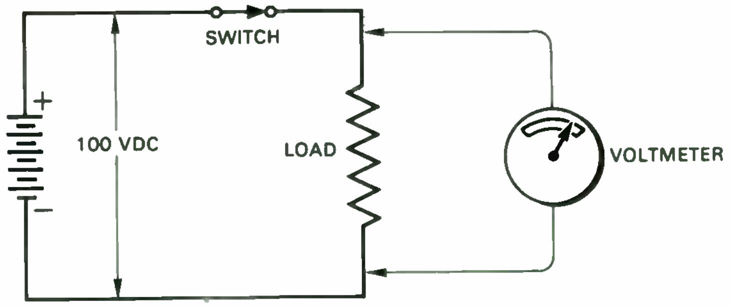

Figure 11 — A series DC circuit used to produce a level.

derstand the relationship between AC and DC voltage, re-examine a simple battery-resistor circuit (Fig. 11). When the switch is closed, the voltage rises almost instantly to 100 volts and remains at that level. If we were to transfer this level on to an AC voltage waveform of equal force, the AC peak would rise above the 100-volt DC level (Fig. 12).

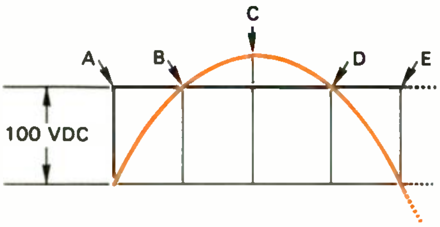

Figure 12 — An AC alternation superimposed on a DC level of equal strength.

Closing the switches of both an AC and DC circuit simultaneously, the DC rises almost instantly at point A (Fig. 12). The AC, however, rises more slowly and does not become equally effective until point B. Somehow it must make up for its failure to perform at full potential during the interval from A to B. It does so by continuing to rise above the DC level. While at point C, it continues generating greater than the DC level for a time (Fig. 12—C to D). This prepares in advance for the time period D—E when it once again fails to equal the DC level.

RMS (ROOT MEAN SQUARE)

If we were able to separate a portion of the AC voltage above the DC level and redistribute it into the gaps at A–B and D–E, the AC quantity would then approximate the DC quantity. Peaks above the DC level have been removed and dissected, and then inserted into the blank spaces (Fig. 13).

In Figure 14, the complete cycle is shown redistributed on the DC level. This is done by flipping the negative peak over; it now appears above the line, adjacent to the positive alternation. The shaded areas illustrate where the quantities of AC from the peaks have been inserted to show how the total AC during a time period of one cycle equals the DC during the same time period.

Our main interest in comparing AC to DC is in determining what quantity of AC does the same amount of work as a quantity of DC. Physicists and mathematicians

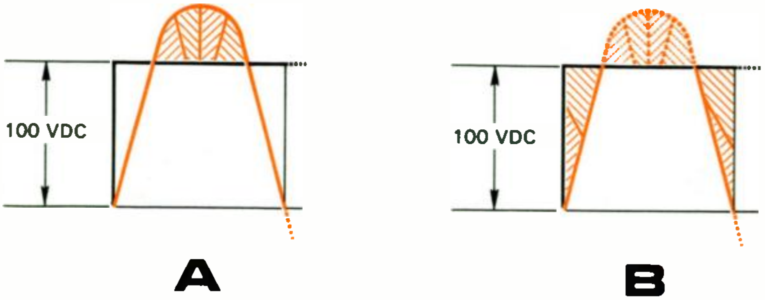

Figure 13 — A—DC level with ½ cycle sine wave of equal strength superimposed onto it. B—Peak re-distributed to show how it fits into the gaps.

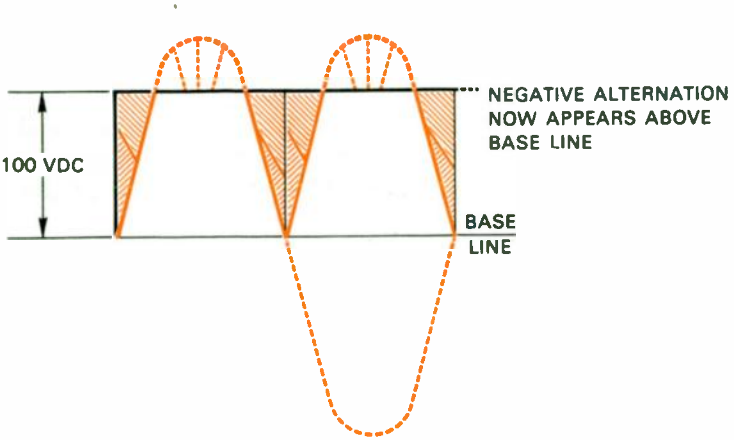

Figure 14 — One complete cycle of a sine wave altered to show its relationship to a DC level of equal force.

have determined that AC with a sine wave peak of 141 equals a steady DC level of 100. These figures apply to voltage in volts or current in amps.

It could also be said that a DC level of like-energy would rise to approximately 70 per cent of the AC peak. The true figure is 70.7 which is known as the RMS or Root Mean Square value. This is also called the effective value of AC.

One RMS amp of alternating current is as effective in producing heat as one steady amp of direct current. For this reason, an RMS amp of alternating current is also called an EFFECTIVE amp.

WHENEVER AN ALTERNATING VOLTAGE OR CURRENT IS STATED WITHOUT QUALIFICATIONS, IT IS ASSUMED TO BE AN EFFECTIVE VALUE.

It may be necessary occasionally to convert from effective to peak or vice-versa. In Figure 15, the peak value of a sine wave is 1.414 times the effective value, and therefore

E(max) = E(RMS) × 1.414

I(max) = I(RMS) × 1.414

It is sometimes necessary to convert a peak value of sine wave current or voltage to an effective value

E(RMS) = E(max) × 0.707

Similarly for current:

I(RMS) = I(max) × 0.707

141.4 volts peak
× .707
9898
9898
99.9698–Rounded off is 100 volts RMS

A few AC meters read in terms of peak, or peak-to-peak, but most are designed to read RMS.

We have previously spoken of AC in your home in terms of 120 volts. This 120 volts of AC is RMS and is

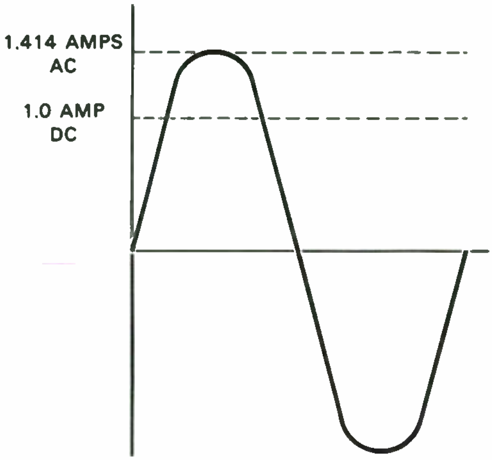

Figure 15 — 1.414 amps of peak AC is equal to 1.0 amp DC.

equal in force to 120 volts DC. What is the peak value of 120 V AC?

E(max) = E(RMS) × 1.414

$$\begin{array}{r} 120 \\ \times\ 1.41 \\ \hline 120 \\ 480 \\ 120 \\ \hline 169.20 \end{array}$$ volts

This 169.2 volts is the maximum voltage developed by 120 volts RMS.

PULSATING DIRECT CURRENT

Electric current and voltage can vary in strength without changing direction. A plot of these variations may resemble an alternating current waveform; however, it does not fall below the zero level (Fig. 16). The waveform must fall below the zero level to constitute a change in direction.

Current which changes in value without reversing direction is called pulsating DC or PDC. It does not necessarily always drop to zero. Pulsating DC may depart from the normal DC level by only a small amount, or there may be considerable variation in amplitude.

Figure 17 illustrates what is sometimes called ripple or AC riding on DC. The amplitudes of the variations are small relative to the normal DC level.

Signals are often routed through electronic gear as pulsating direct current. These signals can be handled by direct current devices which would be destroyed by the change in direction of alternating current.

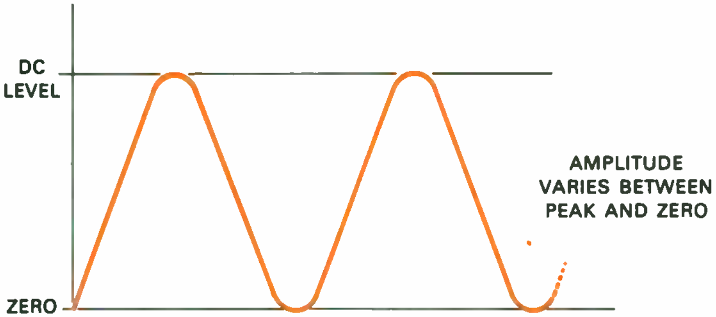

Figure 16 — A sine wave of pulsating DC which flows in only one direction.

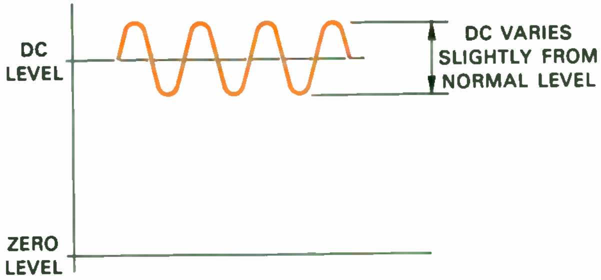

Figure 17 — A small amount of variation in a DC level.

NON-SINE WAVEFORMS

Many waveforms other than sine are produced, but rarely are any used for power. Their application is generally in communications, data processing and control circuits. Figures 18 and 19 show several common types. The square wave (Fig. 18A) rises instantly to a positive level, holds for a time and drops suddenly toward zero. At zero it does not pause, but reverses instantly and repeats in a negative direction. The effective energy in a square wave relative to DC approximates peak value. Square waves are quite common in data processing equipment and are also used extensively for troubleshooting problems in Hi-Fi amplifiers.

The sawtooth wave (Fig. 18B) will seldom be encountered in AC form. Generally it appears in the form of a pulse either positive or

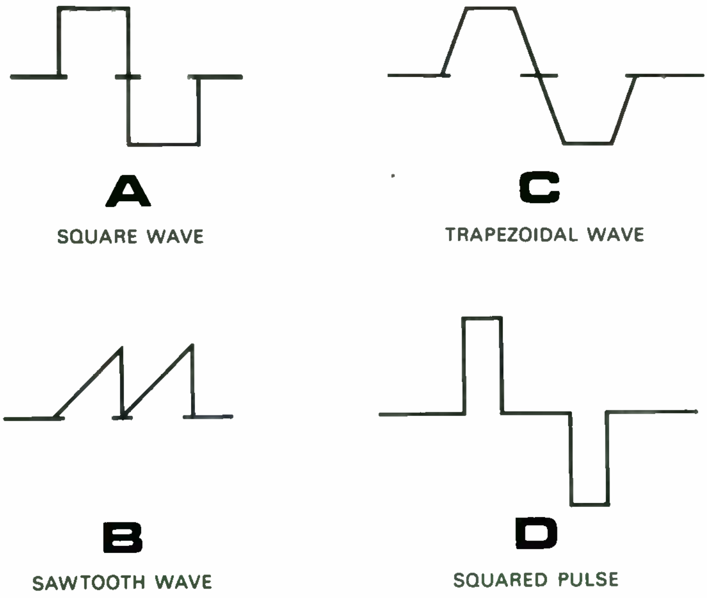

Figure 18 — Various waveforms other than sine.

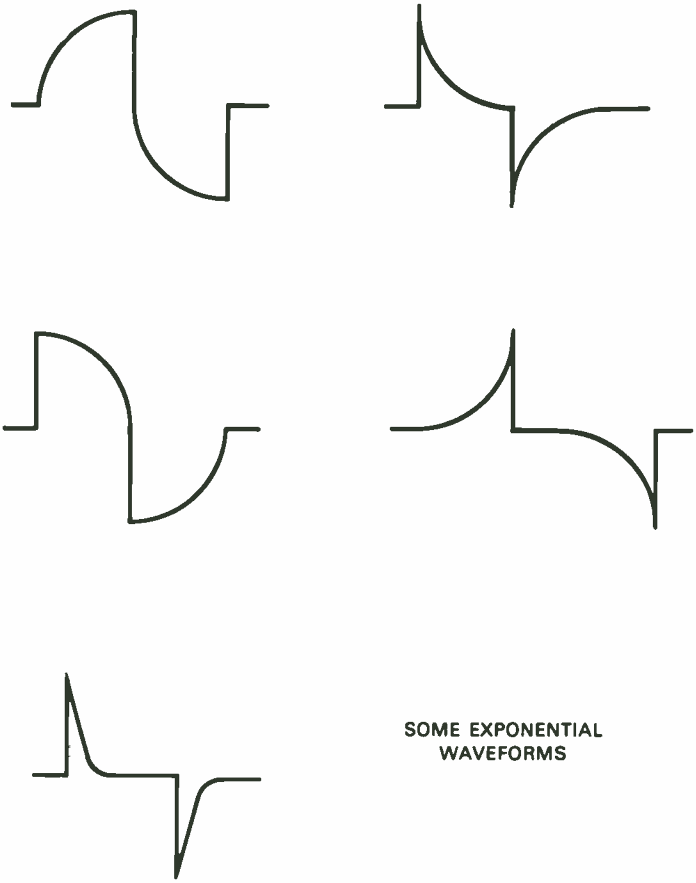

Figure 19 — Some exponential waveforms.

negative. It is this type of current pulse which drives the electron beam across the face of the picture tube in your television set.

The trapezoidal waveform (Fig. 18C) is similar to an AC sine wave with its peaks clipped. It is one that you will seldom encounter unless you enter some specialized field of electronics.

Some form of Figure 18D will be encountered frequently in most phases of electronics. Positive or negative peaks of this form are used extensively. The master clock pulses which synchronize many computers are squared pulses. These pulses allow a computer to do many things, some simultaneous, and then accurately combine the results. In television, squared pulses appear on the waveform transmitted by the station. The TV receiver interrogates them and with their help is able to re-assemble small amounts of video information into a composite picture for your enjoyment. The squared pulse (Fig.

18D) is similar to the square wave (Fig. 18A); however, it does not last as long.

The waveforms of Figure 19 are called exponential, because of the shape of the curved portion which either begins or ends an alternation. This curve is totally unlike any part of the circumference around a circle. If you begin drawing an exponential curve, the ends could never meet even if you continued, forever. Exponential pulses are used extensively in many phases of electronics.

Waveforms other than sine waves are generally not referred to in terms of effective value. In troubleshooting, they are generally viewed with an oscilloscope for proper shape and correct peak, or peak-to-peak, values. In any event, the calculations and numerical values used to determine effective values for sine waves do not apply to other waveforms.

ENERGY TRANSFER THROUGH MAGNETIC COUPLING

In MAGNETISM, Lesson 4, it was stated that when current flows in a wire, a magnetic field surrounds it. The field starts from the wire and expands outward when current begins to flow (Fig. 20). When the current stabilizes, the magnetic field also stabilizes and remains at that strength. If the current is interrupted, the magnetic field collapses back toward the wire (Fig. 21).

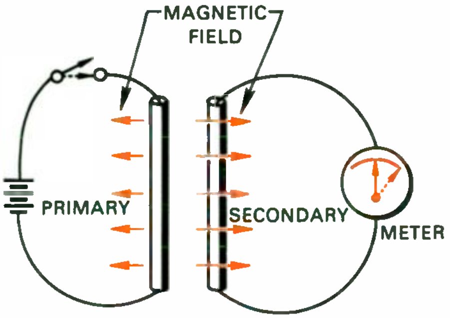

Figure 20 — Momentary forward voltage is induced in the secondary when the switch is closed in the primary circuit.

Place a neutral conductor, which we shall call a **secondary**, near this wire, the **primary**, and close the switch. As the magnetic flux lines move outward from the primary and cross the secondary, free electrons are excited and rush toward one end. Once the flux lines stop moving across the secondary, electrons receive no further stimulus and redistribute.

When the magnetic field is in motion during initial current build-up, voltage is induced in the secondary by the moving magnetic field. With a load connected across the ends of the secondary, current will momentarily flow (Fig. 20).

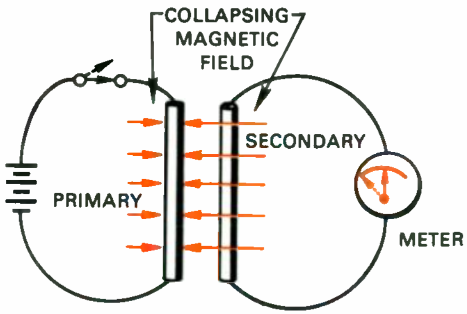

Figure 21 — Momentary reverse voltage is induced in the secondary when the switch in the primary is opened.

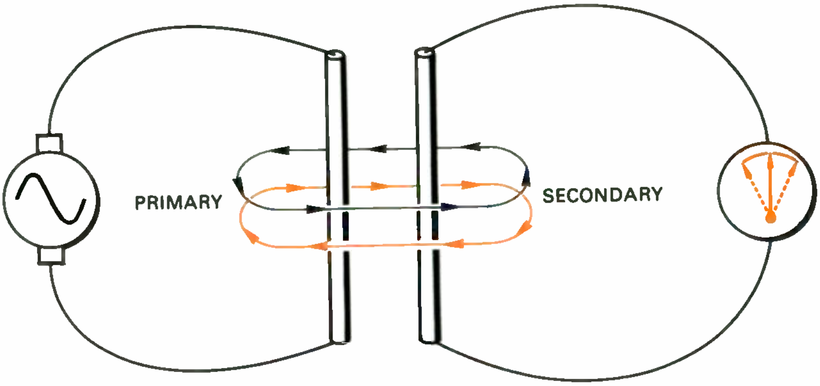

Figure 22 — Arrows indicate direction of magnetic field when AC current flows in a conductor. The field expands and then contracts as current changes. The meter indicates induced voltage in the secondary. It moves up scale on the forward alternation and down scale when the field reverses.

If the switch is opened, flux lines again cross the secondary as the magnetic field collapses. Again electrons are set in motion, and voltage is induced, but in a direction opposite to the closed switch situation (Fig. 21). This is because the magnetic field now moves in an opposite direction and causes electrons to do likewise.

If the primary wire is connected to an AC source, the magnetic field surrounding it moves constantly; first, away from the wire as the current builds, and then toward the wire as the current subsides and flows in the opposite direction. With AC current flowing, the magnetic field is constantly changing, crossing and then re-crossing the neutral or secondary conductor (Fig. 22).

PRIMARY—SECONDARY WAVEFORMS

The voltage waveform induced in the secondary conductor is an exact duplicate of the current waveform through the primary. The voltage is, in theory, the same value as that applied to the primary.

If two secondary conductors were connected in series and placed in an AC Magnetic field, the voltage across the two would now be twice as great (Fig. 23). In effect, we have demonstrated how voltage can be increased. We do not gain in energy, however, because the current available from these two secondary conductors is less than that in the primary. The voltage doubling effect is similar to series connecting batteries or cells.

When voltage is doubled through magnetic coupling, in theory the current available is now half that flowing in the primary. Although we have reduced the current, more voltage is available which produces the same amount of power. It appears that no power has been used in the primary even though it is drawing current from the source.

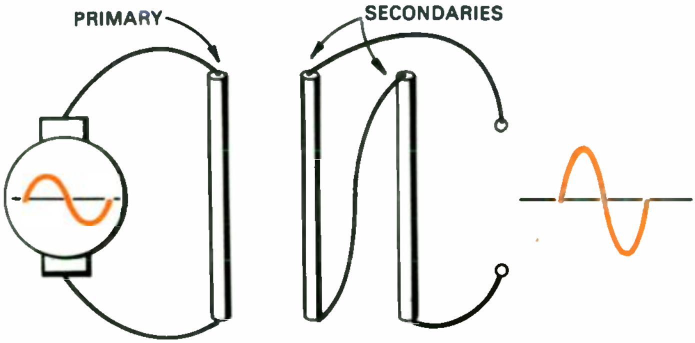

Figure 23 — Two series secondary conductors are shown in the AC magnetic field of one primary. The voltage developed in the secondary is twice that developed across the primary.

The power is in effect, transferred to the secondary where it is available to a load.

Figure 24 illustrates two series-connected primary conductors, but only one secondary conductor. In this case, the voltage in the secondary is one-half the voltage across the primary. The current available from the single secondary conductor, however, is twice that flowing in the two-conductor, primary. This describes how AC voltage can be reduced with an increase in available current.

The principles described in this section represent voltage step up and step down through transformer action. These principles will be discussed in detail in future lessons.

SUMMARY

Alternating current is continually changing in amplitude and periodically changing in direction. AC is produced from a simple AC generator called an alternator. An alternator does not require a commutator to convert the output waveform into DC as required by a DC generator.

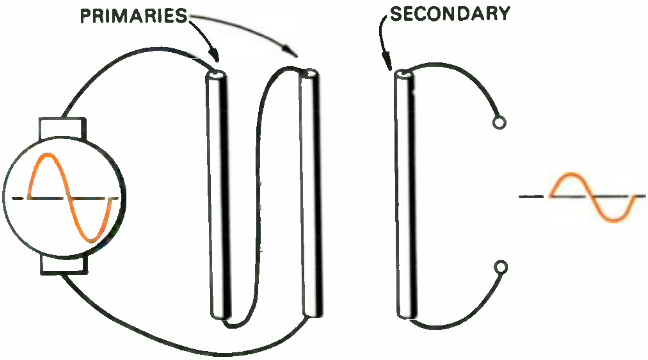

Figure 24 — Two primary conductors are shown in which AC current is flowing. The voltage in the single secondary is one half that of the voltage in the primaries.

Power transmission using direct current wasn't economical. All wire contains a certain amount of resistance and as current flows through the wire a voltage drop will develop. The larger the current flow through the wire, the larger the voltage drop. Using alternating current, the voltage applied to the transmission lines is increased at the power station and decreased to a usable level at the consumer. This gives the same power output without the appreciable line loss that would result if a large DC current were used for transmission.

The frequency of a waveform is measured in hertz and represents the number of cycles of the waveform completed in one second. The period of a waveform is the length of time required to complete one cycle. Period is measured in seconds. The amplitude of a sine wave is continually varying. This presents a problem as far as the actual voltage or current measurement. The RMS (effective) value of a sine wave would produce the same heating effect as a comparable amount of direct current. The formula to solve for RMS voltage is

$$E(RMS) = E(max) \times 0.707$$

If AC voltage or current values are given without qualification then they are the effective or RMS values.

TEST

Lesson Number 9

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-009-1.

1. Almost all electric power is generated and distributed as

A. DC.
[✓ B. AC.]
C. Non-Sine.
D. Trapezoidal.

2. Current that flows in only one direction is called

[✓ A. DC.]
B. AC.
C. Power.
D. Sine.

3. Current that flows first in one direction and then in the opposite direction is called

A. DC.
B. Power.
[✓ C. AC.]
D. Exponential.

4. AC is superior to DC for long distance transmission, because it

A. moves faster.
B. has more energy.
[✓ C. can be transmitted with less current and less waste.]
D. has more electrons.

6 **5. The period of a sine wave that completes 2 cycles in 1 second is**
   A. 2 seconds.
   B. 10 seconds.
   C. 5 seconds.
   D. 1/2 second.

6. AC voltage
2 A. can be easily raised or lowered.
   B. cannot be changed.
   C. is lower than DC voltage.
   D. requires huge conductors.

7. 1 RMS amp of alternating current is as effective in producing heat as
1' A. 4 amps direct current.
   B. 1 amp of direct current.
   C. 1/2 amp of direct current.
   D. 10 amps of direct current.

8. The accepted unit of measure of frequency is
5 A. volts.
   B. amps.
   C. hertz.
   D. ohms.

2 **9. When a greater potential is applied to an electron,**
   A. it gets colder.
   B. its energy does not change.
   C. it can do more work.
   D. it does less work.

10. When a curve is drawn to represent an AC waveform, the negative portion is
3 A. drawn below the zero line.
   B. drawn above the zero line.
   C. represented by the zero line.
   D. less than one alternation.

Notes

Notes

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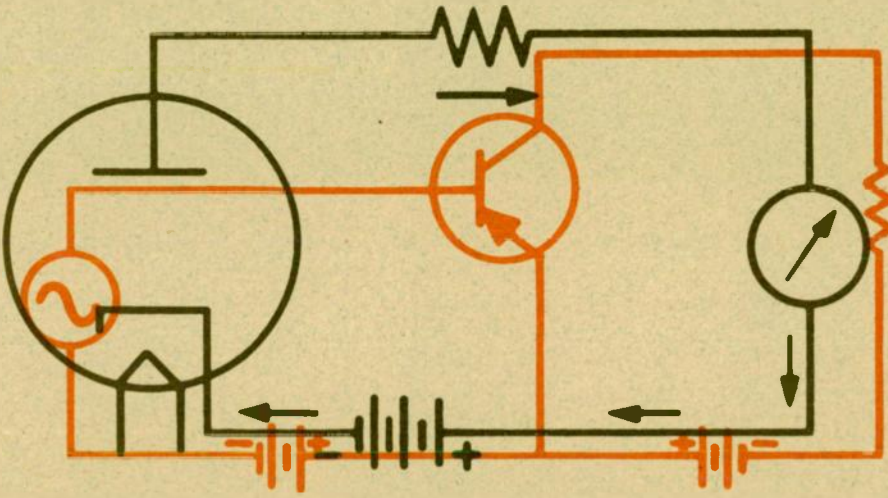
As in any business good service usually tends to bring the customer back; when customers return for your service they are, in fact, telling you they are pleased with the treatment they have received. It is very important to be able to diagnose the problem quickly and efficiently. Your ability to evaluate the situation in a short span of time will enable you to give your customer good service at the best possible price. This will ultimately result in larger profits and a good reputation for fast, professional service.

S. T. Christensen

LESSON NO. 10

REVIEW FILM OF LESSONS 6 THROUGH 9



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-010

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

312

Revised 6/73

REVIEW FILM TEST

Lesson Number 10

The ten questions enclosed are review questions of lessons 6, 7, 8, & 9 which you have just studied.

All ten are multiple choice questions, as in your regular lesson material.

Please rerun your Review Records and film before answering these questions.

You will be graded on your answers, as in the written lessons.

REMEMBER: YOU MUST COMPLETE AND MAIL IN ALL TESTS IN THE PROPER SEQUENCE IN ORDER FOR US TO SHIP YOUR KITS.

REVIEW FILM TEST

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-010-1.

1. All batteries
A. are primary cells.
B. are secondary cells.
C. are sources of AC.
[✓ D. are sources of DC.]

2. All secondary cells
A. produce 12 volts.
[✓ B. are re-chargeable.]
C. are connected in series.
D. produce 6 volts.

3. In electricity and electronics DC stands for
A. direct connection.
B. diameter of a circle.
[✓ C. direct current.]
D. "D" cell.

4. Resistance is measured in
A. feet.
[✓ B. ohms.]
C. pounds.
D. meters.

5. Ohm's Law is:

A. $E = I \times R$
B. $I = E/R$
C. $R = E/I$
[✓ D. all of the above]

6. A resistor has the following bands, first band orange, 2nd orange, 3rd red, 4th silver. What is its value?

A. 220 10%
[✓ B. 3,300 10%]
C. 33,000 5%
D. 22,000 20%

7. In Electronics AC stands for

A. activated charcoal.
B. automatic circuit.
[✓ C. alternating current.]
D. accumulated charge.

8. AC generators produce:

A. direct current.
[✓ B. alternating current.]
C. resistance.
D. none of the above.

9. The AC generators in the USA produce alternating current that has

A. 50 Hz exactly.
[✓ B. 60 Hz exactly.]
C. 55 – 65 Hz.
D. 120 Hz exactly.

10. A pure sine wave is

[✓ A. a single frequency.]
B. direct current.
C. changing in frequency.
D. always positive.

Notes

"School Without Walls"
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Write Your Own Ticket ...Use Your Time Wisely

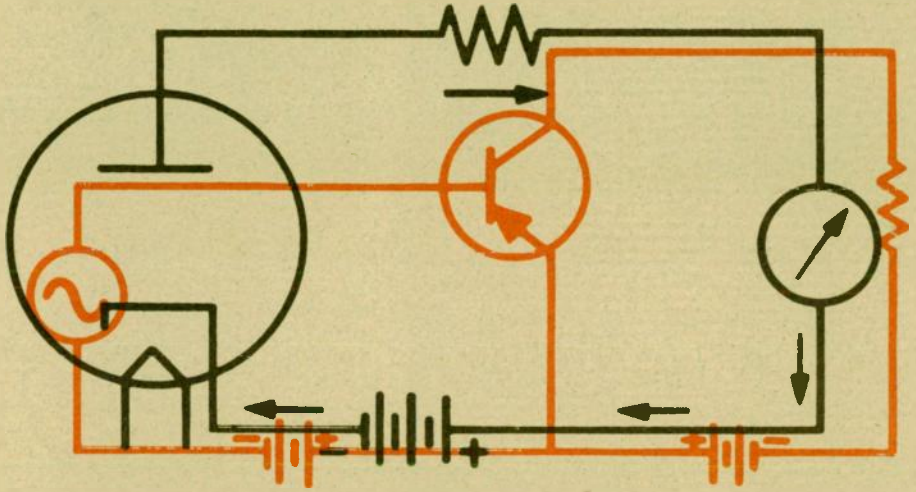
Careful use of time is important for the student studying at home. We all are aware of the fact that most home study students work during the day. In order to give yourself a fair chance with the course of study you are pursuing, you must realize that a sufficient amount of time must be given to this course.

Try to work out some schedule for yourself that will allow you to use your time wisely. It is understandable that every free moment cannot be directed toward your studies; the student must constantly remind himself that he is making an investment in his future and it is an investment that, if channeled properly, can reap great awards. Work hard and make your future one of great promise.

S. T. Christensen

LESSON NO. 11

CAPACITANCE AND CAPACITORS



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-011

305

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5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

LESSON ELEVEN

CAPACITANCE AND CAPACITORS

Contents

Revised 1973

CAPACITANCE AND CAPACITORS

INTRODUCTION

An electronic circuit, whether it contains a dozen or a thousand parts, has only three basic properties. Electric charges can be affected by circuit components in only three ways. They can be limited by resistance, stored in an electrostatic field by capacitance, or stored in an electromagnetic field by inductance. The effects of resistance have been discussed in earlier lessons. We will next concentrate on capacitors; however, a brief review of electrostatics will first be presented.

REVIEW OF ELECTROSTATICS

A charge exists when any material either gains or loses electrons. Extra electrons result in a negative charge; an absence of electrons results in a positive charge. Each quantity of charge may be represented by a line of force (Fig. 1). This line extends from the charged body and exerts a force on any material it contacts. The amount of force that a line exerts is dependent upon the amount of charge and the distance it travels. The greater the distance, the less its effects are felt (Fig. 2). This force will either attract or repel material or particles of material it comes in contact with.

In order to further describe electrostatic action, we repeat a statement from an earlier lesson: "There are two distinct kinds of electrical charges," positive and negative. Some texts state that there are two kinds of electricity, but it is preferable to think in terms of two forces or charges.

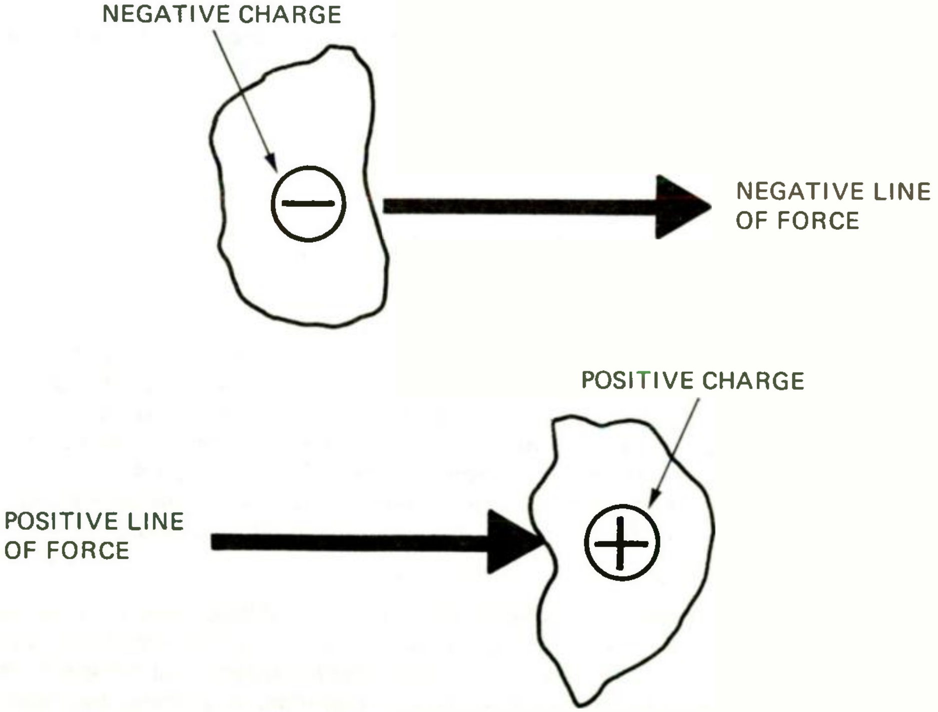


Figure 1 – A line of force from a single unit of negative force and a single unit of positive force.

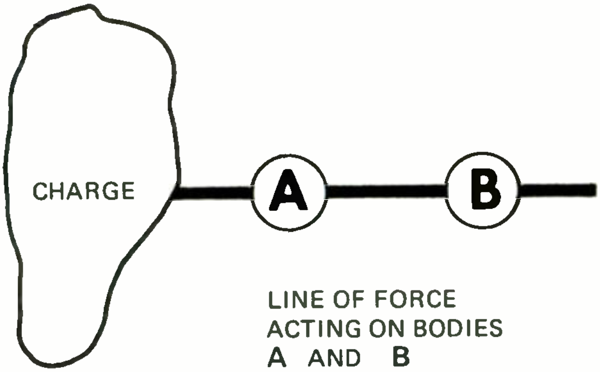


Figure 2 — The effects of a force field on a body are greater at A than at B.

When charges are associated, neither does all the attracting or repelling. Whether charges are positive, negative or mixed, they *interact* when they are in close proximity. Anytime unlike charges are associated, the positive charge exerts an attracting force on the negatively charged body, and the negative charge exerts an attracting force on the positively charged body. The force exerted is dependent upon the strength of the charges and their separation.

For simplicity we previously referred to a single line of force. It is probably more acceptable to think in terms of many lines combined into a field. This is because the individual lines act together as a unit of force.

ENERGY STORED IN ELECTROSTATIC FIELD

Figure 3 illustrates an atom of material in a force field. Negative lines of force are attempting to repel the electron. The atom to which it is attached would probably drift away, if it were not for the attracting force the negative charge has on the positive nucleus. The amount of repelling force applied to the electron is exactly equal to the attracting force on its companion proton. Caught between these two forces, the atom does not move; but its particles are forced from their normal orbits. Figure 4 illustrates an atom being subjected to a line of force from a positive charge. In this case the electron is attracted while the proton is being repelled. Again the atom itself is suspended.

Both positive and negative particles in an atom are shifted from their normal positions by a force field. When this happens, they are under tension, almost as if they were poised in a sling or in a stretched rubber band. Provide a path for the charge in the force field to escape, and the particles snap back into position. In returning they exert a force on the departing charge which acts to hasten its departure. Energy is released during the discharge cycle which was stored during the charge cycle.

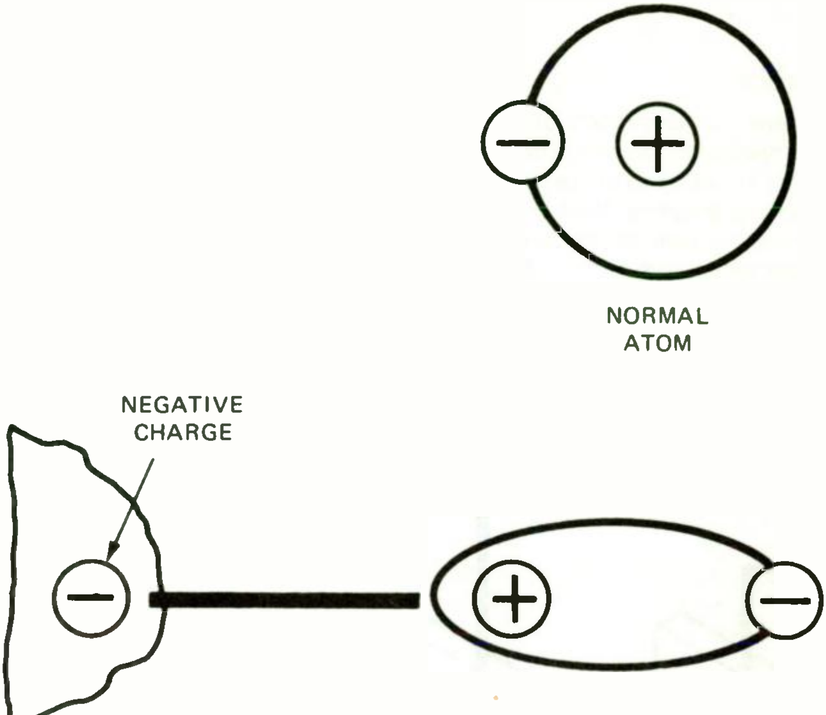


Figure 3 — The particles of an atom are displaced in a negative force field.

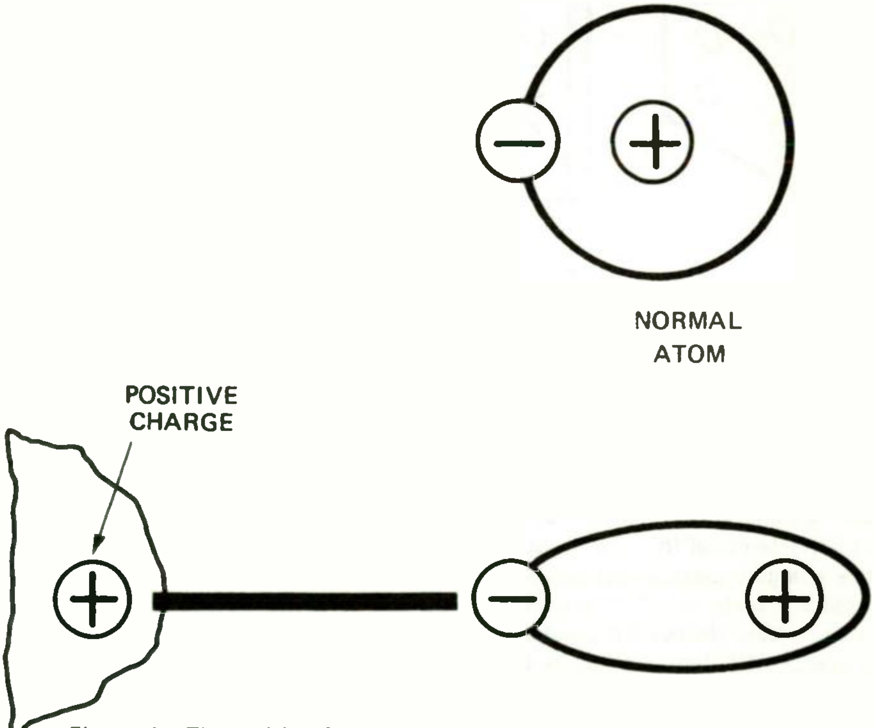


Figure 4 — The particles of an atom are displaced in a positive force field.

CAPACITANCE

Whenever two conductors of electricity are in close proximity but separated, they exhibit a property called capacitance. When they are oppositely charged, a force field in which energy is stored exists between them. Figure 5A pictures two metal plates close together but not touching. Neither is charged and a force field does not exist. Figure 5B shows the symbol used to represent a capacitor. (Capacitors were formerly known as condensers, a term which is now obsolete.) A capacitor is a device used to store energy; capacitance is the electrical property which makes this possible.

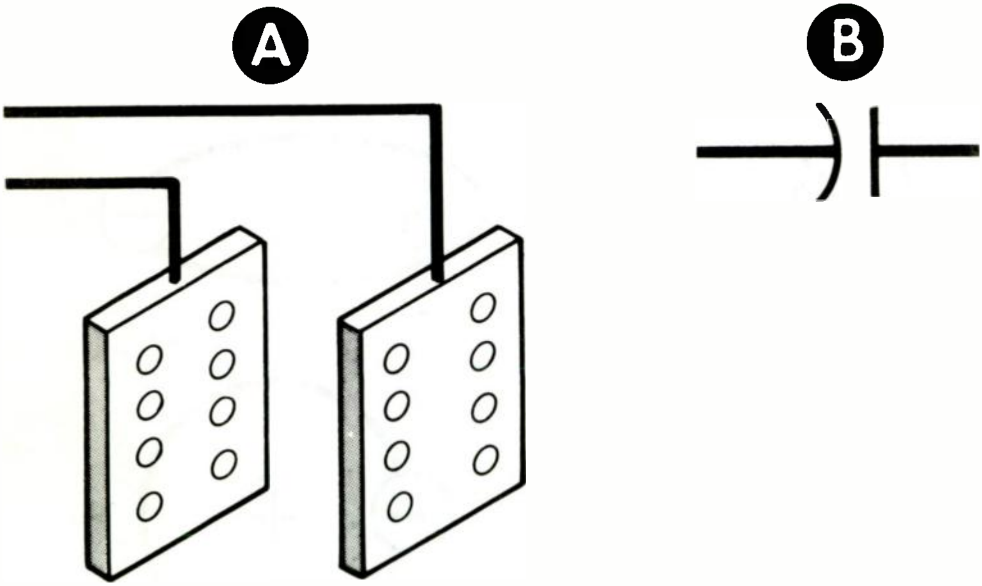


Figure 5 — A: An uncharged capacitor.
B: The schematic symbol for a capacitor.

CHARGING THE CAPACITOR

Figure 6 pictures a capacitor with a battery attached to its plates through a switch. The switch is closed for a time and then opened. *Instantly* when the switch is closed, the positive terminal of the battery begins to extract electrons from its conducting wire, and the negative terminal forces electrons into its conductor. A stream of electrons leave the positive charging plate (attached to the battery's positive terminal). Electrons flow into the opposite plate which is attached to the battery's negative terminal. As electrons continue to leave the positive plate and collect on the negative plate, an increasing voltage or difference of potential develops between these two plates. This potential continues to rise until it eventually equals the battery voltage. At this time electrons cease to flow. After a capacitor has been charged, a voltage equal to the battery's voltage is present across the plates. We say that an electrical charge has been stored in the capacitor.

DISCHARGING THE CAPACITOR

In figure 6 the switch is moved to position 2. Electrons flow from the capacitor's negatively charged plate through the lamp to the positive plate. The lamp glows momentarily during the initial high surge of current. Current continues in decreasing amounts until the plates regain or give up the electrons they have lost or accumulated. At this time current ceases.

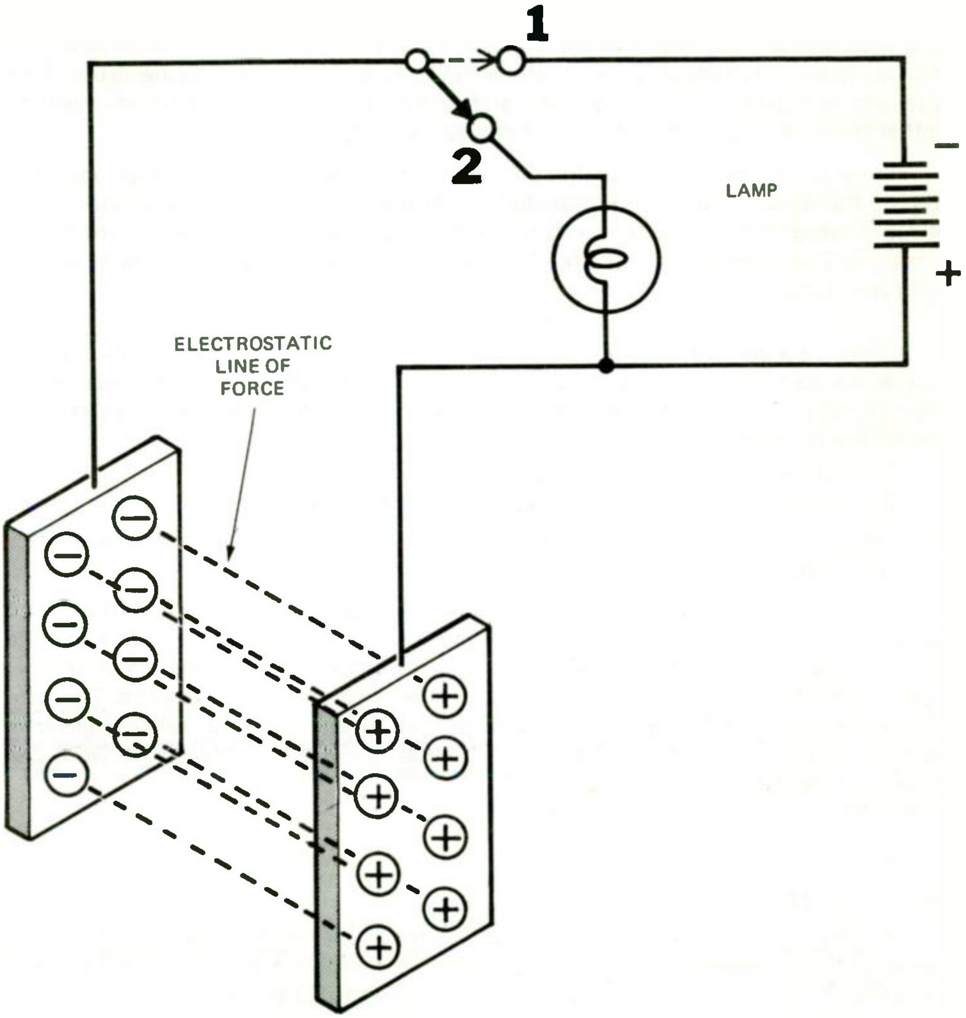


Figure 6 – Charging a capacitor from a battery and then discharging it through a lamp lights the lamp.

AMOUNT OF CAPACITANCE

The amount of energy a capacitor is capable of storing is dependent upon a number of factors:

1. The size of the plates.
2. The spacing between them.
3. The electrical elasticity of material between the plates.
4. The potential of the applied force.

Plates with larger surfaces can store more energy than those with smaller areas. The closer the plates are spaced (without touching), the more energy they can store.

Different types of insulating materials are used between plates of capacitors. One of the characteristics these materials are rated for is electrical elasticity. This is the ease with which particles within these material's atoms can be forced from their normal orbits. Free movement designates greater elasticity and greater storage ability. Greater elasticity signifies less resistance to the force field between the plates.

Large voltage potentials develop greater charges in capacitors than small ones. The limit to the amount of voltage potential which may be applied to a capacitor is the voltage at which the material between the plates breaks down and allows current to pass through it. This potential is called the break down voltage and can permanently damage most capacitors.

There are two instances when current flows in the circuitry (Fig. 6). This circuitry includes the battery, switch, lamp, connecting wiring and the capacitor's plates; but it does not include the dielectric in the space between the plates. The two instances when current flows in the circuitry are:

1. When the capacitor is charged from the battery.
2. When the capacitor is discharged through the lamp.

The discharge current is in an opposite direction to the charging current, and the voltage across a charged capacitor is in opposition to the battery voltage.

The ability of a capacitor to store electrical energy and then return it to a circuit causes it to resist a voltage change. An uncharged capacitor absorbs a rise in voltage; a charged capacitor returns energy when the applied voltage falls below the charge voltage. A capacitor offers resistance to a voltage change which is measurable in ohms. The term for the resistance of a capacitor to changing electrical energy is called *capacitive reactance*, is measured in ohms, and is identified as X_C (X *sub* c). Reactance (X) is also sometimes referred to as *AC resistance*.

UNIT OF CHARGE

A unit has been assigned to measure the amount of energy a capacitor can store. The unit, *farad*, represents a very large quantity; it is a million times too large to be of any practical value in electronics. We therefore use two smaller terms:

1. *Microfarad* is a million times smaller than the farad.
2. *Picofarad* is one millionth of a millionth of a farad.

Microfarad is abbreviated MFD or represented by the Greek letter μ followed by a small "f". Picofarad is abbreviated pf. Memorize the terms and their abbreviations, MFD or μ f and pf. For the present also remember that 1 microfarad is a million times larger than 1 picofarad and also that it (MFD) is one millionth of a farad.

DIELECTRIC

Circuit current capable of producing power actually flows during charging and discharging of the capacitor (Fig. 6). However, electrons do not flow through the material between plates. This material is penetrated only by the force field that exists when a charge is present. The material used between the plates of capacitors is called *dielectric* and may be either solid, liquid or gas.

A term has been assigned to dielectric elasticity. This term is *dielectric constant* and is represented by the letter *K*. The K value of the dielectric is one of the determining factors of how much charge a capacitor can store.

Figure 7 is a chart showing the constants or K factors for several dielectric materials. Air has a K value of 1, resin has a K value of 2.5, hard rubber has a K value of 2.8, etc. If resin with a K value of 2.5 replaces air as a dielectric in a capacitor, that capacitor will then store two and a half times the energy. Its capacitance value will increase two and a half times. Other materials currently being used for dielectrics are dry paper, resin, mycalex, mica, air and titanium dioxide. Additional new materials with better properties are being added to the list regularly.

DIELECTRIC CONSTANTS

Material	Dielectric Constant (K)
Air	1
Resin	2.5
Hard Rubber	2.8
Dry Paper	3.5
Glass	4.2
Bakelite	4.5 to 7.5
Mica	5 to 9
Porcelain	5.5
Mycalex	8
Titanium Dioxide Compounds	90 to 170

Figure 7 — Dielectric constants.

WORKING VOLTAGE

Dielectric strength is stated in volts (Fig. 8) and indicates how much EMF may be applied before the substance shorts and conducts. A capacitor whose plates are separated by one thousandth of an inch of air will withstand 80 volts of EMF. Replace the air with mica and it will be capable of withstanding 2,000 volts (Fig. 8).

A safe working voltage is assigned to capacitors, based on the thickness and type of dielectric used. This factor is stated in volts and is a figure considerably below the destruct voltage. Working voltage is abbreviated either WV or WVDC (working voltage direct current). When you are selecting replacement capacitors, always select one with an adequate voltage rating. A capacitor's working voltage should exceed the highest EMF value that will appear across its plates.

DIELECTRIC STRENGTHS

Material	Dielectric Strength (Volts/0.001 Inch)
Air	80
Fiber	50
Glass	200
Castor Oil	370
Bakelite	500
Porcelain	750
Paper (paraffined)	1200
Paper (beeswaxed)	1800
Mica	2000

Figure 8 — Dielectric Strengths.

LEAKAGE CURRENT

Perfect insulators do not exist, even among the finest materials used for dielectrics; all materials allow small amounts of current to flow. The resistance of dielectric materials is usually very high (hundreds of millions of ohms) and permits only insignificant amounts of leakage current. These small amounts of current are calculated into designs in order to have no effect on circuit function. When you are replacing capacitors, a type similar to the original should be used.

TOLERANCE

Tolerance is a figure used to indicate the amount a capacitor may depart from its indicated capacitance value. A 100 pf (picofarad) capacitor with a tolerance of plus or minus (±) 10% can vary from its stated value by 10 pf. Generally its capacitance value would be close to stated value but occasional units will approach 110 pf while others will have values close to the low limit (90 pf).

Tolerance should not be misinterpreted to mean that a capacitor wanders in value by a factor of ± 10% while in service. Capacitors are automatically produced by machinery which naturally allows some variation from unit to unit. A tolerance of ±10% means that no single capacitor from a manufactured batch shall be more than +10% or -10% from the stated value at some stated value of applied voltage and temperature.

TEMPERATURE COEFFICIENT

The value of nearly any capacitor will vary somewhat with temperature change. This is due to the change in K and some expansion or contraction of the materials.

Certain capacitors called general purpose types vary widely, but their use is limited to circuits in which considerable variation has no adverse effect on circuit functions. Special units are used in circuits in which very little or a specific amount of change is desired.

Temperature coefficients are expressed in terms of parts per million variation per degree C temperature change. Capacitors have been developed which change in either a positive or negative direction. *Positive coefficient* capacitors increase with temperature rise, while *negative coefficient* capacitors decrease in value as temperature increases. A special type, designated *NPO,* is interpreted *negative/positive zero,* and it neither increases nor decreases with temperature change.

An N-1000 coefficient capacitor would vary by 1000 parts per million for each degree of temperature change. Since the coefficient is negative the capacitance value will decrease with temperature rise and increase as the temperature becomes lower.

Positive (P) coefficients are opposite to negative coefficients. If a certain capacitor has a value of one million pf and a P1000 temperature coefficient, it will increase 1000pf for each degree of temperature rise and decrease 1000pf for each degree of temperature drop. Temperature coefficients in parts per million are abbreviated PPM.

PARALLEL CAPACITORS

Earlier you learned that increasing the plate size (surface area) of a capacitor increases the capacitance value. Doubling the plate's size will double the capacitor's value. Relatively the same thing occurs when two or more capacitors are connected in parallel.

Figure 9 shows two capacitors, C_1 and C_2. Connecting C_2 to C_1 is the same as adding plate area of C_2 to C_1. If they have identical values, the result is twice that of a single capacitor. Whenever capacitors are connected in parallel, the capacitance increases.

Figure 10 illustrates three capacitors connected in parallel. The resultant value is the total for all three capacitors.

C_1 = 500 Mfd.
C_2 = 300 Mfd.
C_3 = 200 Mfd.
Total = 1000 Mfd.

The capacitance value of any group connected in parallel is the sum of all the individual values.

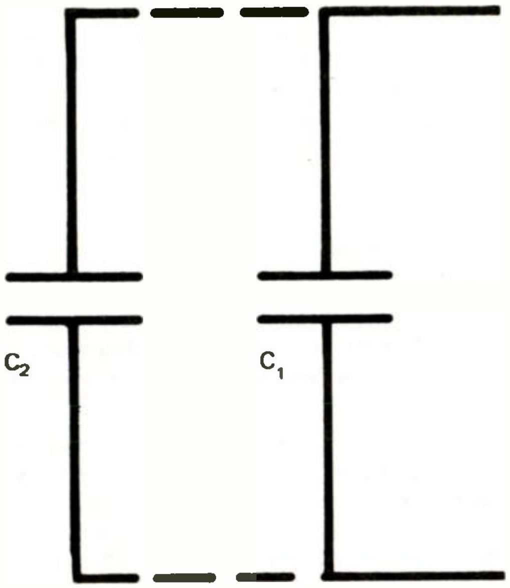


Figure 9 – Two capacitors connected in parallel effectively increase the plate area and capacitance.

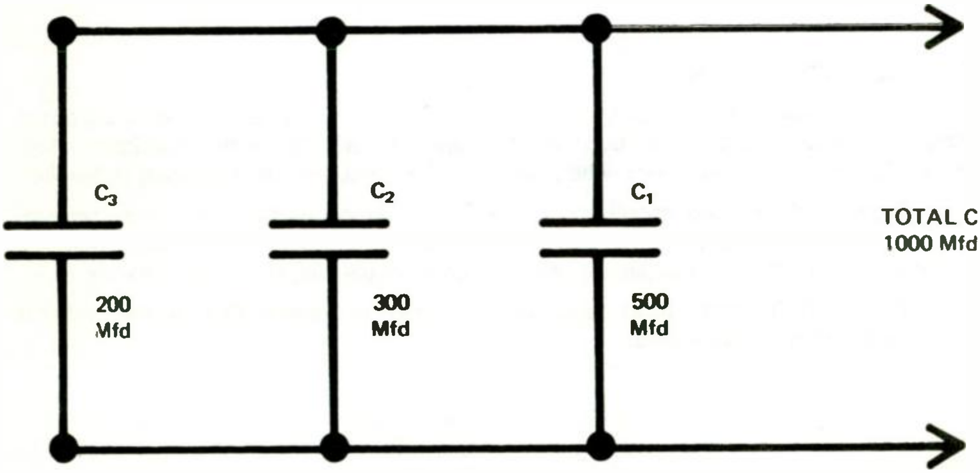


Figure 10 – The capacitance value of capacitors in parallel equals the sum of the individual values.

CAPACITORS IN SERIES

If the space between plates of a capacitor is increased, the capacitance value will decrease. In figure 11 the distance between plates has been effectively increased by including another capacitor C_2 in series with C_1. In this case the value for the series combination is less than that of C_1 or C_2. The formula for finding the value of these two capacitors in series is

$$C \text{ total} = \frac{C_1 \times C_2}{C_1 + C_2} = \frac{4 \times 4}{4 + 4} = \frac{16}{8} = 2 \text{ Mfd.}$$

The capacitance of any group of capacitors in series is always less than any one capacitor of the group. In fact this value is less than the capacitance of the capacitor with the smallest value.

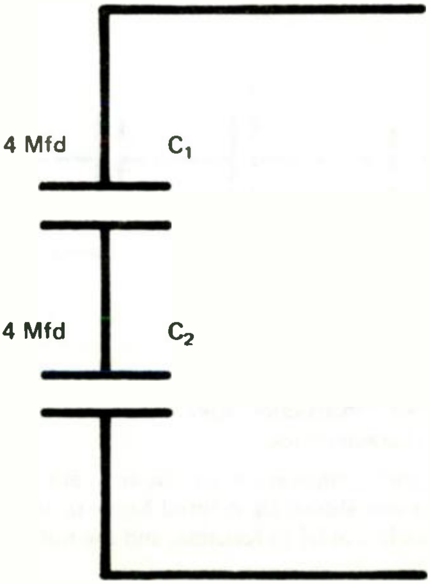


Figure 11 — Connecting capacitors in series increases the spacing between plates and effectively reduces the total capacitance.

Fig. 12 shows three capacitors in series. The formula for finding total C is

$$C\ \text{total} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}} = \frac{1}{\frac{1}{2} + \frac{1}{4} + \frac{1}{8}} =$$

$$\frac{1}{\frac{4}{8} + \frac{2}{8} + \frac{1}{8}} = \frac{1}{\frac{7}{8}}$$

To divide 1 by $\frac{7}{8}$, invert the $\frac{7}{8}$ and

multiply $1 \times \frac{8}{7} = \frac{8}{7}$ which is $1\frac{1}{7}$ Mfd.

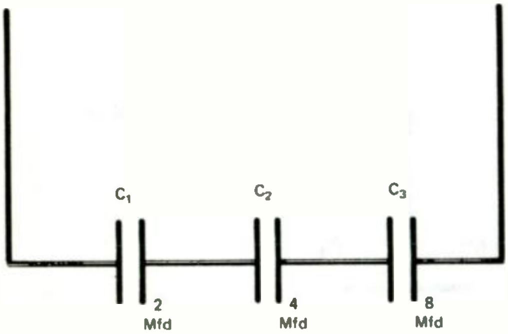


Figure 12 – The capacitance value of two or more capacitors in series is less than the smallest value included.

MARKING SYSTEMS

Figure 13 illustrates several fixed mica capacitors, while those pictured in Figure 14 use a ceramic material in their construction. Like mica capacitors, the ceramic units have good to excellent tolerance characteristics.

Capacity, tolerance and temperature coefficients are stamped into the body material on some capacitors and shown by colored bands or dots on others. The colors used follow a pre-assigned code similar to resistors, and the numerical value of each color is repeated below.

Black = 0
Brown = 1
Red = 2
Orange = 3
Yellow = 4

Green = 5
Blue = 6
Violet = 7
Grey = 8
White = 9

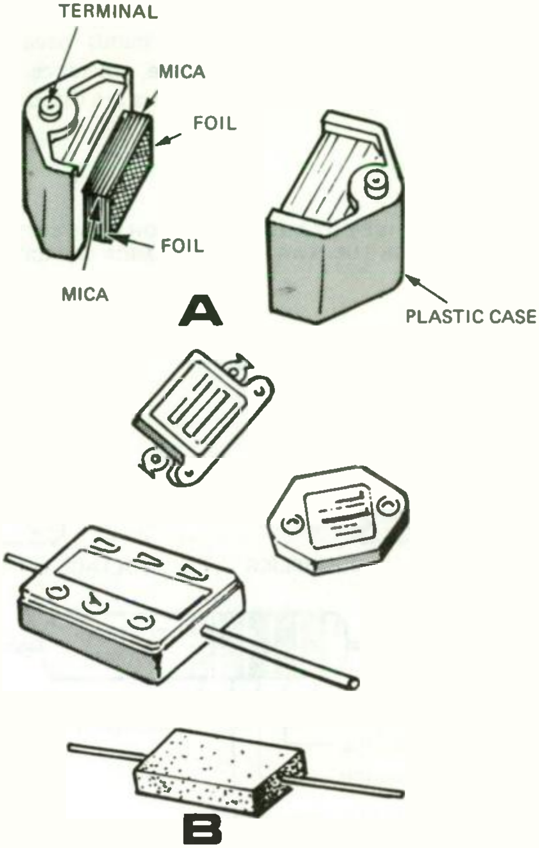


Figure 13 — Mica capacitors.

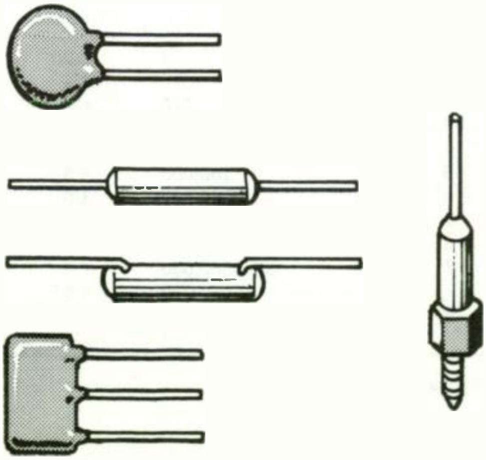
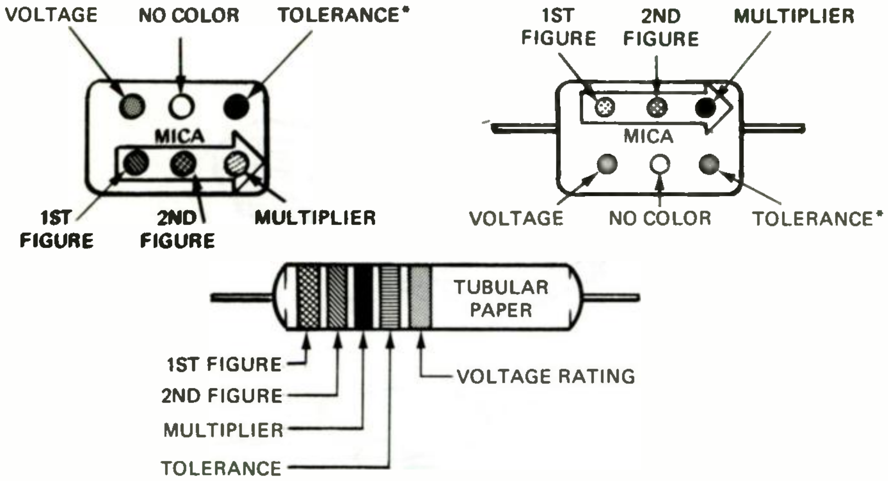


Figure 14 — Ceramic capacitors.

Several arrangements of color dots or bands have been used in the past for designating a capacitor's value, working voltage, tolerance and temperature coefficient. Two of the most common systems currently in use are listed in Figures 15 and 17.

FIVE-DOT AND BAND COLOR CODE SYSTEM
FOR TUBULAR PAPER AND MICA CAPACITORS



COLOR CODE

1 Color	2 First Figure	3 Second Figure	4 Multiplier	5 Tolerance	6 Voltage Rating (volts)
Black	0	0	1	± 20	100
Brown	1	1	10	± 1	200
Red	2	2	100	± 2	300
Orange	3	3	1000	± 3	400
Yellow	4	4	10,000	± 4	500
Green	5	5	100,000	± 5	600
Blue	6	6	1,000,000	± 6	700
Violet	7	7	10,000,000	± 7	800
Gray	8	8	100,000,000	± 8	900
White	9	9	1,000,000,000	± 9	1000
Gold	–	–	0.1	± 5	2000
Silver	–	–	0.01	± 10	–

*No color indicates tolerance of +20%.

Figure 15 – Five-dot and five-band color code for mica and tubular paper capacitors.

Colors have been assigned to a capacitor (Fig. 16) for illustration. The upper three dots, orange, green and red (in that order), denote a capacitance of 3500pf (picofarad). The voltage dot, green in this case, denotes a 600V rating. The tolerance color is silver, which indicates that the actual value may be as much as 10% less or greater than 3500pf. A color band is not included on ceramic capacitors for working voltage, because nearly all ceramics are rated at 500 volts (Fig. 17A). The first band signifies temperature coefficient in PPM. For a list of colors and coefficient designations, refer to column 7 of Figure 17.

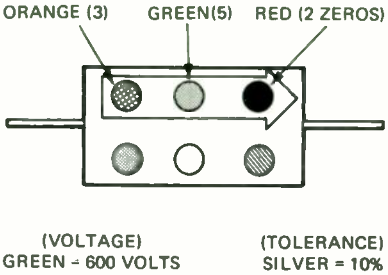


Figure 16 — A mica capacitor with a value assigned.

CERAMIC CAPACITOR COLOR CODE

1	2	3	4	5	6	7
				Tolerance		Temperature
Color	First Figure	Second Figure	Multiplier	More than 10 pf (%)	Less than 10 pf (pf)	Coefficient
Black	0	0	1.0	± 20	+2	0
Brown	1	1	10	± 1	—	–30
Red	2	2	100	± 2	—	–80
Orange	3	3	1000	± 3	—	–150
Yellow	4	4	10,000	± 4	—	–220
Green	5	5	—	± 5	+0.5	–330
Blue	6	6	—	± 6	—	–470
Violet	7	7	—	± 7	—	–750
Gray	8	8	0.01	± 8	+0.25	+30
White	9	9	0.1	± 10	+1	+120 to –750
Gold	—	—	0.1	± 5	—	—
Silver	—	—	0.01	± 10	—	—

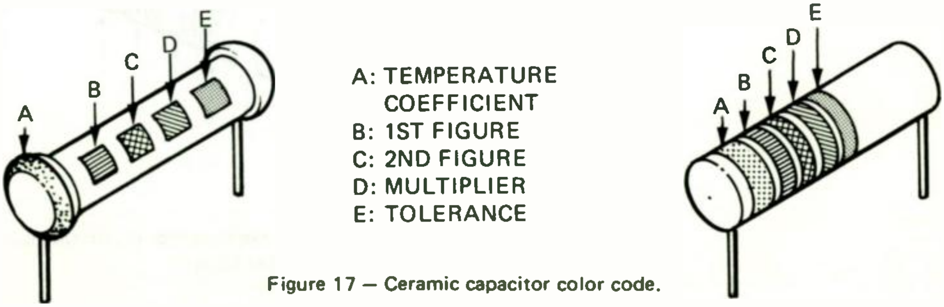


Figure 17 — Ceramic capacitor color code.

An example is shown in Figure 18 of a ceramic unit with colors assigned. This is a 35pf capacitor, ± 1% tolerance with a -750 PPM coefficient.

The colors gold and silver in the fourth columns (Figs. 15 and 17) are decimal multipliers. These indicate that the decimal point should appear either before the first or the second figure from the right. The capacitance value of the unit (Fig. 19) is 2.5pf. This is derived by multiplying 25 by .1. Multiplying by .1 does not change the values of the 2 and the 5, but it does cause the decimal point to be moved one place to the left. Grey or silver (Fig. 20D) causes the decimal point to appear two places to the left.

Example:

$$\begin{array}{r} 25 \\ \times .01 \\ \hline .25 \text{ pf} \end{array}$$

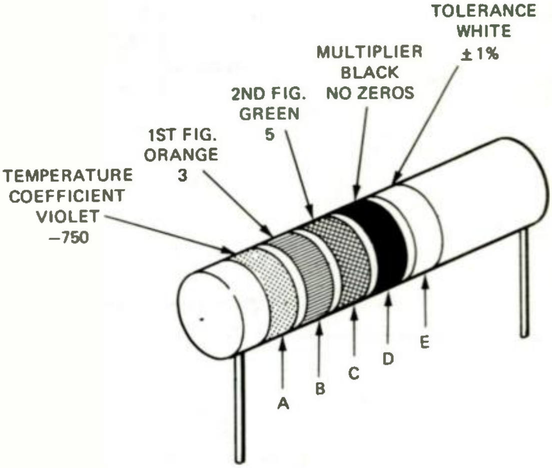


Figure 18 – A ceramic capacitor with value assigned.

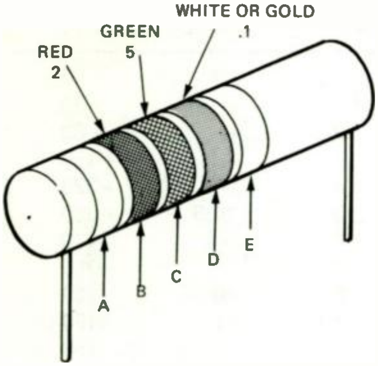


Figure 19 – A ceramic capacitor illustrating use of multiplier band.

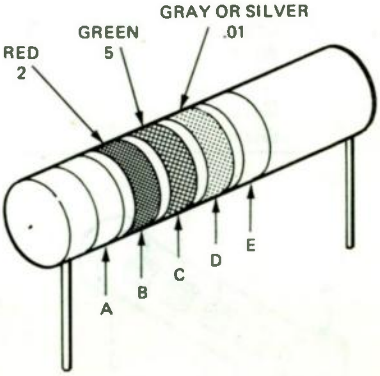


Figure 20 – A ceramic capacitor illustrating use of multiplier band.

CAPACITANCE AND AC CURRENT

In figure 21 the two alternations of an AC waveform in a capacitive circuit are shown. Current in a positive direction is illustrated in A, while B represents current in a negative direction. During the (+) alternation, current flows into plate 1 and out of plate 2 of the capacitor. Electron current actually flows through the connecting wiring and within each plate. Once the peak charge voltage has been reached, current ceases to flow. In figure 21B the current is reversed during the negative alternation. Plate 1, which has excess electrons after completion of alternation A, begins to give up its excess electrons, and plate 2, which is positive, begins to accept electrons.

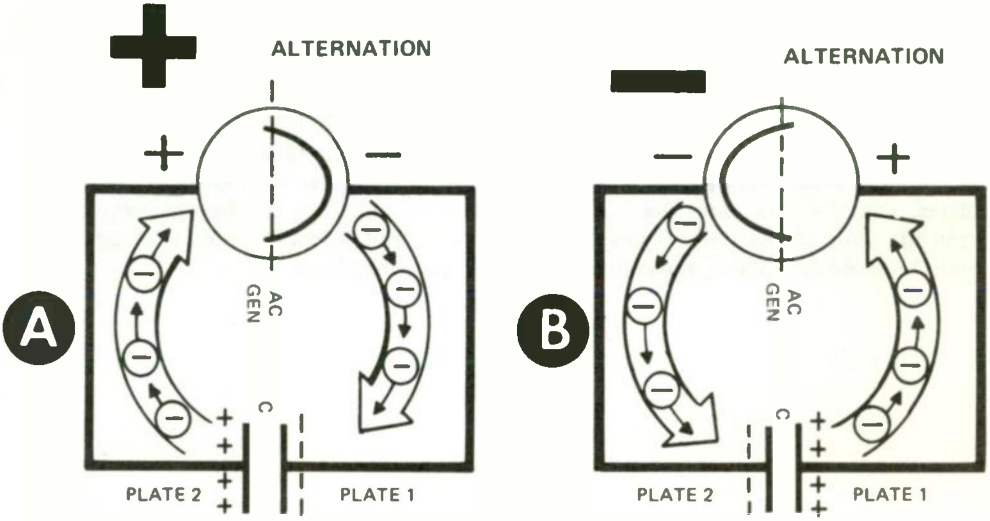


Figure 21 – A capacitor being subjected to an AC source. A, forward direction; B, reverse direction.

If a load is inserted into the wiring, it will absorb power as current flows in the connecting wiring between the generator and capacitor's plates during each alternation. But this current does not flow through the capacitor; it flows in and out of the capacitor and through the remaining circuitry. In figure 22 we show how current in and out of a capacitor illuminates a lamp.

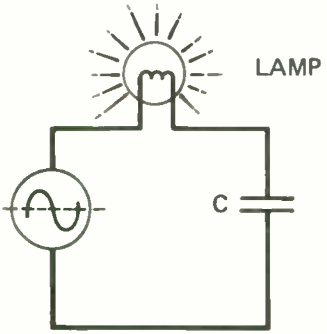


Figure 22 – Current flows in a capacitance circuit powered from an AC source.

The larger the value of C (capacitance) in an AC circuit, the greater the current. The *AC resistance* or capacitive reactance decreases as capacitance increases, thus allowing current to flow more freely. Another way of increasing current is to increase the frequency of alternations. Capacitors offer less opposition to current flow at higher rates of change than at lower rates.

FIXED CAPACITORS (NON-POLAR)

Non-polarized, fixed value capacitors, account for a large percentage of the capacitors used in electronics.

1. A fixed capacitor is one whose capacitance value cannot be changed.
2. A non-polarized capacitor is a type which accepts current and voltage in either direction. The applied voltage may be alternating or pulsating.

Early capacitors were brown or black rectangular blocks with two sets of plates which were separated by a mica or paper dielectric. A wire was attached to each set of plates, and the two wires were either attached to terminals or they projected from opposite ends of the unit. Figure 23 illustrates multiplate construction of a capacitor. Solid lines indicate plates; the dielectric is shown as dashed lines.

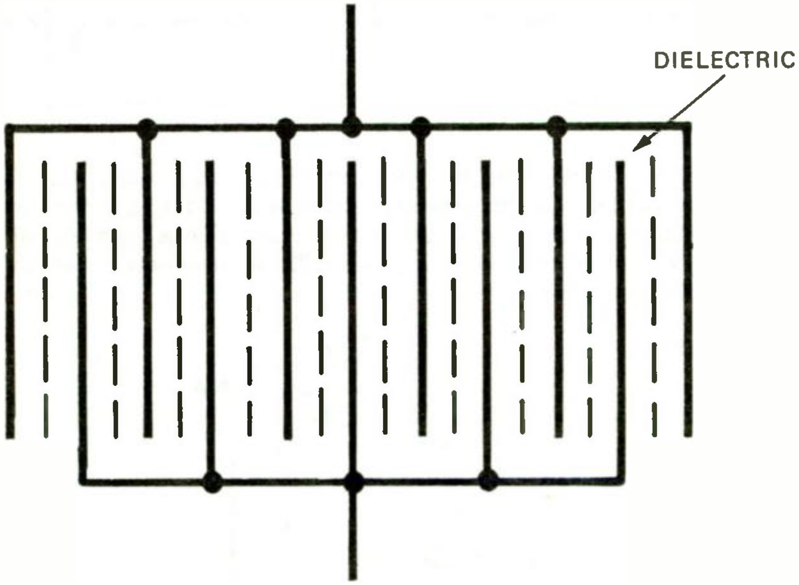


Figure 23 — Multiplate construction of a capacitor.

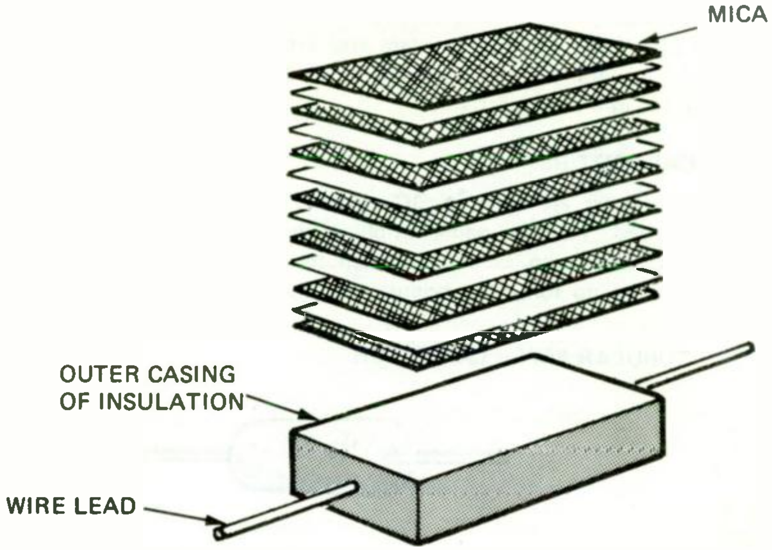


Figure 24 — Construction of a Mica Capacitor.

The physical characteristics of a mica capacitor are shown in figure 24. Mica capacitors were the first type developed with good stability characteristics. They are still used, but in many instances their requirements can be satisfied by ceramic capacitors (Fig. 25). Ceramic types are easy to manufacture and have fair to good electrical characteristics.

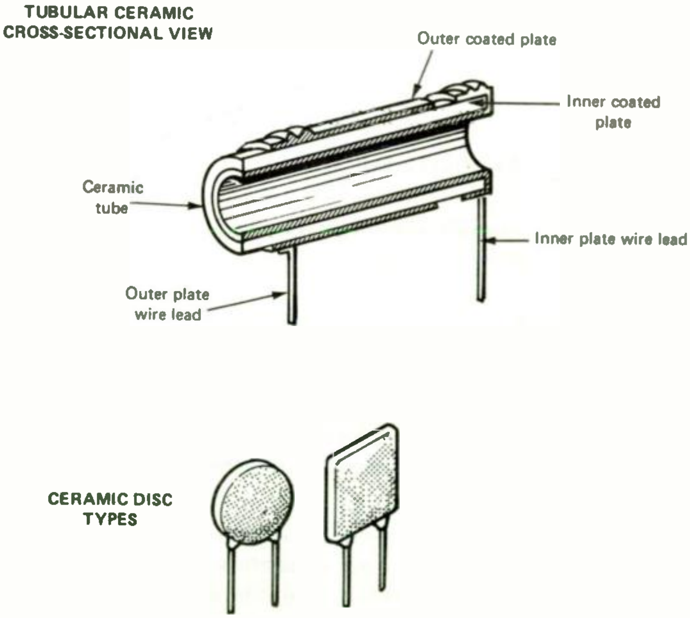


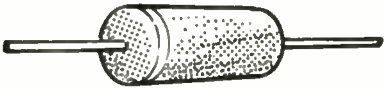
Figure 25 — Additional ceramic capacitors.

Figure 26 illustrates how foil backed paper is rolled to form a tubular capacitor. This is one way to pack large amounts of plate area into small units. Tubular units have adequate stability for general purpose applications and are used where large values of capacitance are required at a small cost.

ELECTROLYTIC CAPACITORS

Electrolytic capacitors are used in DC circuits in which very large amounts of capacitance are required. As the name implies, electrolytic capacitors contain an electrolyte. This electrolyte can be in the form of either a liquid or a paste. Wet electrolytic capacitors are no longer in popular use due to the care needed to prevent spilling.

TUBULAR PAPER CAPACITOR



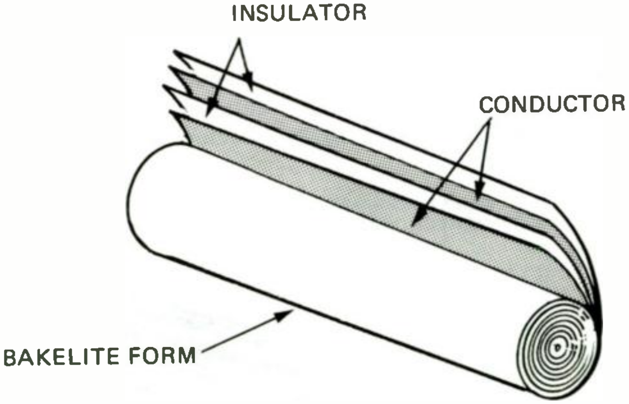


Figure 26 — Rolled construction of a tubular paper capacitor.

Dry electrolytic capacitors consist essentially of two metal plates, each surrounded by electrolyte. In most cases the capacitor is housed in a cylindrical aluminum container which also serves as the negative terminal (Fig. 27).

Positive terminals are in the form of lugs at the bottom of the container. The size and voltage ratings of these capacitors are generally printed on the side of the aluminum can.

An example of a multi-section capacitor is depicted in figure 27. The cylindrical aluminum container encloses four capacitors in one can. Each section is electrically independent of the other sections, and one section may be defective while the other sections are still good. The can is the common negative connection with separate positive

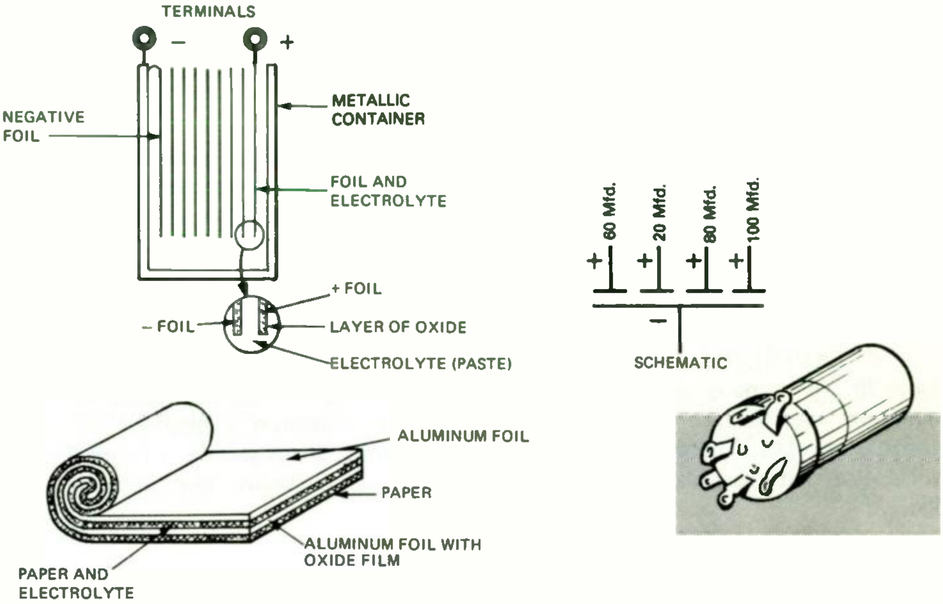


Figure 27 — Construction of a dry-type electrolytic capacitor.

terminals for each section. The section identifying marks on electrolytic capacitors are a half moon, triangle, square and blank. By looking at the bottom of the container and the identification on the side of the container, each section can be identified.

The rolled construction of an electrolytic capacitor is similar in appearance to a paper capacitor. The positive plate consists of aluminum foil covered with a thin film of oxide formed by an electro-chemical process. This thin oxide film acts as the dielectric. Next to and in contact with the oxide is placed a strip of paper or gauze which is saturated with the paste-like electrolyte. The electrolyte acts as the negative plate. A second strip of aluminum foil is then placed against the electrolyte to provide continuity between it and the negative electrode. When the three layers are in place, they are rolled up into a cylinder (Fig. 27).

Electrolytic capacitors have two primary disadvantages; they are POLARIZED, and they have a LOW LEAKAGE RESISTANCE. Should the positive plate be accidently connected to a negative EMF, the thin oxide film will dissolve and the capacitor will conduct. Since electrolytic capacitors are polarity sensitive, their use is restricted to DC circuits or circuits where a small AC voltage appears on a DC voltage level. Special electrolytic capacitors are available for certain AC applications, such as starting a motor. Dry electrolytic capacitors vary in size from about 1 microfarad to several thousand. Only a few have a working voltage that exceeds 500 volts DC.

The type of dielectric used and its thickness govern the amount of voltage that can be safely applied to a capacitor. Should the voltage be excessive, *an arc through* will take place between the plates. Unless the capacitor is self-healing, its effectiveness will then be impaired. The maximum safe voltage (WORKING VOLTAGE) is indicated on the body of the capacitor. Because of the possibility of voltage surges (brief high amplitude pulses), a margin of safety should be allowed between the circuit voltage and the working voltage of a capacitor. The working voltage should always be higher than the maximum circuit voltage.

OIL CAPACITORS are often used in radio transmitters where high output is desired. Oil-filled capacitors are nothing more than paper capacitors immersed in oil. The oiled paper has a high dielectric constant which lends itself well to capacitors that have a high value. Many other high quality capacitors use oil with their dielectric material to prevent arcing between the plates. If an arc through occurs, the oil tends to reseal the hole; therefore, these capacitors are often called *SELF-HEALING.*

A TANTALUM ELECTROLYTIC with its element designations is shown in figure 28. This type is usually manufactured for high capacity-low voltage applications in miniature transistorized equipment. Its principle of operation is identical with other electrolytic types. The symbol for an electrolytic capacitor is shown in figure 29. You will notice that the polarity is identified by marking the positive plate with a plus (+) sign.

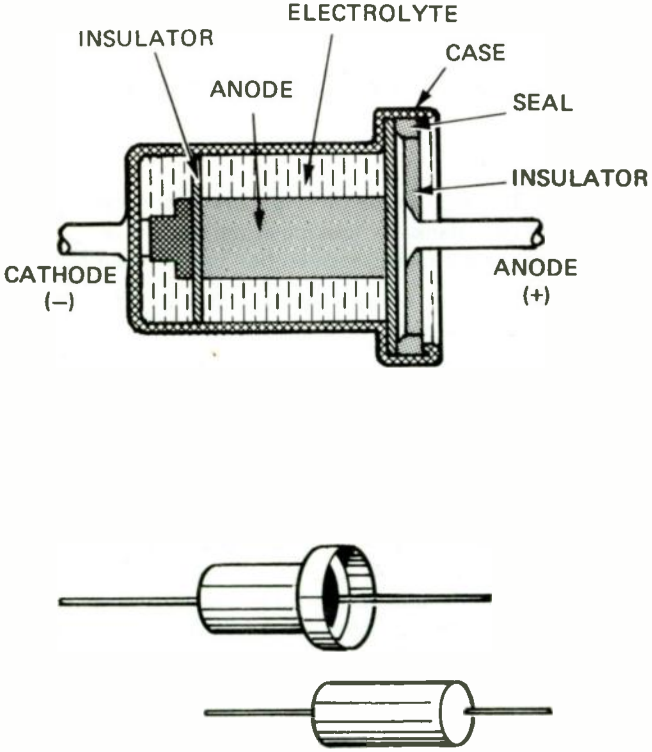


Figure 28 – A Tantalum Capacitor.

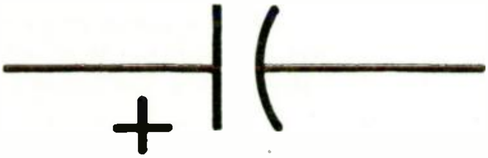
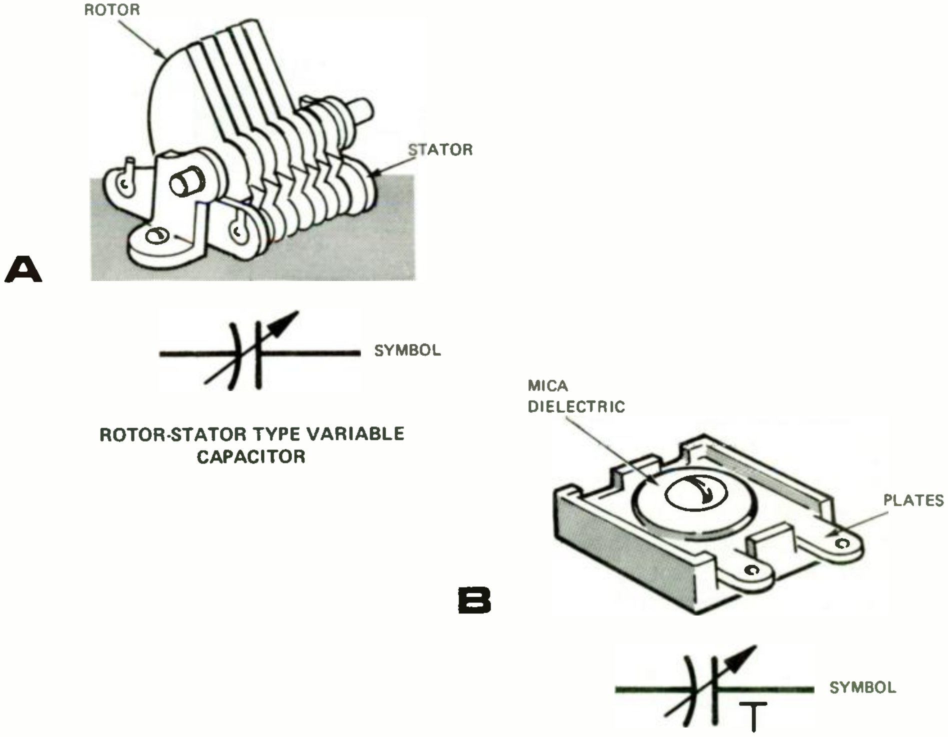


Figure 29 — The symbol for an electrolytic capacitor shows polarity.

VARIABLE CAPACITORS

Variable capacitors are designed so that capacitance values can be adjusted by the user. Their value can be altered to conform to circuit requirements. Figure 30 shows a representative of each type of variable capacitor.

The rotor-stator type (A) has a shaft attached to a moveable set of rotor plates that mesh with a stationary or stator set. The capacitance is increased by rotating the moveable plates so that more of the plates' surface areas mesh. These are available with different quantities of plates with various spacings between them. Their primary purpose is for tuning radios to desired frequencies or stations.



ROTOR-STATOR TYPE VARIABLE CAPACITOR

TRIMMER CAPACITOR

Figure 30 — Trimmer capacitors.

Often, more than one variable capacitor is ganged or connected together with a single shaft (Fig. 31), so that more than one circuit can be adjusted with a single tuning knob. Multi-section variables are called ganged tuning capacitors or tuning gangs.

Figure 30B pictures another type of variable capacitor called a trimmer. The capacitance is varied by changing the spacing between its plates. This is accomplished with a screw that forces the plates closer together when it is tightened, and allows them to spread when it is loosened. Trimmers are used to compensate for variations in circuitry at the time of manufacture. Once they are properly set at the factory, they are not intended to be altered except by a qualified serviceman as required when other components change value with age. Trimmer capacitors are manufactured in a number of different shapes and sizes and usually have a screwdriver slot for service adjustment. Three common trimmers are shown in figure 32.

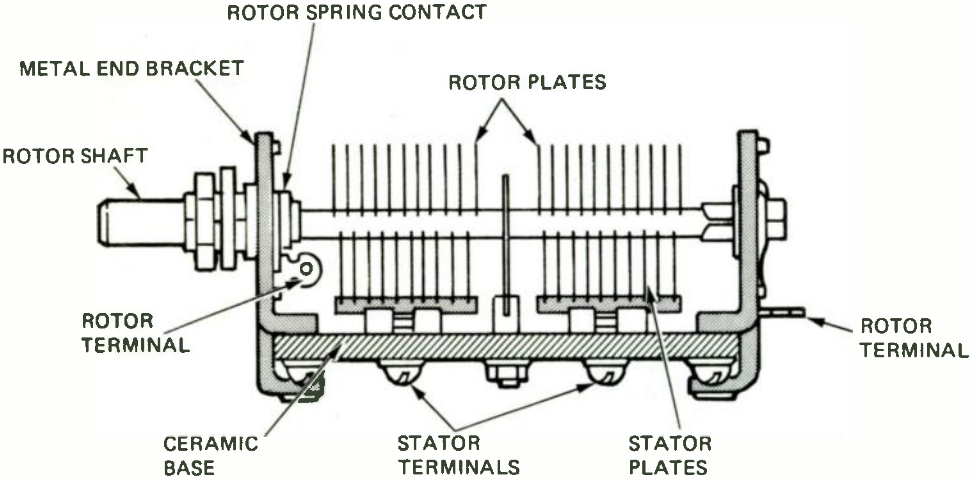


Figure 31 — Multisection variable capacitor.

CURRENT – VOLTAGE IN CAPACITORS

Figure 33 represents schematically a battery connected to a capacitor through a switch. The switch is open, and C is not charged. The voltage across C is zero, while 10 volts appear across the battery's terminals. Close the switch, and current will rush into the capacitor. This current is limited only by the circuit's resistance and the opposing voltage being developed as the capacitor charges. During the initial current surge, most of the voltage will appear across C. The capacitor voltage rises and begins to oppose the battery voltage and limit the current flow. The current decreases steadily as the voltage across the capacitor increases until eventually current ceases to flow. This occurs when the voltage across C equals the battery voltage.

The two functions, maximum or minimum voltage and current, do not occur at the same time. Maximum current flows into C when minimum voltage appears across it, and maximum voltage occurs at the moment current ceases. Peak voltage actually lags behind peak current. This establishes two rules:

1. In any capacitive circuit, peak current leads the peak voltage.
2. In a pure capacitive circuit, current leads voltage 1/4 cycle or 90°.

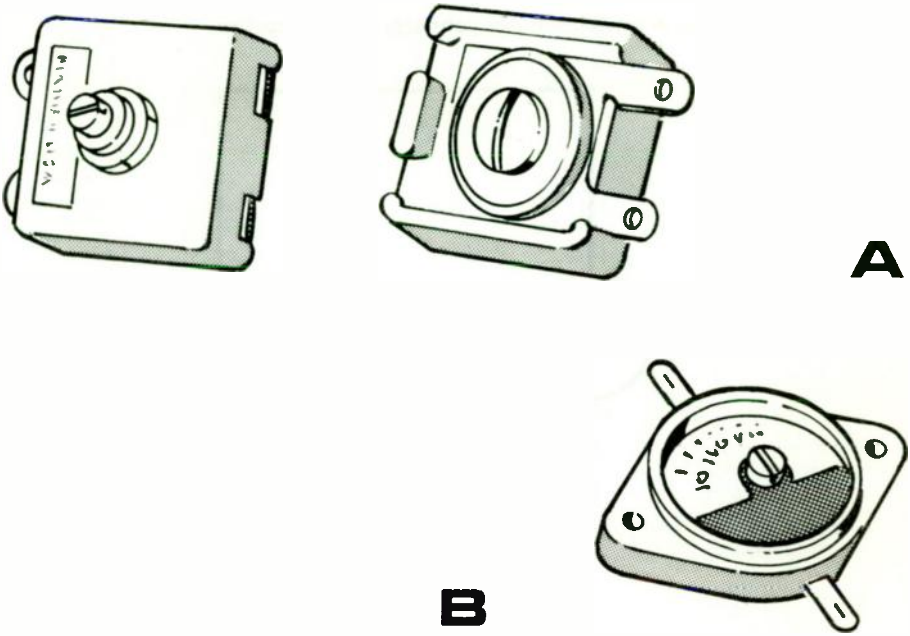


Figure 32 — Common trimmer capacitors.

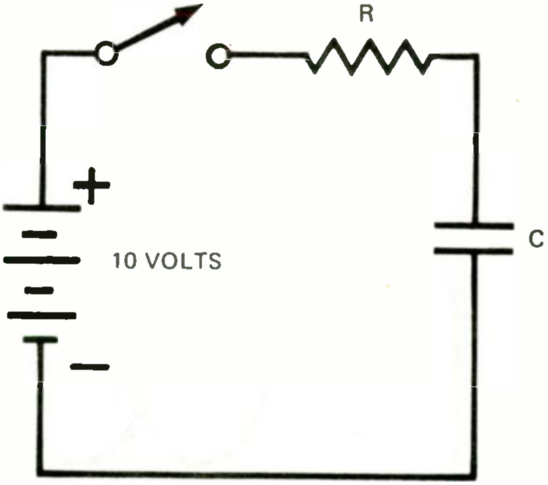


Figure 33 — Charging a capacitor with DC through R.

Figure 34 shows a sine wave generator connected to a capacitor.

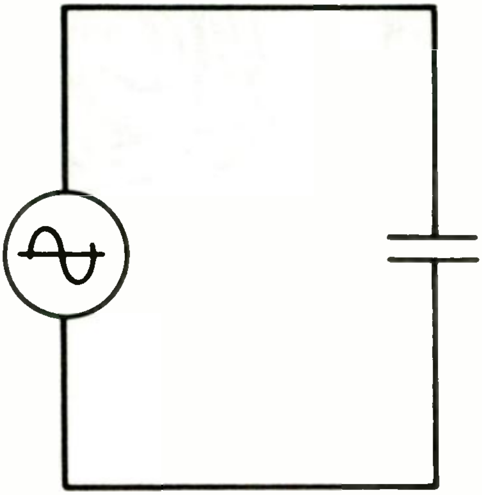


Figure 34 — Charging a capacitor with AC.

Figure 35 pictures the current waveform into a capacitor and the voltage waveform that appears across it. You will notice that voltage begins to rise only after the point of maximum current has been reached 90° later, or 1/4 cycle after current first began to flow. Current is said to lead the voltage by 90°.

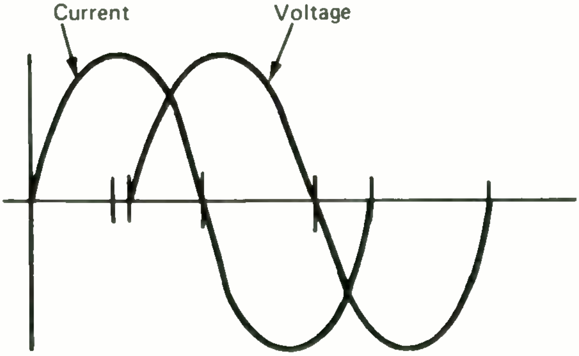


Figure 35 — Current leads voltage 90° in a pure capacitive circuit.

CHARGE – DISCHARGE TIMES

Figure 36 shows a series resistor-capacitor or RC network connected to a battery through a switch. Move the switch to position 1, and current will flow into C, restricted by R. A certain amount of time will pass before the EMF rises to an assigned level. This time is dependent upon the capacitance value C and the resistance R. The combination R and C provides a time constant for charging or discharging C. One time constant is equal to resistance in ohms multiplied by capacitance in farads and results in time in seconds. A capacitor will charge to 63.2% of source voltage during one time constant. The formula is T (1 time constant) = RxC. During time constant No. 2, the charge will increase 63.2% of the remaining 36.8 to 86.4% of source voltage. Figure 37 shows two graphs. One represents the charging of a capacitor, and the other represents the discharging. The two curves are identical only when they are inverted. You will notice from studying these charts that during each time constant, a change of 63.2% takes place. In each case, this is 63.2% of the amount that the capacitor needs to complete its charge or to completely discharge. After five time constants the capacitor is considered to be either fully charged or discharged. Five time constants represent more than 99% of the change that occurs.

Move the switch in figure 36 to position 2, and C will begin to discharge through R. The curve of the decreasing voltage is illustrated by the curve in figure 37B. This is a reversed duplicate of the charging curve.

The capacitor will dump 63.2% of its charge during the first time constant and 63.2% of the remaining 36.8% during the second. It will continue to lose 63.2% of whatever remains during each successive time constant.

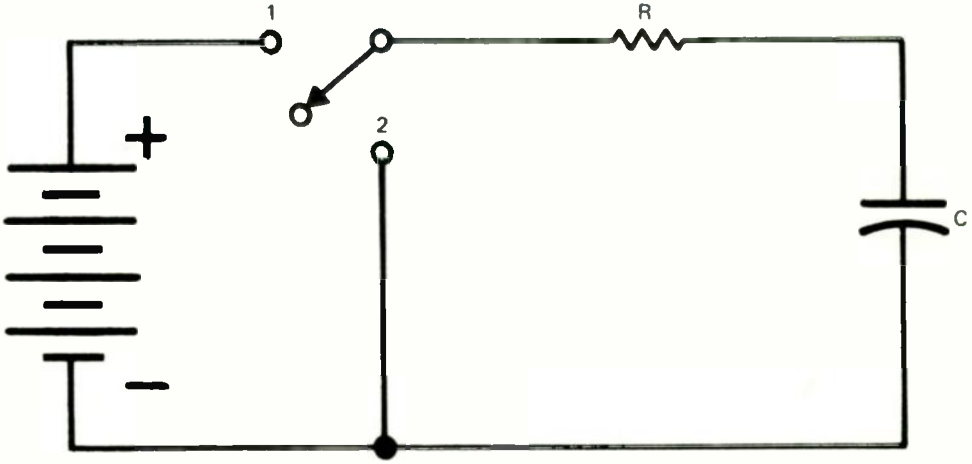
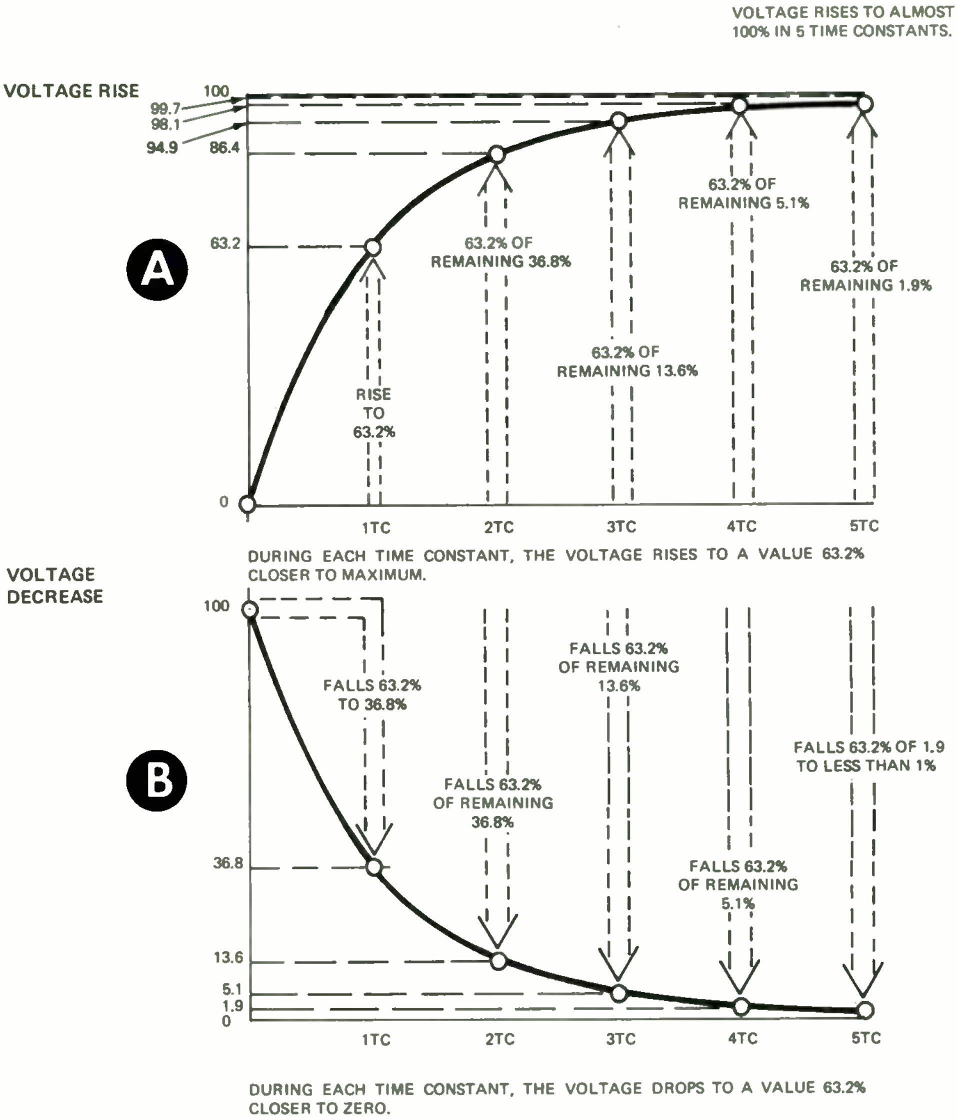


Figure 36 – A capacitor-resistor network setup to illustrate time constants.



VOLTAGE RISES TO ALMOST 100% IN 5 TIME CONSTANTS.

DURING EACH TIME CONSTANT, THE VOLTAGE RISES TO A VALUE 63.2% CLOSER TO MAXIMUM.

DURING EACH TIME CONSTANT, THE VOLTAGE DROPS TO A VALUE 63.2% CLOSER TO ZERO.

Figure 37 — A, charge, and B, discharge curves.

The illustration in figure 38 has values assigned to R in megohms (MΩ) and values assigned to C in microfarads (μf). The chart (Fig. 39) shows that the results using megohms and microfarads will be in seconds. Let's calculate the amounts of charge at the end of each time constant. Remember that one time constant equals R times C.

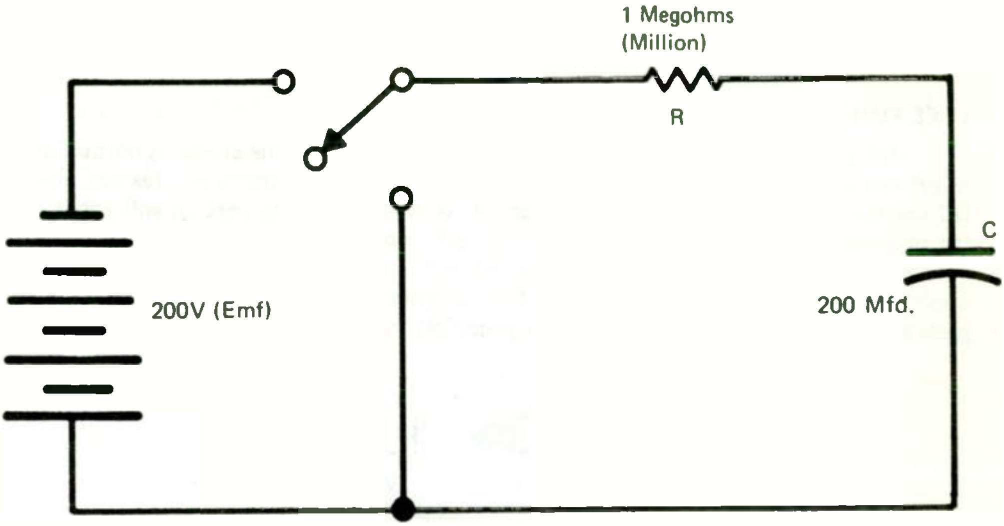


Figure 38 — Circuit for charging and discharging a capacitor through a resistance to establish time constants.

T (seconds) = (megohms) x (Mfd.) = sec. per T. C.

1st TC 200 sec: .632 x 200 volts = 126.4 volts or 63.2%, 73.6 volts remaining.

2nd TC 400 sec: .632 x 73.6 + 126.4 = 172.9 volts or 86.4%, 27.1 volts remaining

3rd TC 600 sec: .632 x 27.1 + 172.9 = 190 volts or 95%, 10.0 volts remaining.

4th TC 800 sec: .632 x 10 + 190 = 196.3 volts or 98.1%, 3.7 volts remaining.

5th TC 1000 sec: .632 x 3.7 + 196.3 = 198.6 volts or 99.3%.

UNITS OF CAPACITIVE TIME CONSTANTS

If R Is In	And C Is In	Then T Is In
Ohms	Microfarads	Microseconds
Kilohms	Microfarads	Milliseconds
Megohms	Microfarads	Seconds
Ohms	*Picofarads	Microseconds/1,000,000
Kilohms	Picofarads	Microseconds/1,000
Megohms	Picofarads	Microseconds

*Also known as micromicrofarad.

Figure 39 — Units of capacitive time constants.

After five time constants or 1000 seconds, the 200 Mfd capacitor has attained 99.3% of its charge through a 1 megohm resistor. The preceding illustration is of an RC network. These are used extensively for wave shaping in electronic circuits.

USES FOR CAPACITORS

One of the prime uses for fixed value capacitors is to pass the changing portion of a waveform while preventing passage of DC levels. Figure 40 illustrates this feature. Since DC current does not flow through a capacitor, only the changing portion will appear at the opposite plate. From the example in figure 40, observe how the 100 volts DC level is isolated while the effects of the 20 volt P/P AC appears at the opposite plate. This provides a way to isolate levels of DC from devices which would be harmed by their presence. This function is called a blocking application, because it blocks the DC voltage.

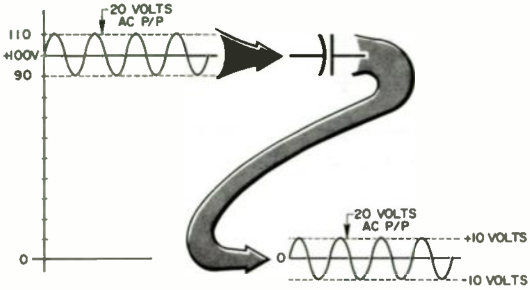


Figure 40 – Capacitor passes AC signal but not DC level.

The ability of a capacitor to store electrical energy during a peak and release it when the voltage drops makes it invaluable for another application. Capacitors are used for smoothing or removing small variations from DC voltage sources. A DC voltage with AC ripple riding on it is illustrated in figure 41. This voltage is applied to an RC filter network. The capacitor charges when the AC level is at peak and discharges when it declines. In this way it fills the dips with energy stored during the peaks.

Capacitors are also combined with inductances to accept or reject certain frequencies. This principle will be discussed in detail in later lessons.

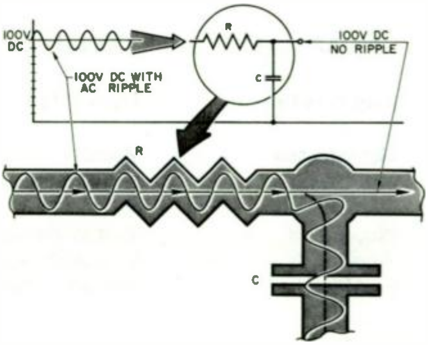


Figure 41 – An RC filter used to remove ripple from a DC level.

LESSON ELEVEN
CAPACITANCE AND CAPACITORS

TEST

1. A capacitor stores energy in

1 A. an electromagnetic field.
— B. an electrostatic field.
C. a magnetic field.
D. an electromotive field.

2. A negative charge results from

1 — A. an excess of electrons.
B. an absence of electrons.
C. a normal amount of electrons.
D. no electrons.

3. An electron is attracted by

A. a negative charge.
2 B. a neutral body.
[✓ C.] a positive charge.
— ~~D.~~ a positive and negative charge.

4. The amount of energy a capacitor can store is determined by:

A. the size and spacing of the plates.
6 B. the applied potential.
C. the kind of dielectric.
— D. all of the above.

5. The unit that designates the amount of energy a capacitor can store is the

A. mho.
6 B. ohm.
— C. farad.
D. gilbert.

6. The term used for AC resistance of a capacitor is

A. AC ohms.
18 B. picofarads.
— C. capacitive reactance.
D. capacitive resistance.

7. The material between the plates of a capacitor is called

A. K material.
7 B. resistive material.
— C. dielectric material.
D. constant material.

8. The term used to designate the safe amount of voltage that can be applied to a capacitor is

A. tolerance.
B. coefficient.
22 [✓ C.] working voltage.
D. leakage factor.

9. Capacitors in parallel

A. subtract.
9 [✓ B.] add.
C. multiply.
D. divide.

10. The value of a variable capacitor

A. is fixed.
23 [✓ B.] can be changed.
C. varies with voltage.
D. varies with current.

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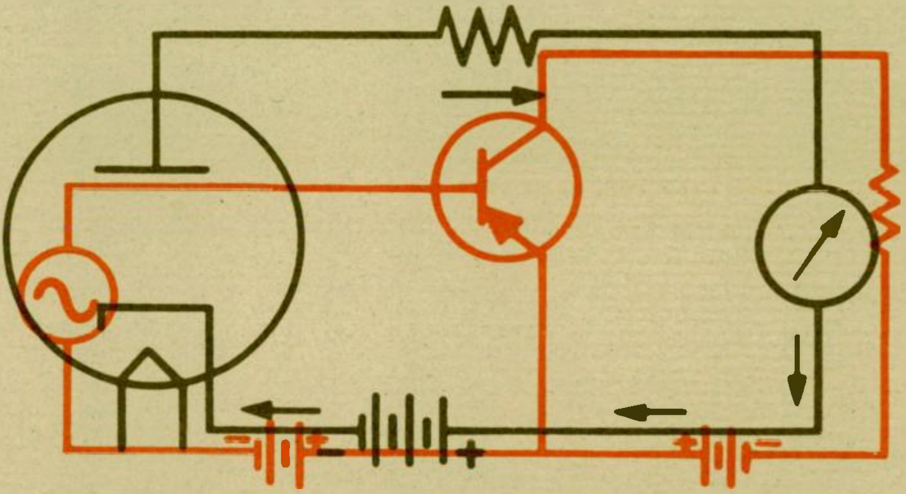
LESSON NO. 12

INDUCTANCE AND INDUCTORS



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Contents

INDUCTANCE AND INDUCTORS

INDUCTORS AND COILS

The word *inductor* is the general term used in describing electrical components that depend upon magnetic lines of force for their action. More specific terms used to identify electromagnetically operated devices are coil, solenoid, buzzer, power transformer, choke coil, and door bell.

Magnetic Lines of Force

These inductors or coils have current flowing through them which produces the magnetic field surrounding them. It is this magnetic field that produces electromagnetic energy. It is important to be able to measure the ability of a coil to produce these magnetic lines of force. We also need a unit of measurement that will tell us what each coil or inductor can do in an electric circuit.

Deflection of a Compass Needle

Magnetic lines of force are generated only when current is flowing in a conductor or in a coil, as discussed and illustrated in previous lessons. A compass needle will not be deflected and will continue to point to the magnetic north, because no current is flowing in the adjacent wire (Fig. 1). When current does flow, the needle will align with the magnetic lines of force (Fig. 2), and it will remain in this new position as long as electrons

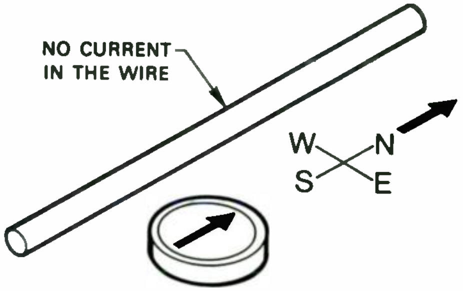


Figure 1 — With no current flowing, the compass needle points to the north.

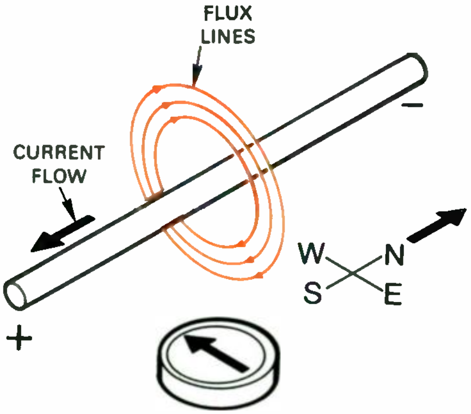


Figure 2 — The compass needle lines up with the flux lines of force, and remains stationary.

flow in the wire at the same current level. If the current is gradually reduced to zero, the needle will gradually return to its original position of pointing to the north.

If we now reverse the direction of current flow in the wire, the compass needle will again align with the magnetic lines of force. However, it will be pointing in the opposite direction, because the direction of current flow and the resulting lines of force are in a direction opposite the first current flow (Fig. 3).

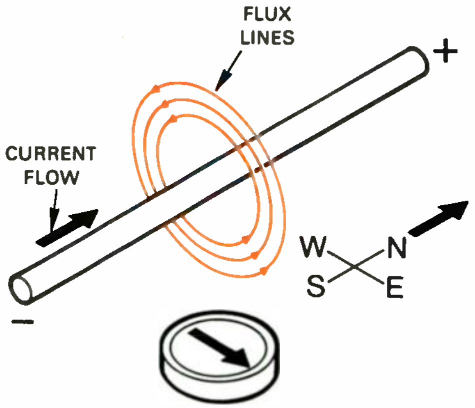


Figure 3 — **With the flux lines reversed, the compass needle reverses its direction.**

Effect of Current Reversal

If we could arrange an electrical system that would allow us to gradually increase the DC from an open circuit condition, which is the same as zero current flow, to a condition of maximum current flow (Fig. 2), the compass needle would turn gradually from north to west. As long as the current flow is at this maximum value, the needle will remain stationary and continue to point west.

When the current is gradually reduced to zero, the needle returns to its original position and again points north. Now reverse the direction of current flow in this electrical system and gradually increase the current from zero to a maximum flow in the opposite direction. The compass needle will gradually turn from north to east (Fig. 3).

This action can be demonstrated similar to the methods used in illustrating alternating current action. The maximum value, however, can be maintained indefinitely in our system. In Figure 4, the current is

increasing at a uniform rate, indicated by the sloping line a; is
constant at a maximum rate, indicated by the horizontal line b; and is
decreasing at a uniform rate, indicated by the sloping line c.

Point d shows where the current has returned to the "no flow" or zero value condition, and also shows where the direction of current has been reversed. When the current is increased and flows through the wire in the opposite direction, the lines of force are generated in the opposite direction also. The compass needle will, therefore, gradually turn to the opposite direction, and the current is

increasing at a uniform rate, indicated by the sloping line e; is
constant at a maximum rate, indicated by the horizontal line f; and is
decreasing at a uniform rate, indicated by the sloping line g.

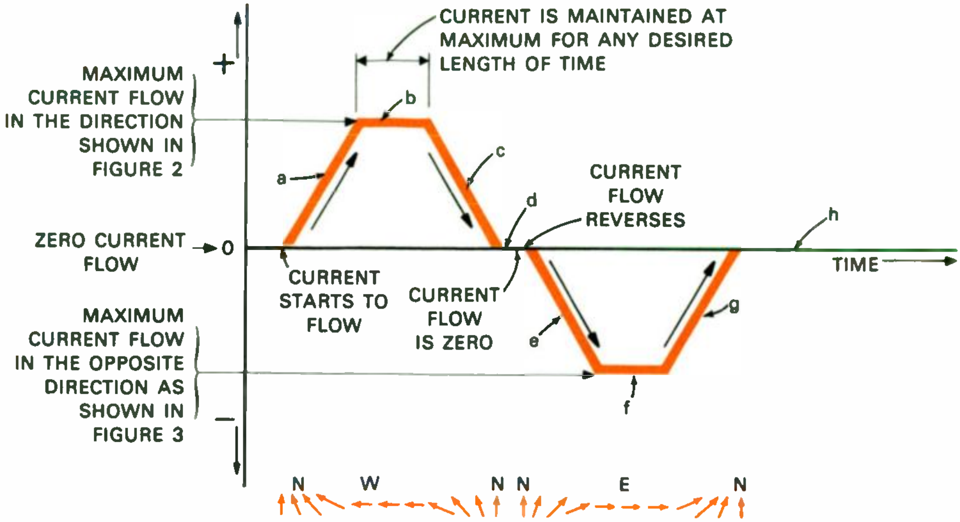


Figure 4 — **Increasing and decreasing the flow of current, and the resulting change of magnetic lines of force.**

Waveshape

The compass needle provides a visual means of observing both the *direction* and the *magnitude* of the magnetic lines of force. It also shows how these flux lines vary as we increase or decrease the current flow in the wire. This action has taken place during a definite period of time; the heavy line h was identified as the "time line" (Fig. 4). The total length of all the lines a + b + c + d + e + f + g, is commonly called a "waveshape", because it shows the shape of the wave.

INDUCED VOLTAGES

Moving the Conductor

We increased the current gradually (Fig. 4) and then held the current steady before gradually decreasing it to its zero value at line d. If we take less time in these three steps, we will not only have a different waveshape but also another action taking place in the wire. This action is similar to the action described in the previous lesson, MAGNETISM. This lesson described how a voltage was induced into a wire that was "cut" by magnetic lines of force (Fig. 5).

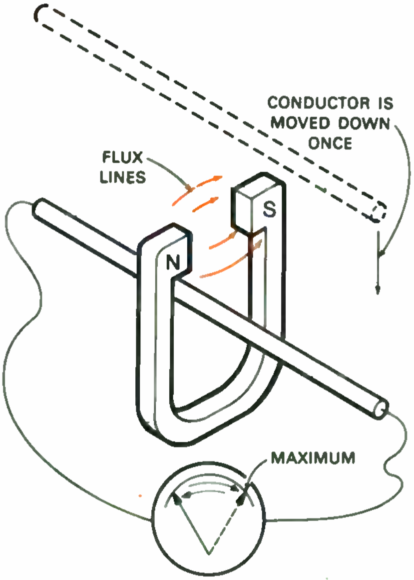


Figure 5 — **Inducing a voltage by moving the conductor thru the magnetic flux lines.**

Moving the Flux Lines

Whenever a conductor "cuts" magnetic lines of force, a voltage is induced into the conductor *while the conductor is moving through the flux lines*, or while the flux lines are *moving past the conductor* (Fig. 6).

The important point to remember here is that *no* voltage is induced into the wire when it is stationary, but

voltage is generated in a conductor

ONLY

during the time the wire is *moving through* magnetic lines of force

or

during the time magnetic lines of force are *moving past* the wire.

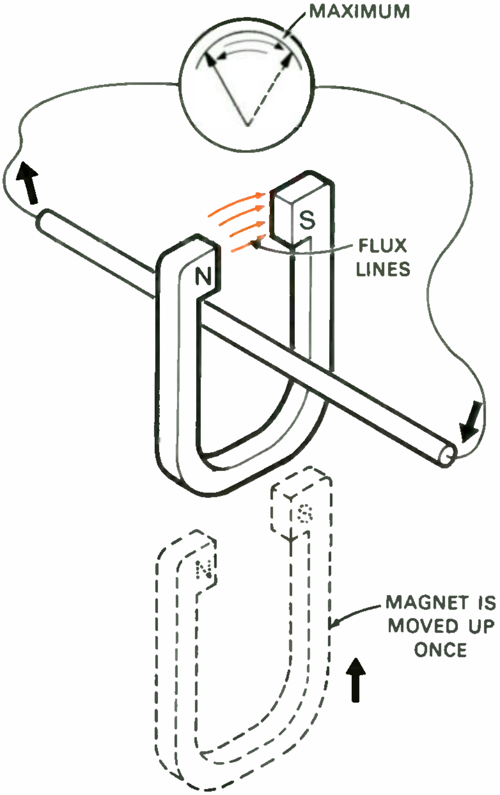


Figure 6 — Inducing a voltage by moving the magnetic flux lines past the conductor.

The voltmeter connected to the conductor (Figs. 5 and 6) indicates that the pointer moved from the left to the right side (the maximum position) of the voltmeter, and then returned to the left side (the original zero position). This forward and backward motion of the pointer on the voltmeter occurred only once, because the wire was moved only once. This single motion of the conductor in relation to the magnetic lines of force was the action that created the voltage induced in the wire. If the wire was moved *up and down* through the magnetic lines of force, the induced voltage would have an opposite polarity when it was moved *upward*. The small arrows located at each end of the conductors (Figs. 5 and 6) indicate that the current flow is in the same direction in both cases. The current flow must be in the same direction, because the relative motion (Figs. 5 and 6) was simply "bringing together" the permanent magnet and the conductor.

Generating an Alternating Current

If we decide to move the wire up and down, we would need a voltme-

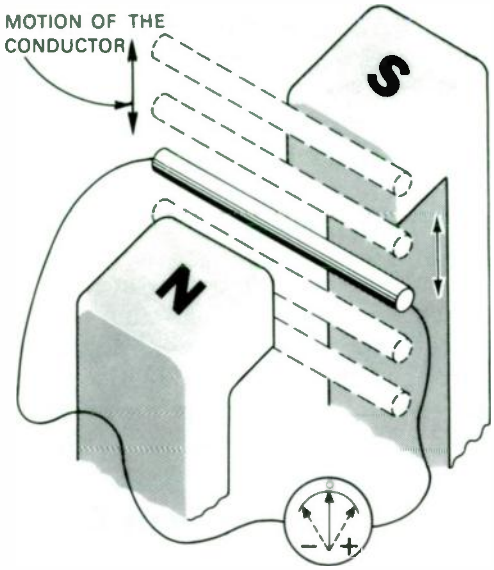


Figure 7 — Generating an alternating current.

ter with a zero position at the center of the dial face. Then the pointer of the meter would move to the right or to the left, depending upon the polarity of the induced voltages (Fig. 7).

Generating a Sine Wave

Because there is room between the north and south poles of the magnet to follow separate up and down paths for the conductor, Figure 7 is drawn again to show the relationship of the induced voltages to the position of the conductor (Fig. 8). It also shows that the number of flux lines is constant between the two poles of the magnet. The

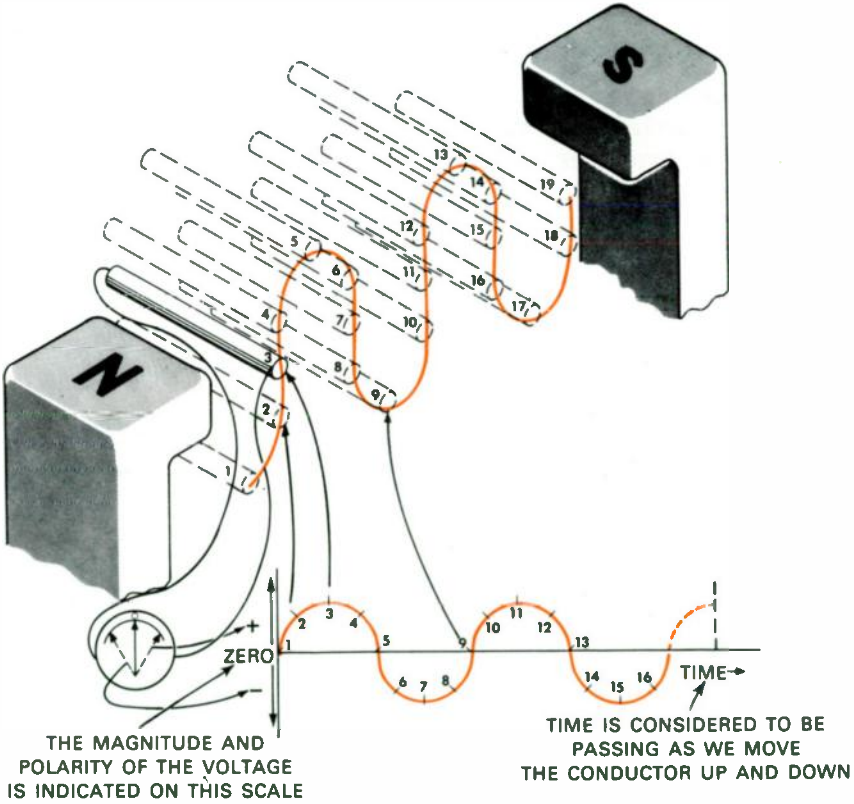


Figure 8 — Moving a conductor at the proper speed can generate a sine wave, as represented by the numbered curve.

nearness of the wire to the north or south pole has no effect on the number of magnetic lines of force that exist across the two poles.

Observe the development of the voltage in the conductor as it is moved up and down between the poles of the magnet (Fig. 8). The magnet may be stationary, and the conductor moved; or the magnet and its flux lines may be moved, and the conductor may remain stationary. This concept is important to remember, because from now on we will only investigate magnetic fields that are generated solely by a current that increases or decreases in a conductor.

GENERATING FLUX FIELDS

A single conductor or a single "turn" of wire (technically called a single turn coil) produces a certain amount of magnetic flux. If the same current flows through a two turn coil, each turn will produce the same amount of flux. The flux from one turn will reinforce the other and finally produce a total flux greater than the sum of the fluxes from each turn.

Multi-Turn Coils

Since a one turn coil creates a magnetic field, a multi-turn coil of three turns produces a much stronger magnetic field. This is due to the reinforcing action of each turn upon its neighbor (Fig. 9).

Primary and Secondary Coils

The drawings in Figure 10 illustrate what occurs when a one turn coil is close to another one turn coil but is not electrically connected to it. Voltage will be induced in the second coil during the time that the first coil is building its magnetic field. (Remember, voltage is induced only when flux lines are increasing or decreasing). There are many cases in which two coils close

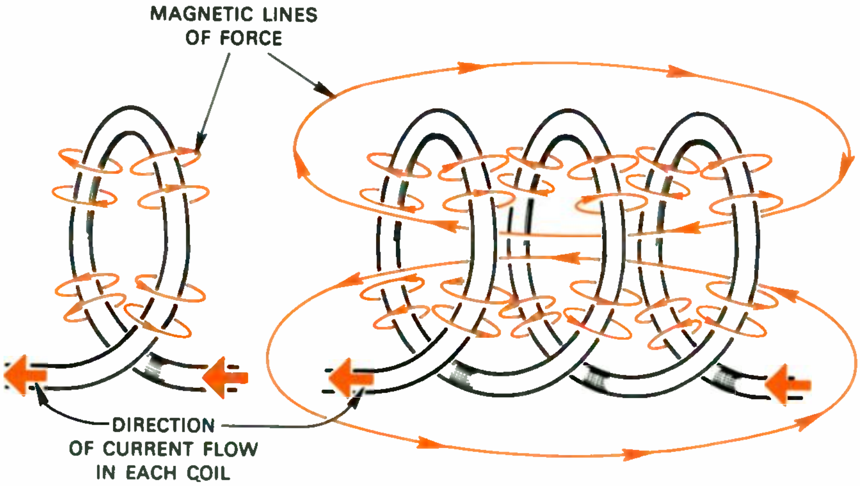


Figure 9 — Each turn of a coil produces flux, helping to multiply the total flux lines.

A NO CURRENT IN THE PRIMARY, SO THERE IS NO VOLTAGE IN THE SECONDARY

B CURRENT IS INCREASING IN P, AND VOLTAGE IS BUILDING UP IN S.

C CURRENT HAS REACHED ITS MAXIMUM VALUE IN P WHICH HAS PRODUCED THE MAXIMUM VOLTAGE IN S

D AS THE CURRENT FLOW IN P IS NOW STEADY, THE FLUX IS STEADY AND UNCHANGING, SO NO VOLTAGE IS INDUCED IN THE SECONDARY

Figure 10 — Voltages are induced only when flux lines are increasing or decreasing.

together enable one coil to induce a voltage in a second coil. The name

primary has been given to the coil that is producing the magnetic field, and the name

secondary has been given to the coil in which the voltage is induced.

These two names are often abbreviated to P and S (Fig. 10).

Self-Induced Voltages

It has previously been stressed that it is the increase or decrease of the magnetic lines of force cutting the turns of wire in a coil, that induces a voltage in the adjacent coil. Because these same flux lines also cut the turns in the original or primary coil, they induce a voltage in the original coil. Thus, the expanding or collapsing of the magnetic field around a coil induces a voltage in the coil itself. This property that induces this additional voltage or electromotive force (EMF) in the original coil is called *self-induction.*

The self-induced EMF in the original coil producing the magnetic lines of force has both *a magnitude* and *a polarity.* The magnitude indicates the amount of this self-induced EMF, while the polarity indicates the direction it is flowing in the original coil.

MAGNITUDE OF THE INDUCED EMF

The magnitude of the induced EMF is affected by the frequency of the current and the amplitude of the current. If the lines of force are increasing and decreasing at a rapid rate (at a "high" frequency), the induced EMF will reach a higher value. If the same current value was increasing and decreasing at a lower rate (at a "low" frequency), the value will, of course, be lower.

If we had to maintain the same value of induced EMF but were required to use the "low" frequency, we would have to increase the amplitude of the current. Increasing the amplitude would increase the number of lines of force cutting the conductor. This has the effect of maintaining the same value of induced EMF.

Therefore, the magnitude of the induced EMF is dependent upon the frequency of the current changes and the amplitude or peak value reached by the current. These relationships are shown in Figure 11, where the power source is drawn as an alternating current generator.

Polarity of the Induced EMF

One surprising factor remains; the EMF *induced* in the original coils is in an opposite direction of the current producing the magnetic lines of flux. Consider a direct current increasing from a zero value to some maximum at a slow rate. Visualize the flux lines that expand outward from the center of the conductor, like ripples on the surface of a lake when a stone has been dropped into the water. As these flux lines are initially generated in the exact center of the conductor that forms the coil, you can realize that the expanding flux lines cut the conductor on their way out. Thus, they generate this new EMF. If this newly created EMF had the same polarity as the original current and flowed in the same direction, it would reinforce the original current and create additional lines of force. These additional lines of force, in turn, would create more induced EMF. If this was what actually happened, the current would

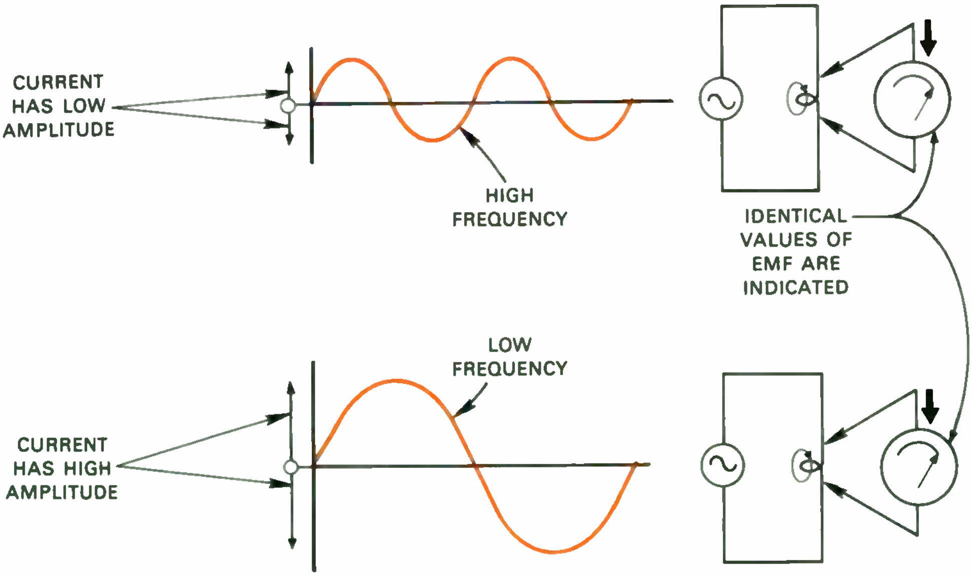


Figure 11 — Magnitude of the induced voltage depends upon frequency and amplitude of the current.

soon become so large that the conductor would become overheated and burn out.

Lenz's Law

This relationship between the induced EMF and the original direction of current flow is stated in Lenz's law. Lenz, a physicist, explained that

a change in current produces an EMF whose direction is such that it opposes the change in current.

Consequently, when the original current is increasing, the polarity of the induced EMF is opposite the direction of the original current and tries to prevent the current from increasing. The action of resisting the *change* in current is also present when the original current is decreasing, but now the induced EMF is in the same direction as the current and attempts to prevent the original current from decreasing. This self-induced EMF is known as a back EMF or a counter EMF and is abbreviated as CEMF.

DEFINITION OF INDUCTANCE

The property of a coil of wire that opposes any change in current is called *inductance.* This characteristic of a coil is evident by the opposition to the starting, stopping or changing of current flow. It is not difficult to find a physical analogy of inductance. Pushing an automobile or a wheelbarrow to start it moving is more work than keeping it moving. The car and the wheelbarrow both possess the mechanical property of inertia. This is characteristic of all massive objects which oppose a *change* in velocity. Inductance displays the same effect on current in an electric circuit as inertia does on the velocity of a mechanical object; that is, it resists change.

Counter Electromotive Force (CEMF)

In an electric circuit, the CEMF (counter electromotive force) is an induced EMF or voltage. This voltage is induced in conductors of the circuit not by an external magnetic field, but by the magnetic field already surrounding any conductor carrying a current. Any change in current varies the intensity of this magnetic field, and the resultant induced EMF, the counter EMF, is a self-induced voltage. The property of a circuit which produces such an EMF is called self-inductance.

All elements in a circuit, including connecting wires, show some self-inductance. But, for all practical purposes, only those elements designed to use this property to their advantage are inductances or inductors.

Counter EMF is present in any AC circuit, but its effect is slight in most electrical devices. For instance, an electric lamp which presents an almost pure resistance as a load has very little inductance. The effect of counter EMF, however, is considerable in circuits, even of very low power, which use an inductance as part of the load. An example of this would be the primary of the power transformer in an ordinary radio receiver.

Effect of Counter EMF

The effect of counter EMF can be illustrated by checking the resistance of the primary winding of an ordinary power transformer used in a typical radio receiver. The DC resistance is found to be approximately 6 ohms. But from Ohm's law, the direct current would be

$$I = \frac{E}{R} = \frac{120}{6} = 20 \text{ amps}$$

This calculated value of direct current is not the value of AC current. When the AC flow is measured, it is found to be approximately 1 amp. (Fig. 12).

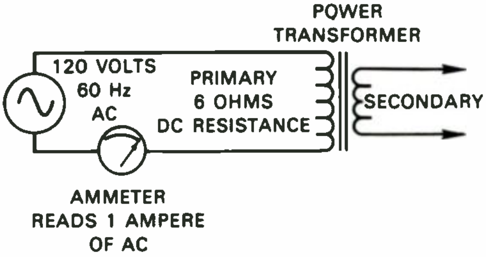


Figure 12 — The effect of CEMF on current flow.

Some opposition other than the 6 ohms of resistance is present in an AC circuit. This opposition is the CEMF. If such a radio set is connected to a 120-volt DC line, the current through the primary of the transformer would be 20 amps, and the transformer would burn up. Hence, Ohm's law must be modified to include this effect of electrical inertia present in AC circuits.

Measurement of Inductance

The unit of measurement of inductance is the *henry*, named after Joseph Henry, the co-discoverer of the principle of electromagnetic induction. A henry is defined as the inductance of a circuit in which a current change of 1 amp per second causes a counter EMF of 1 volt.

The inductance of a coil depends principally upon the length of the coil, the diameter of the coil and the number of turns. If the coil is wound on an iron core of any type, the inductance is increased due to the permeability of the iron core. If these factors are put into a formula, they interrelate, and the inductance L in henrys would be

$$L = \frac{N^2 \mu A}{I} (K)$$

L stands for inductance of the coil in henrys.
N stands for the number of turns in the coil.
μ stands for the permeability of the core in electromagnetic units.
A stands for the cross-sectional area of the core.
I stands for mean length of the core in centimeters (cm).

The K in this formula is a number that depends upon the units, inches, or centimeters, used to measure the coil. There is usually a K in most formulas to account for the different units of measurement. This number K however, has no effect on the interrelationship of the significant parts of a formula.

Permeability Factor

The permeability factor μ is a measure of the ability of a substance to conduct magnetic lines of

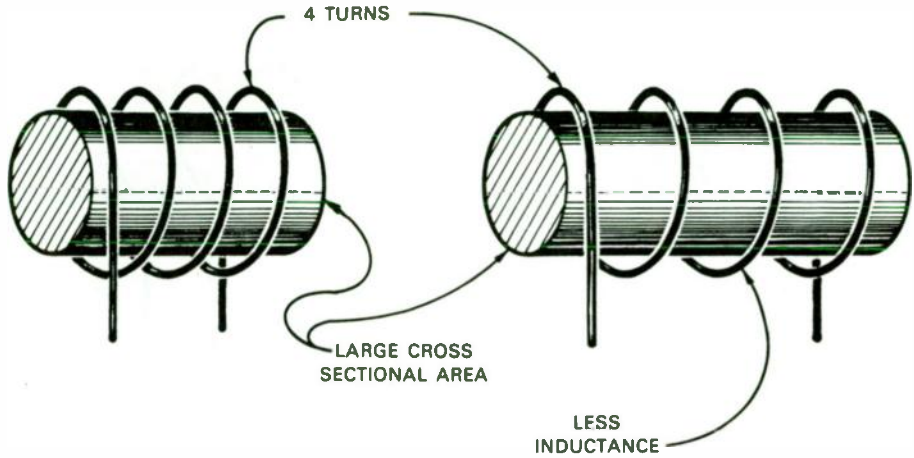


Figure 13 — Less inductance when turns are wider spaced.

force. Many coils operate with only air in the center of their core; therefore, air is used as the basis of permeability and is considered to be 1.0. Any other material, such as iron and steel, that increases the ease of travel of the magnetic lines of force and increases the number of these flux lines will have a permeability greater than 1.0.

How Inductance Varies

This formula reveals the following important relationships:

1. The inductance of a coil is proportional to the square of the number of turns.
2. The inductance of a coil increases directly as the permeability of the material used for the core increases.
3. The inductance of a coil increases directly as the cross-sectional area of the core increases.
4. The inductance of a coil decreases as its length increases. Figure 13 shows two coils of a fixed number of turns having the same cross-sectional areas, but with different lengths. The shorter coil has a greater total flux, and therefore, greater inductance. Figure 14 shows two coils of a fixed number of turns having the same cross-sectional area, but also of different lengths. The longer coil has less total flux, and therefore, less inductance.

Inductors In Series

If several inductors are well shielded or are far enough apart that their magnetic fields do not interact, the individual values of inductance may be totalled, as resistors in series are added together. The formula for inductors in series takes the same form as the formula for series resistors:

$$L_t = L_1 + L_2 + L_3 \ldots + L_n$$

L_t equals the total inductance, and L_1, L_2, are the individual values of each inductance coil.

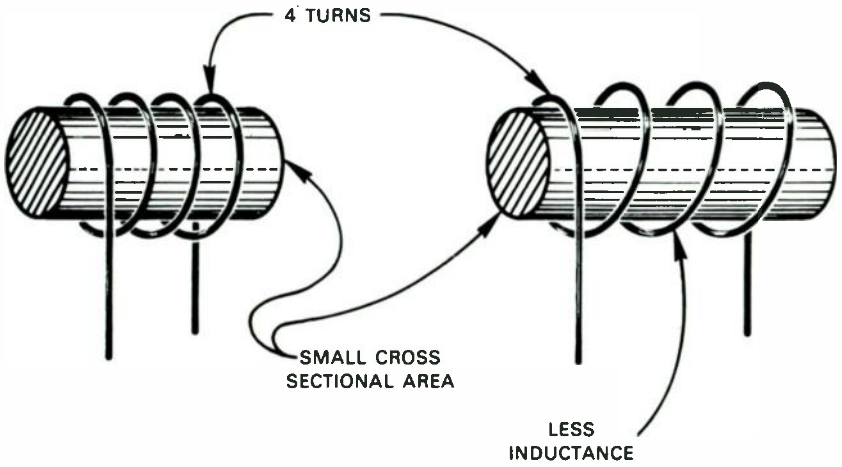


Figure 14 — Much less inductance due to wider spacing and smaller cross-sectional area.

If two coils are not shielded and are close together with their magnetic fields interacting, the formula for the total inductance is

$$L_t = L_1 + L_2 \pm 2M$$

The M stands for the degree of mutual inductance and carries both a + and a − symbol to indicate that the magnetic fields could be aiding or opposing. The actual value of the mutual inductance M is difficult to estimate and is usually determined by measurement. The important fact to be obtained from this formula is that if the inductors are aiding, the + sign is used; if they are opposing, the − sign is used.

Inductors In Parallel

When two inductors are in parallel and the coils are separated sufficiently to prevent interaction, the formula is similar to that used for two parallel resistors.

$$L_t = \frac{L_1 \times L_2}{L_1 + L_2}$$

The familiar product over the sum formula gives the total inductance L_t.

Milli- and Micro-Henry

One henry of inductance is an exceptionally large unit. Therefore, most inductors are measured in millihenrys and microhenrys. *Milli* means one one-thousandth, such as milliamperes. The air core RF choke (Fig. 31) is wound in many sizes and can have inductance values that range from 1 to 100 or more millihenrys. The abbreviation for millihenrys is *mh,* and a 5 millihenry RF choke coil will be listed as "5 mh RF choke, rated at 50 ma max." The "50 ma max" indicates that the choke coil can only handle 50 milliamps of current.

A value of inductance still smaller than a millihenry is a *microhenry.* A microhenry is one one-millionth of a henry. RF choke coils and inductors at high radio frequencies have inductance values as low as a 0.5 of a microhenry and as large as 1,000 microhenrys. One thousand microhenrys is equivalent to 1 millihenry; therefore, the size would be listed in the manufacturer's catalogue as 1.0 mh.

The abbreviation for a microhenry is μh; the μ is pronounced micro. It is the lower case form of the greek letter M which is pronounced "mu".

TIME CONSTANT OF AN RL CIRCUIT

Increasing Current

Since coils are wound with wire, and the wire has resistance, the resistance and the inductance of the coil must be considered together. Thus, we can consider that a coil is really a resistor in series with an inductor. If a coil is connected to a DC supply, the final current will be determined solely by the ohmic resistance of the coil. However, this final value of the current I (calculated by dividing the voltage E by the resistance R) will not rise to this final maximum value immediately, because the inductance opposes any change in current in the circuit.

It is the counter EMF that prevents the current from reaching its maximum value immediately. This effect of controlling the rate of current rise establishes the *time constant* of an inductor. If the resistance value and the inductance value are known, it is very simple to calculate the time constant of a coil. With this information, we can plot a curve showing the rate of current increase (Fig. 15). In an RL circuit, a circuit containing resistance and inductance, the current will always reach 63% of its maximum value at a time T determined by

$$T\ (\text{time}) = \frac{L\ (\text{henrys})}{R\ (\text{ohms})}$$

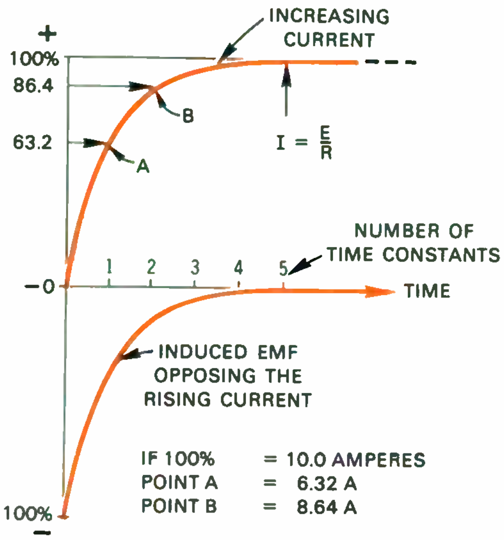


Figure 15 — The rate of current increase is controlled by the induced EMF.

If we had a circuit with an inductance of 0.2 henry and a resistance of 10 ohms, the length of time of one time constant would be

$$T = \frac{L}{R} = \frac{0.2}{10} = 0.02 \text{ second.}$$

This time of 0.02 second simply tells us that if we had connected this coil across a 100 volt supply, we would have 6.3 amps of current flowing 0.02 second after closing the circuit.

To determine the value of current at that *first time constant*, use Ohm's law to solve for the final current:

$$I = \frac{E}{R} = \frac{100 \text{ volts}}{10 \text{ ohms}} = 10 \text{ amps}$$

But at the first time constant, the current is

63% of 10 = 0.63 × 10 = 6.3 amps.

At this instant in time, there remains 3.7 amperes of current to be supplied before the maximum of 10 amps is reached (10.0− 6.3 = 3.7). We can learn more about the rate of growth of this current by continuing to use the time constant of 0.02 second.

The *second time constant* occurs at 2 × 0.02 = 0.04 second after the current initially starts rising; that is, at the end of the second period of 0.02 second or at 0.04 second. At that time, 63% more of the current that remains has been reached or

63% of 3.7 = 0.63 × 3.7 = 2.34 amps.

This 2.34 is added to 6.30 to obtain 8.64 amps flowing at the end of the second time constant.

These computations are illustrated in an enlarged curve (Fig. 16). The computations are based on 100% as the maximum flow of current. From this curve, any maximum current value may be determined at any one of the five time constants shown. Simply use as a multiplier the percentage listed for each of the five time constants. If the current in a particular circuit reaches a maximum of 20 amps, and we wanted to know the amount of current flowing at the third time constant, we would multiply

20 amps × 94.9% = 20 × .949 = 18.98 amps

which is the current flowing at that instant.

Determining the Current Value

From this curve we can determine the value of current flowing in a coil at any time while the current is rising to its maximum flow rate. Such information is helpful to designers of electronic circuitry. Even though we will not be developing any equipment, a knowledge of how the current rises and how induced voltages react with the supply voltages makes it easy to understand how an electronic circuit operates.

Decreasing Current

There is one other action that occurs in a coil, however. If the current is flowing at its maximum amount, and the power supply is disconnected from the inductor, the lines of magnetic force begin to collapse. These decreasing flux lines are moving toward the center of the coil in a direction that is opposite to the direction they took when they were increasing. Since the direction of these decreasing flux lines is now opposite, the induced EMF is also opposite to the direction of flow of the original induced current.

When the current was increasing, the induced EMF attempted to prevent its rise due to its direction of flow. When the current is decreasing the direction of induced EMF is now in the opposite direction; therefore, this induced EMF is attempting to maintain the current flow. Consequently, the current is effectively being reinforced, and it tends to take time before it falls to zero (Fig. 17).

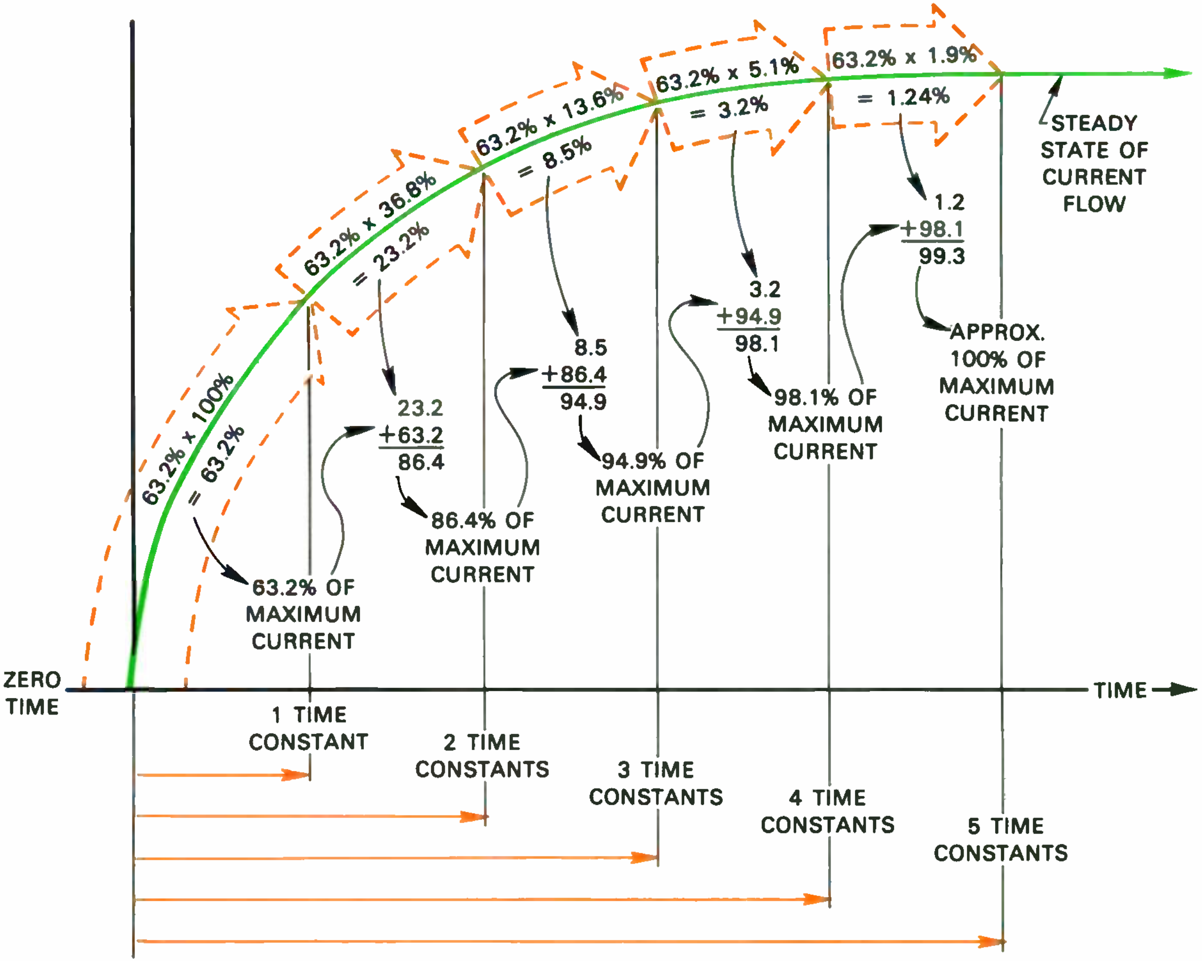


Figure 16 — Current value has increased 63.2% at the end of each time constant until it reaches its maximum value.

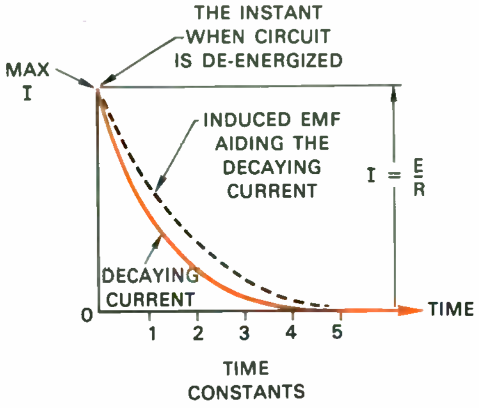


Figure 17 — A decaying current decreases at a given rate.

Arcing

These two curves illustrate the decay or decrease of both the *current* and the *induced EMF*. The current does not fall to zero immediately, due to the induced EMF. As current flow is maintained for a definite length of time, the current forms an electric arc across the switch contacts that have been opened to break the circuit. This attempt to maintain current flow burns switch contacts and accounts for the rating of switches. Switches are rated for household use by both current and voltage; a conventional wall switch for the home might indicate:

10 amps @ 120 volts (1200 watts)
5 amps @ 240 volts (1200 watts).

The manufacturer would probably have obtained Underwriters Laboratories' approval and be allowed to place the UL symbol on his product, if it passed their tests for safety.

Symmetrical Curves

Figure 18 gives detailed information about the percentage value of the current at each time constant. A comparison of these percentages with the percentage values (Fig. 16) indicates that they are the same; the two curves, therefore, have the same shape. Since both curves have the same shape, they are symmetrical both above and below the horizontal zero-current line. Any current that is being supplied to a coil as an alternating current will produce an induced voltage symmetrically shaped. In other words, the induced voltages produced by an alternating current are symmetrical.

CIRCULAR REPRESENTATION

Using DC for Explanation

Experience has shown that it is always helpful to explain a new aspect of electrical action using direct current as the power source. DC has a constant voltage, and consequently, the current will reach a constant value. AC, on the other hand, has both a rising and falling EMF; its direction is also reversed.

A conventional graph can illustrate the action of both DC and AC voltages and currents. Since alternating current is harmonically generated, the use of a circle to show the relationship between alternating currents and voltages is helpful.

Quadrants of a Circle

The curve and circle (Fig. 19) show two methods of illustrating an alternating current increasing

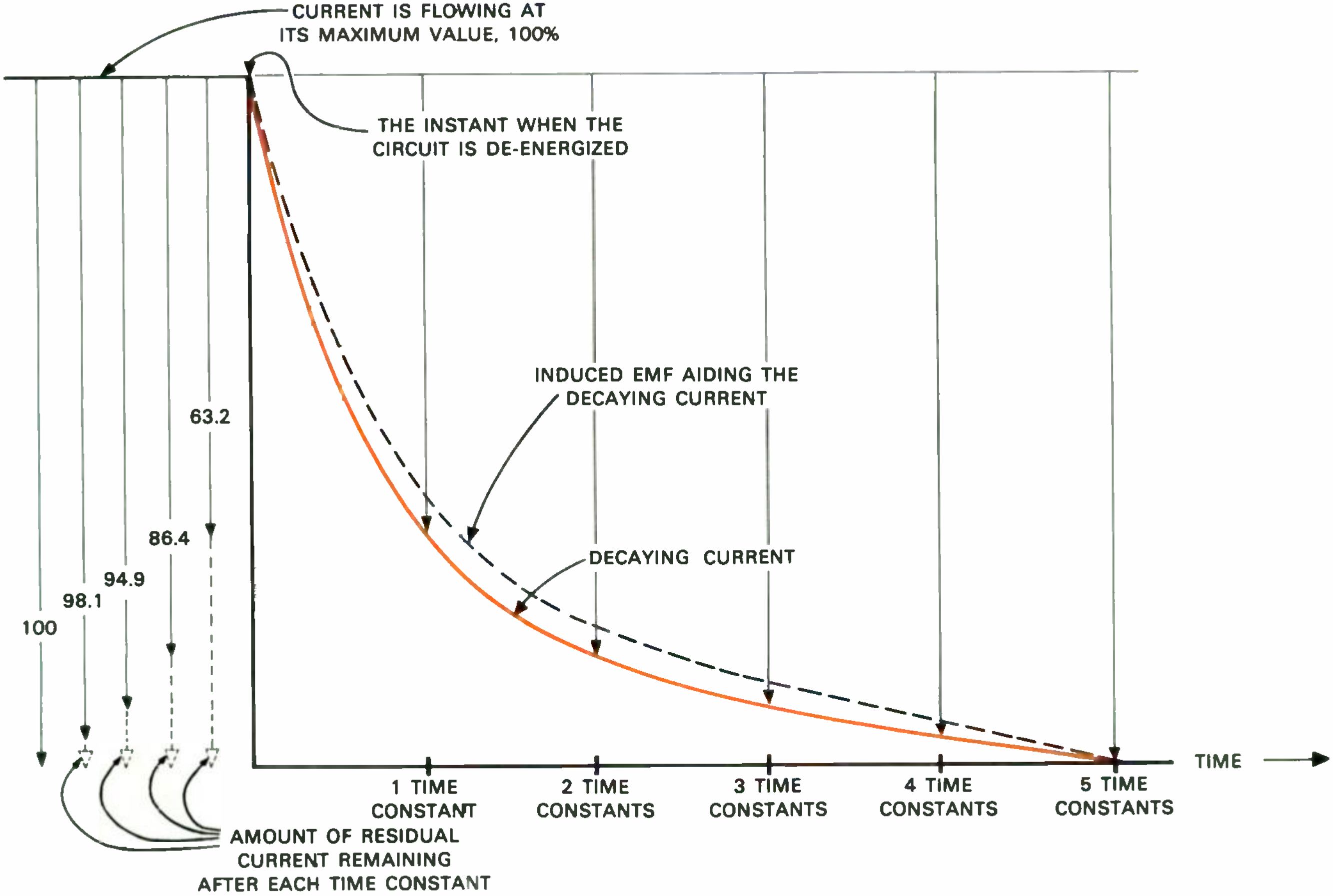


Figure 18 — Current value has decreased 63.2% at the end of each time constant until it reaches it minimum value.

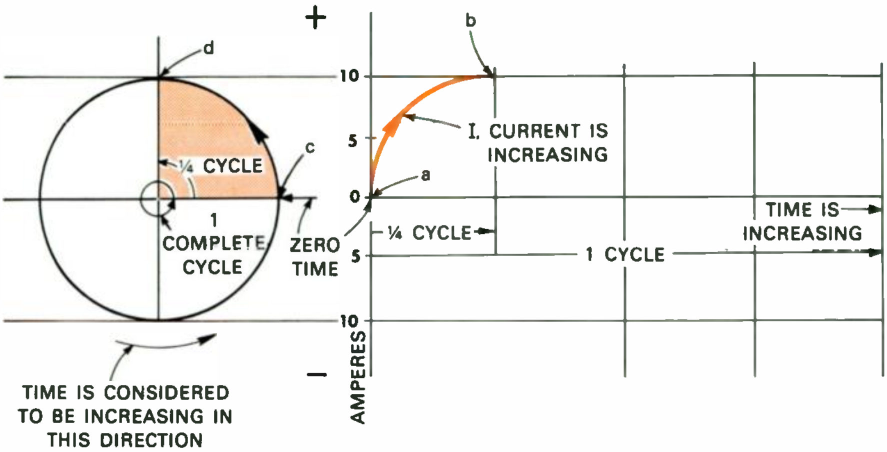


Figure 19 — Using a curve and a circle to illustrate current increase.

from zero to 10 amps. The curve I shows that the current has started at point a and reached its maximum at point b. Point a is also considered the point where time starts and is called zero time. In Figure 19 the illustration at the left is similar to the face of a clock, except that time, in the case of electrical waves, begins at the point we know as 3 o'clock, at point c. Point c on this clock face corresponds to point a of the first curve and again represents zero time. That portion of the clock face, from 3 o'clock to 12 o'clock, is the most appropriate part of the circle to use, because it most easily corresponds to the graph of the current when the current is increasing. This first quarter of the circle is called the first quadrant, and the remaining quarters of the circle are called the second, third and fourth quadrants.

The decreasing portion of the current I is represented in the second quadrant of the circle (Fig. 20). The use of a circle is helpful in representing an alternating current. This alternating current varies in amplitude, in addition to changing its direction; it is necessary to determine the amplitude or the actual value of the current at various times throughout the cycle.

Amplitude

A means of determining the amplitude is shown in Figure 20. The vertical line g_1 -e_1 in the second quadrant is the same length as the line g_2 -e_2 under the curve. The first half of travel, or 45° of travel in the second quadrant is where the point e_1 on the circle is located. If a horizontal line is drawn from this point e_1 until it crosses the curve, point e_2 can be determined. At any place where we stop circular rotation, a vertical line can be drawn. The length of this vertical line represents the actual value or the actual amplitude of the current at that time.

An important fact to observe is the relationship between the position of point e_1 and the length of

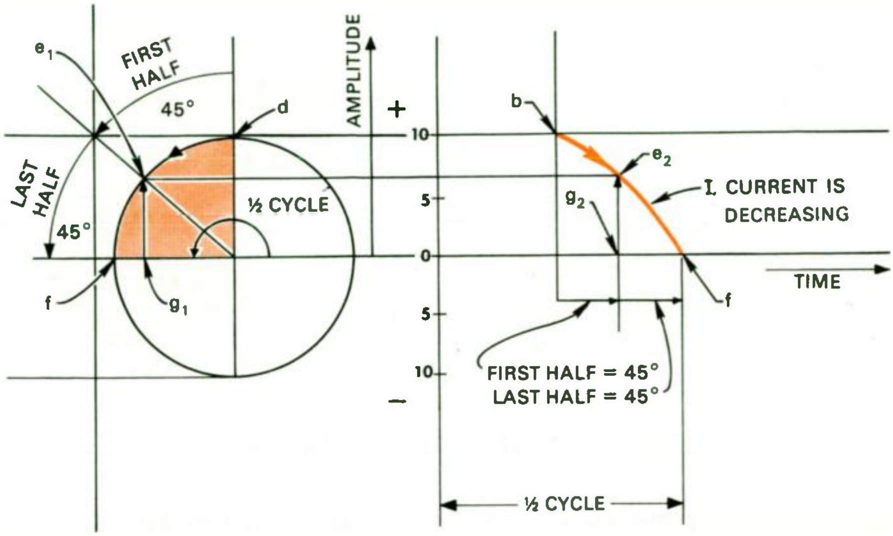
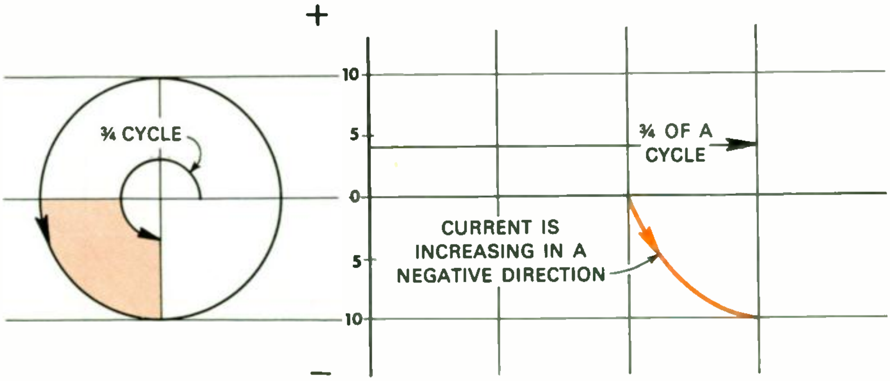


Figure 20 — Illustrating amplitude in the second quadrant.

line g_1-e_1. Point e_1 is in the middle of the second quadrant, at the 45° point. This point is half-way around the quadrant, but the length of the line g_1-e_1 is more than half-way to the top of the circle. This vertical line has a length equivalent to the effective value of the current. The effective value is equal to 0.707 × the peak value of the sine wave. The multiplier of 0.707 can only be used when dealing with a pure sine wave. Since we will not do any electrical design, you should simply remember this fact.

The current curve at point f (Fig. 20) is passing through zero and is also changing in direction. Figure 21 is the continuation of this curve and shows the current increasing toward a maximum value in the negative direction. The third quadrant represents this increase. Figure 22 illustrates the remaining



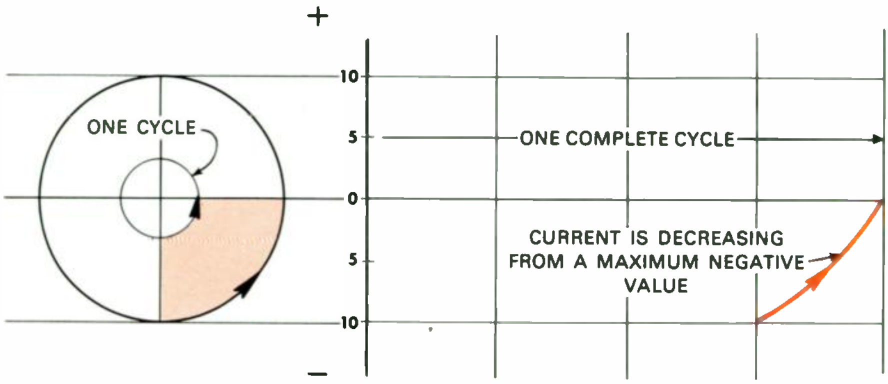


Figure 22 — Fourth quadrant representation.

portion of this current curve. The fourth quadrant also gives an accurate representation.

The four curves in Figures 19 to 22 have been combined to form the complete sine wave (Fig. 23). (Also note the circular form on the left.) There are three representations of amplitude, lines a, b and c, which originated from the left of the drawing of the sinewave. Line a indicates the amplitude when the current curve has passed through 60° of the cycle. Lines b and c are the same amplitude and represent values at 240° and 300°. Lines b and c are equal in amplitude, but b is increasing at the 240° point, while line c is decreasing at the 300° point.

Vectors

The length of the lines a, b, and c were originally determined by the lines A, B, and C. Lines a, b, and c are *vectors* and will be called by this name in future lessons. A vector has both *direction* and *length,* but does not indicate whether it is increasing or decreasing. Therefore, we need both methods to represent curves. The current curve I (Fig. 23) gives certain information, while the circular representation at

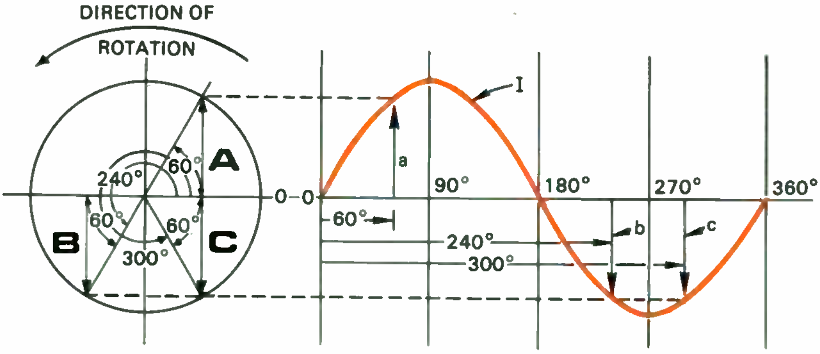


Figure 23 — Using vectors to represent current values at three points in one cycle of a sine wave.

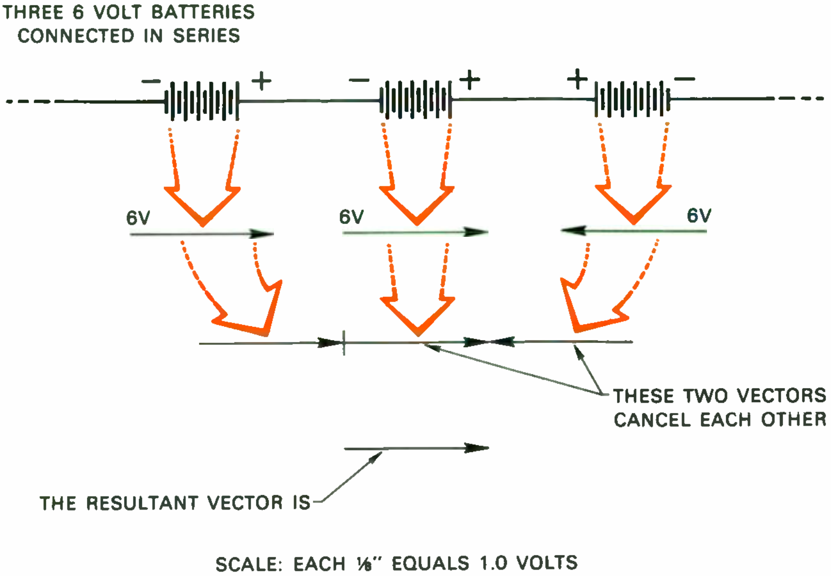


Figure 24 — Representing voltages by vectors.

the left allows us to compute and represent additional information.

Vectors will be used to illustrate additional electrical actions, because they are a convenient means of representing the magnitude of electrical quantities. We have really been using vectors previously to illustrate the voltage and direction of DC batteries connected in series. Once we establish a scale, such as the scale used in Figure 24, simply add the length of the lines to determine the final voltage.

RELATIONSHIP OF CURRENT AND VOLTAGE IN AC CIRCUITS

Counter EMF Lags the Current

A current always induces a counter EMF in the circuit containing the inductor. At the time that the current is at its point of maximum rate of *change,* the counter EMF reaches its maximum negative value (Fig. 25). This cycle of a sine curve illustrates how the alternating current induces a

counter EMF that lags 90° behind the current wave.

This might be a difficult concept to accept until you remember that the counter EMF opposed the current (Fig. 15). The first 90° of this sine wave (Fig. 25) has been drawn with bold lines to show that this portion of the current and the CEMF have the same interrelationship as in Fig. 15. Remember, the

> CEMF is maximum when the current is at its maximum rate of change (positions a), and the CEMF is minimum when the current is at its minimum rate of change (positions b).

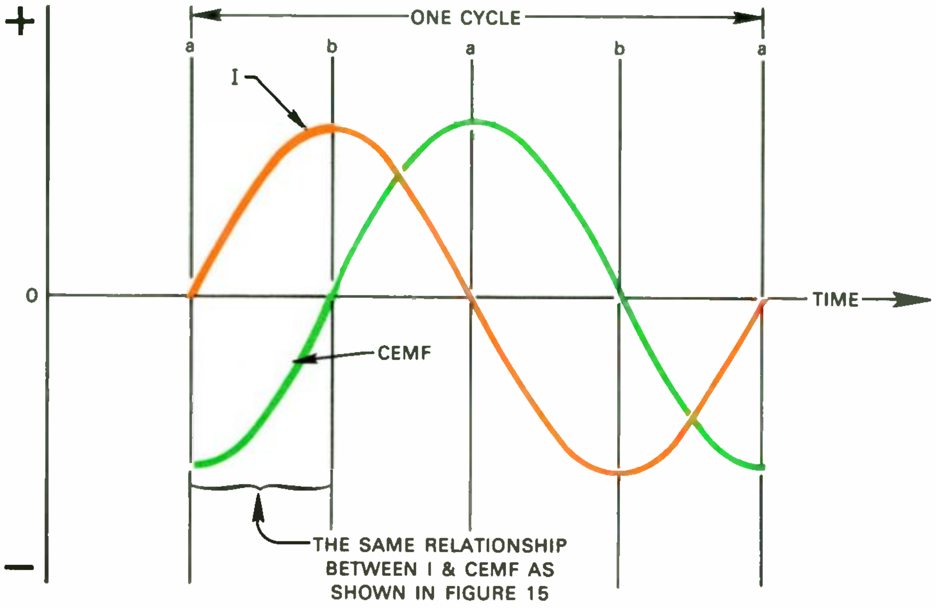


Figure 25 — The relationship of counter EMF and the current, when it is a sine wave.

This explains why the CEMF curve is one-quarter of a cycle away from the current curve. As time elapses from left to right on the graph, the counter EMF curve is at its maximum negative value (point a) at the beginning of this time period for one cycle. While the CEMF is at its maximum negative value (point a), the current is at its position of greatest change. The greatest change is at the point of direction reversal of the current. This change is from a negative to a positive value—or from a positive to a negative value—as it crosses the zero line.

EMF Leads the Current

Although it was assumed that an EMF was forcing the current through the circuit, this source EMF curve was not shown on the graph (Fig. 25). Since "counter EMF" implies that the induced EMF is *counter to* or *opposite* the source EMF, this EMF curve must be drawn on the graph opposite the CEMF curve. The relationship of the source *EMF,* the *current,* and the *CEMF* is shown in Figure 26.

Note on this graph that the source EMF is at a positive maximum when the current is zero. Consequently, in this circuit the voltage is *leading* the current, and this action, voltage leading current, always exists when the coil is a pure inductance and has no resistance. It is important to remember that the source EMF leads the current by 90°. In a circuit with a pure inductance (Fig. 26),

> EMF reaches a positive maximum 90° before the current is maximum,

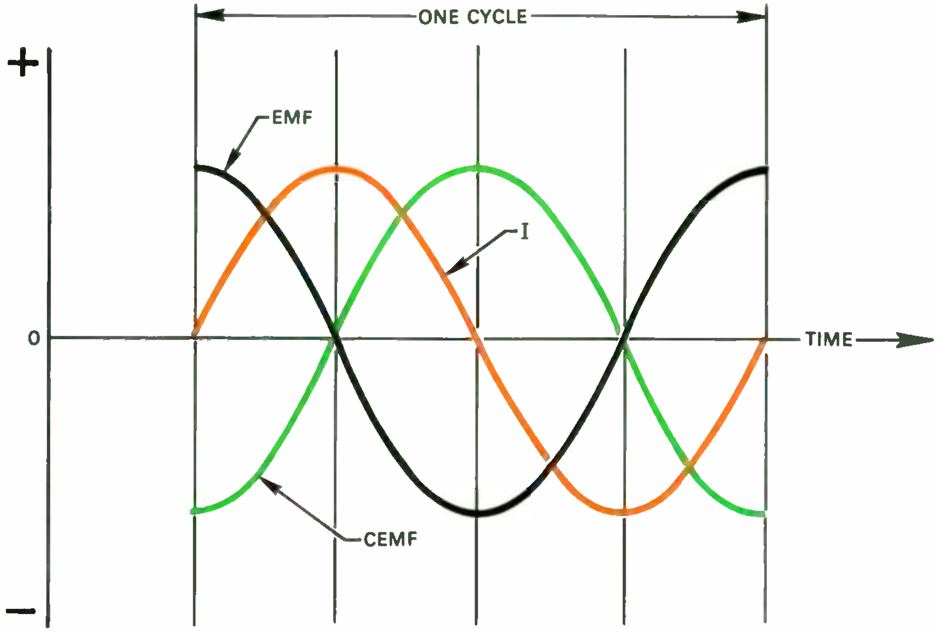


Figure 26 — The 'counter EMF' is in opposition to the EMF, and lags the current curve.

CEMF reaches a negative maximum 90° before the current is maximum; therefore, the

EMF and CEMF are exactly 180° opposite.

Angular Representation

The angular relationship of the two waveshapes on the graph can also be illustrated on the clock face (Fig. 27). The voltage E at the 12

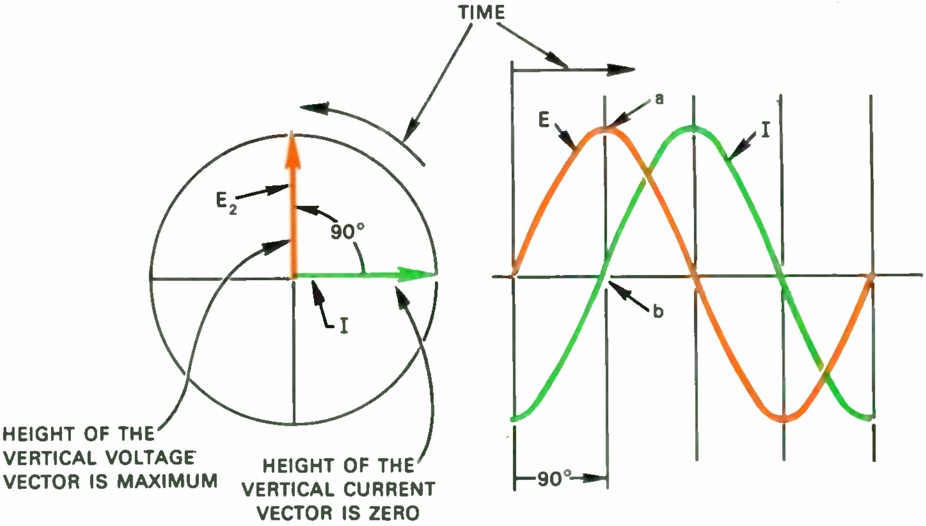


Figure 27 — The voltage E leads the current I by 90° in an inductance.

o'clock position is 90° ahead of the current I at the 3 o'clock position. If we draw a vertical line from the point of the arrow at 12 o'clock to the center of the circle, this vertical line would lie directly on line E_2 and would be the same length. This new line would be the voltage vector at its maximum value, as indicated by the height of the line at point a.

The current I is lying on the zero line (at 3 o'clock). Since it has no *vertical* height, its value is zero. This is verified by the position of the current curve, because it is passing through zero at point b.

Vector Representation

Additional examples will help clarify how the voltage and current vary as the sine waves pass through their alternations. Vectors for both voltage and current are drawn on the clock face (Fig. 28), for three different times throughout a single cycle.

Phase Angle

When the voltage and the current rise and fall at the same time (as they do when we are considering only pure resistance in a circuit), we say that the voltage and current are "in phase." When one curve (or one waveshape) representing either voltage or current is leading the other curve (or the other waveshape), we say they are "out-of-phase."

It is conventional to state that the phase angle between a pure inductance's current and the voltage in an AC circuit is 90°. When a circuit contains inductance with resistance or capacitance with resistance, the phase angle between the current and voltage may be any value up to 90°. These relationships will be more fully explored in future lessons.

COILS

Coils take many forms depending upon their use. Coils that are wound on iron cores are used as "choke" coils in conjunction with capacitors in power supplies. This combination reduces the ripple of the rectified voltage to enable the system to supply an almost pure DC.

Permeability

Coils with an iron core have considerably more inductance than coils with only air in their center. The increase in the number of magnetic lines of force in a coil with an iron core indicates an increase of both the inductance and the permeability. Testing a coil with its iron core in place and with the iron core removed will verify this fact.

If we pass a given current through the coil (Fig. 29), we would find that there are 40,000 lines of force in the core. If we remove the iron core and use the same value of current, the flux density drops to only 50 lines. The ratio of the flux density with the iron core to the flux density with an air core gives the permeability of the particular iron used in the core. (Remember, the current was the same in both cases.) In this example, the perme-

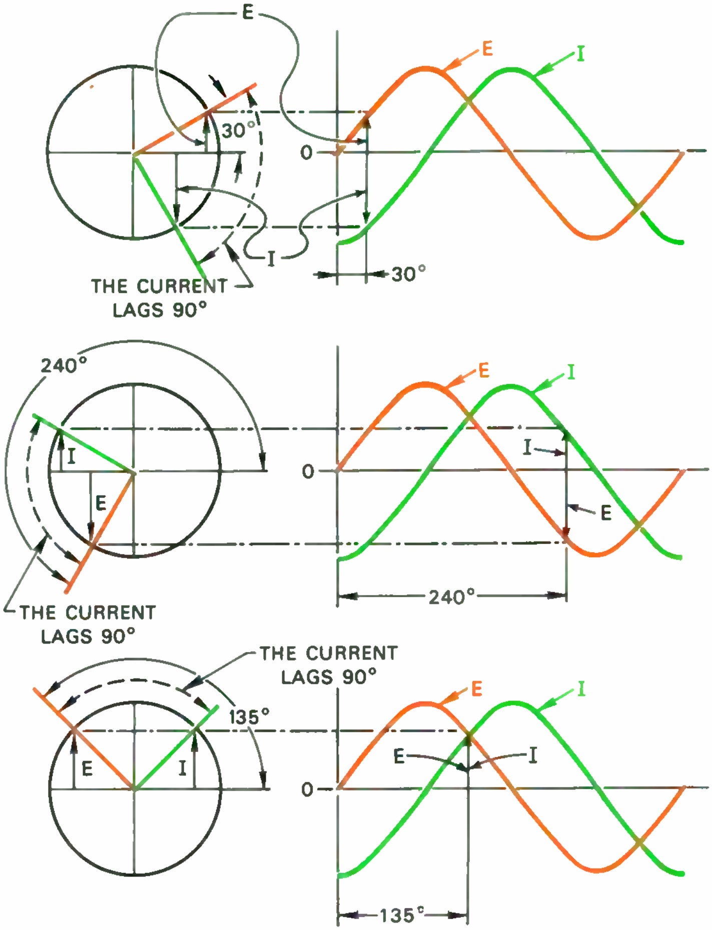


Figure 28 — Vectors show the magnitude of voltage and current at three times during a cycle. The phase angle is 90°.

ability of the iron is 40,000/50 or 800. This also means that the inductance of the coil is increased 800 times when an iron core is used. All other variables, such as the current or frequency, must not be changed, however.

Power Transformers

When two or more windings are located on an iron core, this device is known as a power transformer.

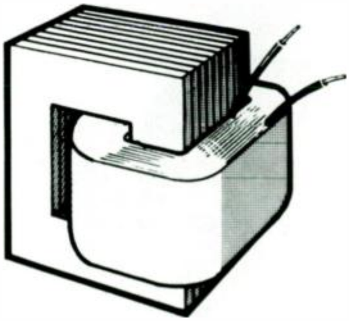


Figure 29 — A choke coil on a laminated iron core.

Power transformers are made in all sizes, from the giant ones in the distribution yards of electric utilities to the very small ones that power radios, Hi-Fis, and TVs. The small transformers convert the 120 volts from the commercial mains to higher or lower voltages, depending upon the number of different voltages required. Representative power transformers are illustrated in Figure 30.

RF Transformers

Transformers are also used to transfer radio frequency power from one circuit to another, just as commercial power is transferred. Some of these RF transformers have an iron core, while others are air-core transformers, and those with a single winding are RF chokes (Fig. 31).

SUMMARY

Inductance is that property of an inductor that opposes any change of current in a circuit. The henry is the unit of inductance which becomes greater as the number of turns and the diameter of the coil increases, and decreases if the length of the coil is increased. If the

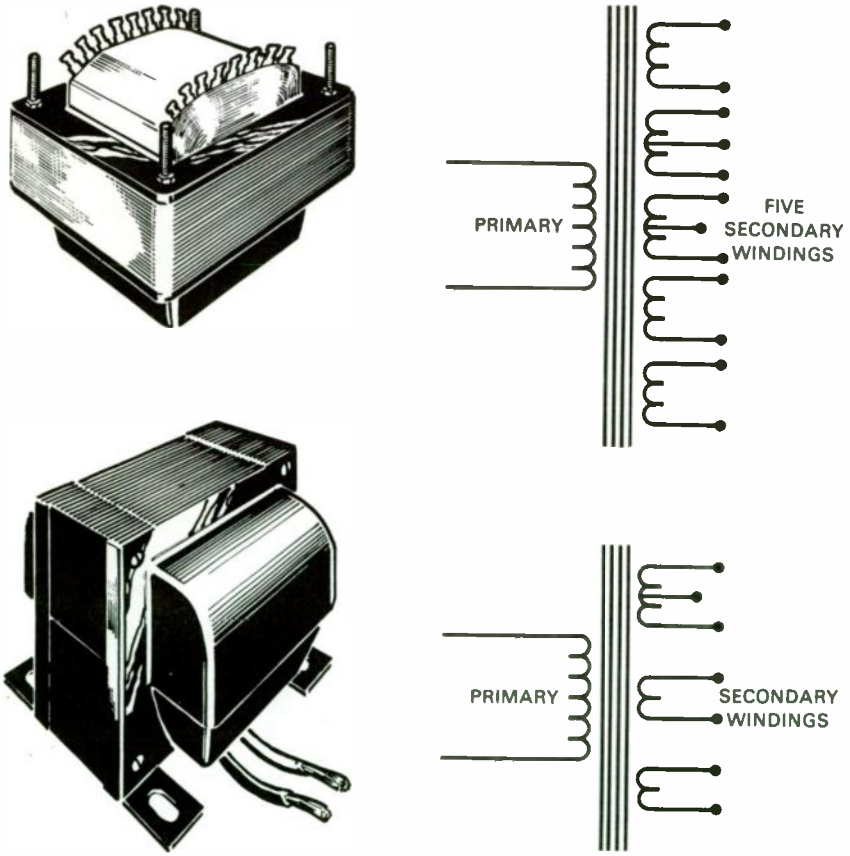
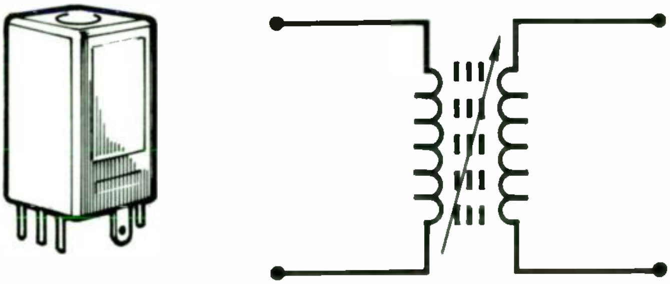


Figure 30 — Power transformers.



AN RF TRANSFORMER WITH AN ADJUSTABLE IRON CORE

AIR CORE RF CHOKES

Figure 31 — RF chokes and transformers.

coil has iron in the core to increase its permeability, the inductance is increased many times.

Lenz's law states that any change in current in a circuit also produces an EMF whose direction opposes the change in current. With a coil in an electrical circuit, a current increase induces a CEMF that opposes the applied voltage, while a current decrease induces a CEMF that tends to maintain the current and oppose the current decrease.

The rate of current growth or current decrease depends upon the time constant of the circuit. The inductive time constant T is equal to the inductance L divided by the resistance R, or T = L/R. A steady state or maximum current condition is reached after five time constants.

In addition to using curves to represent current and voltage waveshapes, circular methods are employed. The angular difference between E and I permits phase angles to be shown clearly by circular representation. It also allows vectors to be drawn to show the magnitude of E and I at any time during a cycle.

Any pure inductance in an AC circuit forces the current to lag the applied voltage by 90°, and the CEMF lags 90° behind the current.

TEST

Lesson Number 12

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-012-1.

1. A voltage will be induced into a conductor when the conductor is

1+ [✓ A. moving through magnetic lines of flux.]
B. stationary.
3 C. outside the influence of magnetic lines of flux.
(4) D. shorted.

2. The unit of measure of inductance is the

A. ohm.
B. farad.
10 [✓ C. henry.]
D. beta.

3. Inductance is defined as the

A. DC resistance of a wire.
9 [✓ B. property of a coil of wire that opposes any change in *current*.]
C. property of a coil of wire that opposes any change in *voltage*.
D. ability to amplify.

4. To determine the time constant (T) of an RL circuit we must know the values of

A. E and I.
13 [✓ B. L and R.]
C. R and E.
D. E, L, and I.

5. The second quadrant of a circle corresponds to circular degrees from

- A. 60° to 180°.
- 18 B. 90° to 180°.
- C. 90° to 270°.
- D. 0° to 180°.

6. Two hundred millihenrys is abbreviated as

- A. 0.200 mh.
- B. 2.0 mh.
- C. 200 mh.
- D. 200 μh.

7. Vectors always have the same magnitude when

- A. they are at the same angular position.
- B. they have the same length.
- C. the arrows point in the same direction.
- D. the arrows point in opposite directions.

8. Vectors used in circular representation illustrate the magnitude of the waveshape of

- A. current
- B. voltage.
- C. power.
- D. all of the above.

9. In an AC circuit containing only a pure inductance the

- 22 A. current lags the counter EMF.
- B. source EMF leads the current by 90°.
- C. current leads the source EMF.
- D. counter EMF and the source EMF are in phase.

10. If the permeability of the core of an inductor is *increased* the inductance will

- A. decrease.
- 24 B. remain the same.
- 11 C. decrease to zero.
- D. increase.

Notes

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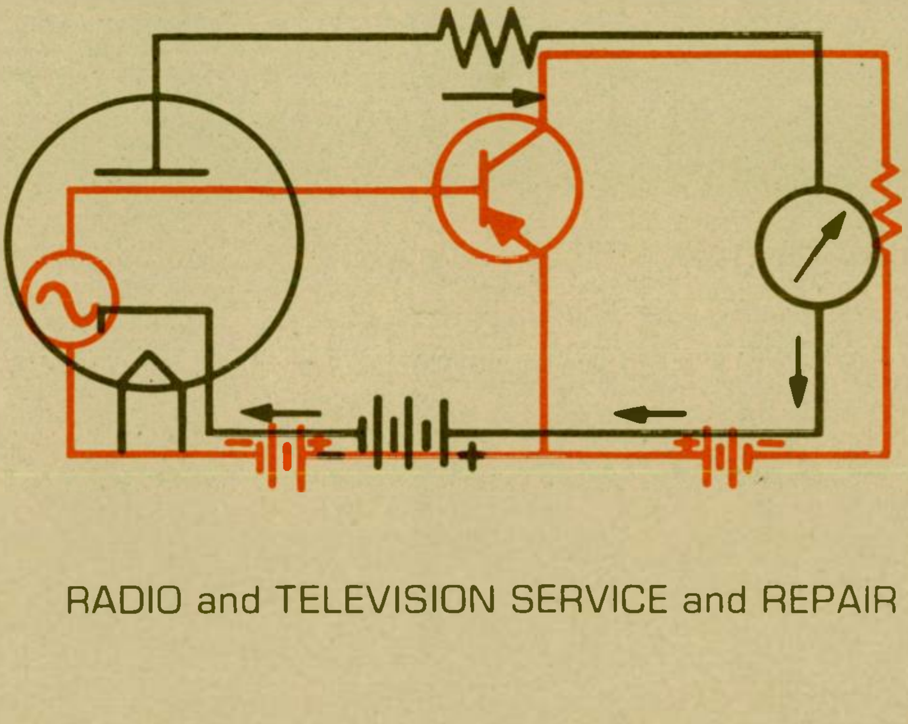
S. T. Christensen

LESSON NO. 13

WIRING AND SOLDERING



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-013
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ADVANCE SCHOOLS, INC.
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52-013

WIRING AND SOLDERING

INTRODUCTION

Today's electronic products bear slight resemblance to those of a few years ago. Even earlier products appear almost unrelated. Radio sets of the twenties consisted of parts bolted to phenolic bases or attached to boards with screws. The interconnection of components was accomplished at screw terminals and terminal boards (Fig. 1). Only a small number of parts were involved and these were huge by today's standards. Since space was not a problem, crude methods and parts were adequate in 1925; but as radios became more complex, advanced techniques and smaller components became essential.

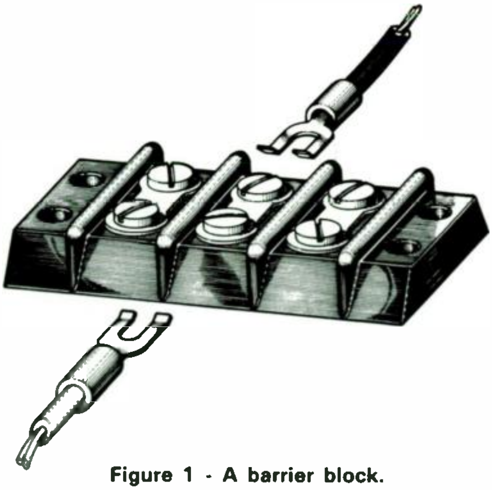

Figure 1 - A barrier block.

The quantities of electronic components in products, jumped from a dozen or less in the 1920's to hundreds and now thousands in current designs. Pressured by increasing complexity, engineers soon produced miniature, sub-miniature and microminiature components. Component sizes were shrunk, first by a dozen and then by a hundred or more times.

As component quantities and sizes changed so did the methods of mounting and joining them. By 1940, the screw terminal was almost non-existent. It had been replaced by wired and soldered junctions. Also in the 40's earlier, "bolt it to the chassis" thinking yielded to "secure it with twist tabs or mount it with rivets" concepts.

Component quantities were prevented from skyrocketing as devices began to serve not only more functions, but also *more complex functions.* This was accomplished with multi-purpose parts. Probably, the earliest generally used multi-purpose components were vacuum tubes. These were manufactured with more than one tube in a single envelope.

Following closely after the adoption of multi-function tubes were multi-component packages. These consisted of several resistors and capacitors in a common block. Some of the electrical interconnections were made within these blocks which resulted in less wiring in the final product.

Printed Circuitry or *PC boards* evolved and began to replace wires and wiring during the 1950's. This was almost simultaneous with the increasing use of transistors in place of larger and less versatile vacuum tubes. With printed circuitry the function of ordinary wiring is replaced by strips of foil bonded to the surfaces of sheets of epoxy glass or other composition material.

Components are mounted to PC boards by inserting their leads into holes through the board. Circuit connections are made by soldering these leads to the copper foil. The foil's routing is such that it connects certain components together electrically, to form circuits.

Until recently, printed circuitry and transistors were thought to be the ultimate in compactness. This was before the development and almost instant adoption of microcircuitry and integrated circuits. One integrated circuit pack can serve all the functions of thirty or more individual transistors. This pack can even include most of the associated components, such as capacitors, resistors and diodes. Even more amazing is the fact that they are smaller in size than some of the words which have been used to describe them, such as, FANTASTIC or IMPOSSIBLE.

A complete radio can now rest on a postage stamp without obscuring its borders. Tomorrow, a complete TV set may hide in its shadow. The only limit now seems to be the knobs which must be large enough for a human to manipulate.

COMPONENT INTERCONNECTION

Electronic products consist of a large number of different size and style components, connected to perform a function. Five basic methods are used to electrically interconnect all these parts.

1. *Lugged wires* are tipped with either a soldered lug or a crimped on lug and then joined with others at screw terminals (Fig. 1). Extensive used of this method is limited because of high cost and space requirements.
2. *Solder wrapped* connections have been the kinds most widely used. These connections are joined with solder after the wires have been wrapped onto terminals. Solder wrapped connections are gradually being phased out by other methods.
3. *Wire-wrap* junctions are becoming increasingly more prominent; especially when a large number of connections are involved. These are made with a special tool that spins wire along a slender terminal in a tight spiral.
4. *Printed circuitry* replaces both terminal junctions and much of the interconnecting wiring. Strips of copper foil bonded to the flat surfaces of circuit boards, inter-

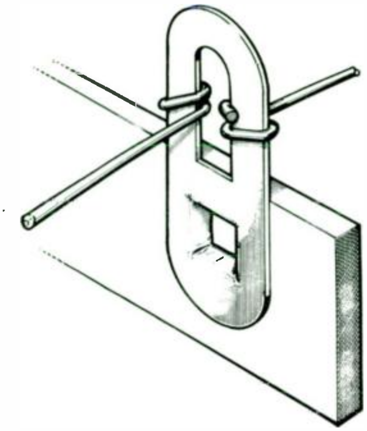

Figure 2 - A wired terminal lug (open type).

connect between components. Wires or part leads are inserted through holes and then soldered to the foil backing.

5. *Sockets* and *quick disconnects* have been in use since early radio. Vacuum tubes and some other components were plugged into sockets for quick and easy replacement. Solid state devices sometimes use a separate socket but most of them are now soldered into the printed circuitry. Wiring between assemblies in the form of cables frequently terminates in a plug-socket arrangement.

REQUIREMENTS OF A JUNCTION

A connection or junction must fulfill two essential requirements — First, it must be mechanically rugged, second, it must have good electrical conductivity. An ideal connection would have continuity characteristics equal, or superior, to the connecting wiring.

Other considerations exist which are also of primary importance. A junction must be able to resist deterioration from a corrosive environment. It must also be able to withstand the effects of shock and mechanical vibration and to remain firm when subjected to expansion and contraction due to changing temperatures.

TERMINALS

Signal and power in electronic circuits are routed through wiring and components which are interconnected at junctions. One of the earliest forms of junctions was made by connecting wires and/or part leads together at terminal blocks (Fig. 1). A connecting device called a terminal lug was installed on the ends of wires and secured under a screw. This method proved to be both expensive and space-consuming.

The solder wrapped connection was adapted to early electronic devices and is still in use (Figs. 2 and 3). This connection consisted of wires attached to terminals and then soldered.

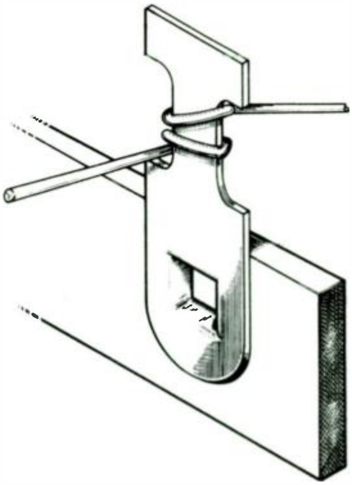

Figure 3 - A wired terminal lug (closed type).

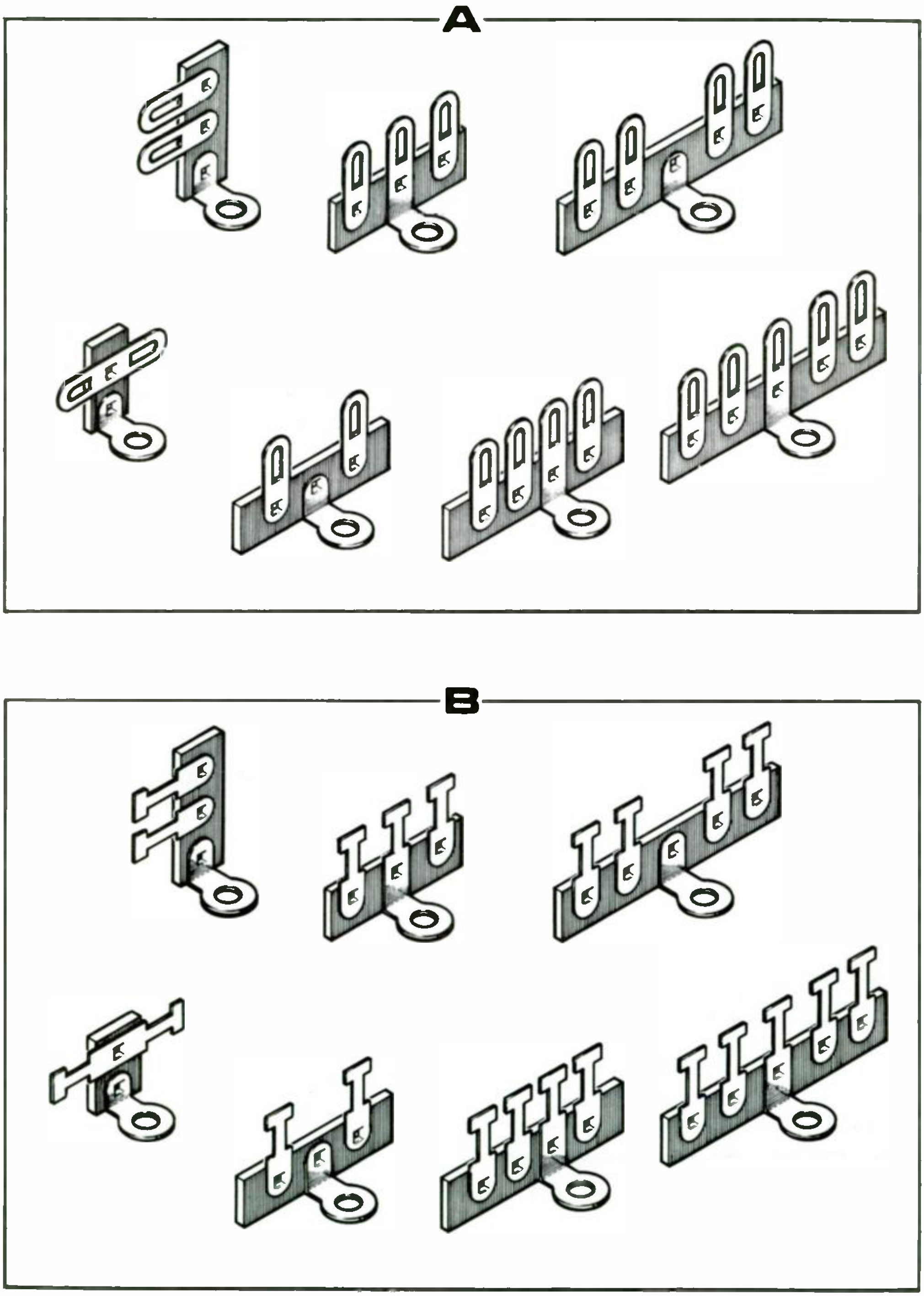

Figure 4 - Solder terminal strips.

Figures 4A and 4B picture a number of solder terminal strips and Figure 5 shows several components that have solder terminals attached. Several components (resistors, capacitors, diodes) are illustrated in Figure 6. These are some of the components that make up electronic products.

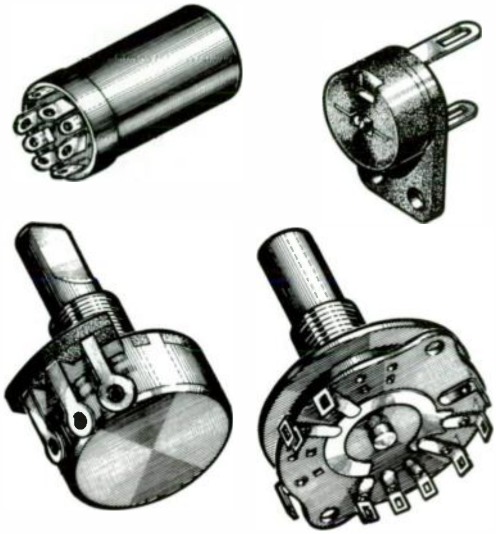

Figure 5 - Components with solder terminals.

Stake terminals of various kinds and sizes are sometimes used with printed circuitry (Fig. 7). These usually resemble a miniature lighthouse. They are riveted to circuit boards with the riveted end contacting the foil. Wires to speakers, switches, and controls are attached and then soldered.

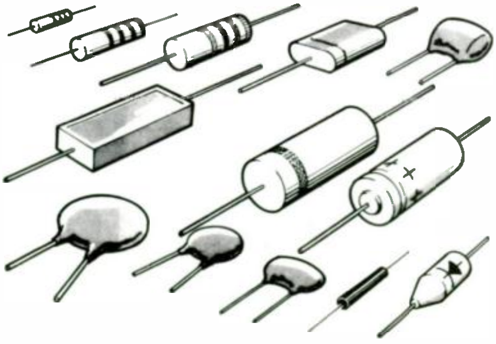

Figure 6 - Some standard components.

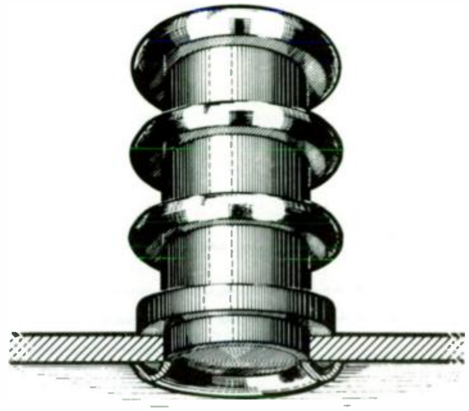

Figure 7 - A stake terminal.

Wire-wrap junctions began to replace soldered connections in the 1950's. A family of terminals was developed to accommodate these connections. The one shown in Figure 8 is from this family. It is the kind that is inserted into a printed circuit board and soldered to the foil.

Other types of terminals will be encountered in certain manufacturer's products. Some are limited use, standard hardware

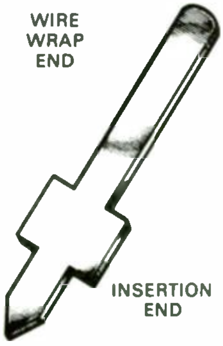

Figure 8 - A wire-wrap terminal.

items, while others are designed to one manufacturer's specifications. Since it is impossible to list them all, what we have shown are only representative samples.

INSULATION AND SLEEVING

Long lengths of wire are provided with an insulated covering. This prevents them from inadvertently shorting together or shorting to terminals (Fig. 9).

Insulation is rated for operating temperature and breakdown voltage. Its composition is usually either plastic or fabric covered rubber, but teflon covering is becoming increasingly more popular. Operating temperatures for insulation range upward from 85°C, to several hundred degrees for teflon. The breakdown voltages are in thousands of volts per centimeter.

Figure 10 illustrates insulating sleeving being used on bare wire leads of a component. This sleeving (sometimes called tubing or spaghetti) is available in sizes suitable for different wire gauges. Its composition varies from a material that will operate at 85°C to one which will withstand temperatures of a thousand degrees.

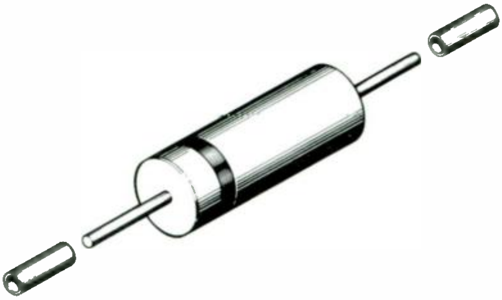
Figure 10 - Sleeving for a component's leads.

Figure 11 illustrates sleeving positioned correctly on a component's leads; notice how snugly it fits at the terminal, exposing only a minimum expanse of bare wire.

WIRING TO TERMINALS

A solder lug to which wires have been attached is shown in Figure 12. Observe how the wires are wrapped

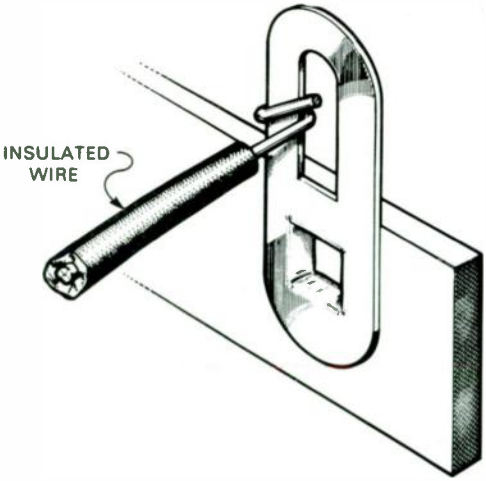

Figure 9 - Insulated wire attached to a terminal.

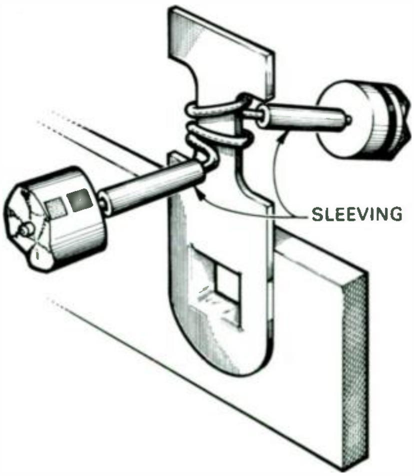

Figure 11 - Sleeved components attached to a terminal.

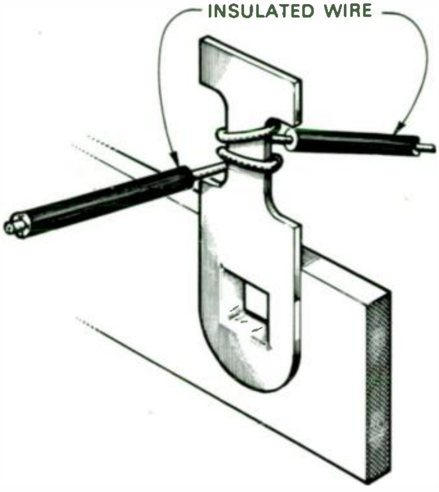

Figure 12 - A wired terminal lug.

securely on the terminal to assure mechanical strength.

The junction described is started with wire from which a section of the insulation has been removed at the end. After it is attached to the terminal, excess bare wire is snipped off with side cutters to eliminate the possibility of shorts to adjacent terminals.

If you prefer, when making connections, you can preform a hook at the end of the wire (Fig. 13). This hook is then placed into or onto the terminal and either closed tightly or wrapped.

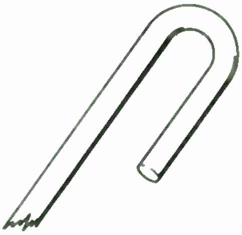

Figure 13 - A preformed hook in the end of a wire.

A multi-deck wafer switch is illustrated in Figure 14. This is one of the components which can be easily damaged by rough handling. Figure 15 shows leads and wires attached to the terminals of some other components. In each case a preformed hook is used and squeezed together to prevent distortion of the terminal.

When both leads of a component are attached to terminals on the same wafer switch a simple loop in the wires is adequate to secure them (Fig. 16).

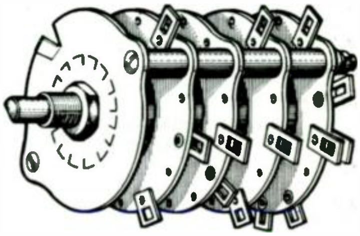

Figure 14 - A multideck wafer switch.

Figure 16A through 16D demonstrate the correct way to form, cut, insert and crimp component leads. If you follow these steps you will not damage a component or the terminal to which it attaches . . . More about forming later.

A *wire-wrap* connection is illustrated in Figure 17. This type of junction does not require subsequent soldering, the wire is wrapped so tightly that it actually bites into the terminal's material and makes a good mechanical and electrical connection. A special tool is used to spin these connections. If it is necessary

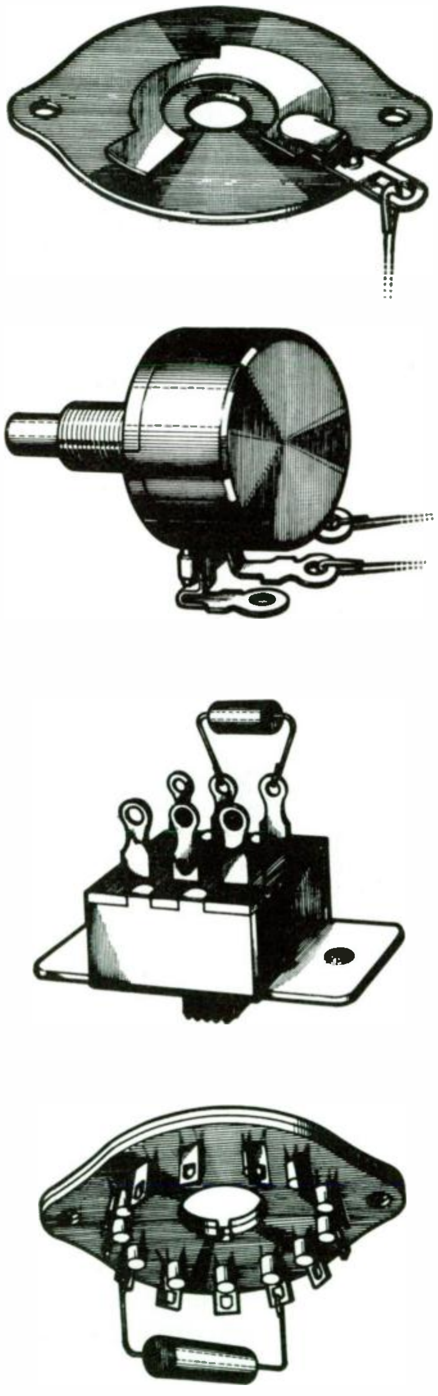

Figure 15 — Wires and component leads attached to component solder lugs.

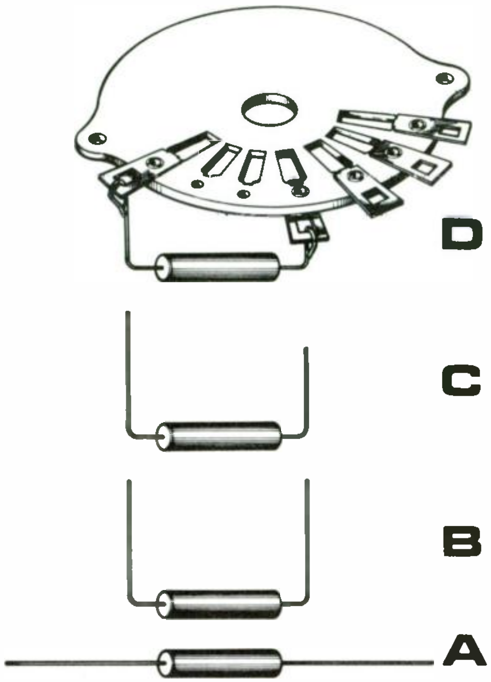

Figure 16 - Forming a component for wiring.

to replace a wire that has been *wire wrapped*, it can be replaced by giving the new wire a couple of turns around the post and then soldering it.

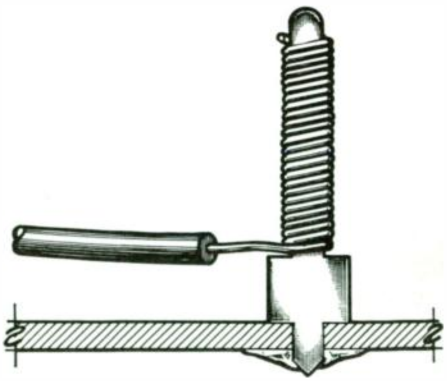

Figure 17 - A wire-wrap connection.

FORMING COMPONENT LEADS

There is a correct way to form component leads and good-sound reasons for doing it correctly. Figure 18 illustrates these reasons. Follow the correct procedures and you will not be put on the spot. Many a serviceman has discovered that through carelessness he has just broken his last ¼ watt resistor of the desired value.

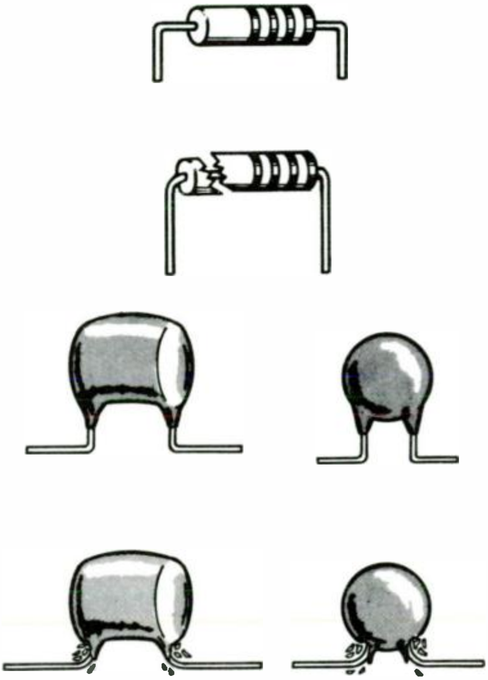

Figure 18 - Bending part leads.

When it is necessary to space a component's leads closer than the part form allows, use the method shown in Figure 19. This allows proper spacing without placing the part under a strain. Anytime stress is present at the point where a lead enters a part, the sealing material is likely to fracture. This allows contaminants to enter and shorten the component's life.

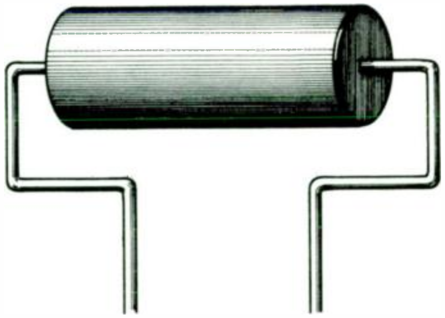

Figure 19 - Close spaced forming of a components leads.

WIRING FOR STRAIN RELIEF

In the interest of neatness, kit builders and repairmen frequently shorten component leads and wires excessively. They have a tendency to suspend parts and wires tightly between points like musical instrument strings. This practice keeps a part under constant tension and can contribute to its failure. Figure 20 shows both the correct way and the wrong way to route a component. The part in Figure 20A, is subjected to considerable tension because there is an absence of slack in the leads. In Figure 20B you see how tension is relieved by putting a small kink in each lead wire. This allows for expansion and contraction and protects the part when it is subjected to vibration.

Errors are frequently committed when inserting components into circuit boards. Most common is the practice of sharply bending the leads close to the part's body (as discussed in component wiring and

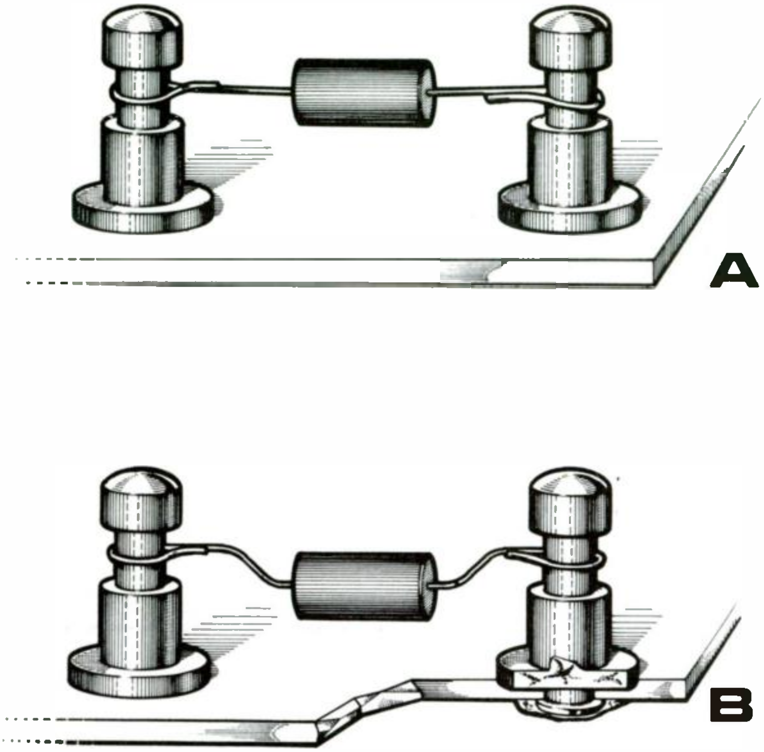

Figure 20 - Wiring for strain relief A. wrong B. correct

illustrated in Figure 18). Another bad practice is that of forcing a component tightly against a circuit board. Some technicians even tug on the leads of a part to tighten it. Figures 21 and 22 show two correct methods of installing components into circuit boards. Notice how the ends of the leads are bent to lock the component in place until it can be soldered.

Transistors are sometimes mounted flush to a circuit board but this is not an acceptable practice. When possible, space should be provided

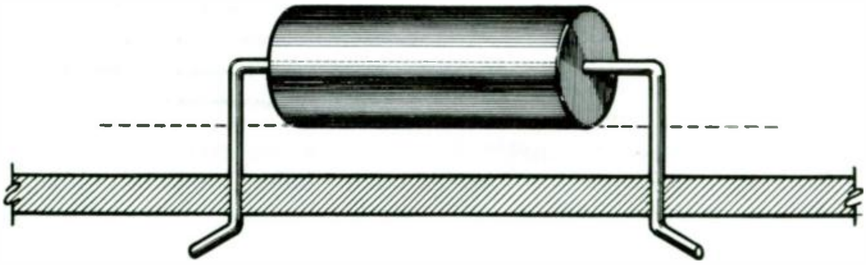

Figure 21 - Spacing a printed circuit component.

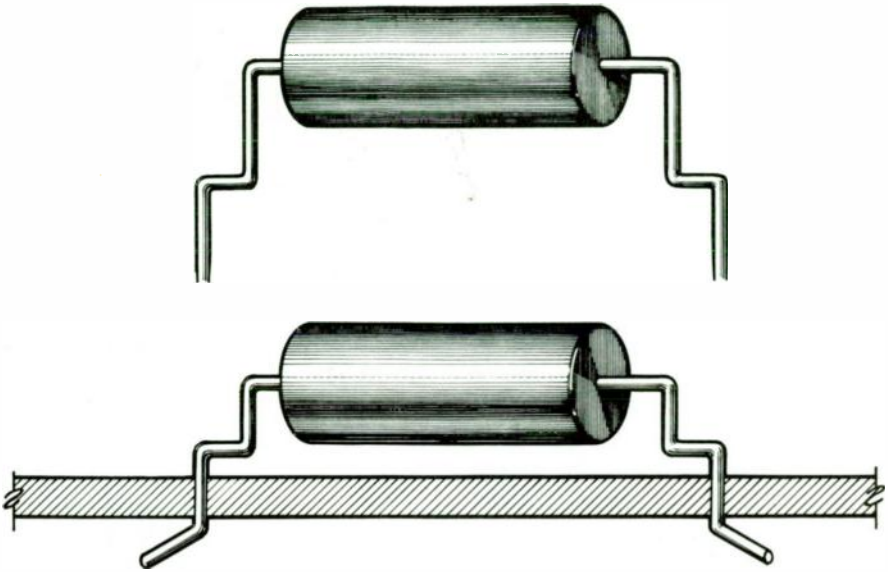

Figure 22 - Forming a PC component for strain relief.

beneath the device. Figure 23 illustrates how leads may be formed to keep a transistor from bottoming against a circuit board. In Figure 24 you see a plastic ring which is frequently used to space a transistor; this is the more acceptable method of providing strain relief. When installing a transistor, its leads may be left intact until after soldering and then clipped short with side cutters.

Figure 23 - Forming a transistor leads.

WIRE ROUTING AND TYING

The appearance of an otherwise neat layout is frequently spoiled by careless technicians who fail to re-install cable clamps, hold-downs and ties which were removed during repairs. A professional repair should appear like a newly manufactured product. Any hardware removed should be re-installed in its original location.

Figure 24 - A plastic ring used to space a transistor.

Professional electronics gear displays the degree of attention devoted to neatness in layout and manufacture. This is especially evident in the way wires and cables are formed. Most wiring is routed to follow the perimeter of the chassis. It is either confined to groups; or the individual wires are gathered into bundles and then laced or tied to form cables. These cables are formed to turn sharply at corners and neatly around obstacles. In addition, they are routed clear of all hot components, such as power tubes, rectifiers and power resistors. A cable which crosses sharp edges is protected from damage either with sleeving, tape or a slotted insulating strip on the sharp edge. As a final precaution the cable is then anchored to the chassis at frequent intervals with ties or clamps.

Signal wires are usually isolated from power wiring; especially AC power wiring. The signal input wiring in audio equipment is particularly sensitive to disturbances and noise from power leads. Wiring arrangements should never be altered in electronic equipment.

All damage which occurs to wiring when making repairs should be corrected. Burned insulation should be taped over, and partially broken wires should be cut and then spliced at the break. The splice is then taped, or sleeved with insulation.

An example of how wires are formed into a cable is shown in Figure 25. The cable follows the edge of the circuit board and individual wires break from the cable close to their terminations. Clamps and ties are strategically located to

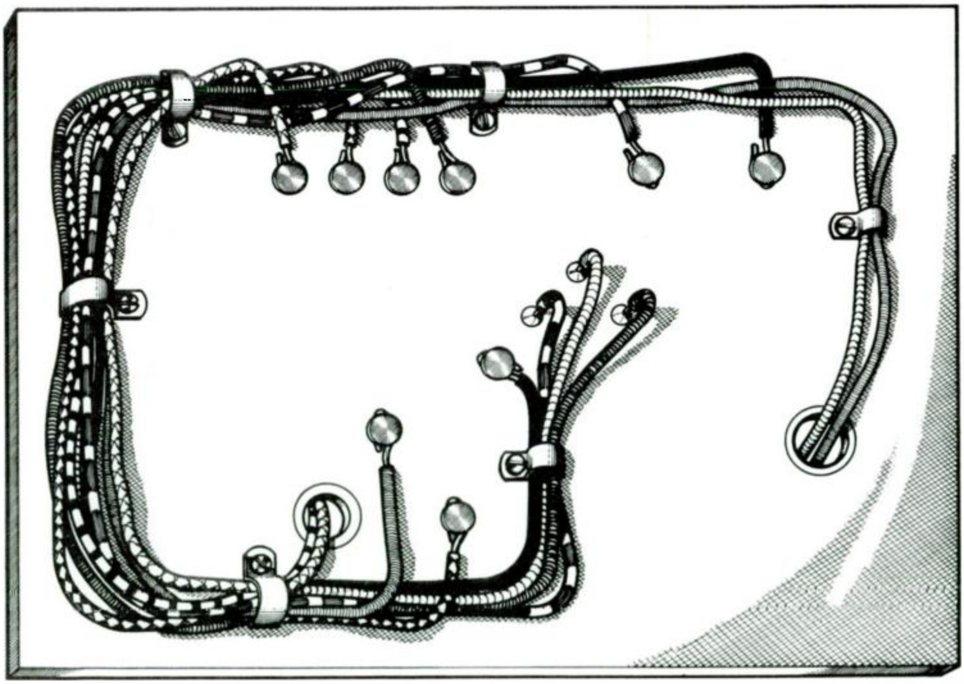

Figure 25 - Cable routing and typing.

hold the cable. Instead of using ties, the cable could have been either laced with waxed twine, or enclosed in a plastic spiral wrap especially made for this purpose.

PRINTED CIRCUITRY

Massive amounts of wiring were eliminated with the adoption of printed circuitry of which there are several kinds. One kind is called single-sided and has copper foil on only one side (Fig. 26). A clever layout of components is essential to prevent interference between individual lines of foil. Another kind of circuitry (double-sided) has copper on both sides and is much more versatile. Should a line of foil be prevented from reaching its destination by conflicting foil it can be continued on the opposite side. A copper eyelet, or a metal plate-through process is used to connect foil through the board.

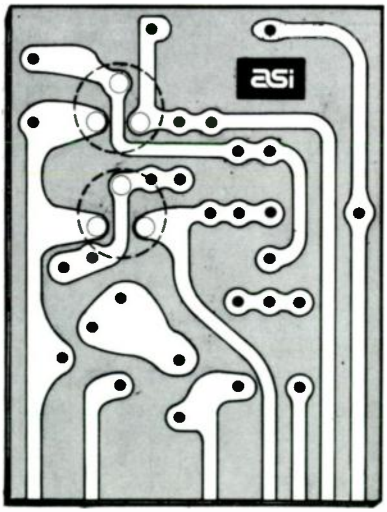

Figure 26 - A printed circuit board.

Multi-layer circuitry has several layers of material sandwiched together with insulation between each layer. The necessary interconnections are made between layers using the plate-through process. Holes are drilled at connection points and conductive metal is deposited inside the hole and onto the copper foil. Multi-layer circuitry is versatile for component layout, but it is expensive.

SOLDERING IRONS

In the early phases of electronic development, a need for rapid assembly methods soon became evident. Especially necessary was a quick and easy method of interconnecting wiring and part leads that would also provide good electrical conductivity. The practice of wrapping wires onto terminals, replaced screw terminal assembly methods. Soldering was adapted from other crafts to seal out corrosion and assure continued electrical continuity.

Soldering is performed by flowing a molten mixture of tin and lead into a connection. This mixture is called solder and is deposited with the aid of a soldering iron. The kind of iron used in electronic servicing has a self contained electric heating element. Heating elements range from a few watts for delicate work to several hundred watts for soldering to heavy bus bars. A soldering iron incorporates a tip to assure heat transfer from the iron to the work. Several kinds are used in electronics. The solid copper tip is most frequently used, but many workmen prefer metallic iron types. Iron retains heat longer than copper and distributes the heat more evenly to the work. To improve heat transfer, soldering iron tips are manufactured with an outer jacket of copper or the surface is overlayed with a gold flash.

All tips must be protected with a coating of solder during use; this is called tinning. New tips should be tinned when first heated, especially the gold-flashed, iron type. Prolonged heating without tinning, causes the metal surface to deteriorate and suffer permanent damage.

A soldering tip requires constant cleaning to assure good work. This may be done by wiping it frequently with a damp cloth. A better solution is to trim a household sponge to fit into a metal soap dish. Wet the sponge and keep it handy, near the iron. Clean the iron frequently by drawing the tip across the sponge while rotating it so as to clean all sides. Follow up this cleaning operation by tinning the tip with fresh solder. Cleanliness applies to quick heating solder guns as well as regular irons.

SOLDER FOR ELECTRONICS WORK

Solder used in electronics work is a mixture of tin and lead. Minute quantities of other metals may be added by certain manufacturers. Electronic circuitry is soldered with a wire type solder which usually comes wound on a spool. This solder has a central core of cleansing flux, usually rosin. Rosin core solder is preferable for most electronics work. Acid core solder should never be used in electronics.

Solder is available in various wire sizes and with different combinations of tin and lead. The tin/lead content is indicated numerically as 63/37, 60/40, 50/50, etc. Each has an advantage in specific applications but the one most versatile is 60/40 tin over lead. Fine wire solder is generally used for delicate work with the larger diameters being reserved for coarse work. Solder size is identified by diameter in thousandths of an inch.

The rosin flux contained in the solder is adequate for cleaning most connections. It flows freely onto the connection with the solder, eliminating the necessity of a separate cleaning operation. However, when severe cases of corrosion exist additional cleansing may be required. This may be done by scraping the corrosion away with a knife or brushing it off with a stiff wire brush.

INDUSTRIAL SOLDERING

Most manufacturers of printed circuit equipment use automated soldering. One method, called the *dip process*, involves momentarily floating the foil side of a circuit board on the surface of molten solder in an electrically-heated pot. Wave soldering is accomplished by pumping melted solder up to a circuit board as it passes closely overhead on a moving conveyor. The parts are obviously inserted prior to soldering.

SOLDERING TO TERMINALS

A connection is soldered by laying the iron firmly on the terminal and the wires it's connecting. Solder is applied to the connection, not to the iron. Faster heat transfer may sometimes be effected by rocking the iron slowly on the work. A small quantity of solder applied directly onto the iron prior to soldering a connection will hasten heat transfer. Pause a moment after wetting the iron and then apply first the iron and then fresh solder to the connection. Avoid excessive solder or you will end up with a blob of solder on the terminal (Fig. 27). A properly joined connection will be completely coated with a faint outline of the attached wiring visible (Fig. 28). Insufficient solder leads to a weak joint, unsealed against contamination and corrosion.

Avoid overheating a connection. Remove the iron promptly once the flux has boiled to the surface. Be careful not to overheat wires which have plastic sleeving or insulation. The plastic will melt and look messy.

One good habit to form is to tin all wires before inserting them into terminals. This is done by flowing solder onto them; less heat will be required during final soldering and the finished connection will be much neater. Clean all connections with a commercial flux solvent soon after soldering in order to prevent future corrosive action.

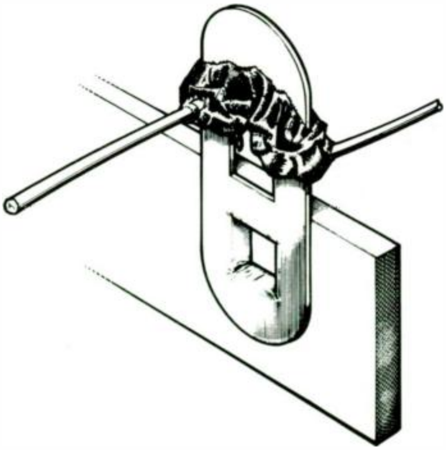

Figure 27 - A poor solder connection.

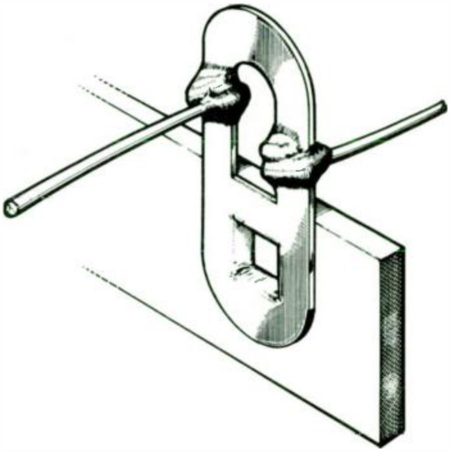

Figure 28 - A good solder connection.

SOLDERING TO COMPONENT TERMINALS

The method used to solder wires to terminals on a component is nearly identical to that used for solder strips, except that added care must be exercised. A switch or potentiometer can be permanently damaged by allowing solder to flow into the part. When possible, solder these with the part positioned so that the terminals hang down. If this is not possible, lay the iron firmly on the extreme tip of the terminal. The heat of the iron will attract the solder and prevent it from flowing into the part.

Wafer switches, in particular, can be easily ruined by excess solder. Avoid allowing solder to flow under the eyelet which stakes the contacts to the bakelite wafer. This destroys the flexibility provided by the eyelet and leads to lowered tension on the wiper contacts. If solder is accidentally flowed onto the contacts or wiper of a switch, the switch becomes unreliable and should be replaced. Any solder-damaged part should be replaced; because it will only cause trouble later. Replace it even if the damage was done by a prior workman; It's your reputation that is now at stake.

COMPONENT REPLACEMENT

Most repairing of electronic products involves replacement of defective parts. Components being removed may have been wired and then soldered to terminals, or inserted into circuit boards and soldered to foil. It is essential that part replacements be done without damaging other components, circuitry, or wiring.

Removing a wired component involves unsoldering the junction and detaching its leads. A component may be removed from printed circuitry by heating the solder junction and pulling the part lead from the circuit board, this can be more professionally done by heating it quickly, drawing off the solder and then removing the component.

Two basic tools are available which actually vacuum molten solder from a connection. One is used in conjunction with a conventional soldering iron; the other has a built in heat source which makes solder removal a *one tool, one hand operation.* Solder removing tools are basically vacuum pumps which operate from either a squeeze bulb or a spring loaded plunger. Their nozzles are made from a material to which solder will not adhere, a material which is unaffected by high temperatures. These tools have been nicknamed *Solder Suckers.*

To use a solder sucker, first squeeze the bulb, or set the plunger and then heat the junction. Place the tool's nozzle in the molten pool and release the bulb or plunger to draw off the solder. This leaves the component's lead free for removal.

Many components have more than one lead inserted into a circuit board. In this case the solder should be removed from all its leads before any attempt is made to extract it. This is especially true of integrated circuits (ICs) which have a dozen or more leads connected within a very small area. Any attempt to forcefully remove an IC without first removing the solder can rip the foil or break the circuit board.

A terminal connected part can be removed easily once the solder is drawn off. It may be simply unwrapped or the wire can be snipped in the center of a loop with sidecutters and removed in two separate pieces, the latter method is preferable if the connection is at a switch terminal or at another easily damaged component.

When applying heat to a printed circuit connection the iron should be placed on the protruding lead . . . not on the foil. When foil is subjected to excessive or prolonged heat and scuffing from a soldering iron, it will loosen and break. Loose or broken foil is extremely difficult to repair.

The new part should be replaced in the exact location of the old part. Particular attention should be given to polarity marks on components. Observe such signs as the + mark on electrolytic capacitors and cathode markings on diodes. Metal encased transistors (small types) usually have one specific lead marked by a tab protruding from the case.

Component preparation and installation has been covered in earlier sections of this lesson. These instructions apply to individual parts which must be formed prior to insertion. Today the trend is not toward individual or discrete components, but toward multiple component packs.

Encapsulated packs or IC's contain numerous parts which may be interconnected so as to perform a complete function. A complete phono amplifier for example, may be contained in less than one square inch of space. The only external additions necessary are controls and a speaker. Most of the commonly used IC's are available, ready for installation. Their leads are spaced and cut at the time of manufacture.

A complete new generation of components has been developed especially for use in compact printed circuitry. Most of these components have precise dimensions relative to lead locations. Direct replacement components are available from several manufacturers and replacement of any of these with a different style part is seldom necessary.

If possible, always obtain an identical replacement for a defective part. If an exact duplicate is unavailable, suppliers will in most cases recommend a suitable substitute. Suitable substitutes are designed to fit into the required space without crowding other components. They can also be installed without altering the circuitry. In addition their electrical characteristics will match those of the old component. In all cases of part substitution select one easily adaptable to the situation; do not alter the circuitry or mechanics of a product to match a component.

HEAT SINKING

Early solid state devices and some other components required special consideration when soldering. It was necessary to prevent high temperatures from traveling through the leads into the device. To prevent this, special spring loaded clips or heat sinks were available which could be snapped onto a lead prior to soldering. These were made from a material which absorbed heat and conducted it away from the device. If you need a heat sink and it is unavailable, an alligator clip like the one used on equipment leads will serve as an effective substitute.

Some of the components which should always be heat sinked are germanium transistors, signal diodes and micro-miniature resistors. You will be further advised about heat sinking in future lessons which deal specifically with components in servicing.

SUMMARY

Wires and components are connected at junctions. There are five basic methods for component connections: lugged wires, solder wrapped, wire-wrap, printed circuitry, and sockets. A connection must be mechanically sound, have good electrical conductivity, and resist deterioration from a corrosive environment.

Component leads should be formed in such a way as to prevent component breakage or excessive component lead length. A component lead should not be stretched too tightly between junctions, but should allow a suitable strain relief.

An important consideration when selecting a soldering iron for use on a printed circuit board should be the wattage rating of the iron. A small wattage iron should be used in printed circuit work. When soldering, apply the soldering iron to the connection and allow the connection to heat. Apply the solder to the heated connection (do not apply the solder directly to the iron) allowing the solder to flow into the connection. Remove the soldering iron and allow the connection to cool. *Do Not* move the leads until the solder has cooled or a cold solder joint will result. A cold solder joint provides poor mechanical strength and is a poor electrical connection. By using the proper tools and the correct soldering technique a good connection is assured.

TEST

Lesson Number 13

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-013-1.

1. Components and wires are interconnected
A. by welding them.
17 [✓ B. at junctions.]
\+ C. by stapling them together.
3 D. by glueing them together.

2. A good junction must have
A. good continuity.
3 B. mechanical strength.
C. corrosion resistance.
[✓ D. all of the above.]

3. One of the most durable electronic connections is made by
A. soldering only to a terminal.
B. wrapping only to a terminal.
2 [✓ C. wrapping and soldering to a terminal.]
D. welding to a terminal.

4. To prevent wires and component leads from shorting they are covered with
A. solder.
6 [✓ B. insulation and sleeving.]
C. paint and varnish.
D. gold flashing.

5. Wafer switches
A. can withstand abuse.
7 B. require lots of solder.
[✓ C. must be wired and soldered carefully.]
D. require a tight wrap.

6. When components are inserted into a circuit board, strain relief is provided by
A. tugging on the wires.
9 B. pressing the part down securely.
[✓ C. spacing the component from the board.]
D. bending the leads sharply at the part body.

7. A transistor can be spaced with a
A. cable tie.
11 [✓ B. plastic ring.]
C. cable clamp.
D. tie clamp.

8. The adoption of printed circuitry has eliminated
A. ties.
13 B. clamps.
[✓ C. wiring.]
D. components.

9. The most frequently used soldering iron tip is made of
A. gold.
B. silver.
13 C. ceramic.
[✓ D. copper.]

10. Electronic soldering
A. should be done with acid core solder.
14 B. may be done with acid core solder.
[✓ C. should never be done with acid core solder.]
D. can be done with any kind of solder.

Notes

Notes

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Work Safety

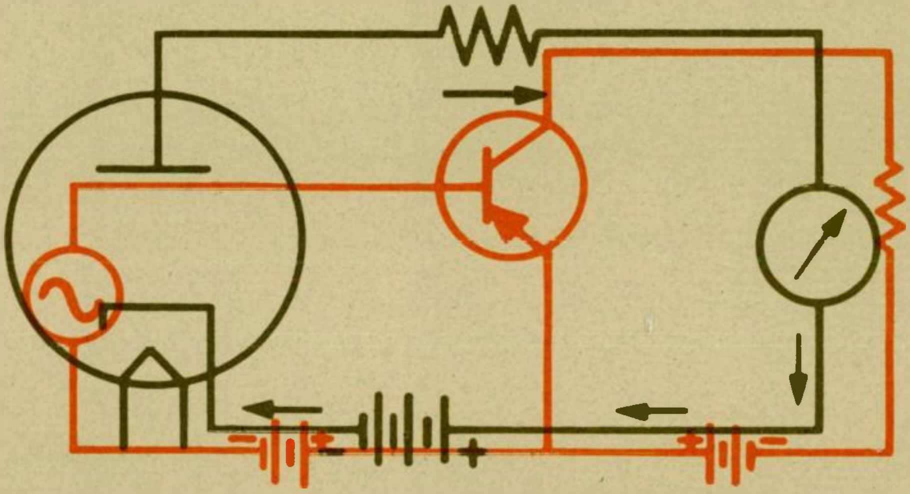
Stamp Out Serious Accidents! Too many times we take our knowledge of common day occurrences for granted. Safety is one of those things taken for granted. Always try to familiarize yourself with the newest safety techniques and equipment. Knowing what to do could mean the difference in saving a life or preventing a serious accident.

In our rapidly progressing society, technology is moving in great leaps and bounds. Let's not be the one to fall behind. Open your eyes to progress and insure yourself of a safe future.

S. T. Christensen

LESSON NO. 14

AUDIO AND RADIO FREQUENCY



RADIO and TELEVISION SERVICE and REPAIR

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Contents

AUDIO AND RADIO FREQUENCY

INTRODUCTION

You speak and across the room someone responds (Fig. 1). They listen . . . hear . . . then comment or answer. This exchange takes place because of the existence of invisible sound waves, rapid vibrations in layers of surrounding air. These vibrations are set in motion when air is squeezed past membranes in the human larynx causing them to vibrate. Our voice box, or larynx, is a sound producer because its membranes are capable of originating vibrations, which are then transferred to a stream of air. Radio, TV and Hi-Fi speakers are sound reproducers; they do not originate sound, they only echo what has been previously produced.

Sound waves radiate from their point of origin in a fashion similar to waves generated on a pond into which a pebble has been thrown (Fig. 2). They travel outward at a constant rate of speed, becoming progressively weaker with distance. These sound waves travel through a material, without some form of matter as a conductive medium they cannot exist. Radio frequency (RF) energy, unlike sound waves, can and does travel through a vacuum. It, too, is vibrating energy but the vibrations are electromagnetic. RF energy is identical to light waves; it differs only in rate of vibration. RF waves, like light, travel at a constant rate of speed, which is much faster than the speed of sound.

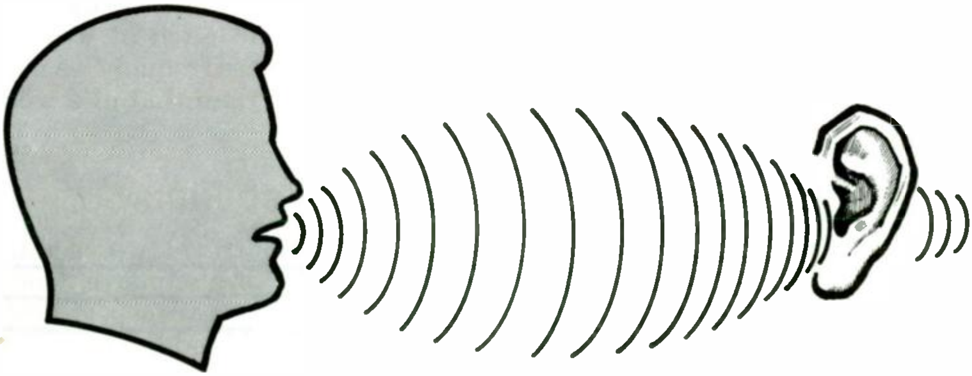

Figure 1 — Verbal communication.

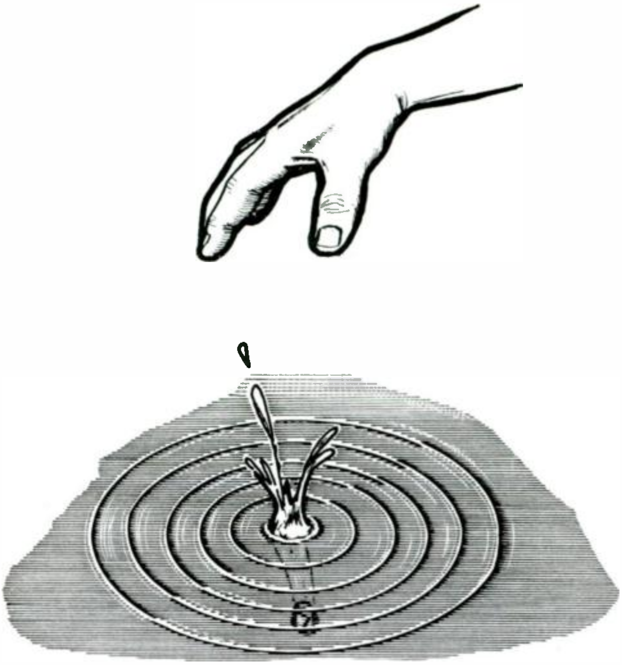

Figure 2 — Waves on the surface of water.

FREQUENCY OF AUDIBLE SOUND

Audible sound is considered to be any physical vibration that can be recognized by the human ear. It ranges in frequency from 16 hertz to 20 kHz (k is kilo, meaning a thousand, Hz is hertz which is cycles per second). Twenty (20) kHz is twenty thousand vibrations per second. A person with normal hearing responds to tones as high as 15 kHz, perhaps higher except when advancing age has limited the upper range. The low limit is usually between sixteen and twenty hertz.

We speak of high and low tones relative to the rates of vibration. Highs are those with rapid vibration rates (frequencies); lows are those tones which vibrate at lesser frequencies. The rumbling of thunder or the sound of a slow moving train are examples of low pitched sounds. An example of high pitched sound is the shriek from a jet plane, trimmed for landing.

The range of human speech is further limited within the range of audibility. Nearly all conversation, for example, occurs between 300 Hz and 3 kHz. The pitch of a man's voice within these frequencies is, in general, lower than that of a woman's.

SPEED OF SOUND

Sound cannot travel in a vacuum; it needs some form of matter (solid, liquid, or gas) as a transport medium. The velocity and the ease with which it travels depends on the density of the transport medium.

Solids (being the most dense) are generally the most speedy conductors, followed by less massive liquids and then gases. Sound travels at approximately 1100 feet per second through air at sea level and even more rapidly in water. The slowest common medium is rarefied air in the upper atmosphere.

Sound moves through matter by compressing and decompressing layers of substance. The amount of compression or decompression is determined by the volume or loudness of the sound. Once a sound wave is set in motion it continues moving outward, away from its source, constantly losing strength until it dissipates.

WAVELENGTH

Each sound wave lasts a given amount of time and travels a given distance. The physical distance between the beginning and end of one cycle is called the wavelength. This distance is determined by the speed at which it travels and the frequency. The wavelength of a 1000 hertz tone in air at sea level is slightly greater than one foot and a cycle of a 10,000 hertz tone is less than 1.5 inches long under the same conditions. As we have explained, the higher frequencies have shorter wavelengths while lower frequencies have longer length waves. Project these same frequencies through a more dense medium and the speed and wavelength both will increase.

SOUND WAVEFORMS

Pure audible tones appear as sine waveforms (Fig. 3); however, tones seldom exist in a pure state unless generated by special laboratory equipment. Most audible sounds

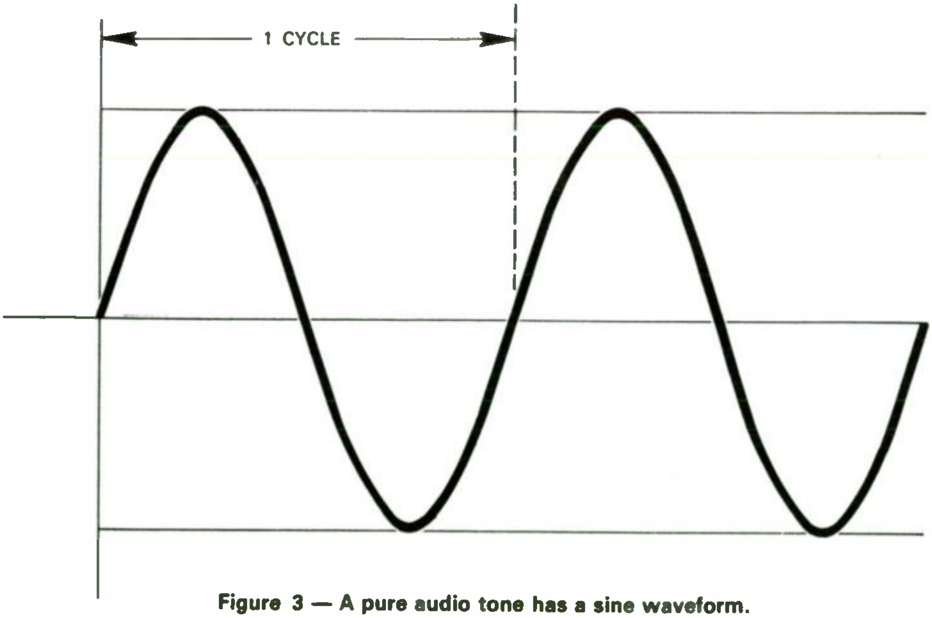

Figure 3 — A pure audio tone has a sine waveform.

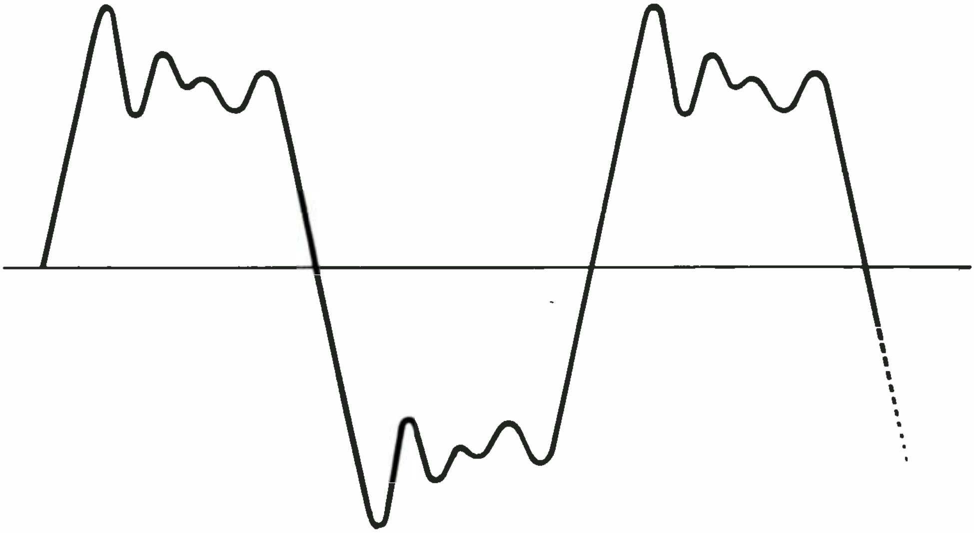

Figure 4 — A complex sound waveform.

are complex waveforms; combinations of different frequencies with differing amounts of vibrating energy. Figure 4 illustrates how a plot of a complex sound wave might appear.

Audible sound may be generated or produced by one of two basic methods:

1. A column of air passing or in contact with a vibrating-membrane, reed or string generates audible sound. These reeds, strings or membranes may be set in motion by moving air, or by some other physical means.
2. Sound is produced when a stream of air is directed across an opening to a cavity. The frequencies produced by a cavity are dependent upon its size and shape, and upon the size, shape, and location of the opening.

Examples of item 1 are string or wood-wind musical instruments and the human larynx. Certain other instruments identify with this group although they do not actually contain vibrating reeds or membranes. The lips of a trumpet or trombone player vibrate and produce sounds which are resonated by passages within these instruments. Examples of item 2 are flutes, fifes, and whistles. The surfaces of a cavity vibrate whenever they are excited by a moving column of air.

When a stringed instrument is caused to produce sound, vibrations travel from end to end along its strings. Figure 5 illustrates the arc described when a string vibrates while under tension. If this were the only vibratory pattern produced, you would hear a pure, crisp, and rather obnoxious tone. This is the fundamental vibration frequency. However, additional vibra-

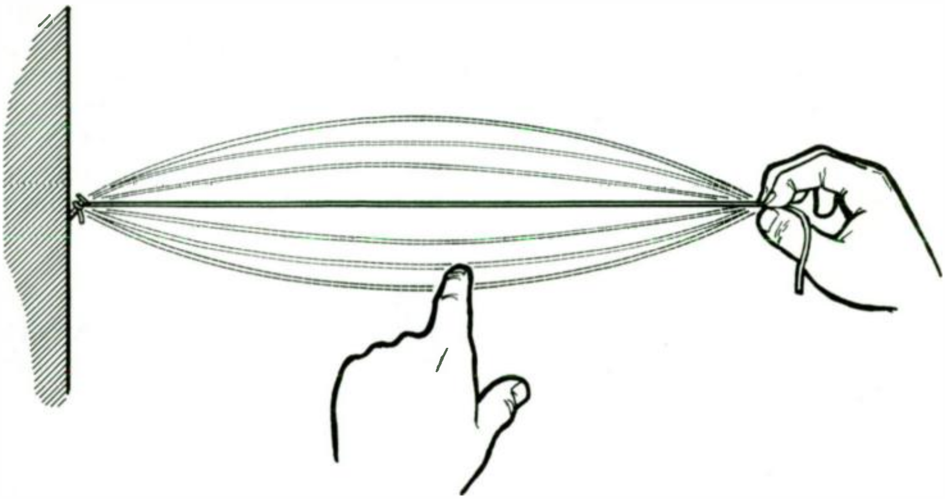

Figure 5 — Fundamental vibration of a string.

tions called *Harmonics* are produced which have lengths of only $^1/_2$, $^1/_3$, $^1/_4$ . . . etc. of the full length of the string. These harmonic tones (Fig. 6) are 2nd . . . 3rd . . . 4th . . . etc. multiples of the fundamental and their frequencies are 2 . . . 3 and 4 times greater. The pitch of these harmonics or overtones is said to be higher and they are more shrill and squeaky than the fundamental.

Overtones blend with the fundamental note to remove harshness and make it pleasing to the ear. This pleasant quality is sometimes further enhanced when tones mix to form additional combinations called cross products.

In all cases the fundamental note or frequency (from a single originating source) is the most prominent; it is that which your ear

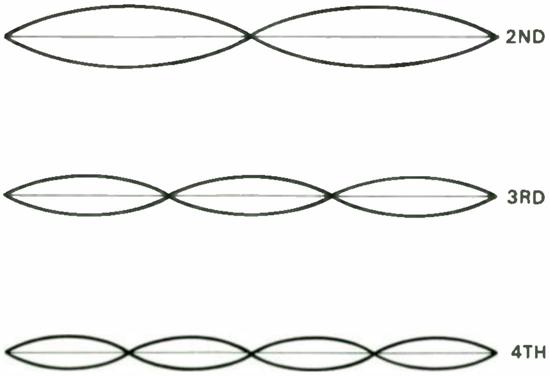

Figure 6 — Harmonic patterns in a vibrating string.

identifies. Harmonics and cross products are less prominent because their total energy content is less than the fundamental from which they are derived. When there is a mixture of sounds it is sometimes difficult to identify individual tones. This is especially true of music. A certain combination of professional musicians can be identified by the way they select and combine their individual sounds toward a cumulative result.

Sounds begin as basic sine waveforms (Fig. 3), but the presence of harmonics causes this shape to change. Figure 7 illustrates what happens to a sound's waveshape with the addition of harmonics. Significant percentages of harmonics are being added as we progress from left to right. Each subsequent addition after the fundamental, causes the waveform to more nearly approximate a triangle which we shall call a sawtooth waveform. Figure 7B from left to right shows the inclusion of harmonics 2, 3, and 4 as they are added to previous products. Figure 7A illustrates how the solid-line-curves more nearly approximate the dashed line sawtooth form as more harmonics are included.

Another way of stating this is to define a sawtooth wave. A perfect sawtooth wave will contain a fundamental and specific amounts of all its harmonics.

In Figure 8A, a square wave is shown as a broken line; from left to right we progressively add specific amounts of odd harmonics. At the extreme right (Fig. 8) you will notice how these combinations nearly approximate a square wave after the fifth harmonic is added. A square wave contains a fundamental frequency plus specific amounts of all its odd numbered harmonics.

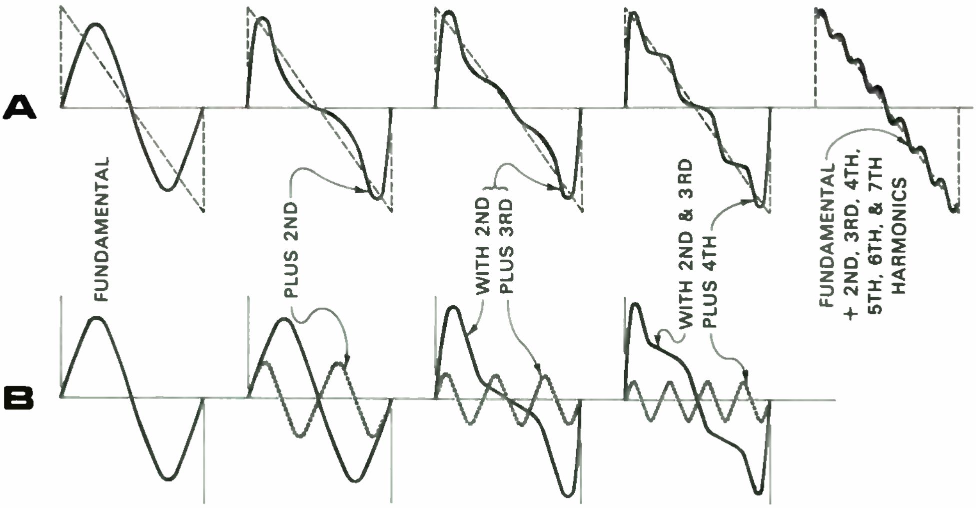

Figure 7 — Formation of a sawtooth wave by adding harmonics.

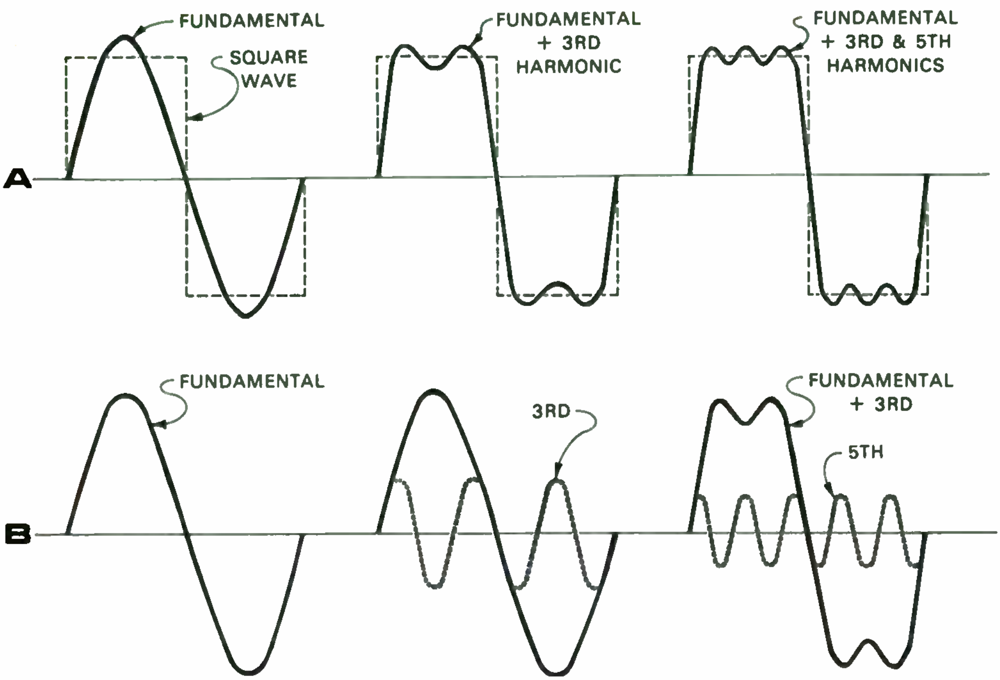

Figure 8 — Formation of a square wave by adding odd numbered harmonics.

Square waves are invaluable for checking the response of Hi-Fi audio amplifiers. Frequency discrimination of an amplifier can be determined by passing a square wave through it and then observing the output with an oscilloscope. Malfunction causes misshaping of the waveform by eliminating or suppressing certain harmonics.

ELECTROMAGNETIC WAVES

The signals which bring sound and video programs into your home are not vibrations in a physical substance. They are bursts of vibrating magnetic energy.

Radio broadcasts begin in studios as sound, which is converted to impulses of electric current. These electrical variations are tagged to a Radio Frequency (RF) carrier of fixed frequency. This RF frequency with its piggy-back sound information is presented to a transmitting antenna (Fig. 9). The antenna acts somewhat like an inductor; a powerful magnetic field is formed which extends for great distances. This field generates electric currents in any other conductor it crosses. The currents generated have the same vibratory nature as the field which produces them. These currents when induced into the receiving antenna of a radio set are transferred to an amplifier and boosted in strength. The sound portion is then extracted, further amplified and presented to a speaker. The speed of this whole process is

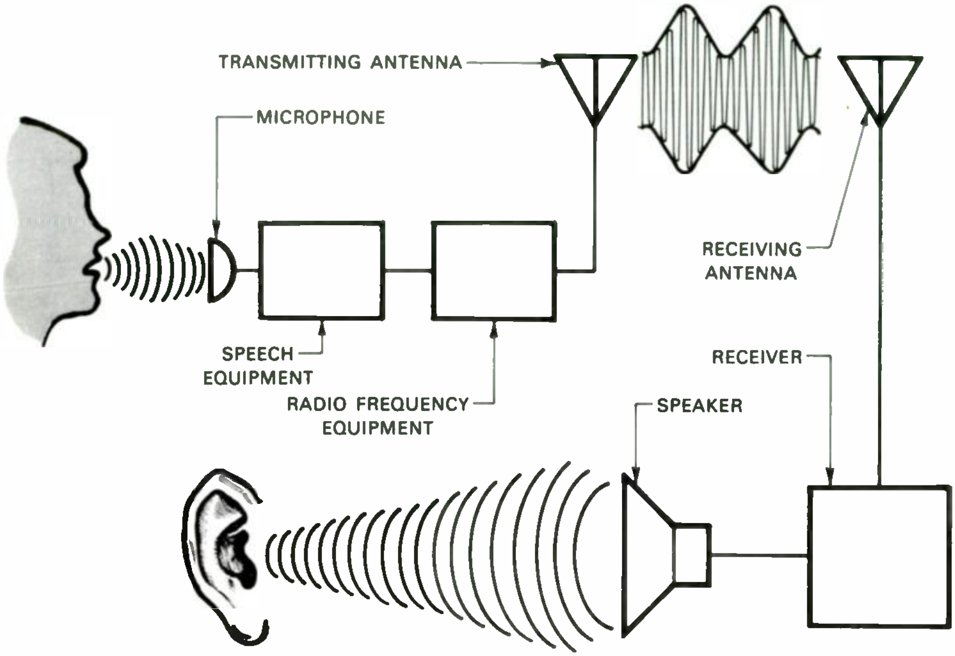

Figure 9 — Radio communication from microphone to speaker.

incomprehensible—from studio to family room in less time than it takes you to identify a letter of one word.

Electromagnetic waves travel at a constant speed of 300,000,000 meters per second. In miles this would exceed 186,000 miles each second. Since the rate of travel is constant, it is quite easy to determine the length of an RF wave when the frequency in hertz is known.

$$\text{Wavelength (meters)} = \frac{300{,}000{,}000}{\text{f (frequency in hertz)}}$$

The commonly used symbol for wavelength is the Greek letter lambda "λ".

FREQUENCY BANDS

Useable communication frequencies extend from below 10 kHz (k is kilo meaning thousand) to above 30,000 megahertz (mega is million). Frequencies above 30,000 megahertz also radiate, but they are infra-red heat, light, x-rays, etc.

Our standard AM broadcast band is served by frequencies between 540 kHz and 1600 kHz. FM is transmitted within a band from 88 MHz to 108 MHz. Television begins at 54 MHz and extends to 890 MHz with a gap where FM and some other services occur.

Groups of frequencies are called bands and these have been named and designated (Fig. 10). Each band

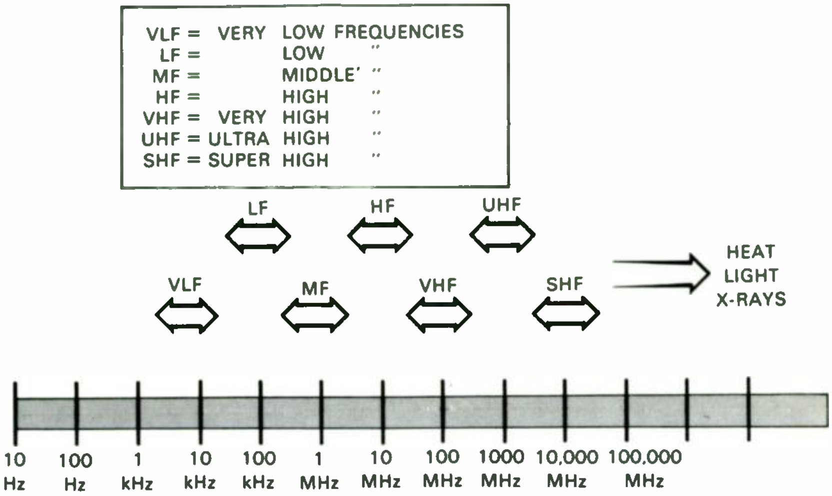

Figure 10 — The radio frequency spectrum.

has certain advantages for specific purposes. Pronounced skip effect makes the HF (high frequency) segment ideal for Ham (amateur) operation while the shorter wave lengths in the Super High band are ideal for Radar. AM broadcast falls in the Mid-frequencies where insignificant fading conditions occur.

RF SIGNAL RADIATION

RF energy is greatly affected by physical surroundings. It is absorbed by mountains, forests, and bodies of water, or reflected by towers and other tall structures. Even electrically charged layers in the upper atmosphere affect radiated electromagnetic waves.

Figure 11 shows the directions of two different wave fronts from a transmitting antenna. At certain frequencies below 30 megahertz, the ground wave rapidly loses strength so that we must depend on Sky Waves for communication. These sky waves are repeatedly returned to earth by layers of charged gases which range between 25 and 400 miles from the earth's surface. This height varies with season, weather, sunspot cycle activity, time of day, and numerous other conditions.

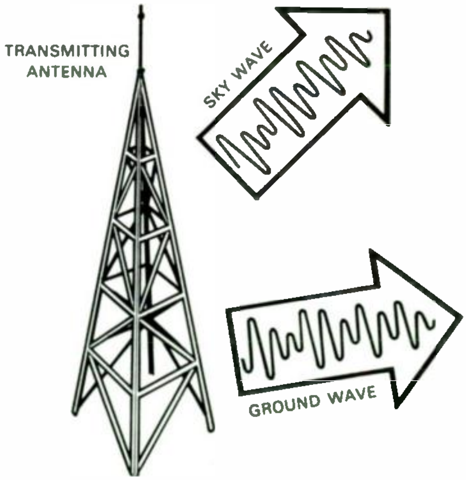

Figure 11 — Radio wave front directions from a transmitting antenna.

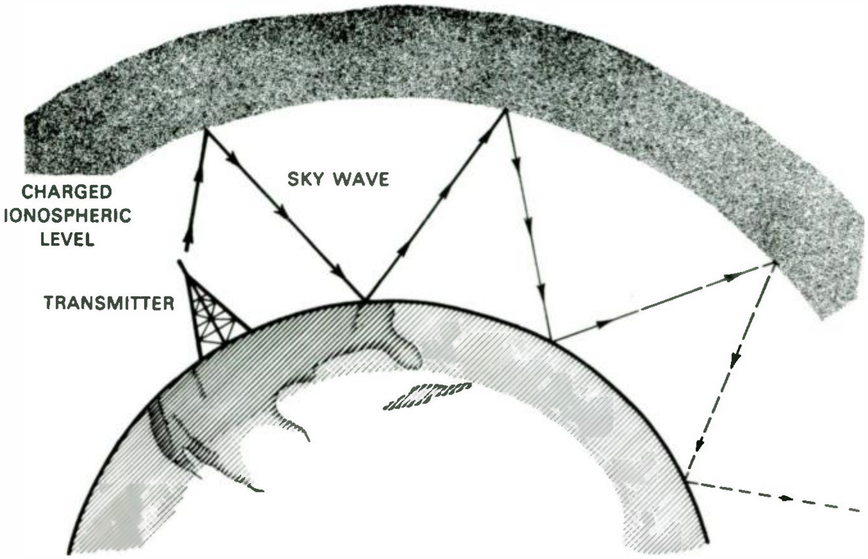

Figure 12 — High frequency radio waves are reflected in a skipping fashion.

The illustration in Figure 12 shows how a sky wave skips great distances by being reflected back to earth from the Ionosphere. Amateur operators use this skip effect to communicate with distant points using low power. The advantages of skip disappear above 30 megahertz because shorter wave lengths penetrate the charged layer and dissipate in space rather than being reflected.

LINE-OF-SIGHT TRANSMISSION

Figure 13 pictures the useable line-of-sight pattern at frequencies above 50 megahertz. Due to the earth's curvature, effective distance is limited to an absolute maximum of 125 miles. It is at approximately this distance that these waves strike the ground and are either absorbed or bounced off into space. Included in the line-of-sight frequencies are TV and FM transmissions. Transmitting antennas for these are usually located on tall buildings, hilltops, or mountain peaks in order to provide the best surrounding coverage.

Radio waves serve many purposes in addition to communications. Uses for microwaves range from—aircraft guidance and identification to heat generation in home ovens and industrial metal processing. Uses are being found for microwaves at a constantly accelerated pace.

SUMMARY

Sound waves are vibrations that require some medium for transfer. This medium may be a solid, liquid, or a gas. Sound does not travel in a perfect vacuum because there is no

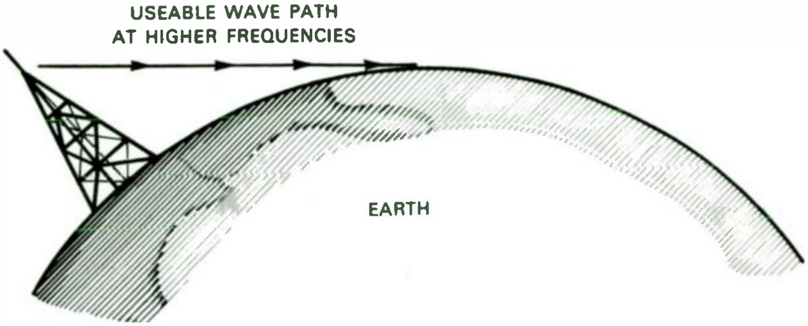

Figure 13 — Line-of-sight transmission.

medium for transfer. Each sound wave travels a given distance in a given time. This distance is determined by the frequency of the sound and is known as the wavelength.

All sound consists of a fundamental frequency, with side products called harmonics superimposed on and produced by the fundamental frequency. Harmonic frequencies are nothing more than multiples of the fundamental frequency. For instance, the second harmonic of a fundamental frequency of 60 hertz is 120 hertz. The third harmonic of the 60-hertz frequency is 180 hertz. Hence, the seventh harmonic of a frequency of 60 hertz is 420 hertz and so on. A sawtooth waveform or a square waveform may be produced by adding harmonics of a certain frequency to the fundamental waveform.

TEST

Lesson Number 14

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-014-1.

1. Sound waves are

A. electromagnetic energy.
2 [✓ B. vibrations in matter.]
C. similar to light.
D. vibrations in water only.

2. Audible sound frequencies range from 16 hertz to

A. 3 kHz.
2 B. 100 kHz.
C. 1600 kHz.
[✓ D. 20 kHz.]

3. Of the following frequencies, select the frequency with the shortest wavelength:

A. 10 hertz.
3 B. 100 hertz.
[✓ C. 1000 hertz.]
D. 1 hertz.

4. The second harmonic of a frequency of 60 hertz is

[✓ A. 120 hertz.]
// B. 30 hertz.
C. 90 hertz.
D. 240 hertz.

⑤ A sawtooth wave is produced by ____________ the fundamental waveform.

ℓ
- A. adding even harmonics to
- [✓ B. adding even and odd harmonics to]
- C. adding odd harmonics to
- D. removing all harmonics from

6. Square waves are formed by ____________ the fundamental waveform.

6
- A. adding all harmonics to
- B. adding even harmonics to
- C. excluding all harmonics from
- [✓ D. adding odd harmonics to]

7. Radio frequency waves are

7
- [✓ A. electromagnetic energy.]
- B. vibrations in matter.
- C. dissimilar to light.
- D. vibrations in water only.

8. When a radio frequency wave crosses a conductor,

7
- A. it produces physical vibrations.
- B. it has no effect.
- [✓ C. it induces currents.]
- D. it travels faster.

9. Radio waves travel at a rate of

8
- A. 30,000 feet per second.
- [✓ B. 300,000,000 meters per second.]
- C. 3,000 miles per second.
- D. 300,000,000 miles per hour

10. Line-of-sight transmission

10
- [✓ A. travels in straight lines.]
- B. follows the earth's curvature.
- C. follows a skip pattern.
- D. occurs only at low frequencies.

Notes

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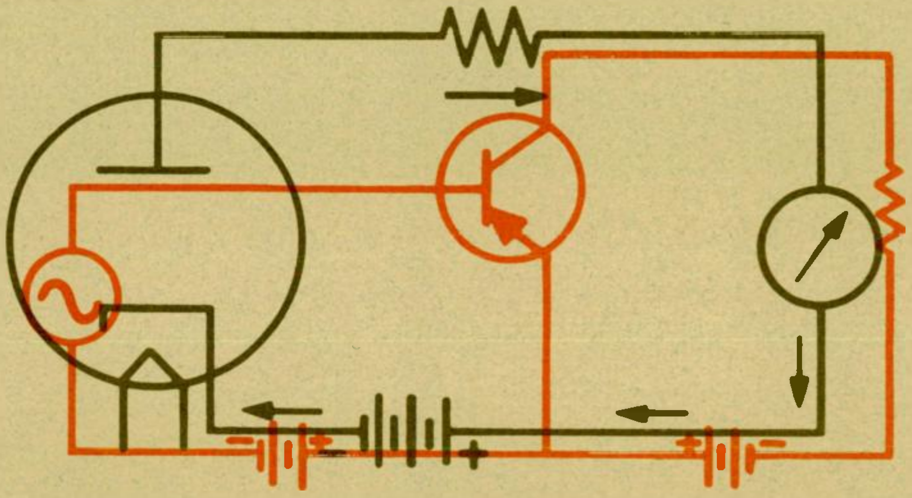
S. T. Christensen

LESSON NO. 15

REVIEW FILM OF LESSONS 11 THROUGH 14



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-015

403

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

Revised 6/73

Reprinted March 1974

REVIEW FILM TEST

Lesson Number 15

The ten questions enclosed are review questions of lessons 11, 12, 13, & 14 which you have just studied.

All ten are multiple choice questions, as in your regular lesson material.

Please rerun your Review Records and film before answering these questions.

You will be graded on your answers, as in the written lessons.

REMEMBER: YOU MUST COMPLETE AND MAIL IN ALL TESTS IN THE PROPER SEQUENCE IN ORDER FOR US TO SHIP YOUR KITS.

REVIEW FILM TEST

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-015-1.

1. Capacitance depends upon the
A. size of the plates.
B. type of dielectric.
C. distance between the plates.
[✓ D.] all of the above.

2. The unit of capacitance is the
A. ohm.
[✓ B.] farad.
C. henry.
D. hertz.

3. In a capacitor the current ________________ the voltage.
[✓ A.] leads
B. lags
C. equals
D. is

4. The inductance of a coil depends upon the
A. number of turns of wire.
B. permeability of the core material.
C. cross-sectional area of the core.
[✓ D.] all of the above.

5. The unit of inductance is the

A. ohm.
B. farad.
[✓ C. henry.]
D. hertz.

6. A coil of wire with current changing at the rate of 1 ampere per second induces 1 volt into the coil, the inductance of the coil is

A. 2 henrys
[✓ B. 1 henry.]
C. 2 farads.
D. 1 farad.

7. A proper solder connection is

A. bright and shiny.
B. also a good mechanical connection.
C. made with resin core solder.
[✓ D. all of the above.]

8. For a properly soldered connection, the soldering iron or gun should be

A. cool.
B. an AC/DC type.
[✓ C. the correct wattage rating for the particular job.]
D. OSHA approved.

9. Frequency is expressed in

A. ohms.
B. farads.
C. henrys.
[✓ D. hertz.]

10. RF stands for

A. right front.
[✓ B. radio frequency.]
C. regulated frequency.
D. reactance frequency

Notes

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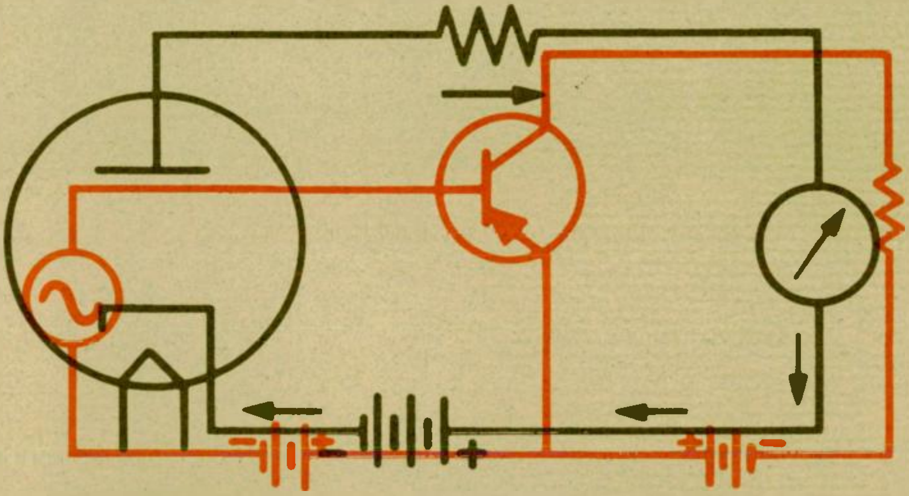
S. T. Christensen

LESSON NO. 16

MODULATION AND DEMODULATION



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-016
406

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

Revised 6/73

Reprinted June 1974

Contents

Advance Schools, Inc.

52-016

MODULATION AND DEMODULATION

INTRODUCTION

When radio waves were first used as a means of communication between two stations, the radio wave was simply turned off and on at the transmitter in a sequence of dots and dashs to form letters. Attempts were made almost from the beginning of radio to develop a radio system to transmit the human voice. It was not until the widespread development of the vacuum tube that radio became a reality.

RADIO WAVES

A radio wave from a broadcasting station is an alternating current sine wave at a high frequency. It must be connected to an antenna for radiation purposes. If this radio wave is not interrupted, it would not produce a tone in a conventional broadcast receiver. We are speaking here of AM broadcasting stations and AM receivers; AM stands for amplitude modulation.

Sine Wave

The radio signal from an AM broadcasting station is conventionally represented as a series of sine waves. Since the frequencies of broadcast stations range from 540 kHz to 1600 kHz, only a very short length of time is actually represented by the few cycles in A of Figure 1. This series of sine waves can represent any frequency assigned to an AM broadcast station. This steady, constant frequency that

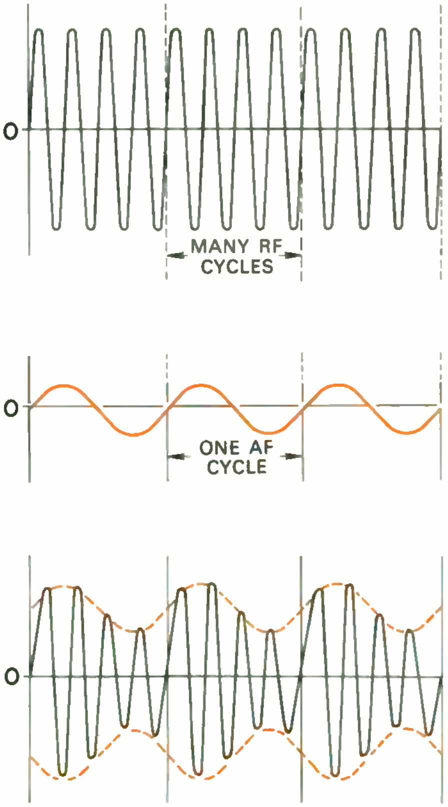


Figure 1 — Amplitude modulation.

transmits voice, music, or the civilian defense warning tone is called the carrier frequency of simply the *carrier.*

The intelligence transmitted on the carrier consists of much lower frequencies known as audio frequencies. The audio frequency in B of Figure 1 rides on the carrier so that it changes the shape of the carrier and produces the wave shape in C. This action of an audio frequency upon a radio frequency is known as *modulation.* Because the amplitude of the RF is varied, the action is called *amplitude modulation.*

AMPLITUDE MODULATION

Amplitude modulation may be defined further as the variation of both the *strength* of the RF wave and the *frequency* of the RF wave that is radiated by the transmitter.

Strength of a Modulated Signal

The strength of the RF wave varies *directly* with the loudness of the audio signal. There is, however, a limit to the amount of audio power that may be used to properly modulate the transmitter. A properly modulated transmitter is one that is 100 percent modulated. Any greater amount of audio signal will produce overmodulation and distortion of the audio signal.

Frequency of the Modulated Signal

The frequency of the RF wave varies in *proportion* to the frequency of the audio signal modulating it. If the audio signal in Figure 1 was a tone of exactly 1000 Hz or 1 kHz, the RF wave would be modulated or changed in frequency exactly 1 kHz above the RF carrier frequency and 1 kHz below the RF carrier frequency.

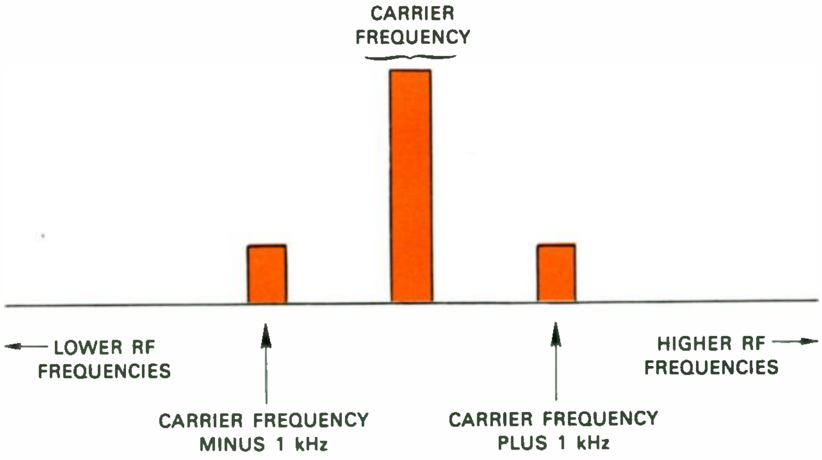


Figure 2 — A single tone modulating a carrier.

This single frequency of 1 kHz that modulates the carrier frequency generates three distinct frequencies (Fig. 2). Because these two new frequencies are located on each side of the fundamental carrier frequency, they are called sideband frequencies or *lower sideband* and *upper sideband.*

Sidebands

Three distinct frequencies exist when a single tone modulates a carrier wave (Fig. 2). These three frequencies can be distinctly heard on a radio receiver selective enough to distinguish between three frequencies that are separated by only 1 kHz. If two audio tones were generated and applied to the RF carrier, four distinct sidebands would be produced (Fig. 3). The carrier is assumed to be an AM broadcasting station operating on 1000 kHz, while the two audio tones are 1 kHz and 3 kHz. The amplitude of the various signals are represented by their heights; the actual frequencies are listed beneath each sideband. These two audio tones generate four sidebands with two above and two below the carrier. If twenty separate and distinct audio tones were applied to a carrier, there would be a total of forty sidebands generated; twenty would be located on each side of the center frequency.

When the human voice modulates a carrier to transmit intelligence, complex RF sidebands that are generated follow these complex voice frequencies. Voice and music frequencies range from 16 hertz upwards to 20 kHz when the overtones are included. Consequently the sidebands would be 20 kHz wide on each side of the AM carrier, if a limit had not been placed on the width of AM sidebands by the FCC (Federal Communications Commission).

Bandwidth

The FCC rules limit each sideband to a width of 5 kHz either side of the carrier frequency; therefore,

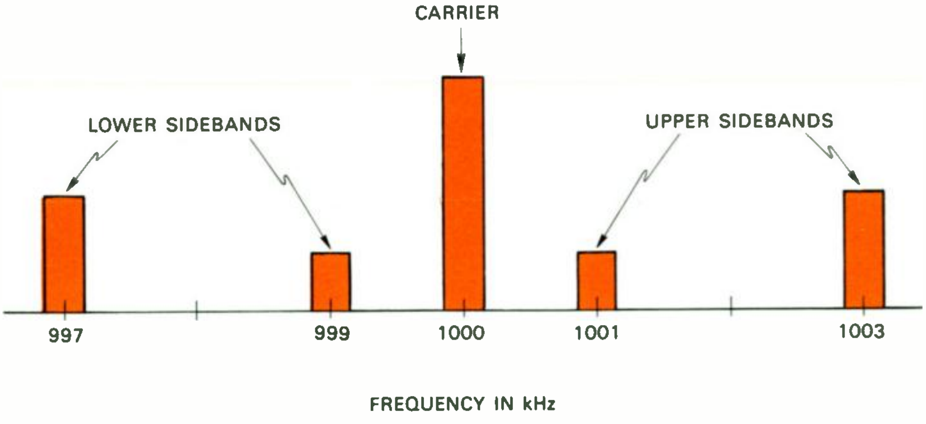


Figure 3 — An audio frequency of 1 kHz produces side frequencies of 999 and 1001 kHz, while an audio frequency of 3 kHz produces side frequencies of 997 and 1003 kHz.

AM broadcasting stations must employ electrical filters that cut off all audio frequencies above 5 kHz. This permits each station a bandwidth of 10 kHz. Since the standard broadcast band starts at 540 kHz and extends to 1600 kHz, there are 107 channels available for use.

Frequency Allocation by FCC

The FCC is required by law to designate frequency bands for all radio transmission within the United States. Unregulated operation of radio transmission would obviously result in a chaotic condition if the frequency of operation and the power of the station were not controlled. Because 107 channels do not provide enough spectrum space for the thousands of AM stations on the air during the daylight hours, the FCC has exercised additional control by assigning a frequency and a power level to a certain geographical area to prevent interference between nearby stations.

Clear Channel Frequencies

Specific allocations such as these have permitted many small stations to operate during daylight hours when the area to be covered by a signal of a known strength can be determined. Many of these stations are not permitted to operate during the hours of darkness, because their AM signal can travel much farther during the night and cause interference with other stations. Some stations are permitted to continually operate on a so-called "clear channel" and to use the maximum amount of power plus a modulation range of 7.5 kHz.

Limiting the width of each sideband to 5 kHz cuts off all audio frequencies above this limit, but does not materially decrease the amount of information that is transmitted. There are combinations of sound frequencies that produce harmonics extending above the 5000-hertz limit. These higher frequencies, however, are not absolutely necessary to convey either voice or music. This is demonstrated each time you listen to voices or music from an AM station, since speech intelligence is less than 3000 hertz and the fundamental frequencies of most musical notes are less than 5000 hertz.

Voice Waveshapes

The human voice generates an almost infinite number of waveshapes. No two people create exactly the same waveform even when pronouncing the same word. A representative voice wave is illustrated in Figure 4A, and the resultant amplitude modulated signal in Figure 4B. The carrier prior to modulation is also shown.

Percentage of Modulation

The signal from an AM broadcast station varies greatly in wave shape when it is being modulated by voice and musical instrument frequencies. Care must be taken, however, to prevent overmodulation of the carrier, or distortion will result. The amount of the modulation is expressed as a percentage of the amplitude of the

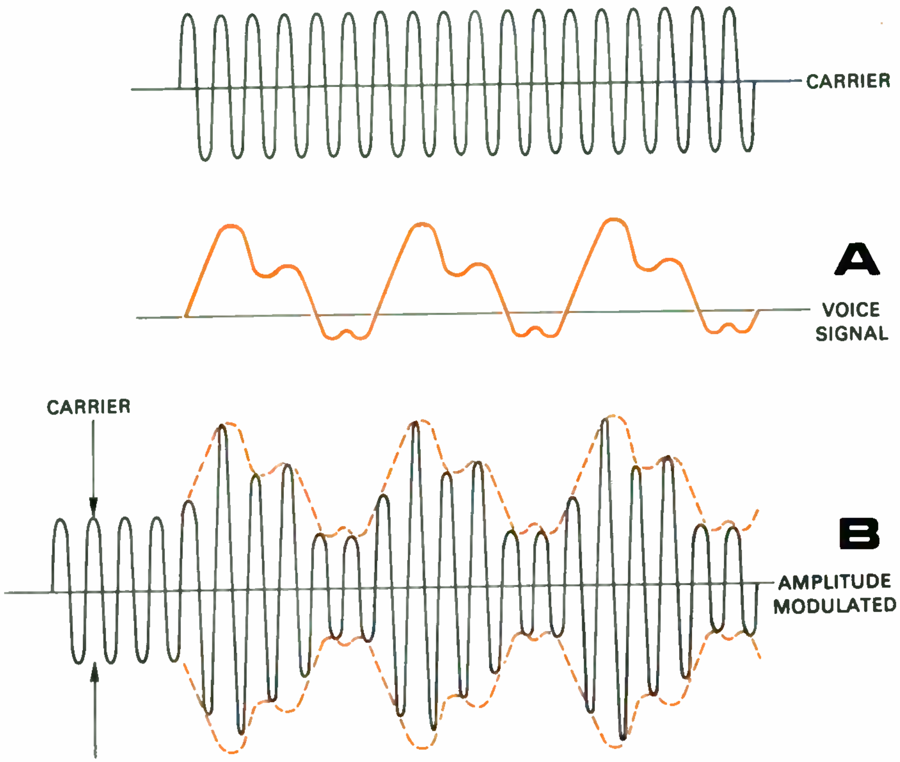


Figure 4 — A voice wave modulating an RF carrier.

unmodulated carrier. Figure 5 illustrates two levels of modulation of the same carrier. If we apply the formula

$$\text{percentage of modulation} = \frac{a\text{-}b}{b} \times 100\%,$$

for the 50% modulated waveform shown at A, we can determine the exact values. If we assume for the carrier *b*, a value of 100 volts, and the modulation *a*, a value of 150 volts, then the

$$\text{percentage of modulation} = \frac{150\text{-}100}{100} \times 100\% = \frac{50}{100} \times 100\% = 50\%.$$

If we assign comparative values for the larger modulating wave at B, the result would be carrier *b*, a value of 100 volts, and the modulation *e*, a value of 200 volts; therefore, the

$$\text{percentage of modulation} = \frac{e\text{-}b}{b} \times 100\%, \text{ or}$$

$$\text{percentage of modulation} = \frac{200\text{-}100}{100} \times 100\% = 1 \times 100\% = 100\%.$$

Overmodulation

In both of these examples, when the carrier is modulated, the modulated waveshape is always present even though it has fallen to zero at point d. It has *not* fallen *below* zero at point d. If it had, it would have the effect of turning off the carrier. The carrier would be turned off as the result of overmodulation or

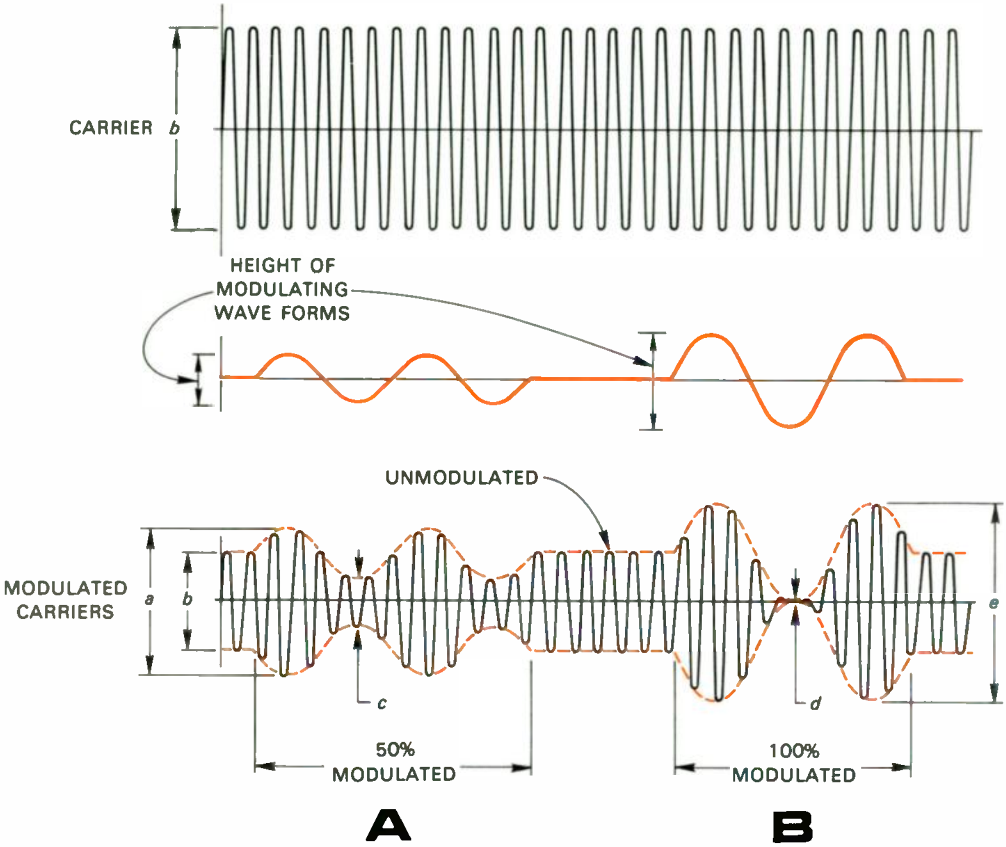


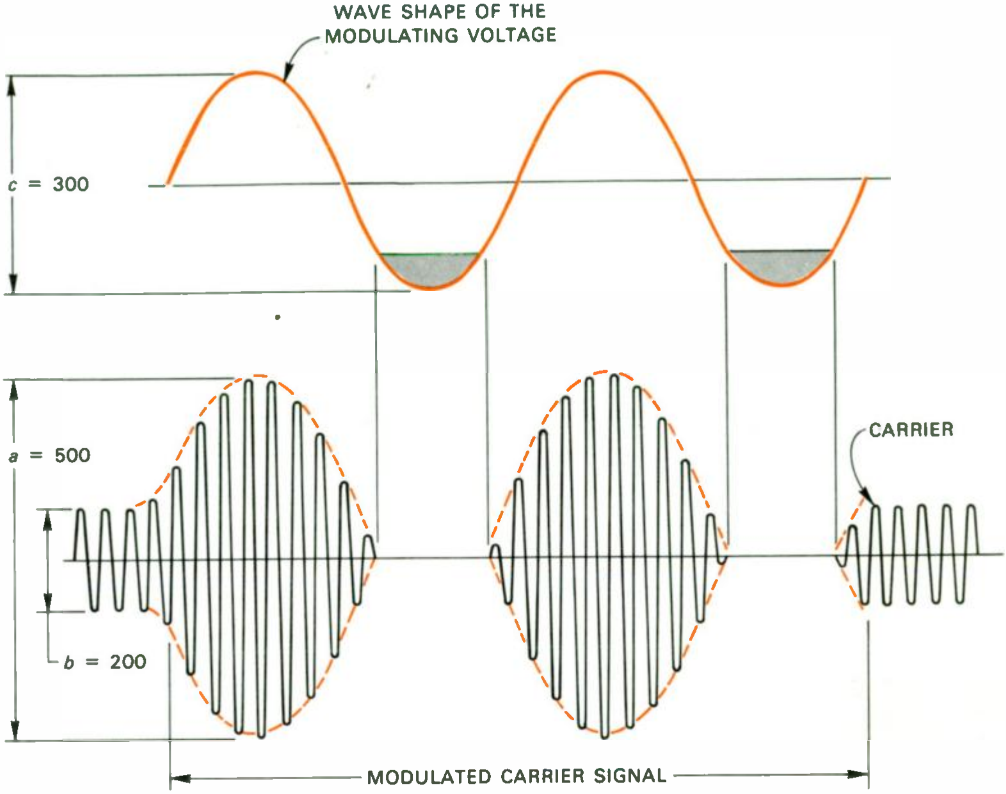
Figure 5 — Illustrating two modulated waveforms.

modulation greater than 100% (Fig. 6). The audio amplitude is shown as a sine wave that is producing the overmodulation. The waveshapes in these illustrations can represent either voltage or current, since the representation of the effect on the carrier will be the same.

The amplitude of these signals shows why overmodulation is detrimental. A comparison of the amplitudes shows that the peak-to-peak voltage of the carrier signal *b* is 200 and the modulating signal *c* is 300. Modulated signal *a* is 500 with the positive half reaching 250, but the negative half only reaching a value of 200. The shaded part of the modulating signal indicates the portion that exceeds the negative amplitude of the carrier signal, blocking it off so that the carrier does not exist during that time.

METHODS USED TO OBTAIN AMPLITUDE MODULATION

Modulating an RF carrier by varying its amplitude can be done in several ways. The two principal



$$\% \text{ OF MOD.} = \frac{a - b}{b} \times 100\% = \frac{500 - 200}{200} \times 100\% = 1.5 \times 100\% = 150\%$$

Figure 6 — Illustrating overmodulation of a carrier signal.

systems used to vary the amplitude are *plate modulation* and *grid modulation*. These two systems have different operating efficiencies, which become important as the size of the transmitter becomes larger.

The names of the part of the circuit into which the modulating signal is injected identifies the modulation system that is used. Grid modulation indicates the use of the *grid circuit*, and the *plate circuit* is used for plate modulation. In most cases, the amplitude modulator of either the plate or grid type controls the RF amplifier section of the transmitter.

Plate Modulation

The most widely used system to produce an amplitude modulated signal is the method known as *plate modulation*. The technical aspects of this system will be explained in a later lesson, but the primary feature of this system is simple to understand. The powerful RF signal is modulated before it is sent to the transmitting antenna to be radiated into space. In Figure 7, the

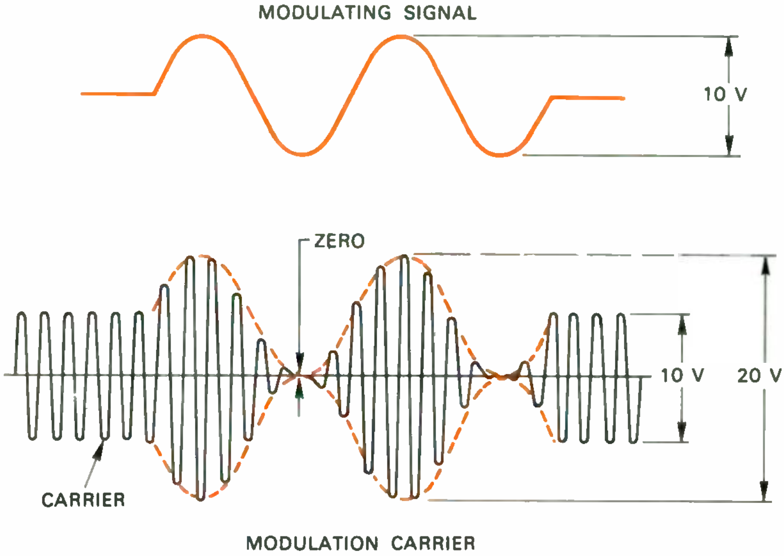


Figure 7 — A 100% modulated signal.

modulating signal is 10 volts peak-to-peak, which is the same value as the amplitude of the carrier signal. When modulation occurs, the modulating signal goes far enough positive to double the peak-to-peak value of the carrier.

During the negative portion, the modulating signal goes negative far enough to reduce the peak-to-peak value to zero. This amount of action on a carrier produces the desired 100 percent effect, because it completely modulates the carrier signal. Anything less produces a weaker AM signal due to less than complete modulation. More than 100 percent modulation would produce a greater positive-going signal, but it would also generate an incomplete negative signal, or a less-than-zero-signal, which develops the distorted part of the signal.

The system of plate modulation is represented in a block diagram (Fig. 8). The level of sound of the voice goes to the speech amplifier. It is then further amplified in the amplitude modulator to a level strong enough to vary the RF signal produced by the RF generator and strengthened in the RF amplifier. There are many individual steps in each block of the diagram, but the functions of all major operations are summarized in these four blocks.

Grid Modulation

This type of modulation also varies the amplitude of the RF carrier signal. However, it acts upon the input to the RF amplifier, rather than upon the output side of the RF amplifier (as in plate modulation). The grid modulation system does not require as much audio power as the plate modulation system because the modulating signals are applied to one of the grid elements in the amplifier. Some disadvantages of grid modulation are lowered ef-

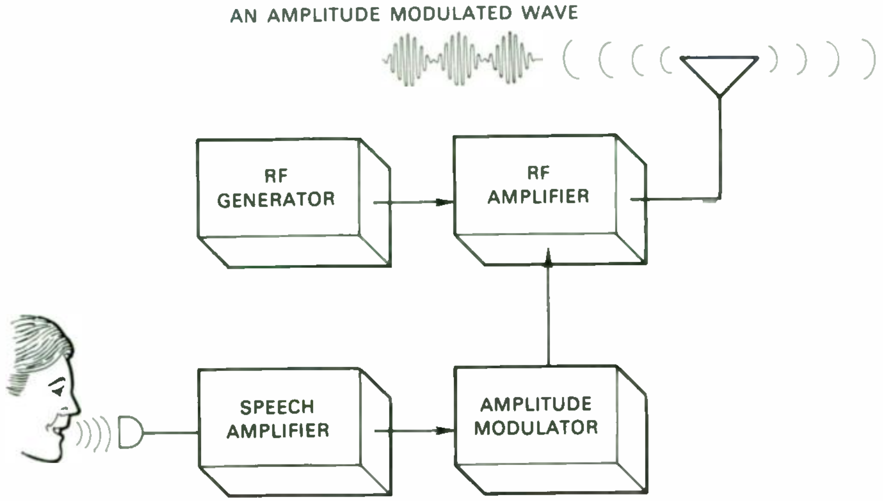


Figure 8 — Block diagram of an AM transmitter.

ficiency, a reduction in power output from a given size of vacuum tube, and the complexity of adjustment to obtain satisfactory modulation.

Because the modulating signal for both grid and plate modulation is applied to the RF carrier, Figure 8 is representative of both types of AM transmitters.

FREQUENCY MODULATION

In our study of amplitude modulation, we learned that the RF carrier was affected in two ways. The amplitude of the carrier was varied depending upon the loudness of the audio signal. The frequency of the carrier was also increased and decreased in direct proportion to the audio frequency modulating it.

Figure 1 illustrated how the amplitude varies, and Figure 2 demonstrated how the sideband frequencies are created in an AM system. When the audio signal gets louder, the amplitude grows larger; when the frequency increases, the frequencies of the sidebands increase proportionally. AM is susceptible to electrical noise such as static, sparking from DC motor commutators and auto ignition. These electrical discharges ride on top of the already-modulated AM signal, creating additional modulation that comes through as noise in the radio receiver.

Constant Amplitude

As the name implies, *frequency modulation* produces only a variation in the frequency of the RF carrier and does not change the amplitude. This frequency modulated carrier maintains a *constant amplitude*, but the *RF frequency* is increased on the positive part of the audio signal and is decreased on the negative side (Fig. 9). This is the important fact about an FM

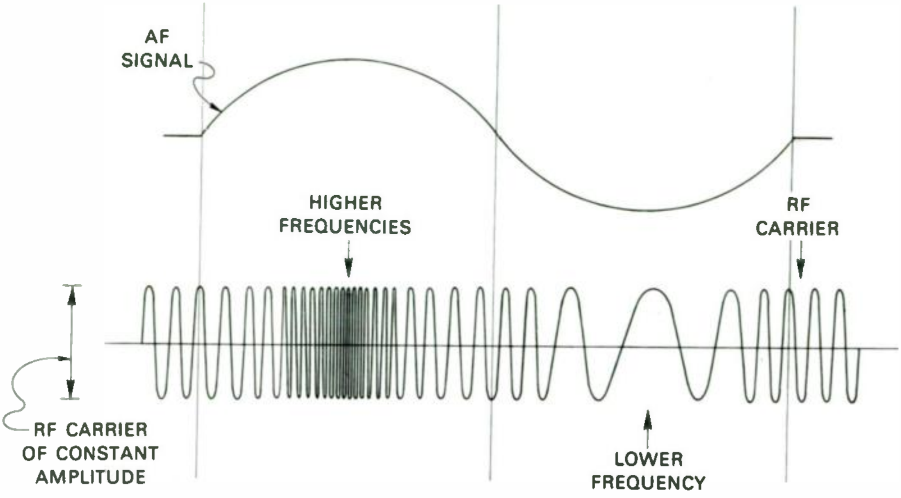


Figure 9 — The frequency modulated signal is increased in frequency on the positive portion of the audio and decreased on the negative part of the cycle.

signal — there is no change in amplitude, only a change in frequency.

Two Types of AF Variation

An FM signal must convey two types of audio frequency variation; the effect of *audio amplitude* which corresponds to the loudness or softness of voice or music, and the effect of *audio frequency* which varies with the pitch of voice or music. These two variations exist in every FM signal and provide all of the information necessary to convey intelligence on the carrier. Before investigating how these two effects are produced on the carrier, we will analyze in detail the exact result that a single 10-kHz audio tone produces on a 100-MHz RF carrier (Fig. 10). During just a single cycle of the audio at

0° the carrier frequency remains at 100.00 MHz

90° the carrier frequency increased to 100.01 MHz

180° the carrier frequency returned to 100.00 MHz

270° the carrier frequency decreased to 99.99 MHz

360° the carrier frequency returned to 100.00 MHz

Because both the human voice and musical tones create many frequencies, the FM signal will vary above and below the carrier frequency in step with all of these frequencies.

Effect of Audio Amplitude

It was explained previously that the FM signal is at its highest frequency when the audio signal is at its positive maximum. It is at its lowest frequency when the audio signal is at its greatest negative point. When the signal becomes *louder*, the carrier increases to a higher frequency; if the signal becomes *softer*, the frequency decreases. This effect on the RF

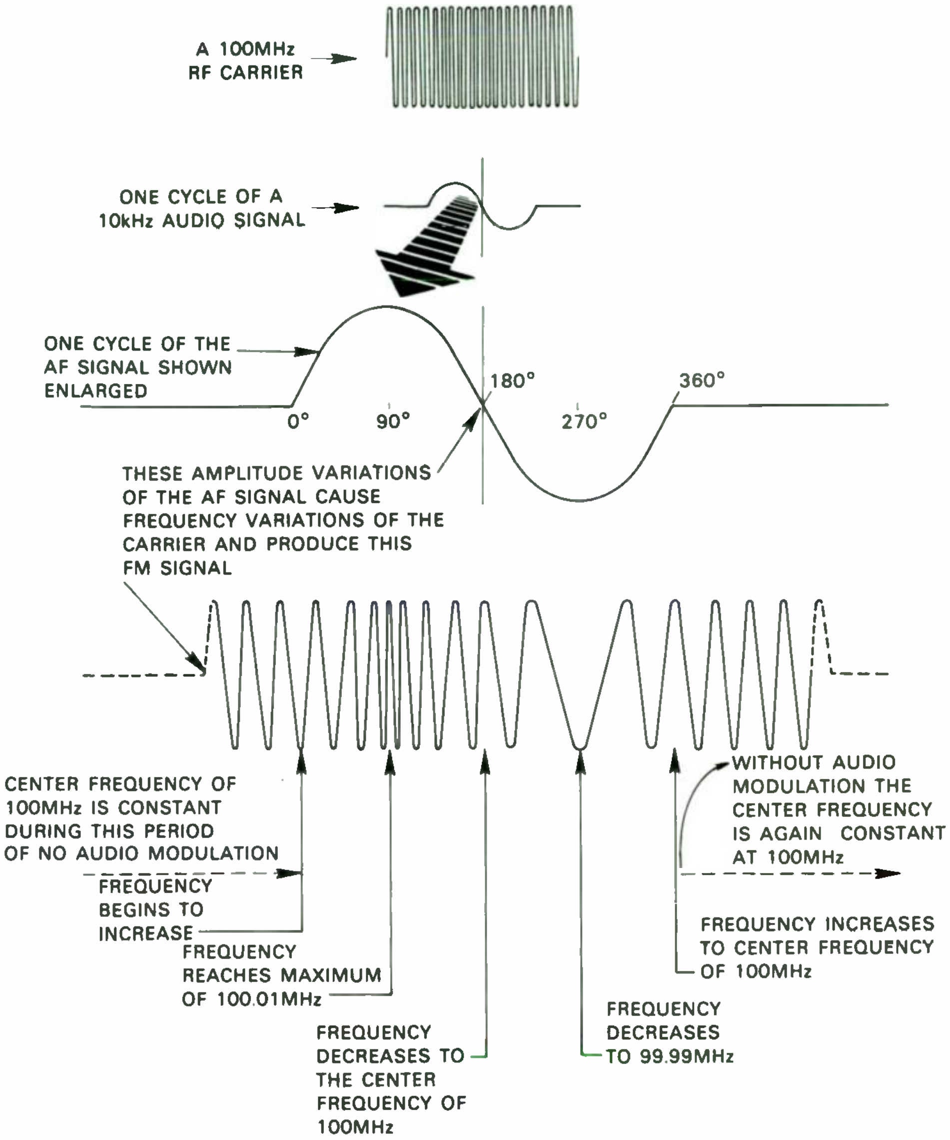
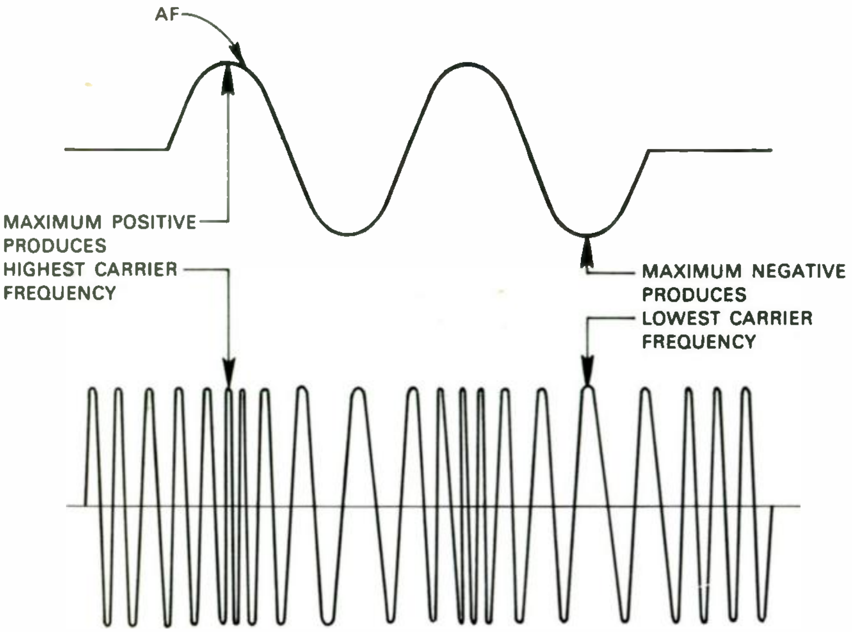


Figure 10 — Showing how a radio frequency signal has been changed in frequency by an audio frequency.

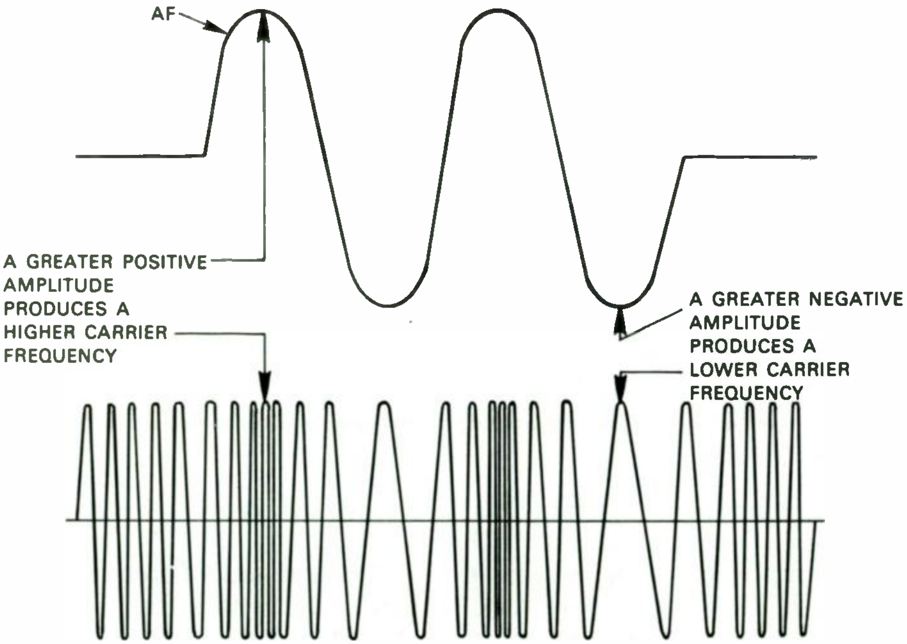
carrier frequency by an audio signal of the same frequency, but with different amplitudes, can be seen in Figure 11. It illustrates this effect of frequency deviation from the center frequency, or as it is sometimes called, deviation from the resting frequency.

Effect of Audio Frequency

The amount of frequency change from the center frequency is controlled by the amplitude of the audio signal, but this frequency deviation will not tell us anything about the *actual* frequency or frequencies of



EFFECT OF A LOW AMPLITUDE SIGNAL



EFFECT OF A LARGE AMPLITUDE SIGNAL

Figure 11 — Effects of audio amplitude.

the audio signal. The frequency of the audio signal affects the *rate of change* of the carrier signal, because the carrier signal follows the audio frequencies. We can illustrate how an audio frequency affects the rate of change by using an audio generator to modulate an FM carrier. We will look at the FM carrier to observe the effect produced by three audio frequencies at three separate times, assuming that we can view each one for only one one-thousandth of a second. Each cycle of a 1000-hertz frequency requires one one-thousandth of a second; 2000-hertz frequency would complete two cycles in one one-thousandth of a second; a 3000-hertz frequency would produce three cycles in one one-thousandth of a second, etc.

Thus, the *rate of change* of the audio frequency is forcing the RF carrier to both increase and decrease in frequency as many times per second as the audio signal changes frequency (Fig. 12).

FM Side Frequencies

An RF carrier that is amplitude modulated by one modulating frequency produces only two sideband frequencies. One sideband frequency is above the carrier frequency, and the other sideband frequency is below the carrier frequency.

When the RF carrier is frequency modulated, many sidebands are produced on each side of the center or resting frequency. The first two sidebands, the ones closest to the carrier, are located from the carrier a distance equal to the modulating frequency. The next two sidebands, again one on each side, are also spaced by an amount equal to the modulating frequency. There are an infinite number of these sidebands, but fortunately those that are produced *beyond* the frequency *swing* of the carrier during modulation are relatively low in amplitude and do not materially contribute to the overall signal strength.

Figure 13 represents an unmodulated RF carrier and the same RF carrier modulated by an audio signal. The vertical height of the lines represent the energy in the carrier and in each sideband. Note that the height of the carrier in B is lower during modulation than it is in A in a resting condition. Since information is contained in the sidebands and an increase in modulation energy would increase the energy in the sidebands, it becomes obvious that the energy in the carrier will decrease. Thus, a level of modulation approaching 100 percent would leave only a small amount of energy in the carrier, because most of the energy would have been transferred to the sidebands.

The six sidebands (Fig. 13) are equally spaced by the amount of the audio frequency. Thus, if the AF is 1 kHz, both X1's are spaced 1 kHz from the carrier; both X2's are spaced 2 kHz from the carrier; and both X3's are spaced 3 kHz from the carrier. For this example, the frequency deviation is 3 kHz by definition.

These sidebands are formed while the carrier is shifting. The number of sidebands formed depends upon both the *amplitude* and the *frequen-*

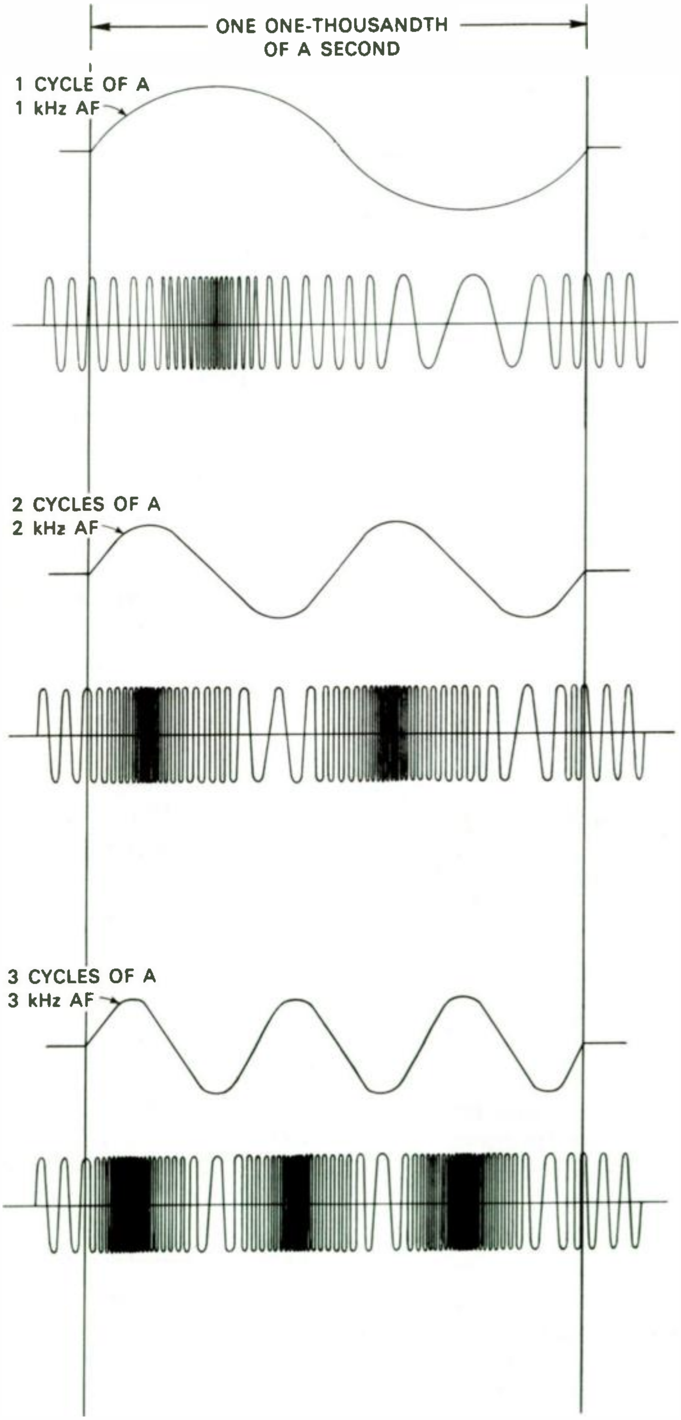


Figure 12 — Showing how three audio frequencies produce three rates of change of an FM carrier.

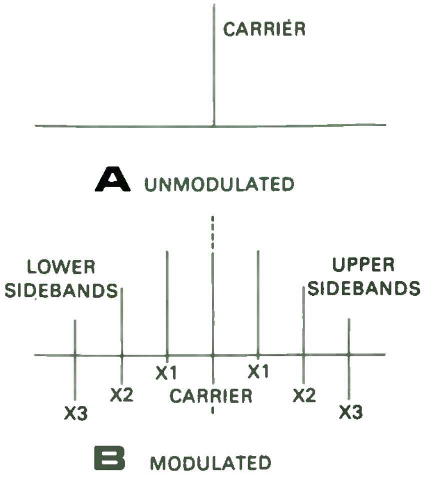


Figure 13 — An FM signal with its sidebands.

cy of the audio signal. As the frequency swing increases due to an increase in the amplitude of the audio signal (that is, the width of the swing of the RF is increased), the number of sidebands or sideband pairs is increased. In addition to the amplitude of an audio signal affecting the number of sidebands produced, the frequency of the audio signal also has an effect, but in the opposite manner. *More* sideband pairs are produced when this AF signal frequency *decreases.*

We can summarize the effect produced by the *amplitude* and the *frequency* of an audio signal by remembering that FM sideband pairs will increase with an *increase in amplitude* and increase with a *decrease in frequency.* We can use this data to give us information about the characteristics of the FM signal.

Modulation Index

The modulation index gives us information about the FM signal, using the data that we have already obtained. We have learned about Frequency Deviation (the shift in frequency from the carrier frequency), and Modulation Frequency (the modulating audio frequency).

With these, we can determine a ratio known as the

$$\text{Modulation Index} = \frac{\text{Frequency Deviation}}{\text{Modulation Frequency.}}$$

If a particular FM signal had a frequency deviation of 10 kHz and was modulated by a 5 kHz signal, the modulation index would be 10/5 = 2.

The modulation index is related to the number of significant sideband pairs in a certain relationship (Fig. 14). The modulation index is actually an instantaneous value, because

$$M = \frac{\text{DEVIATION OF FM CARRIER}}{\text{FREQUENCY OF MODULATING SIGNAL}}$$

M = MODULATION INDEX CARRIER

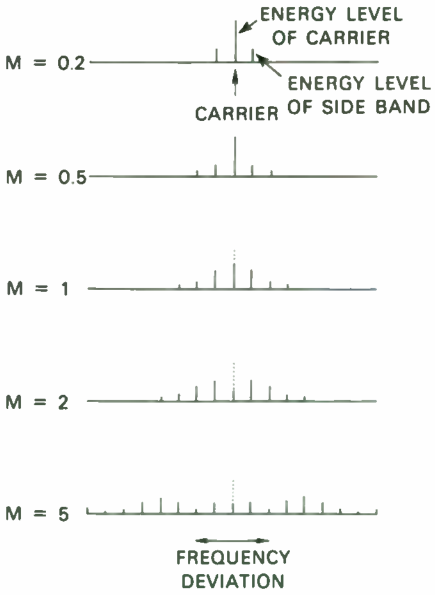


Figure 14 — Frequency and energy distribution for 5 values of modulation index of an FM wave.

the strength and frequency of the modulating signal is continually changing. The modulation index also has a relationship to the number of effective sidebands as shown in the table (Fig. 15).

Carrier Swing

The FCC has established limits of audio modulation of 5 kHz in AM broadcasting and an audio modulation frequency of 15 kHz in FM commercial broadcasting. They have also regulated the carrier shift; the maximum shift allowed cannot exceed ± 75 kHz from the center frequency. The FCC has also placed a 25-kHz guardband on each edge of the FM signal, because some significant sidebands might be generated and extend beyond this limit. When we add these frequencies, we would have 75 kHz either side of the center frequency and the guardband of 25 kHz on either side. This would total 200 kHz for one FM channel.

The FCC rules place a limit on the *amount of frequency deviation* and the *maximum modulation frequency.*

Deviation Ratio

We use some of these values to determine another important number known as the deviation ratio. It is simply the

$$\frac{\textbf{maximum amount of frequency deviation}}{\textbf{maximum frequency of the modulating signal}} = \textbf{deviation ratio.}$$

The FCC rules governing commercial broadcasting allow the carrier a

Modulation Index	Number of effective sidebands above and below the CARRIER	Bandwidth is obtained by multiplying modulating FREQUENCY 'F'
0.5	2	4xF
1.0	3	6xF
2.0	4	8xF
3.0	6	12xF
4.0	7	14xF
5.0	8	16xF
6.0	9	18xF
7.0	11	22xF
8.0	12	24xF
9.0	13	26xF
10.0	14	28xF
11.0	15	30xF
12.0	16	32xF
13.0	17	34xF
14.0	18	36xF
15.0	19	38xF

Figure 15 — Relationship of modulation index, sidebands, and bandwidth.

maximum deviation of 75 kHz, and the FCC allows the audio or modulating frequency a maximum value of 15 kHz. Thus, the maximum value of the deviation ratio is

$$\frac{75\text{ kHz}}{15\text{ kHz}} = 5.0,$$

If there was a softer audio signal at the same 15-kHz frequency (that is, the same 15-kHz signal, but at a lower amplitude), an FM signal would have a frequency deviation less than 75 kHz and a correspondingly smaller modulation index. The opposite would be obtained with the same 75 kHz of frequency deviation, but with an audio frequency less than 15 kHz. We would then obtain a larger modulation index. A number of frequencies and ratios computed from this data are listed on Figure 16. The formulas will tell how the computations are made.

Modulation Percentage

To explain 100 percent modulation in an FM system, we should first review the same condition for an AM wave. When the amplitude of the envelope varies between zero and twice its normal unmodulated value, 100 percent modulation of AM exists. At this time, there is a corresponding increase in power of 50 percent. The amount of power increase depends upon the degree of modulation. Because the degree of modulation varies, the AM transmitter cannot be operated at maximum efficiency continuously.

In frequency modulation, 100 percent modulation has a different meaning, because the AF signal varies only the frequency of the transmitter. Therefore, the transmitter operates at maximum efficiency continuously, and the FM signal has a constant power input at the transmitting antenna, regardless of the degree of modulation. A modulation of 100 percent simply means that the carrier is deviated in frequency by the full amount. For example, an 88-MHz FM station has 100 percent modulation when its

Radio Frequency		Audio Frequency		Modulation Index	No. of Sidebands Either Side of Carrier	BAND WIDTH From Fig. 15, last column KHz	Percentage of Modulation %
Frequency of Deviation each side of carrier in KHz Allowable	Actual	Frequency of the modulating Signal KHz	Relative Amplitude (100 = Max. Value.)				
75	70.0	10	93.3	7	11	220	93.3
75	75.0	15	100	5	8	240	100.0
75	37.5	15	50	2.5	5	150	50.0
75	30.0	15	100	2	4	120	40.0
50	50	5	100	10	14	140	100.0
50	50	10	100	5	8	160	100.0
50	25	10	50	2.5	5	100	50.0
50	50	10	100	5	8	160	100.0

Figure 16 — Examples of information that may be determined about 8 FM signals.

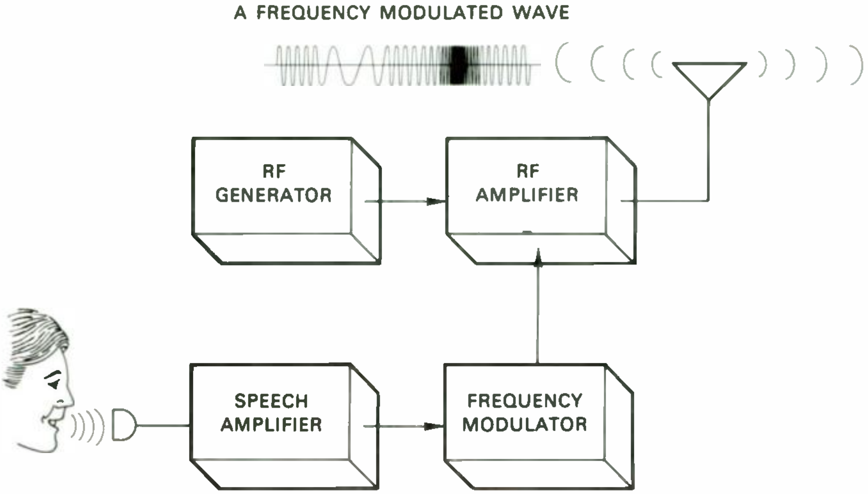


Figure 17 — Block diagram of an FM transmitter.

audio signal deviates the carrier 75 kHz above and 75 kHz below the 88-MHz value when this value is assumed to be the maximum permissable frequency swing. For 50 percent modulation, the frequency would be deviated 37.5 kHz above and below the resting frequency.

METHOD USED FOR FREQUENCY MODULATION

FM Transmitter

An FM transmitter contains the same basic parts as an AM transmitter. A comparison of Figure 17 with the AM transmitter in Figure 8 will show that the only difference is the type of modulator that is used. The method of connecting the modulator into the circuit of the FM transmitter is different, but much of the equipment is similar. An FM transmitter operates on much higher center frequencies than an AM transmitter, due to its need for more frequency space when the carrier is frequency modulated.

Frequency Allocation

The FCC has alloted a frequency space of 88 to 108 MHz for all FM stations. Since these frequencies are not reflected by the ionosphere, an FM wave from an antenna located outside a large, metropolitan community may range only 50 miles. This line-of-sight limitation permits many more FM stations to operate around the clock. The range of coverage of any line-of-sight signal can be increased if the height of the antenna can be increased. This fact accounts for the extreme heights of many antennas and the use of tall buildings as antenna sites.

PHASE MODULATION

Most people at one time or another have heard a radio signal decrease in volume as the intensity faded. This fading of a signal is due solely to a loss of signal strength and has nothing to do with a change in the frequency of the transmitted signal. An FM signal, on the other hand, could experience a shift in the center carrier frequency if it was not properly stabilized.

As intelligence is conveyed in FM by a variation from the center frequency, a distorted signal would result from any unwanted shift of the center frequency.

Phase modulation is a system developed to produce an FM signal that has a very stable center frequency. The phase of the signal is shifted by the audio signal that modulates the carrier. All the features of FM are present in PM (phase modulation). PM produces an FM signal that is transmitted in the same manner as the FM system we have already studied.

DEMODULATION

Demodulation or detection is the opposite of modulation and provides a method of detecting the intelligence conveyed on the carrier wave. When a radio carrier wave is amplitude modulated, the intelligence is imposed on the carrier in the form of amplitude variations of the carrier. The demodulator of an AM wave produces currents or voltages that vary with the amplitude of the wave. If the RF carrier wave was frequency modulated, the carrier would vary in frequency. The FM detector changes the frequency variations into currents or voltages that vary in amplitude with the frequency changes of the carrier.

AM Detection

To most people, an AM radio receiver is a device that picks an unseen radio signal out of the air and mysteriously converts it into the voice or music that comes from the speaker. But a receiver performs several functions between the input of the signal at the antenna and the conversion of the intelligence to an audible signal. Figure 18 illustrates by a block diagram some of the major functions of an AM receiver. We are considering at this time only the function of the detector.

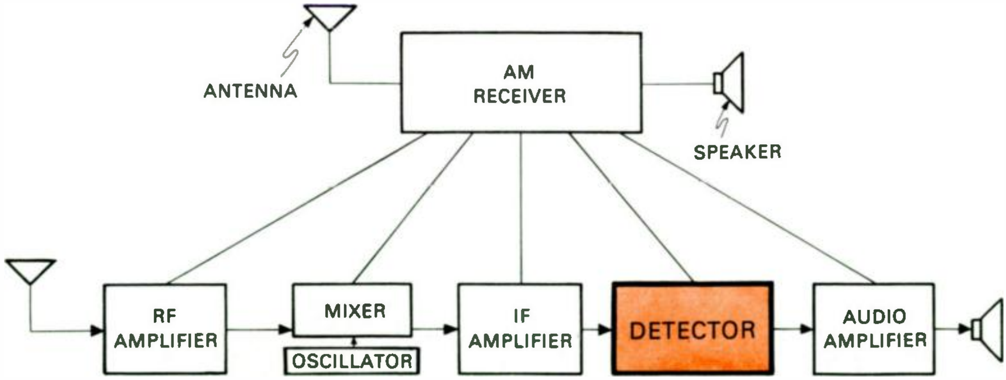


Figure 18 — Block diagram of AM receiver.

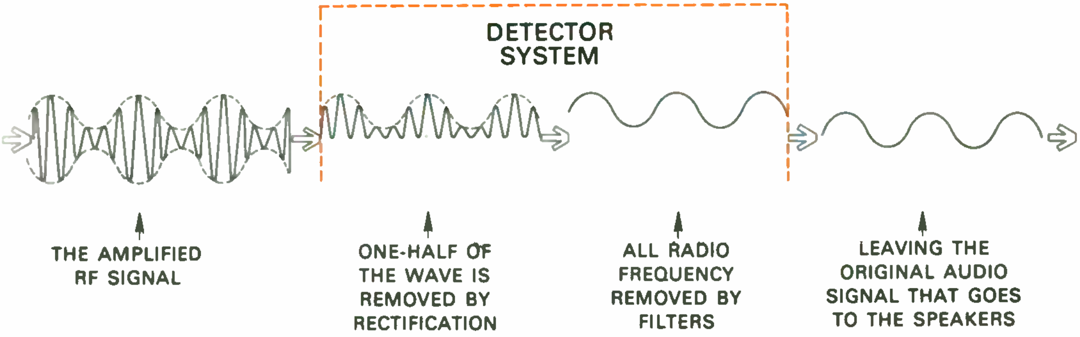


Figure 19 — Basic operation of an AM detector.

When the signal is received at the antenna, it is processed through various amplifiers and mixers. These devices do not change its characteristics but simply make the signal stronger before it is fed to the detector. It is in the detector that its characteristics are changed.

In the AM detector system one-half of the RF wave is removed (Fig. 19). When all the RF is filtered out of the signal, the original shape and relative amplitude of the audio signal remain. If neither the AM transmitter nor the AM receiver has distorted the signal, the result is an exact duplicate of the modulating signal. Specific details of how the detector functions will be covered in a future lesson.

FM Detection

The detection of an FM signal involves the use of a different detector system than the one used to demodulate an AM signal. An inspection of the block diagram of an FM receiver (Fig. 20) shows that the detector of the AM system has been replaced by a limiter and discriminator.

In FM transmission, the transmitted intelligence causes a

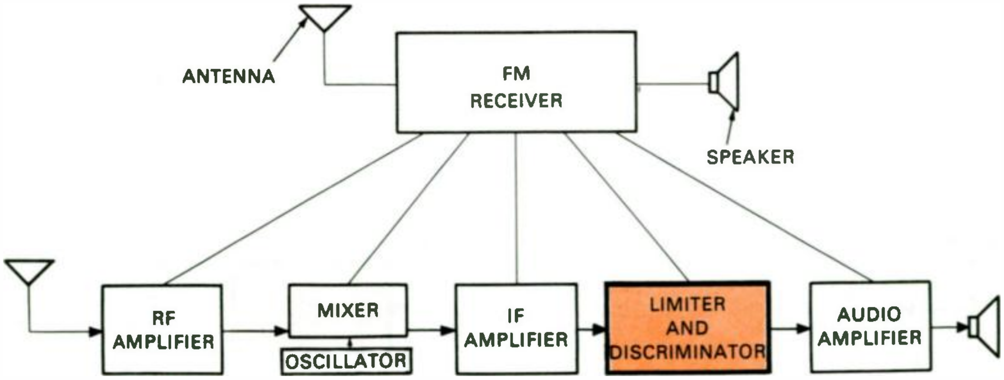


Figure 20 — Block diagram of an FM receiver.

variation in the instantaneous frequency of the carrier either above or below the center or resting frequency. The detecting device must, therefore, be constructed so that its output will vary linearly according to the instantaneous frequency of the incoming signal. Also, the detecting device must be insensitive to amplitude variations produced by interference or by receiver problems; thus, a special limiting device called a limiter must precede the FM detector.

The limiter acts on the incoming signal (Fig. 21). The incoming FM signal for the first time has been drawn with amplitude variations for a very good reason. These amplitude variations are not caused by the FM signal itself, but are created by electrical noise from static, electrical motors, etc. The limiter does exactly what its name implies; it limits the amplitude of the FM signal. When we eliminate the amplitude variations before demodulation or detection, the noise caused by amplitude modulation is removed.

This undistorted FM signal is now fed to the discriminator in the receiver circuit. This is a device that responds to the frequency variations of the FM signal. The FM signal varies above and below the RF center frequency at an audio rate, and we must simply *discriminate* between the frequencies existing in the FM signal. This is the sole function of the discriminator. Just as the detector does in an AM receiver, the discriminator supplies a signal to the speaker that varies at exactly the same audio frequency as the voice or music at the broadcasting studio. There are several different discriminator circuits, which will be discussed in future lessons.

SUMMARY

A radio wave can be stopped and started to transmit information. Modulating this radio wave with an

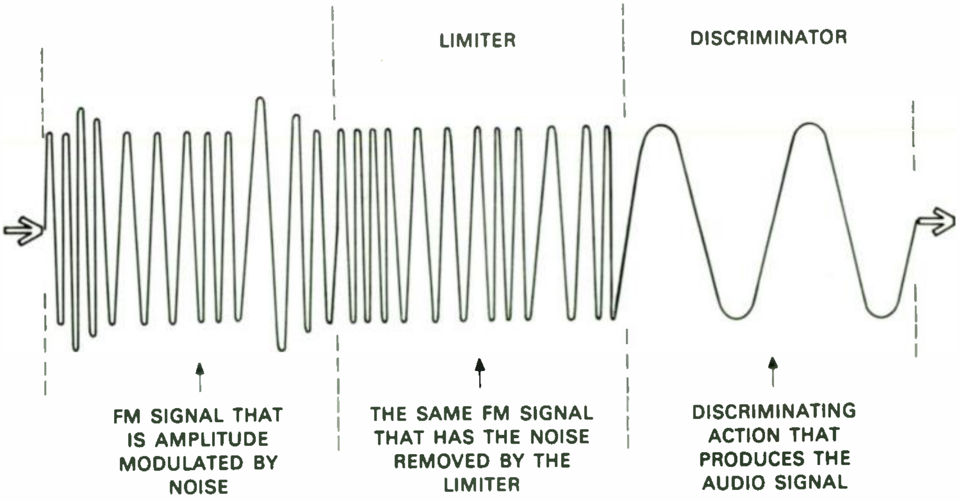


Figure 21 — Basic operation of an FM demodulator.

audio frequency permits voice and music to be transmitted. When voice or music change the characteristics of a radio wave, the high frequency wave is said to be modulated. An unmodulated radio wave is called the RF carrier wave.

Amplitude modulation and frequency modulation are the two principal methods used to impress information on the carrier. Amplitude modulation varies the peak-to-peak amplitude of the carrier, while frequency modulation varies the frequency of the carrier.

The AM signal consists of the original carrier frequency and an upper and lower sideband. At any give time, the upper sideband has a frequency equal to the carrier frequency plus the audio frequency, while the lower sideband has a frequency equal to the carrier frequency minus the audio frequency.

The FM signal does not change in amplitude like an AM signal. In FM the carrier frequency varies its center frequency to a greater and lesser amount, depending upon the amplitude of the audio tone. A louder audio signal forces the resting frequency to swing to both a higher and a lower frequency. A low volume sound would only force the resting frequency to swing a small amount either side of the center frequency.

In addition to conveying knowledge about the amplitude of the audio signal, the frequency of the audio signal must also be transmitted. In FM, this is accomplished by the rate at which the carrier frequency is varied. A low audio frequency would vary the carrier frequency at a slow rate; a high pitched musical note would force the carrier frequency to vary at the identical, high pitched frequency.

An FM signal has many sidebands equally spaced from each other on either side by the audio frequency at any given time. The number of sidebands formed depends upon the amplitude and the frequency of the audio signal. The ratio that results by dividing the frequency deviation (the shift in frequency from the carrier frequency) by the modulation frequency (the modulating audio frequency) is the modulation index. Reference to a table will show the relationship between the modulation index, the number of sidebands and the bandwidth.

The percentage of modulation of an FM signal depends upon how wide the center frequency swings. If it swings to the full permissible amount, it is 100 percent modulation. Any lesser swing of the modulating frequency gives the exact percentage of modulation. In AM, the percentage of modulation is the relationship between the voltage or current of the audio modulating signal to the voltage or current of the unmodulated carrier. Any modulation over 100 percent produces overmodulation and distortion.

When an AM signal is received, recovering the audio intelligence from either one of the sidebands is accomplished by detecting the variation in amplitude of the RF signal. Recovering the intelligence from an FM signal requires the use of a discriminator circuit to produce the audio signal, while a limiter circuit eliminates any noise that has amplitude modulated the FM signal.

TEST

Lesson Number 16

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-016-1.

1. Amplitude modulation is a system that
2 + A. varies the amplitude of an RF carrier wave.
B. produces an infinite number of sidebands.
C. starts and stops the carrier.
D. uses only half of the audio signal.

2. Amplitude modulation produces variations in the
2 + – A. strength and the frequency of the RF carrier.
B. strength of the RF carrier.
C. frequency of the RF carrier.
D. phase of the audio signal.

3. An unmodulated carrier
– A. is a sine wave at a radio frequency.
B. does not exist until it is modulated.
C. exists only at the transmitter.
D. conveys communication.

4. An AM carrier of 1000 kHz is amplitude modulated by a single tone of 2 kHz (2000 Hz), which produces
+ 3 – A. sidebands at 998 and 1002 kHz.
B. an infinite number of sidebands.
C. sidebands that extend to the FCC limit of 5 kHz.
D. sidebands at 1004 and 1008 kHz.

5. **The difference between an AM signal and an FM signal is**
A. the strength of the carrier at the radio receiver.
18 B. that AM is amplitude modulated and FM is frequency modulated.
C. that FM develops two types of frequency change.
D. that AM has only two sidebands.

6. **The *frequency* of an audio signal used to modulate an FM carrier**
A. varies the rate of change of the carrier.
B. varies the amplitude of the carrier.
13 C. does not affect the carrier.
D. varies the audio amplitude.

7. **If a particular FM signal had a frequency deviation of 10 kHz and was modulated by a 5-kHz signal, the modulation index would be**
15 A. 2
B. 4
C. 6
D. 8

8. **In an AM radio receiver, detection is accomplished by**
A. removing one-half of the RF and then filtering the remainder to produce an audio signal.
20 B. simply filtering one of the sidebands.
C. amplifying only.
D. none of the above.

9. **During one one-thousandth of a second, a sine wave with a frequency of 1000 Hz will complete**
13 A. exactly one cycle.
B. exactly 1000 cycles.
C. an unknown portion of a complete cycle.
D. depends whether it is a current or a voltage wave.

10. **The positive portion of an audio frequency signal affects the FM carrier by**
A. increasing the carrier frequency.
10 B. decreasing the carrier frequency.
C. slowing down the carrier frequency.
12 D. increasing the carrier amplitude.

Notes

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Success Is Where Its At

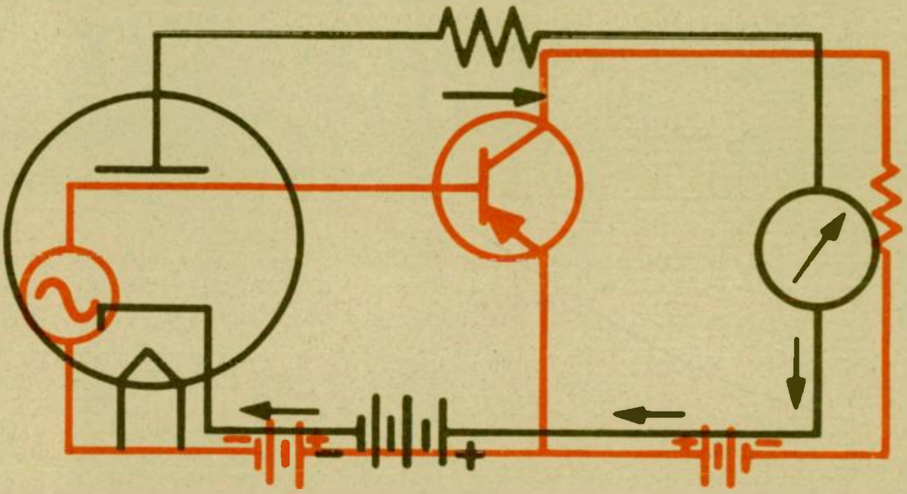
News from the grapevine; it takes a great amount of "follow-through" to accomplish anything worthwhile. These words should echo and re-echo in your ears constantly. Nobody gets anywhere by standing around and doing nothing. Be a doer and try constantly to improve yourself. This improvement will not come along automatically; you will have to earn it.

You can't steal success! You have to work for it. When you started your training with ASI, you were very enthusiastic. Don't lose that spirit. Build your success with good application and planning. Don't let anything block your plant of study; follow through with your ASI training with as much energy as if every lesson were your first.

S. T. Christensen

LESSON NO. 17

REACTANCE AND IMPEDANCE



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Contents

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REACTANCE AND IMPEDANCE

INTRODUCTION

In previous lessons, Ohm's law and Kirchoff's laws explained how current, voltage, and resistance are interrelated. Each has an effect upon electrical action in a circuit.

We studied DC circuits first; the only resistance to the flow of current was the resistor in the circuit. This resistor could have been a toaster, a light bulb, or even a composition resistor used in a radio or TV. Whatever produced the resistance to current flow did not change the relationship between the current and voltage; they both reached their maximum value when a switch was closed and the current started flowing.

However, conditions in a circuit are not this simple when we have a capacitance or an inductance in even a simple DC circuit. When the switch is closed in a DC circuit containing inductance, the current takes some time before it reaches its maximum value. In the case of capacitance, the reverse is true, and it takes some time before the voltage reaches its maximum value.

These actions take place only once in a DC circuit, immediately after the switch is closed. When the switch is opened, the exact opposite occurs; the inductance attempts to keep the current flowing, and the capacitance attempts to maintain the voltage.

An alternating current (AC) is similar to the quick repetitive opening and closing of a switch. If the AC circuit contains a coil or a capacitor, certain actions that determine how the current and voltage rise and fall in the circuit take place. The effect that coils and capacitors produce in AC circuits is called *reactance*. When they are combined with each other (sometimes with resistance), this total effect is termed *impedance*.

In this lesson we will observe the effects of coils and capacitors in circuits. We will review the formulas that designers of electronic equipment use. This will simply give us a clearer picture of how circuits function. These formulas will not be used; they are merely included to help us understand circuit actions. Thus, we will be able to better understand how a change in one component can produce an entirely different sound in a radio, or a faulty picture in a TV receiver.

INDUCTIVE REACTANCE

In the study of inductance, it was learned that a coil opposed any action attempting to change the amount of current flowing through a coil. This opposition of a coil to a changing current was produced by the self-induced voltage, the counter EMF, and measured in volts. Opposition to current flow is normally measured in ohms, however, not in volts. Since a coil *reacts* to a current change by generating a CEMF, a coil is said to be *reactive.* This opposition of a coil is, therefore, called reactance. It is measured in ohms and is represented by an X in drawings and formulas. Since more than one kind of reactance exists, the subscript L denotes INDUCTIVE REACTANCE. Thus, the opposition of a coil to alternating current is inductive reactance and is designated X_L.

Factors Producing Inductive Reactance

A previous lesson illustrated in detail the effect that an inductance had on the rise and fall, the increase and decrease, of current. When an alternating current is applied to an inductor, the inductor reacts and opposes the flow of the alternating current. One cycle of AC is shown in Figure 1, which illustrates how the current I lags the voltage E in a circuit that contains a pure inductance L. With a theoretically perfect inductance in a circuit without resistance, the phase angle between the current and voltage is always 90° (Fig. 1).

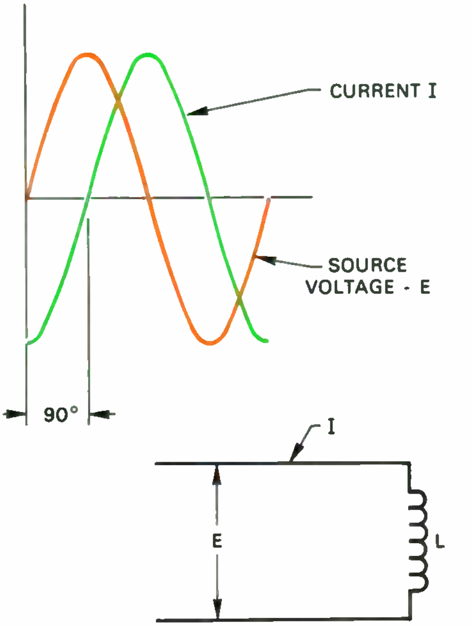


Figure 1 — An inductance L in a circuit with zero total resistance makes the current lag the voltage by 90°.

The same angular relationship between the current and the voltage is redrawn in Figure 2, with the addition of the circular representation of the voltage E and the current I. The circular representation sometimes gives a clearer insight into the relationship between a number of waveshapes that are not in phase. It can be clearly seen on the clock face that the voltage is 90° ahead of the current. Remember that the current and voltage vectors are considered to rotate counter-clockwise. Thus, each of the four quadrants is in the proper and relative position with one complete cycle of the waveshape on the graph to the right.

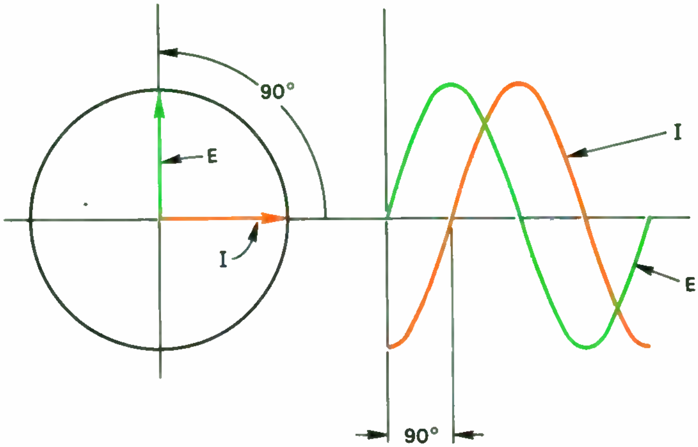


Figure 2 — Graphical and circular representation of voltage leading current.

If we had a coil of many turns of wire with a resulting large value of resistance, the voltage wave would not be 90° ahead of the current wave. Conversely, if the inductance of the coil in the circuit should decrease (but with some resistance in the circuit), the current wave will rise sooner, because it is not being opposed by as large a CEMF. (There is less CEMF produced by the inductor.) When the current wave rises sooner, it approaches the voltage wave and reduces the phase angle from 90° to a lesser value. The effect of these relationships will be studied in detail as these principles are used throughout electronics.

In many examples in which the angle between the voltage and the current might have different values, a symbol is used to indicate the angle. Using a symbol instead of an actual value explains more than one example. The symbol generally used for an angle is the capital form of the Greek letter Theta, θ, which will be used in many future examples.

Formula for Inductive Reactance

The inductance, L, of a coil depends upon its physical size and shape. This value of inductance in henrys is used in the formula to compute the inductive reactance, X_L:

$$X_L = 2\pi fL.$$

The f is in hertz and $2\pi = 6.28$. This formula for X_L is only true when the current and the CEMF have sine waveshapes. (This fact is important only to a designer of electronic circuitry.) Since the inductive reactance of a coil and its counter EMF are closely related, anything which influences one must also influence the other. The counter EMF of a coil depends on its inductance and the rate of flux change around the coil. Consequently, the inductive reactance must also be affected by the same influences.

The rate of change of the magnetic flux per unit of time depends on the FREQUENCY of the current flowing in the inductor. Flux must change more rapidly at high frequencies than at low frequencies. Thus, the inductive reactance of a coil depends primarily on the coil's INDUCTANCE and the FREQUENCY of the current flowing through the coil.

If frequency or inductance varies, the inductive reactance must also vary. The inductance of a coil does not vary appreciably after the coil is manufactured unless it is designed as a variable inductor. Thus, the only variable factor affecting the inductive reactance of a coil is generally the frequency. In nearly all cases, the inductive reactance will vary directly with the applied frequency; the higher the frequency, the larger the inductive reactance.

A Series Circuit Containing R and L

In a circuit containing only resistance, the current and voltage are always in phase: the phase angle θ is zero (Fig. 3). Because any practical inductor must be wound with wire that has resistance, it is not possible to obtain a coil without some resistance.

The resistance associated with a coil may be considered as a separate resistor, R, in series with an inductor, L (Fig. 4). The resistance has been exaggerated in this example to be of the same magnitude as the inductive reactance of the inductor in order to simplify the solution. We have indicated all the various voltage drops in this circuit and the identifying symbols for each.

If an alternating current I_0 flows through the circuit, a voltage drop occurs across both the resistor and the inductor. The voltage E_R across

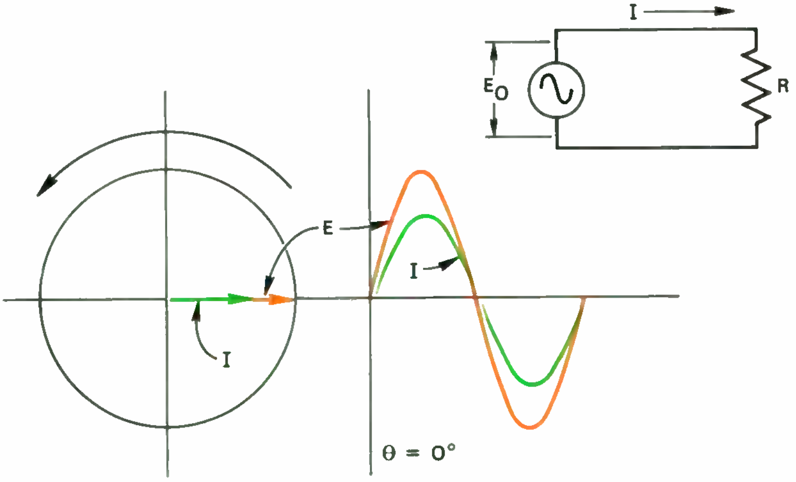
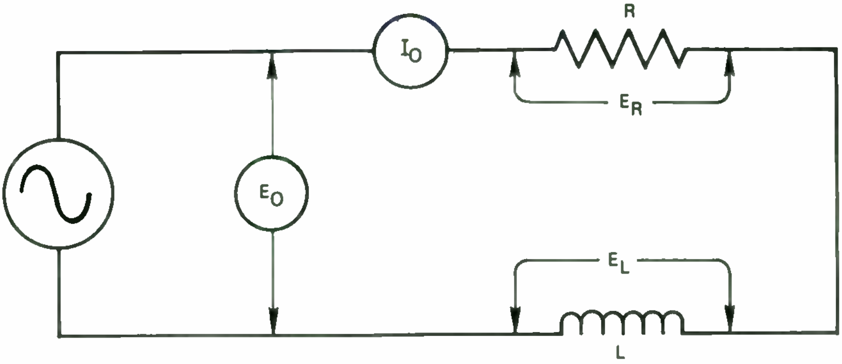


Figure 3 — Voltage and current are in phase in a circuit containing only resistance.



E_O = THE APPLIED VOLTAGE
I_O = CURRENT FLOWING THROUGHOUT THE ENTIRE CIRCUIT
E_R = VOLTAGE ACROSS THE RESISTOR R
E_L = VOLTAGE ACROSS THE COIL L

Figure 4 — Identification of voltages and current in a series RL circuit containing inductance and resistance.

the resistor is in phase with the current, but the voltage drop E_L across the inductor leads the current by 90° (Fig. 5). The voltage across the resistor in a specific circuit was measured as 8 volts, and the voltage measured across the inductor was 15 volts. These two voltages are 90° out of phase (Fig. 5).

Vectorial Sums

Kirchoff's law tells us that the sum of the voltage drops in a series circuit is equal to the supply or applied voltage. This is only true, however, when we are adding voltages in a direct current circuit. In an alternating current series circuit that contains *reactive* components we still add the voltage drops in the circuit, but we must add them vectorially. In this particular example, the *vectorial sum* of 15 volts and 8 volts is 17 volts. This is not the sum you would obtain if you simply added the two voltages. This is because there is a 90° phase difference between E_R and E_L.

This sum of the voltage drops must equal the applied voltage E_O. By measurement, E_O is found to be 17 volts, the exact equal of the voltage drops. Thus, Kirchoff's voltage law is as valid for alternating current circuits as it is for direct current circuits.

We can demonstrate how these voltages add using two methods. The first method is shown in Figure 5; when at a given instant of time, the voltage across the resistor E_R is 0 volts, and the voltage across the coil E_L is 15 volts.

These values of voltages can be verified by inspecting the E_L curve at point a, where its wave shape is at its maximum value. This can also be verified at point b, where the E_L vector is at 90° and is at its

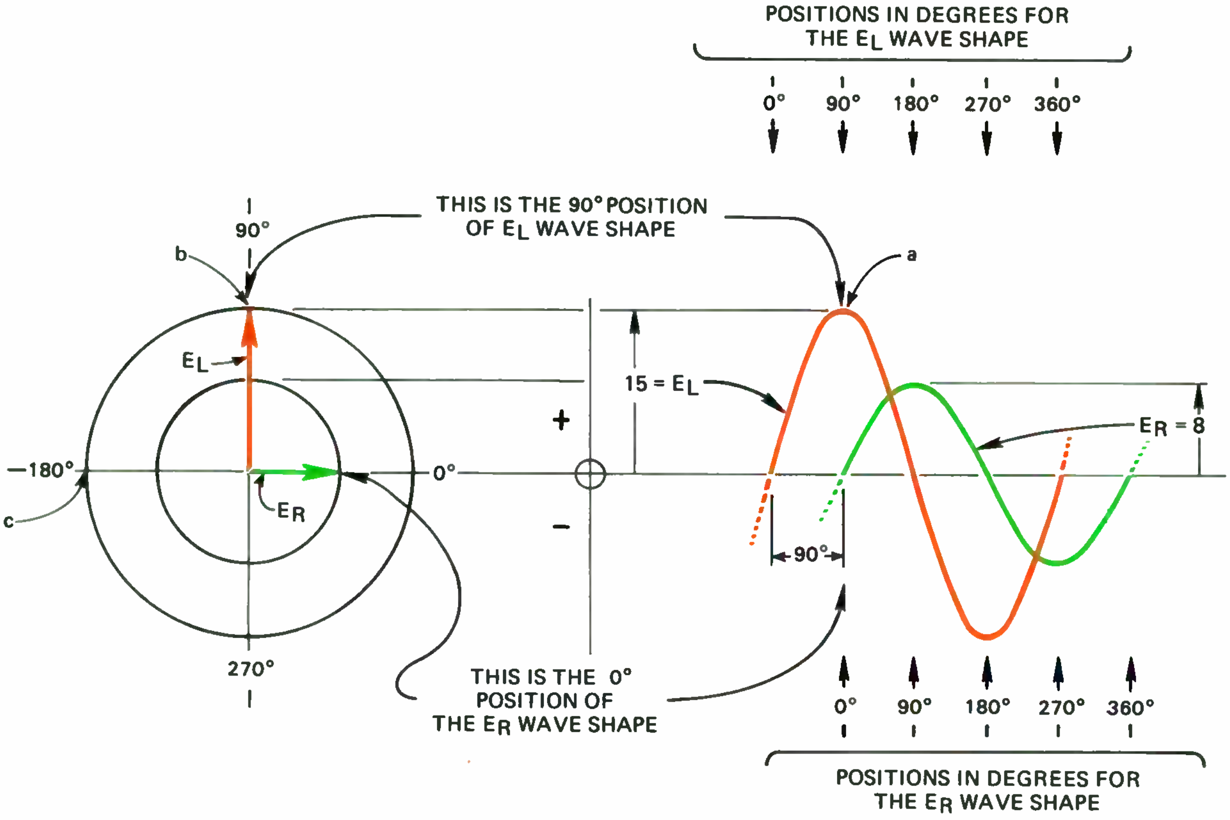


Figure 5 — Angular relationship of voltage drops in a series RL circuit.

longest length above the horizontal zero line at point c.

We still do not know *how* the *actual* voltage drops are added to equal 17 volts, which is the identical voltage supplied by the input or source voltage of 17 volts. To see how this is determined, we have redrawn the two curves in Figure 6, but we have chosen a different time during the cycle to determine the voltage. By choosing a time indicated by the vertical line at b, we have chosen the angular position indicated by the angle a. Choosing this angular position clarifies how the applied voltage E_O is related to the coil voltage drop E_L and the resistor voltage drop E_R.

The same relationship between these three values of E_O, E_L and E_R will exist at any angular position on the clock face. Two additional positions are shown at A in Figure 7. The triangles at B, C and D of Figure 7 show how the values are determined graphically. The triangle at B is the solution for any of the three angular positions on the clock faces (Fig. 6 and 7). The solution has been drawn in a vertical position at B, because this is the conventional method of illustrating it.

The values on the heavy lines at B are values used in the example beginning with Figure 5. Voltmeter measurements show that E_L (coil voltage) measures 15 volts, E_R (resistor voltage) measures 8 volts, and E_O (applied voltage) measures 17 volts. The last value (17 volts) is the same as the sum of the voltage drops or 17 volts. Knowing that E_L is always 90° ahead of E_R permits us to draw the two vectors at right angles. Knowing each voltage value allows us to draw each vector in its proper length. E_R is 8 units long, and E_L is 15 units in length. The dotted lines are then drawn parallel to the E_L and E_R vectors, and the intersection of these two dotted lines establishes the point where the diagonal line is to be drawn. This diagonal line measures 17 units long, which is the exact value of the applied voltage E_O.

Two similar examples are shown at C and D. The triangle at C represents a series circuit where the measurement for E_L (coil voltage) is 7.5 volts, E_R (resistor voltage) is 4.0 volts, and E_O (applied voltage) is 8.5 volts. Since E_L and E_R are drawn to scale, we can measure E_O and use this value as an exact indication of the applied voltage. We can always use this graphical method to determine the exact voltages if the lengths of the vectors are drawn accurately. Any two of the voltages may be used in this graphical construction method to determine the third voltage, but the lines must be drawn correctly and in the proper position.

The example in D is another illustration showing the ease of determining the actual values of voltages by this graphical method. When the voltages are large, however, the scale must be reduced. This results in a decrease in accuracy in both drawing and measuring the lines. One other method to compute the value of E_O is the

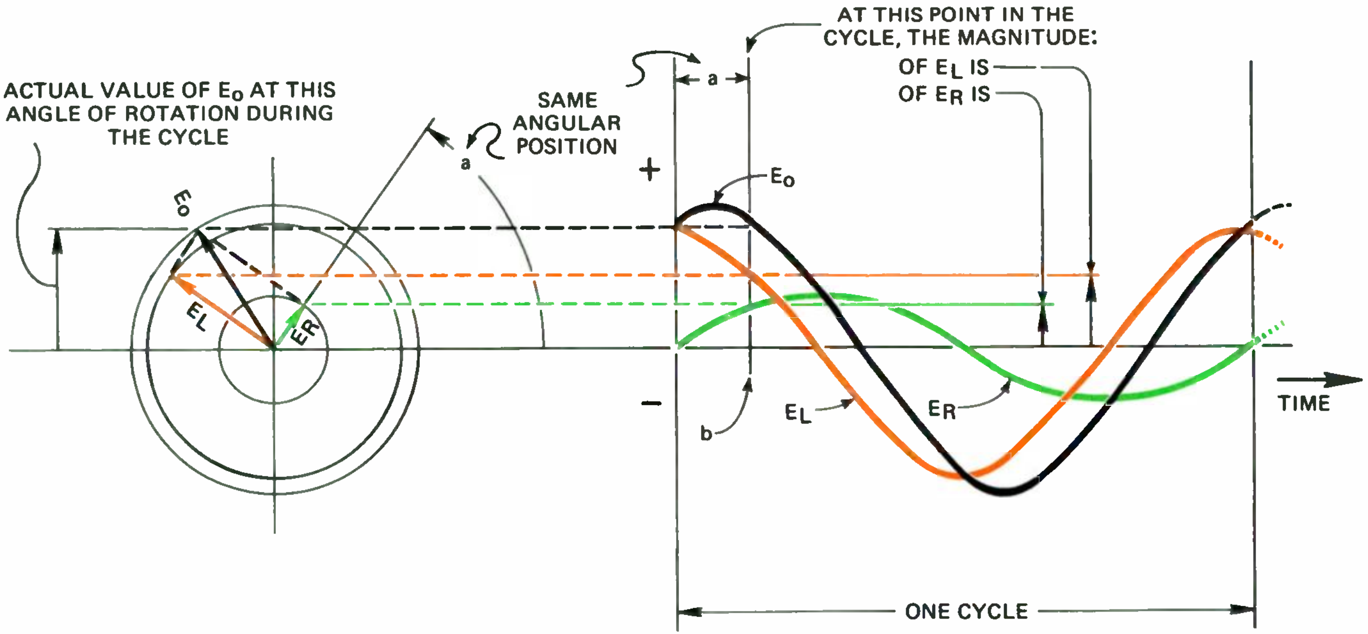
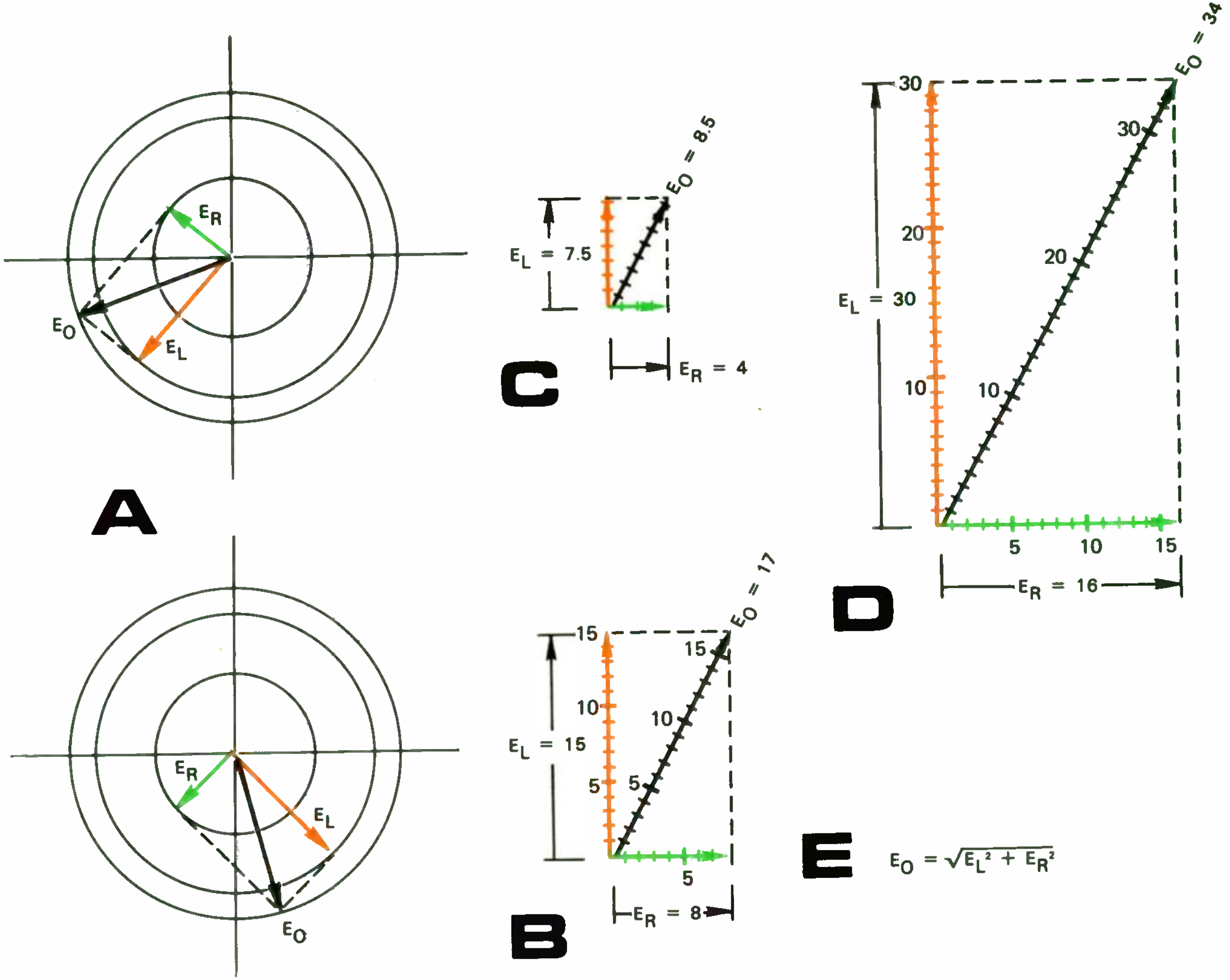


Figure 6 — Phase relationship of the applied voltage E_O to E_L and E_R in a series RL circuit.



$$E_O = \sqrt{E_L^2 + E_R^2}$$

Figure 7 — Graphical determination of the value of the applied voltage in a series RL circuit.

NUMBERS AND SQUARE ROOTS

N	$\sqrt{N}$	N	$\sqrt{N}$	N	$\sqrt{N}$	N	$\sqrt{N}$	N	$\sqrt{N}$	N	$\sqrt{N}$
1	1.000	51	7.141	101	10.050	151	12.288	201	14.1774	251	15.8430
2	1.414	52	7.211	102	10.100	152	12.329	202	14.2127	252	15.8745
3	1.732	53	7.280	103	10.149	153	12.369	203	14.2478	253	15.9060
4	2.000	54	7.348	104	10.198	154	12.410	204	14.2829	254	15.9374
5	2.236	55	7.416	105	10.247	155	12.450	205	14.3178	255	15.9687
6	2.449	56	7.483	106	10.296	156	12.490	206	14.3527	256	16.0000
7	2.646	57	7.550	107	10.344	157	12.530	207	14.3875	257	16.0312
8	2.828	58	7.616	108	10.392	158	12.570	208	14.4222	258	16.0624
9	3.000	59	7.681	109	10.440	159	12.510	209	14.4568	259	16.0935
10	3.162	60	7.746	110	10.488	160	12.649	210	14.4914	260	16.1245
11	3.317	61	7.810	111	10.536	161	12.689	211	14.5258	261	16.1555
12	3.464	62	7.874	112	10.583	162	12.728	212	14.5602	262	16.1864
13	3.606	63	7.937	113	10.630	163	12.767	213	14.5945	263	16.2173
14	3.742	64	8.000	114	10.677	164	12.806	214	14.6287	264	16.2481
15	3.873	65	8.062	115	10.724	165	12.845	215	14.6629	265	16.2788
16	4.000	66	8.124	116	10.770	166	12.884	216	14.6969	266	16.3095
17	4.123	67	8.185	117	10.817	167	12.923	217	14.7309	267	16.3401
18	4.243	68	8.246	118	10.863	168	12.962	218	14.7648	268	16.3707
19	4.359	69	8.307	119	10.909	169	13.000	219	14.7986	269	16.4012
20	4.472	70	8.367	120	10.955	170	13.038	220	14.8324	270	16.4317
21	4.583	71	8.426	121	11.000	171	13.077	221	14.8661	271	16.4621
22	4.690	72	8.485	122	11.045	172	13.115	222	14.8997	272	16.4924
23	4.796	73	8.544	123	11.091	173	13.153	223	14.9332	273	16.5227
24	4.899	74	8.602	124	11.136	174	13.191	224	14.9666	274	16.5529
25	5.000	75	8.660	125	11.180	175	13.229	225	15.0000	275	16.5831
26	5.099	76	8.718	126	11.225	176	13.267	226	15.0333	276	16.6132
27	5.196	77	8.775	127	11.269	177	13.304	227	15.0665	277	16.6433
28	5.292	78	8.832	128	11.314	178	13.342	228	15.0997	278	16.6733
29	5.385	79	8.888	129	11.358	179	13.379	229	15.1327	279	16.7033
30	5.477	80	8.944	130	11.402	180	13.416	230	15.1658	280	16.7332
31	5.568	81	9.000	131	11.446	181	13.454	231	15.1987	281	16.7631
32	5.657	82	9.055	132	11.489	182	13.491	232	15.2315	282	16.7929
33	5.745	83	9.110	133	11.533	183	13.528	233	15.2643	283	16.8226
34	5.831	84	9.165	134	11.576	184	13.565	234	15.2971	284	16.8523
35	5.916	85	9.220	135	11.619	185	13.602	235	15.3297	285	16.8819
36	6.000	86	9.274	136	11.662	186	13.638	236	15.3623	286	16.9115
37	6.083	87	9.327	137	11.705	187	13.675	237	15.3948	287	16.9411
38	6.164	88	9.381	138	11.747	188	13.711	238	15.4272	288	16.9706
39	6.245	89	9.434	139	11.790	189	13.748	239	15.4596	289	17.0000
40	6.325	90	9.487	140	11.832	190	13.784	240	15.4919	290	17.0294
41	6.403	91	9.539	141	11.874	191	13.820	241	15.5242	291	17.0587
42	6.481	92	9.592	142	11.916	192	13.856	242	15.5563	292	17.0880
43	6.557	93	9.644	143	11.958	193	13.892	243	15.5885	293	17.1172
44	6.633	94	9.695	144	12.000	194	13.928	244	15.6205	294	17.1464
45	6.708	95	9.747	145	12.042	195	13.964	245	15.6525	295	17.1756
46	6.782	96	9.798	146	12.083	196	14.000	246	15.6844	296	17.2047
47	6.856	97	9.849	147	12.124	197	14.036	247	15.7162	297	17.2337
48	6.928	98	9.899	148	12.166	198	14.071	248	15.7480	298	17.2627
49	7.000	99	9.950	149	12.207	199	14.107	249	15.7797	299	17.2916
50	7.071	100	10.000	150	12.247	200	14.142	250	15.8114	300	17.3205

Figure 8 — Numbers and square roots.

formula at E. The example at B can be solved in the following manner:

$$E_O = \sqrt{E_L^2 + E_R^2} \qquad (1)$$

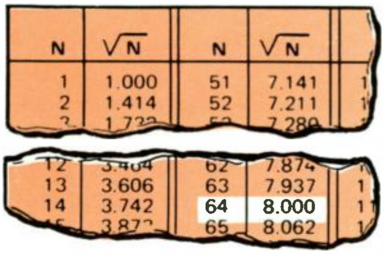
$$= \sqrt{15^2 + 8^2} \qquad (2)$$

$$= \sqrt{225 + 64} \qquad (3)$$

$$= \sqrt{289} \qquad (4)$$

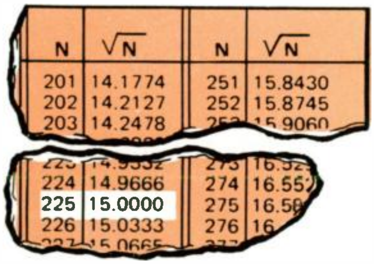
$$E_O = 17 \text{ volts} \qquad (5)$$

The table in Figure 8 was used in these computations. We found from the table that



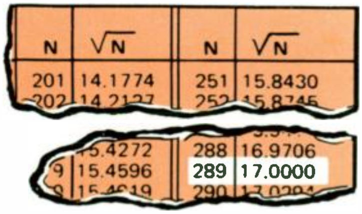
N	√N	N	√N
1	1.000	51	7.141
2	1.414	52	7.211
13	3.606	63	7.937
14	3.742	64	8.000
		65	8.062

squaring 8 equals 64 and



N	√N	N	√N
201	14.1774	251	15.8430
202	14.2127	252	15.8745
203	14.2478		
224	14.9666	274	16.55
225	15.0000	275	16.58
226	15.0333	276	16

squaring 15 equals 225.



N	√N	N	√N
201	14.1774	251	15.8430
		288	16.9706
9	15.4596	289	17.0000

The square root of 289 is 17, as shown.

Example C is computed in the same manner. The square of 7.5, however, does not appear in this short table. Therefore, 7.5 must be multiplied by long hand to obtain the squared value of 56.25. The square of 4 is 16, and when 16 is added to 56.25, the total is 72.25. This number also does not appear in this short table, but as it is between 72 and 73, the square root can be estimated as 8.5 volts. It is in fact exactly 8.5, which can be verified by squaring it to prove that the squared value is 72.25.

The example in D can also be computed as follows:

$$E_O = \sqrt{E_L^2 + E_R^2} \qquad (6)$$

$$= \sqrt{30^2 + 16^2} \qquad (7)$$

$$= \sqrt{900 + 256} \qquad (8)$$

$$= \sqrt{1156} \qquad (9)$$

$$= \sqrt{289 \times 4} \qquad (10)$$

$$= \sqrt{289} \times \sqrt{4} \qquad (11)$$

$$= 17 \times 2 \qquad (12)$$

$$E_O = 34 \text{ volts} \qquad (13)$$

The steps above show that the numbers were substituted in the formula in line (7), then squared in line (8) and totalled in line (9). A large number such as 1156 may be split into two numbers that are the same when they are *multiplied*. In this case 289 times 4 equals 1156, so we may separate each number as shown in line (11). Line (12) shows the square roots of 289 and 4; that is, 17 and 2, respectively. When 17 and 2 are multiplied, the product is 34.

This method of separating large numbers may always be used. But remember the two smaller numbers must equal the single, larger number when they are multiplied.

Not since Figure 3 has the current I_0 been shown in any of the curves, even though it was indicated as the current flowing in the circuit in Figure 4. A current must flow to produce the voltage drops measured (Figs. 5, 6 and 7). Because the current is always in phase with the resistance (Fig. 3), we can illustrate its relationship to the other waveshapes by redrawing Figure 6 and adding the current wave I_0 (Fig. 9).

The current vector I_0 is in alignment with the voltage drop vector E_R. These two vectors must lie on the same line, because they are in phase as shown by the waveshapes. Both the I_0 waveshape and the E_R waveshape reach their maximum and minimum values at identical times as shown at the right of Figure 9.

INDUCTIVE IMPEDANCE

The computation of circuit values such as current flow, voltage drops and resistances is relatively simple in a DC circuit. The computation of these same values, however, is somewhat more complicated in AC circuits, since the reactance of the individual components such as inductances and capacitances must be computed first. Because most devices also have some resistance (particularly at radio or high frequencies), the *combined resistance* of the *reactive* ohms and *resistive* ohms must be computed to obtain the effective resistance.

In some of the preceding figures, we have assumed values for the voltage drops. Voltage drops can only exist when current flows through an electrical component that resists the flow of current. This resisting or opposing the current flow comes from both the resistance of the coil and the inductive reactance of the coil.

The effective resistance of a circuit that contains reactance and resistance is called *impedance,* and the symbol is the letter Z. Just as in the case of voltages that are 90° out of phase, the two ohmic values of reactance and resistance are 90° apart. The methods of computing this effective value of resistance, known in AC circuits as impedance, will be developed in the next part of the lesson.

Calculating Circuit Values

As a sine wave is generated by the rotation of a coil in a magnetic field, a clock face can represent one complete cycle of the waveshape produced during one complete rotation. The use of the clock face and the vectors led directly to the use of trigonometry to solve the triangles (Fig. 7). The triangles can be solved by either the graphical or arithmetical methods (Figs. 7 and 8).

Several relations between voltage and impedance in a series circuit containing inductance and re-

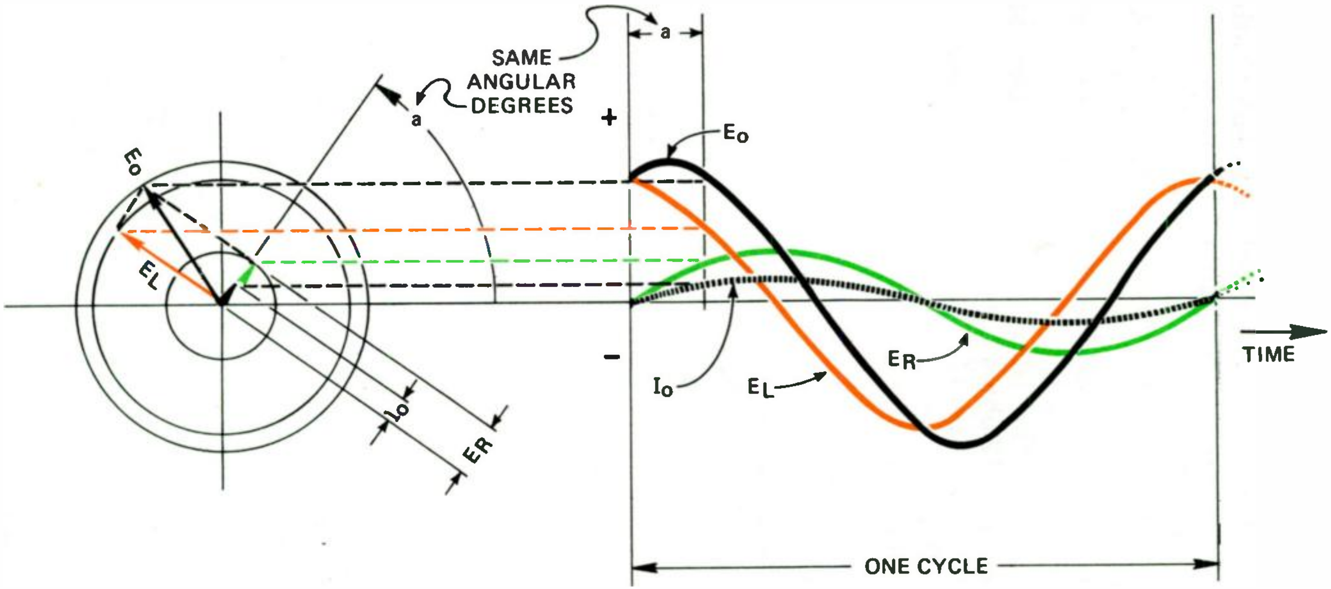


Figure 9 — The current I_o is in phase with the voltage drop E_R across the resistance in a series RL circuit.

sistance are illustrated in Figure 10. This circuit is supplied from a sine wave voltage source. The circuit in A contains 12 ohms of resistance in series with 16 ohms of inductive reactance. The triangle at B is similar to the triangles in Figure 7. From B it is possible to determine the phase relation between the applied voltage E_O, the voltage drop E_R across the resistance R, and the voltage drop E_L across the inductance L. The IR drop across R is 5 amps × 12 ohms = 60 volts, and forms the base of the right triangle. The altitude is the IX_L drop, or 5 amps × 16 ohms = 80 volts, across L. The applied voltage represents the vector sum of the IR drop and the IX_L drop and is the hypotenuse of the right triangle. Its magnitude is 100 volts and is solved by substituting in the formula.

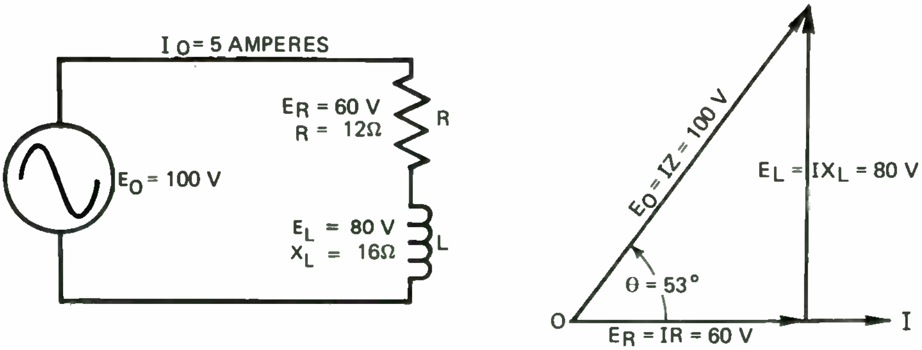
$$E_O = \sqrt{E_L^2 + E_R^2}$$

$$= \sqrt{80^2 + 60^2}$$

$$= \sqrt{6400 + 3600}$$

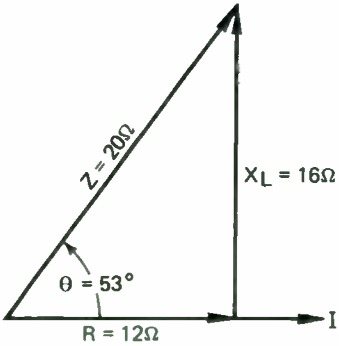
$$= \sqrt{10000}$$

$$E_O = 100 \text{ volts.}$$



CIRCUIT
A

VOLTAGE
B



IMPEDANCE
C

$$E_O = \sqrt{E_L^2 + E_R^2}$$

$$IZ = E_O = \sqrt{(IX_L)^2 + (I_R)^2}$$

$$Z = \sqrt{X_L^2 + R^2}$$

Figure 10 — Relationship of voltage, current and resistance in a series RL circuit.

All of these voltages are the effective values.

The relation between resistance, inductive reactance and impedance is shown by the vectors at C. The resistance R of 12 ohms forms the base of the right triangle. The altitude of this triangle represents the inductive reactance X_L of the coil and has a magnitude of 16 ohms. The combined impedance of the circuit is

$$Z = \sqrt{R^2 + X_L^2}$$

$$= \sqrt{12^2 + 16^2}$$

$$= \sqrt{144 + 256}$$

$$= \sqrt{400}$$

$$Z = 20 \text{ ohms.}$$

In both vector diagrams at B and C, the right triangles are similar. The common factor of current I makes their corresponding sides proportional. Thus the voltage triangle (Fig. 10B) is obtained by multiplying the corresponding sides of the impedance triangle in C by I. The hypotenuse is equal to the applied voltage, or IZ = 5 amps × 20 ohms = 100 volts. The base equals the voltage across R, or IR = 5 amps × 12 ohms = 60 volts. The altitude of the triangle is equal to the voltage across L, or IX_L = 5 amps × 16 ohms = 80 volts.

Power in an RL Circuit

To determine the power in a DC circuit, simply multiply the applied voltage times current. This will give you the value of the wattage in the electrical component. Because an inductive circuit has a voltage drop across the coil E_L, it has a current flow through it. The same condition holds for the voltage drop across the resistance E_R, because the current also flows through it.

In a resistive circuit, power is a measure of how much electrical energy is being converted into heat energy. The energy delivered to a resistor is dissipated in the form of heat and is known as *true power*. An inductor does not dissipate power. The electrical energy is stored in the magnetic field around the inductor. When this magnetic field around the inductor collapses, the energy is returned to the circuit. A reactive component (an inductor or capacitor) appears to consume energy but does not. For this reason, the power that a reactive component appears to consume is called *reactive power* and is measured in volt-amps-reactive (VARs).

Apparent power is the power a source appears to supply to a circuit containing reactive and resistive components. Apparent power is the resultant of vectorially adding *true power* and *reactive power*. The unit of measure of apparent power is volt-amperes (VA).

Figure 11 represents the three power vectors. This triangle is similar to the two triangles in Figure 10 and uses the same circuit values to compute the three power values. The base of the triangle represents the so-called true power computed by the power formula of Ohm's law.

True Power = EI, and because
E = IR, we can substitute
True Power = IRI, or obtain the conventional formula
True Power = I^2R
= 5 amps × 5 amps × 12 ohms
= 300 true watts.

The reactive power is represented by the altitude of the triangle, and the

Reactive Power = I^2X_L
= 5 amps × 5 amps × 16 ohms
= 400 volt amperes reactive (VARS)

The hypotenuse of the triangle permits the calculation of the

Apparent Power = I^2Z
= 5 amps × 5 amps × 20 ohms,
= 500 volt amperes (VA)

This last calculation could also be obtained by multiplying the applied voltage times the current, or 100 volts × 5 amps equals 500 volt-amps. Volt-amps are abbreviated VA and give us what appears to be a wattage value; it is *not,* a true wattage value, however. We will see why it isn't a true wattage value when we consider a constant in this circuit known as the *power factor.*

Power Factor

Power factor relates two things; the *true power,* which is 300 watts in this case,. and the *apparent power,* which is 500 VA. This power factor, however, can be computed in three different ways, because we have information from three triangles. In the three vector diagrams (Figs. 10 & 11), the circuit power factor is equal to the following ratios:

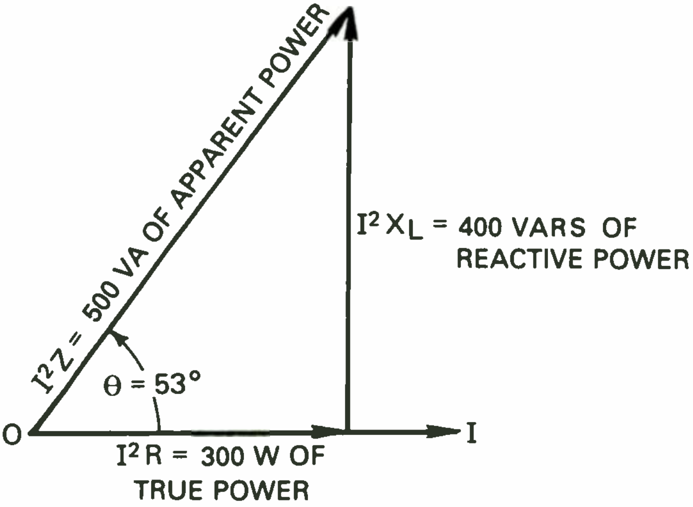


Figure 11 — The power triangle with the values from Fig. 10.

In the *voltage* diagram,

$$\frac{IR}{IZ} = \frac{60}{100} = 0.60.$$

In the *impedance* diagram,

$$\frac{R}{Z} = \frac{12}{20} = 0.60.$$

In the *power* diagram,

$$\frac{I^2R}{I^2Z} = \frac{300}{500} = 0.60.$$

In all three diagrams the power factor is 60 percent. It now becomes possible to compute the *true power* by the formula which is used most frequently:

$$\text{True Power} = \begin{matrix}\text{Applied}\\ \text{voltage}\end{matrix} \times \text{Current} \times \begin{matrix}\text{Power}\\ \text{Factor}\end{matrix} \text{ or}$$

$$\text{True Power} = E_O \times I_O \times \text{P.F.}$$
$$\text{True Power} = 100 \times 5 \times 0.6$$
$$\text{True Power} = 300 \text{ watts}$$

The power factor for the examples in Figure 7 can be determined by using the values in those voltage diagrams. Power factor can be defined in a number of ways, such as

$$\text{P.F.} = \frac{\begin{matrix}\text{Voltage of}\\ \text{the base}\end{matrix}}{\begin{matrix}\text{Voltage of the}\\ \text{Hypotenuse}\end{matrix}} = \frac{E_R}{E_O} = \frac{\begin{matrix}\text{Voltage across}\\ \text{the resistance}\end{matrix}}{\begin{matrix}\text{Applied}\\ \text{voltage}\end{matrix}}$$

In each example, it is easy to substitute the value of the voltages to determine the power factor. All the triangles have the same shape, therefore, P.F. will be the same.

$$\text{P.F.} = \frac{8}{17} = \frac{4}{8.5} = \frac{16}{34} = 0.470$$

We also use this number to determine the angle between the two sides of the triangle, since this ratio of 0.470 gives us the *cosine value of the angle.* This information is mostly useful to designers of electrical electronic equipment, and the method of computation is of interest to us only as background information. In the table of trigonometric values (Fig. 12), small arrows opposite the 62° angle point out the 0.4695 in the column headed cosine. This number is closest to the ratio number of 0.470 that was calculated from the three triangles and indicates that the lower angle of all three triangles is 62°. It is also apparent that the value of the power factor is also the cosine value of the angle as mentioned above, and also permits us to determine the number of degrees in the lower or corner angle.

For the angle 53°, the cosine value is 0.6018 (Fig. 12). This value is closest to the value of the P.F. that was determined for Figure 10, which was 0.60, and indicates how the angle of 53° was determined for all of the triangles in that figure.

Lagging Current in L

In the previous examples the current I is always lagging the voltage E by 90°. If the current is lagging, the voltage is leading. To remember this fact, associate it with the name *ELI.* If the letters in the word stand for *voltage, inductance* and *current,* it becomes apparent that E (voltage) precedes L (inductance) which is ahead of I (current). Since capacitance has an opposite effect on the relationship of current and voltage, we will examine this later.

ANGLE	SINE	COSINE	TANGENT	ANGLE	SINE	COSINE	TANGENT
1°	.0175	.9998	.0175	46°	.7193	.6947	1.0355
2°	.0349	.9994	.0349	47°	.7314	.6820	1.0724
3°	.0523	.9986	.0524	48°	.7431	.6691	1.1106
4°	.0698	.9976	.0699	49°	.7547	.6561	1.1504
5°	.0872	.9962	.0875	50°	.7660	.6428	1.1918
6°	.1045	.9945	.1051	51°	.7771	.6293	1.2349
7°	.1219	.9925	.1228	52°	.7880	.6157	1.2799
8°	.1392	.9903	.1405	53°	.7986	.6018	1.3270
9°	.1564	.9877	.1584	54°	.8090	.5878	1.3764
10°	.1736	.9848	.1763	55°	.8192	.5736	1.4281
11°	.1908	.9816	.1944	56°	.8290	.5592	1.4826
12°	.2079	.9781	.2126	57°	.8387	.5446	1.5399
13°	.2250	.9744	.2309	58°	.8480	.5299	1.6003
14°	.2419	.9703	.2493	59°	.8572	.5150	1.6643
15°	.2588	.9659	.2679	60°	.8660	.5000	1.7321
16°	.2756	.9613	.2867	61°	.8746	.4848	1.8040
17°	.2924	.9563	.3057	62°	.8829	.4695	1.8807
18°	.3090	.9511	.3249	63°	.8910	.4540	1.9626
19°	.3256	.9455	.3443	64°	.8988	.4384	2.0503
20°	.3420	.9397	.3640	65°	.9063	.4226	2.1445
21°	.3584	.9336	.3839	66°	.9135	.4067	2.2460
22°	.3746	.9272	.4040	67°	.9205	.3907	2.3559
23°	.3907	.9205	.4245	68°	.9272	.3746	2.4751
24°	.4067	.9135	.4452	69°	.9336	.3584	2.6051
25°	.4226	.9063	.4663	70°	.9397	.3420	2.7475
26°	.4384	.8988	.4877	71°	.9455	.3256	2.9042
27°	.4540	.8910	.5095	72°	.9511	.3090	3.0777
28°	.4695	.8829	.5317	73°	.9563	.2924	3.2709
29°	.4848	.8746	.5543	74°	.9613	.2756	3.4874
30°	.5000	.8660	.5774	75°	.9659	.2588	3.7321
31°	.5150	.8572	.6009	76°	.9703	.2419	4.0108
32°	.5299	.8480	.6249	77°	.9744	.2250	4.3315
33°	.5446	.8387	.6494	78°	.9781	.2079	4.7046
34°	.5592	.8290	.6745	79°	.9816	.1908	5.1446
35°	.5736	.8192	.7002	80°	.9848	.1736	5.6713
36°	.5878	.8090	.7265	81°	.9877	.1564	6.3138
37°	.6018	.7986	.7536	82°	.9903	.1392	7.1154
38°	.6157	.7880	.7813	83°	.9925	.1219	8.1443
39°	.6293	.7771	.8098	84°	.9945	.1045	9.5144
40°	.6428	.7660	.8391	85°	.9962	.0872	11.4301
41°	.6561	.7547	.8693	86°	.9976	.0698	14.3006
42°	.6691	.7431	.9004	87°	.9986	.0523	19.0811
43°	.6820	.7314	.9325	88°	.9994	.0349	28.6363
44°	.6947	.7193	.9657	89°	.9998	.0175	57.2900
45°	.7071	.7071	1.0000	90°	1.0000	.0000	

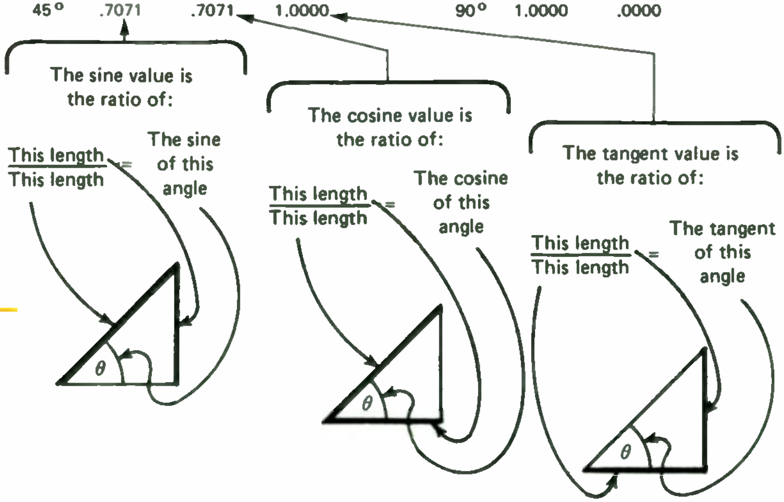
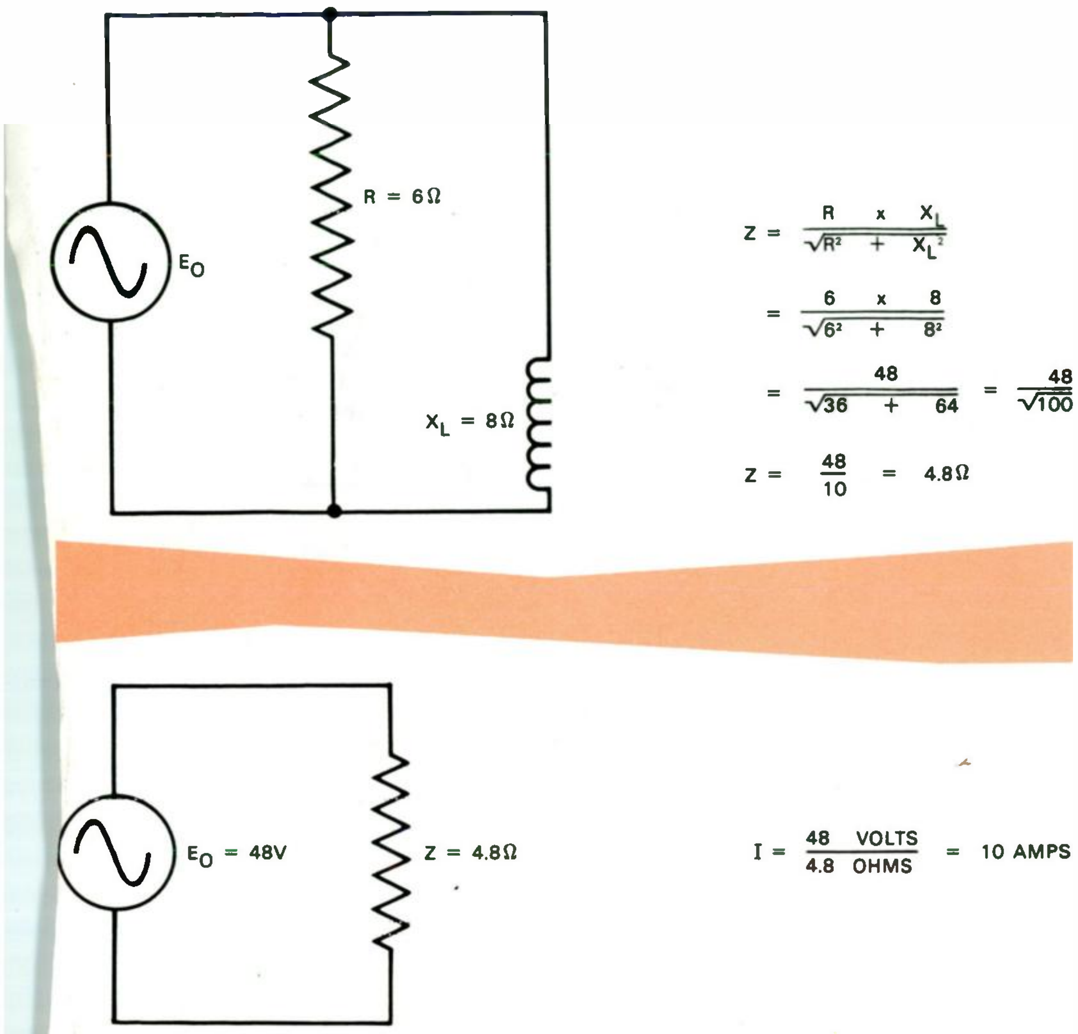


Figure 12 — Natural trigonometric functions.



$$Z = \frac{R \times X_L}{\sqrt{R^2 + X_L^2}}$$

$$= \frac{6 \times 8}{\sqrt{6^2 + 8^2}}$$

$$= \frac{48}{\sqrt{36 + 64}} = \frac{48}{\sqrt{100}}$$

$$Z = \frac{48}{10} = 4.8\Omega$$

$$I = \frac{48 \text{ VOLTS}}{4.8 \text{ OHMS}} = 10 \text{ AMPS}$$

Figure 15 — Calculating the total impedance and current in a parallel RL circuit.

If the frequency were doubled from 60 hertz to 120 hertz, line (16) would be rewritten:

$$X_C = \frac{10^4}{6.28 \times 120 \times 1.33} \qquad (18)$$

$$X_C = \frac{10000}{1000} = 10\Omega \qquad (19)$$

Doubling the frequency cuts the resulting reactance in half. If the frequency were *reduced* from 60 to 30 hertz, the reactance would be doubled to 40 ohms.

Series and Parallel Circuits

The two major RC circuit combinations are the series circuit and the parallel circuit. We will first investigate the circuit actions in a series circuit. The series circuit can consist of a number of resistors and

Grouping Resistance and Reactance

In the formula used to compute the impedance of a circuit, only one term represents the inductive reactance X_L, and only one term stands for the resistance R. Both X_L and R each stand for *all* the inductive reactance X_L and *all* the resistance R in the circuit. The total of all the resistance values is obtained by simple addition in the series circuits we have thus far been investigating. We can also add all the X_L values if the inductances do not interact, which generally is the case.

PARALLEL RL CIRCUITS

It has been explained that the voltage leads the current. We have also studied that the current is in phase with the voltage across a resistance, yet is 90° behind the voltage across the inductance. This information led to the development of methods to determine impedance values, but the explanations dealt only with the relationships in a series circuit. A parallel circuit containing resistances and inductances produces somewhat similar actions between the voltage and the current, but many of the final values of resistance, reactance and impedance must be calculated differently. Although there can be many parallel combinations of resistances and inductances, with a few basic formulas we can examine the electrical action in the circuit.

Explanations of a few of the many possible combinations of components are given in the next few figures. Each drawing contains the circuit and the formula used to determine the circuit constants. Figure 13 illustrates that the applied voltage E_O is the same across the resistance and the inductance. This also means that there is no phase difference between the voltages.

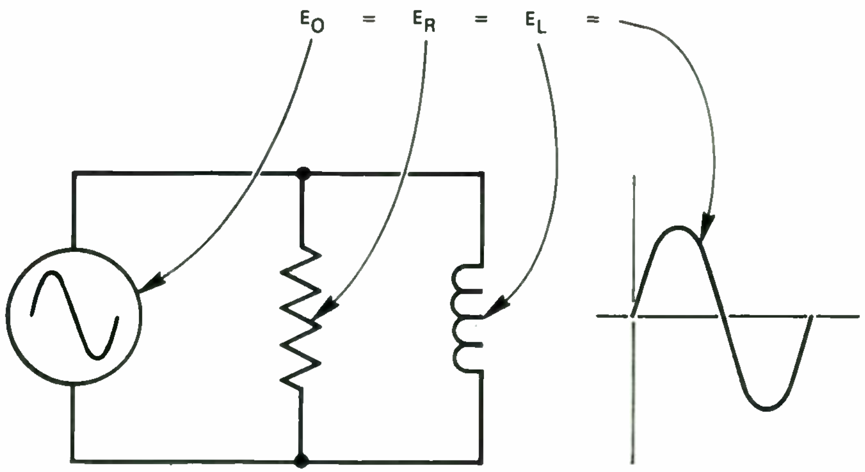


Figure 13 — Voltages are equal in a parallel RL circuit.

This circuit is redrawn to clarify the phase difference that exists between the currents in each branch circuit (Fig. 14). The current in the resistive branch I_R is in phase with the applied voltage E_O. As there is no phase difference between I_R and E_o across the resistance, the I_R vector is on the same horizontal line as the E_o vector. Current in a coil is always 90° behind the applied voltage. Therefore, the current vector I_L is at the 6 o'clock position on the clock face. Because of this phase difference, the individual currents must be added vectorially to find the total or line current I_o. Since the two currents are 90° out of phase and form two sides of a right triangle, we can again use the algebraic formula to find the line current (Fig. 14).

Actual ohmic values of the resistor R and the coil L are used in the example in Figure 15. Here again we use a combination of two types of arithmetic to find the impedance Z in a parallel circuit. This formula is similar to the one used to calculate the effective resistance when two resistors are in parallel; however, the square root of the sum of the squares must first be obtained.

CAPACITIVE REACTANCE

Circuits that contain a capacitor and a resistor in either series or parallel combinations are known as RC circuits. The methods used to solve for RC circuit values are similar to those used in determining RL circuit values. A difference exists, however, because of the opposite phase relationship in a capacitive circuit to the phase relationship in an inductive circuit.

Formula for Capacitive Reactance

The symbol for capacitive reactance uses X and the subscript c, that is, X_c. The formula for capacitive reactance is

$$X_c = \frac{1}{2\pi fC}$$

2 π equals 6.28, f is the frequency in hertz, C is the capacity in farads, and X_c is the value in ohms.

This formula may be further simplified by dividing the value of 2 π (6.28) into 1 and we obtain,

$$X_c = \frac{.159}{fC}$$

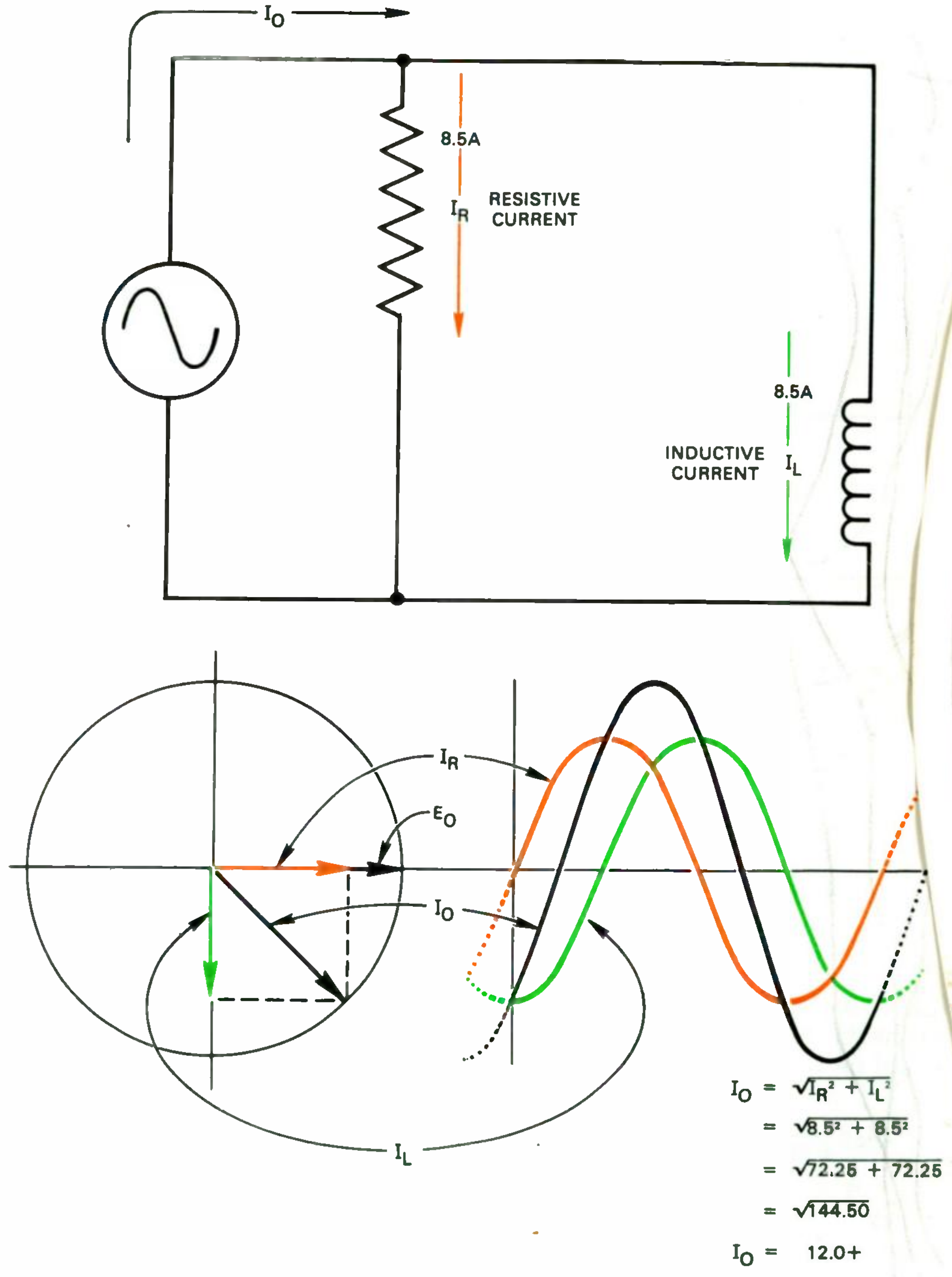
We can make some observations about this formula. Since both frequency f and capacitance C are in the denominator of the fraction, an increase in either f or C will have the opposite effect on the value of X_c. To learn more about this effect, we will find the capacitive reactance of a capacitor in a circuit operating at a frequency of 60 hertz with a capacity of 133μ f (which is 133 microfarads or 1.33×10^{-4} farads).

$$X_c = \frac{1}{2\pi fC} \qquad (14)$$

$$= \frac{1}{6.28 \times 60 \times 1.33 \times 10^{-4}} \qquad (15)$$

$$= \frac{10^4}{6.28 \times 60 \times 1.33} \qquad (16)$$

$$X_c = \frac{10{,}000}{500} = 20\Omega \qquad (17)$$



$$I_O = \sqrt{I_R^2 + I_L^2}$$
$$= \sqrt{8.5^2 + 8.5^2}$$
$$= \sqrt{72.25 + 72.25}$$
$$= \sqrt{144.50}$$
$$I_O = 12.0+$$

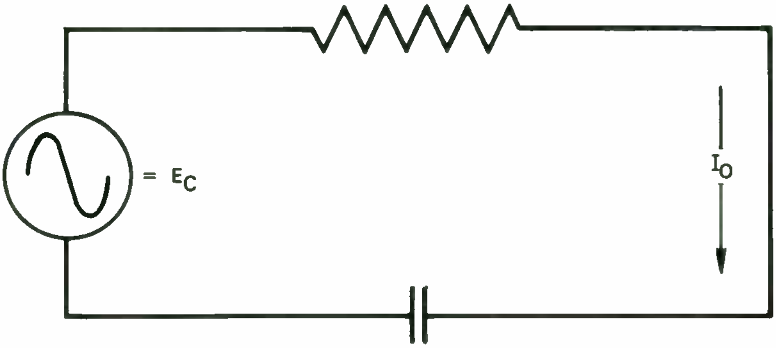
Figure 14 — Determination of total current in a parallel RL circuit.

capacitors, but the different types of components should be grouped before analyzing the circuit. Thus the resistance values should be totalled, to obtain a single value, while a single capacitance value can be computed by the capacitance formula. The resistance values will be totalled, and the capacitors will be computed with the capacitance formula. This will give us the value for both the resistance and the capacitance. Remember, the formula for total capacitance when capacitors are connected in series is

$$\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}$$

Series RC Circuits

The current and the voltage are always in phase at a resistor, but the current *leads* the voltage by 90° in the capacitor in a series RC circuit (Fig. 16). Because the current



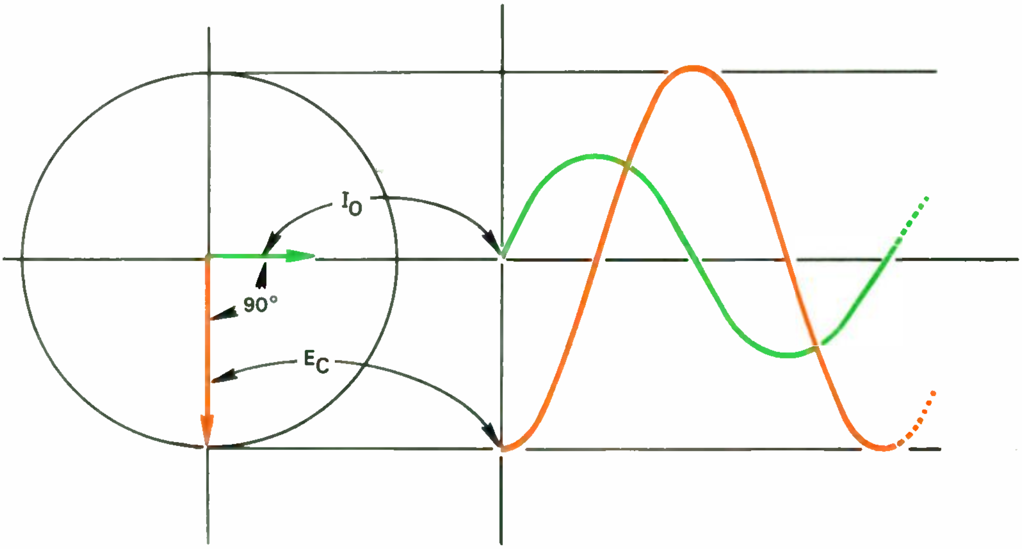


Figure 16 — The current in the capacitor leads the voltage in a series RC circuit.

has the same value throughout the series circuit, and the voltage and current are in phase across the resistor, the circuit current is used as the phase reference for all other circuit quantities. This also makes the current vector the reference, and it is generally placed at zero degrees along the horizontal line. (Remember, the phase angle is the angle between the applied voltage and the total current in the circuit.)

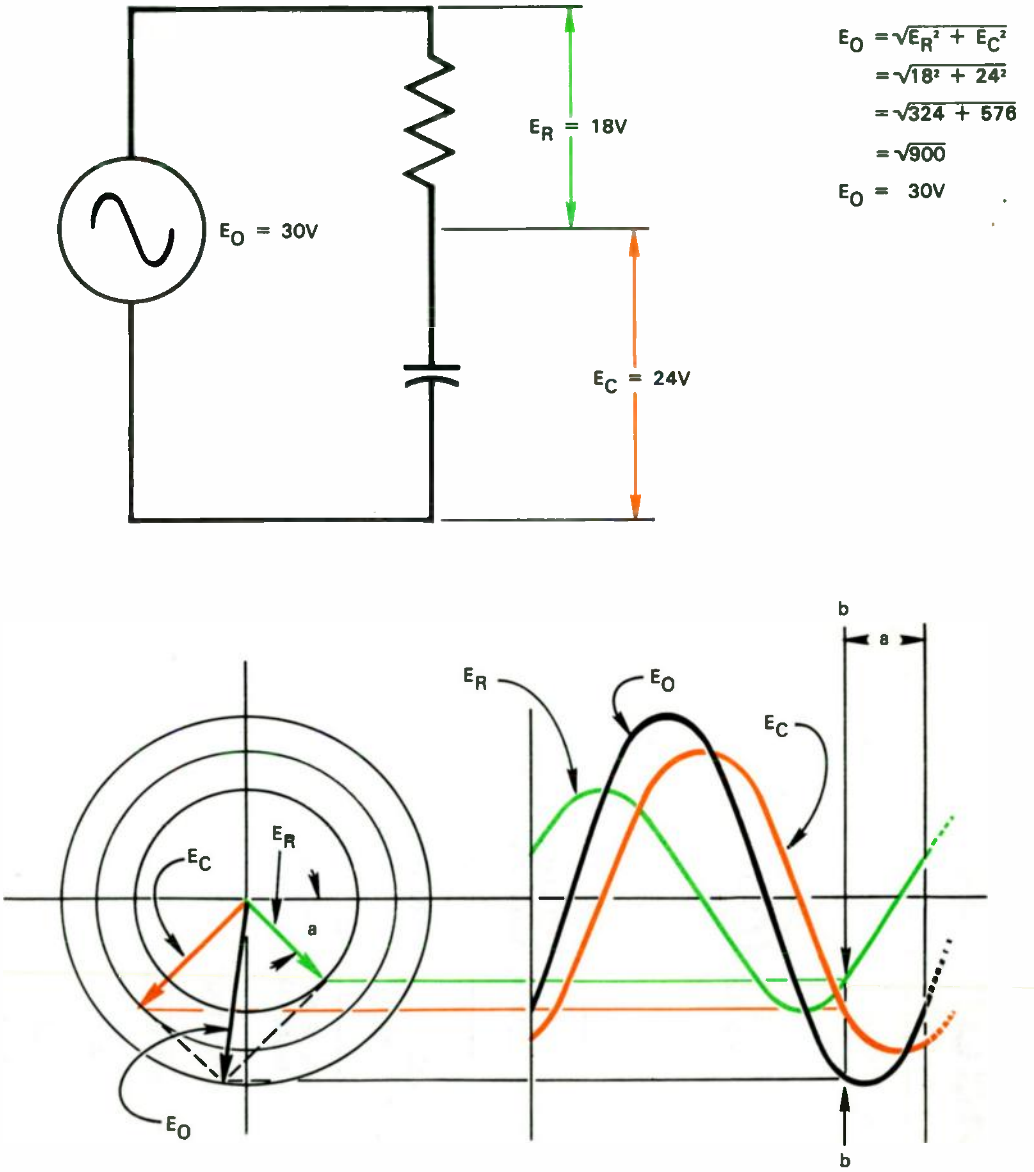
If current is flowing through a series RC circuit, the voltage across the resistor is in phase with the current. At the same time, the voltage drop E_C across the capacitor lags the current by 90°. Angle a (Fig. 17) indicates the time chosen at point b, for the vector E_R. Completing the triangle produces the vector E_O. The waveshapes for E_R and E_C have different maximum values, as shown at the right side of Figure 17. They must be shown with different maximum values, because their average values are different: $E_R = 18$ volts and $E_C = 24$ volts.

Whenever we have analyzed waveshapes, we have compared their relative values at a given instant in time, such as the time chosen at point b (Fig. 17). When we measure the voltage drops across an electrical component, we are reading the effective value of the voltages. These are the voltage values for each component on the circuit diagram. These values are used to compute the resulting voltage, which equals the applied voltage of 30 volts or E_O.

The same trigonometric method is used to compute the effective current, the impedance, the voltages and the various values of wattage in a capacitive series circuit as was used in an inductive series circuit (Figs. 10 and 11). Figure 18 is another series circuit. There are different values for the resistor and capacitor. All the relationships are shown beside each triangle. The triangles are again drawn, and the current I is the reference line.

The circuit in A has all of the given values and additional calculations beside each component. In the voltage triangle in B, the *in-phase* voltage drop vector IR is drawn in line with the current vector I. The lagging voltage drop IX_C is drawn vertically downward since it lags the current by 90°. The total effective voltage is computed for you (Fig. 18).

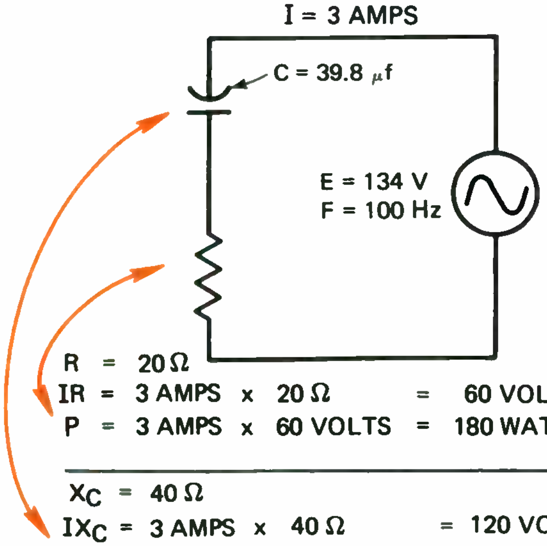
The impedance triangle in C has the same shape and the same relative vector lengths as the other triangles. The impedance is also found by referring to the table (Fig. 8). All the power values are illustrated in D. The base of the triangle represents the true power absorbed by the circuit resistance and has a magnitude of $P = I^2R = 3^2$ amps × 20 volts = 180 watts. Solving by $P = EI$, 60 volts × 3 amps = 180 watts, which is the same value. The altitude of the triangle represents the reactive volt-amps. Remember that the actual power absorbed by the capacitor is zero. The action of a capacitor in a circuit is like the elasticity of a spring. Storing a



$$
\begin{aligned}
E_O &= \sqrt{E_R^2 + E_C^2} \\
&= \sqrt{18^2 + 24^2} \\
&= \sqrt{324 + 576} \\
&= \sqrt{900} \\
E_O &= 30V
\end{aligned}
$$

Figure 17 — Calculating the total voltage drop of a series RC circuit.

CIRCUIT A



$R = 20\,\Omega$

$IR = 3\text{ AMPS} \times 20\,\Omega = 60\text{ VOLTS}$

$P = 3\text{ AMPS} \times 60\text{ VOLTS} = 180\text{ WATTS}$

$X_C = 40\,\Omega$

$IX_C = 3\text{ AMPS} \times 40\,\Omega = 120\text{ VOLTS}$

$P = 3\text{ AMPS} \times 120\text{ VOLTS} = 360\text{ VARS}$

THE CAPACITIVE REACTANCE AT A FREQUENCY OF 100 Hz IS CALCULATED FROM THE FORMULA:

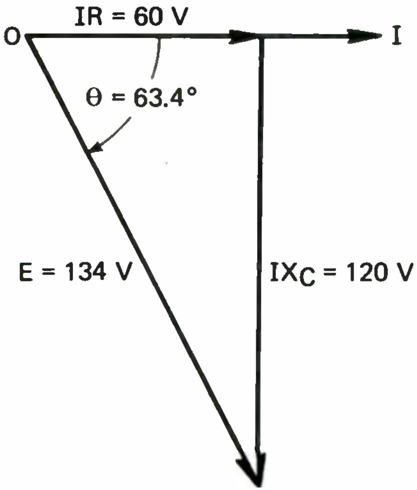
$$X_C = \frac{1}{2\pi fC} = \frac{1}{6.28 \times 100\text{ Hz} \times 39.8\,\mu f}$$

$$= \frac{1}{6.28 \times 100 \times 39.8 \times 10^{-6}}$$

$$= \frac{10^6}{6.28 \times 100 \times 39.8}$$

$$X_C = \frac{1{,}000{,}000}{25{,}000} = 40\,\Omega$$

VOLTAGE B



$$E = \sqrt{E_R{}^2 + E_C{}^2}$$

$$= \sqrt{(IR)^2 + (IX_C)^2}$$

$$= \sqrt{60^2 + 120^2}$$

$$= \sqrt{3600 + 14400}$$

$$= \sqrt{18000}$$

$$= \sqrt{180 \times 100}$$

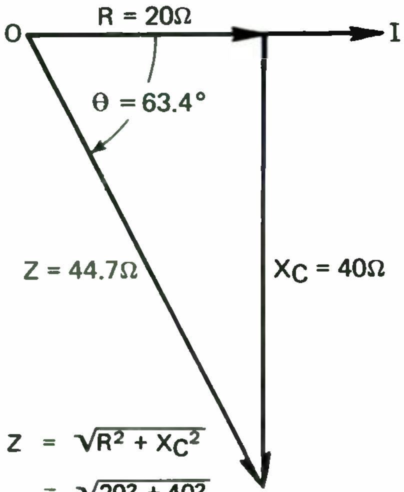
$$= \sqrt{180} \times \sqrt{100}$$

$$= 13.4 \times 10$$

$$E = 134\text{ VOLTS}$$

Figure 18 — Methods used to compute reactance, voltage, impedance and power in a series RC circuit.

IMPEDANCE C

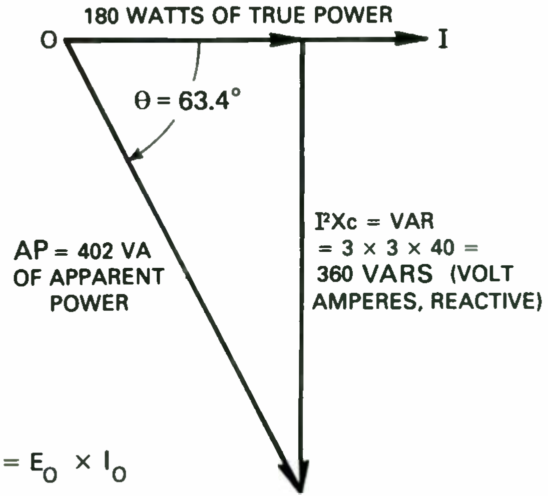


$$Z = \sqrt{R^2 + X_C^2}$$
$$= \sqrt{20^2 + 40^2}$$
$$= \sqrt{400 + 1600}$$
$$= \sqrt{2000}$$
$$= \sqrt{20 \times \quad 100}$$
$$= \sqrt{20} \times \sqrt{100}$$
$$= 4.47 \times 10$$
$$Z = 44.7\ \Omega$$

THE IMPEDANCE CAN ALSO BE CALCULATED BY:

$$Z = \frac{E}{I} = \frac{134 \text{ VOLTS}}{3 \text{ AMPS}} = 44.7\ \Omega$$

POWER D



$$AP = E_O \times I_O$$
$$AP = 134V \times 3A = 402VA$$

or

$$AP = \sqrt{(I^2 R)^2 + (I^2 X_C)^2}$$
$$= \sqrt{180^2 + 360^2}$$
$$= \sqrt{32{,}400 + 129{,}600}$$
$$= \sqrt{162{,}000}$$
$$= \sqrt{16.2 \times 10{,}000}$$
$$= \sqrt{16.2} \times \sqrt{10{,}000}$$
$$= 4.02 \times 100$$
$$AP = 402 \text{ VOLT AMPERES}$$

Figure 18 — cont.

charge in the capacitor is like compressing the spring, and discharging the capacitor is like releasing the pressure on the spring. Thus the circuit is allowed to return its compressed energy.

As previously mentioned, all three triangles are similar. The common factor is the circuit current; and the phase angle θ between E and I equals the same value in all three diagrams. Thus the circuit power factor is equal to

$$\frac{IR}{IZ} = \frac{60}{134} = 0.446$$

$$\frac{R}{Z} = \frac{20}{44.7} = 0.446$$

$$\frac{I^2R}{I^2Z} = \frac{180}{402} = 0.446$$

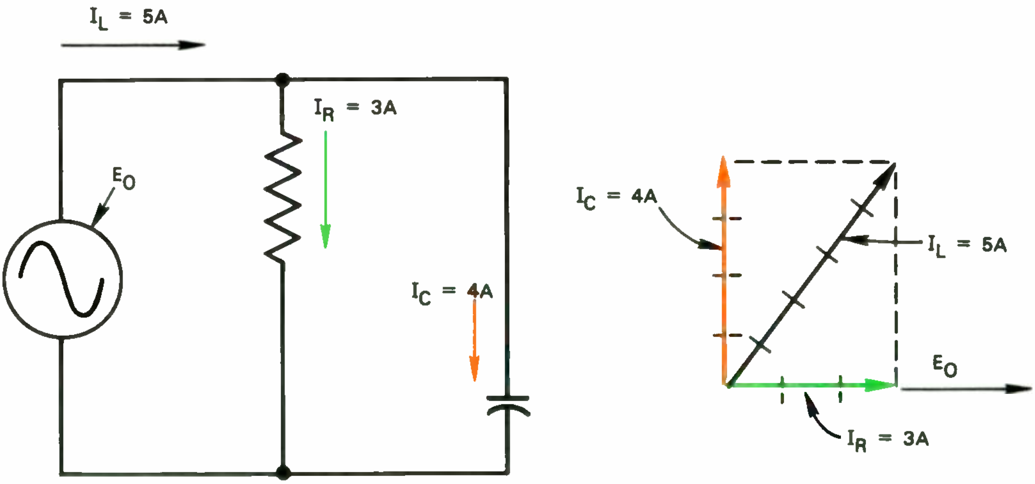
in every case. This ratio of 0.446 is the cosine of the angle between the hypotenuse and the base of the triangle. The angle is 63° + or exactly 63.4° if a more exact trig table is used.

Parallel RC Circuits

In a parallel RC circuit, the applied voltage is the same across each parallel branch. The branch currents, however, will be independent of each other and generally will have different values. The value of the currents in the branches depends on the resistive value R and the reactance value X_C. These values are calculated by

$$I_R = \frac{E_0}{R} \text{ and } I_C = \frac{E_0}{X_C}$$

where E_0 is the applied voltage.



$$I_L = \sqrt{I_R^2 + I_C^2}$$
$$= \sqrt{3^2 + 4^2}$$
$$= \sqrt{9 + 16}$$
$$I_L = \sqrt{25} = 5 \text{ AMPS}$$

Figure 19 — Calculating line current in a parallel RC circuit.

In a series RC circuit, the current vector was the reference vector, because its value was constant throughout the circuit. But it is the voltage in a parallel RC circuit that is the same; therefore, it is used as the reference vector. Since the current in an RC circuit leads the voltage, the line current must be the vector sum of the two individual branch currents (Fig. 19). If the total impedance and the applied voltage are known, we could calculate the line current from

$$I_L = \frac{E_O}{Z}$$

But before we can use this formula, we must know the value of impedance Z.

Calculation of Impedance

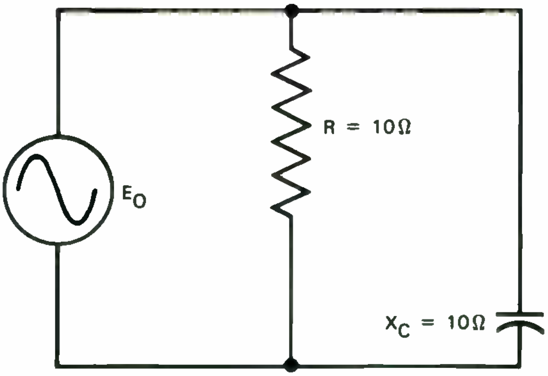
The total impedance (Z) in a parallel RC circuit cannot be determined vectorially. The impedance of the simple RC circuit may be solved as shown in Figure 20. The simplest method to solve for impedance, in complex RC parallel circuits, is to first find the value of the line current. Then by substituting this value in Ohm's formula the value of Z may be obtained.

$$Z = \frac{E_O}{I_L}$$

In either a series or parallel RC circuit, the current leads the voltage. An easy way to remember this is to use the word ICE to relate *current, capacitance* and *voltage.* I (current) precedes C (capacitance) which is ahead of E (voltage).

ANALYZING SERIES LCR CIRCUITS

We have thus far studied the characteristics of circuits containing resistance R with either inductance L or capacitance C. The study included both series and parallel circuits, but neither of these circuits were combining all three fundamental electronic components, L, C and R. We will investigate both series and parallel



$$Z = \frac{R \times X_C}{\sqrt{R^2 + X_C^2}}$$

$$= \frac{10 \times 10}{\sqrt{10^2 + 10^2}}$$

$$= \frac{100}{\sqrt{100 + 100}}$$

$$= \frac{100}{\sqrt{200}} = \frac{100}{14.14}$$

$$Z = 7.07$$

Figure 20 — Calculating the impedance in a parallel RC circuit.

circuits that contain all three, beginning with a simple series circuit. To further simplify the study, we will begin with a circuit containing only L and C (Fig. 21).

The simple LC circuit contains an inductance and a capacitance in series with the source or applied voltage. Every circuit must contain some resistance. But because it is such a small amount, this resistance has no appreciable effect on the operation of the circuit.

Constant Current in a Series LCR Circuit

The constant value in any series circuit is the current. The LC series circuit is no exception. Consequently the current in the inductance L is the same as the current in the capacitor C. Therefore, the current vector I is chosen as the reference direction along the zero axis. If we knew the constant current I flowing in the LC series circuit and the reactance of the coil and the capacitor, we could calculate the voltage drop across each one:

$$E_L = IX_L \text{ and } E_C = IX_C$$

Calculating Voltage Drops in a Series LC Circuit

The voltage drop E_L across the coil is leading the voltage drop E_c across the capacitor (Fig. 21). We must compute the value of the resulting voltage with the vectors. Because the two vectors are on the same line but point in opposite directions, we subtract the lesser voltage from the larger voltage to obtain the resultant voltage (Fig. 22). This is similar to determining the final voltage of a series of dry cells in a flashlight. If we were to put one cell in backwards, we would have to subtract its value from the total voltage of the other cells to obtain the resultant voltage.

Several voltage values are illustrated in Figure 22. The voltages in the first four examples were purposely selected. They illustrate that in every case the total voltage drop was the same (10 volts), and that the individual E_L and E_c voltages were always larger than E the ap-

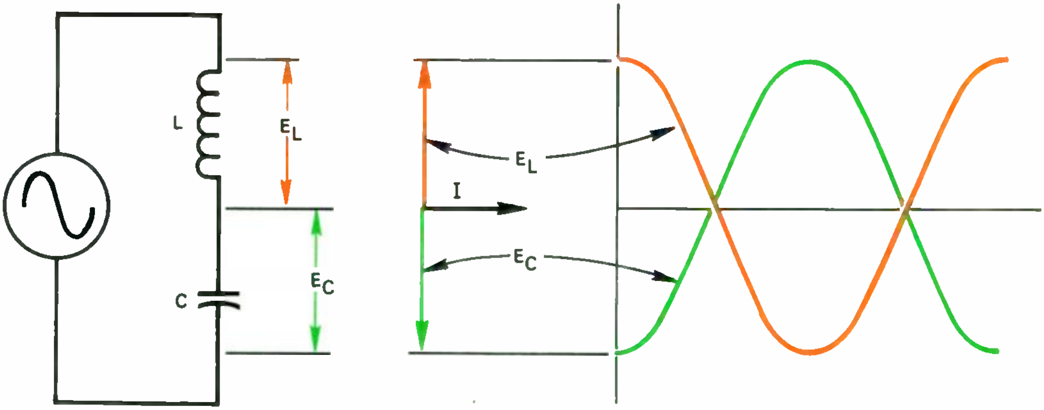


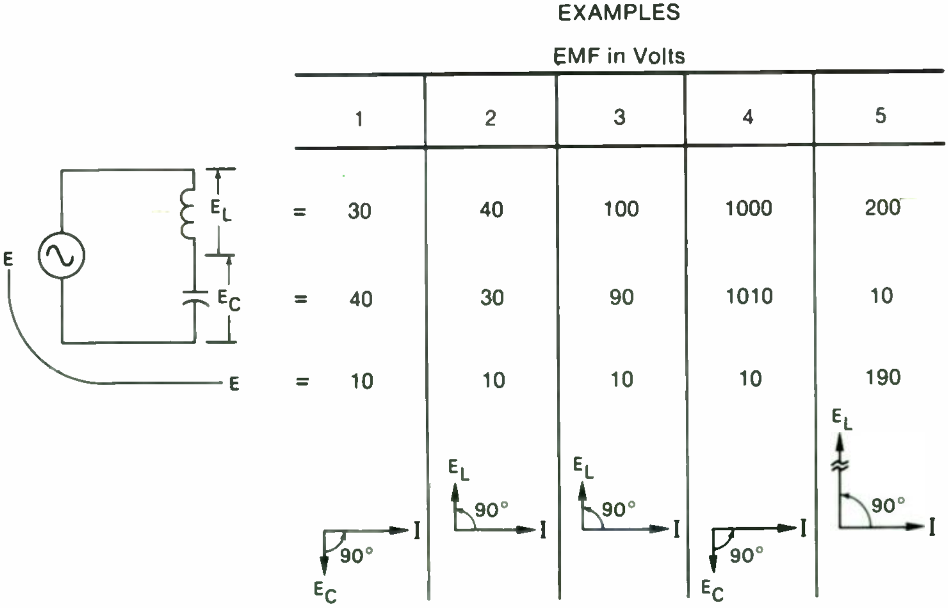
Figure 21 — Phase relationship of voltage drops in a series LC circuit.

plied voltage. These four examples also show that either voltage may be larger, while example 5 shows that the two voltages need not be close in value.

Total Circuit Voltage

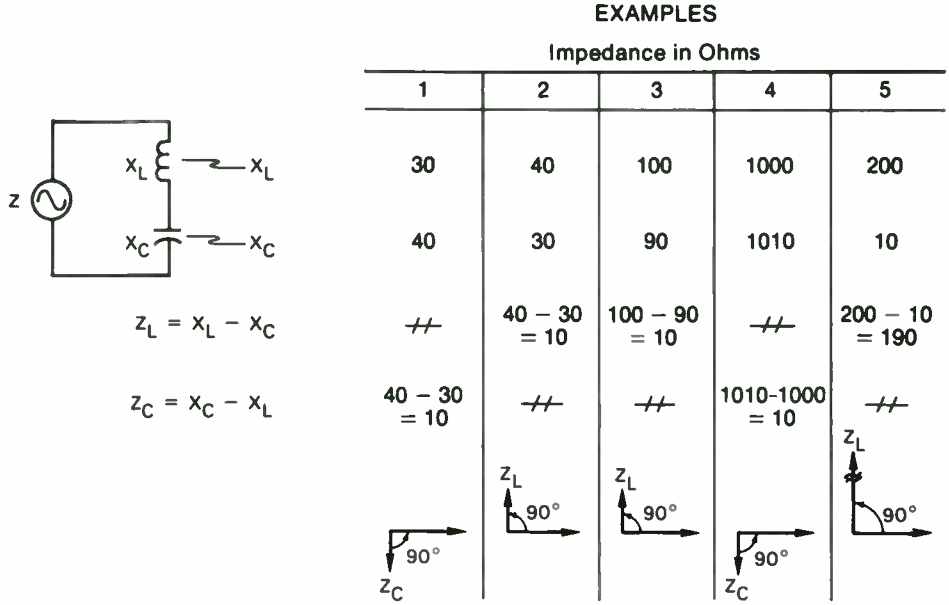
The resultant vector of the two values of voltage is shown below each example (Fig. 22). The larger voltage drop in each case establishes the direction of the voltage in the circuit and consequently determines whether the current or voltage leads in the circuit. The voltage leads the current in examples 2, 3 and 5, while the current leads the voltage in examples 1 and 4. In all five examples the phase angle is 90°, because there is theoretically no resistance in these examples.

The resultant voltage values in these five examples equal the applied voltage. Thus an applied voltage of 10 volts at E is the required voltage for the first four examples, while 190 volts is required for example 5. These values of applied voltage (10 volts and 190 volts) can be calculated with Ohm's law if we know the current I and impedance Z. The impedance is computed from the two reactances X_L and X_c (Fig. 23), but like the voltages that are 180° out of phase with each other, the reactances are also exactly opposite. The larger reactance determines the direction of the final vector and also the *kind* of impedance presented by the circuit. Examples 1 and 4 would be stated as "10 ohms capacitive", and examples 2 and 3 would be stated as "10 ohms inductive". Example 5 is "190 ohms inductive". From these facts we can state that the currents in examples 1 and 4 are purely capacitive; in 2, 3 and 5 the current is purely inductive.



	1	2	3	4	5
E_L =	30	40	100	1000	200
E_C =	40	30	90	1010	10
E =	10	10	10	10	190

Figure 22 — Calculating the total voltage drop in a series LC circuit.



EXAMPLES

Impedance in Ohms

	1	2	3	4	5
X_L	30	40	100	1000	200
X_C	40	30	90	1010	10
$Z_L = X_L - X_C$	-//-	40 − 30 = 10	100 − 90 = 10	-//-	200 − 10 = 190
$Z_C = X_C - X_L$	40 − 30 = 10	-//-	-//-	1010-1000 = 10	-//-

Figure 23 — Calculating the total impedance in a series LC circuit.

Current in an LC Circuit

The current in a series LC circuit can be determined very simply from Ohm's law if we know the applied voltage and the impedance. The formula is $E/Z = I$. The phase angle between the current and the voltage is always 90° in a purely inductive or capacitive circuit. If the values of the two reactances are equal, they would cancel each other and make the impedance Z zero. This is never the case, however, because although the magnitude of the current is large, there is always resistance in the circuit. This condition of minimum value of impedance not only actually occurs, but is a condition designers work toward. When a series circuit has minimum impedance, it is in a condition of *resonance.*

SERIES LCR CIRCUITS

Calculation of Total Voltage Drop

We previously studied a series circuit that contained only inductance and capacitance. What we learned about that circuit action can also be applied to a series circuit that contains resistance and L and C. If the reactance of the LCR circuit is 10 times greater than the resistance, the resistance will not have an appreciable effect. An understanding of its action in a circuit will be helpful.

Because inductance and capacitance have opposite effects, we must first determine the final voltage drop across each reactance (Fig. 24). If we know the voltage drop E_R

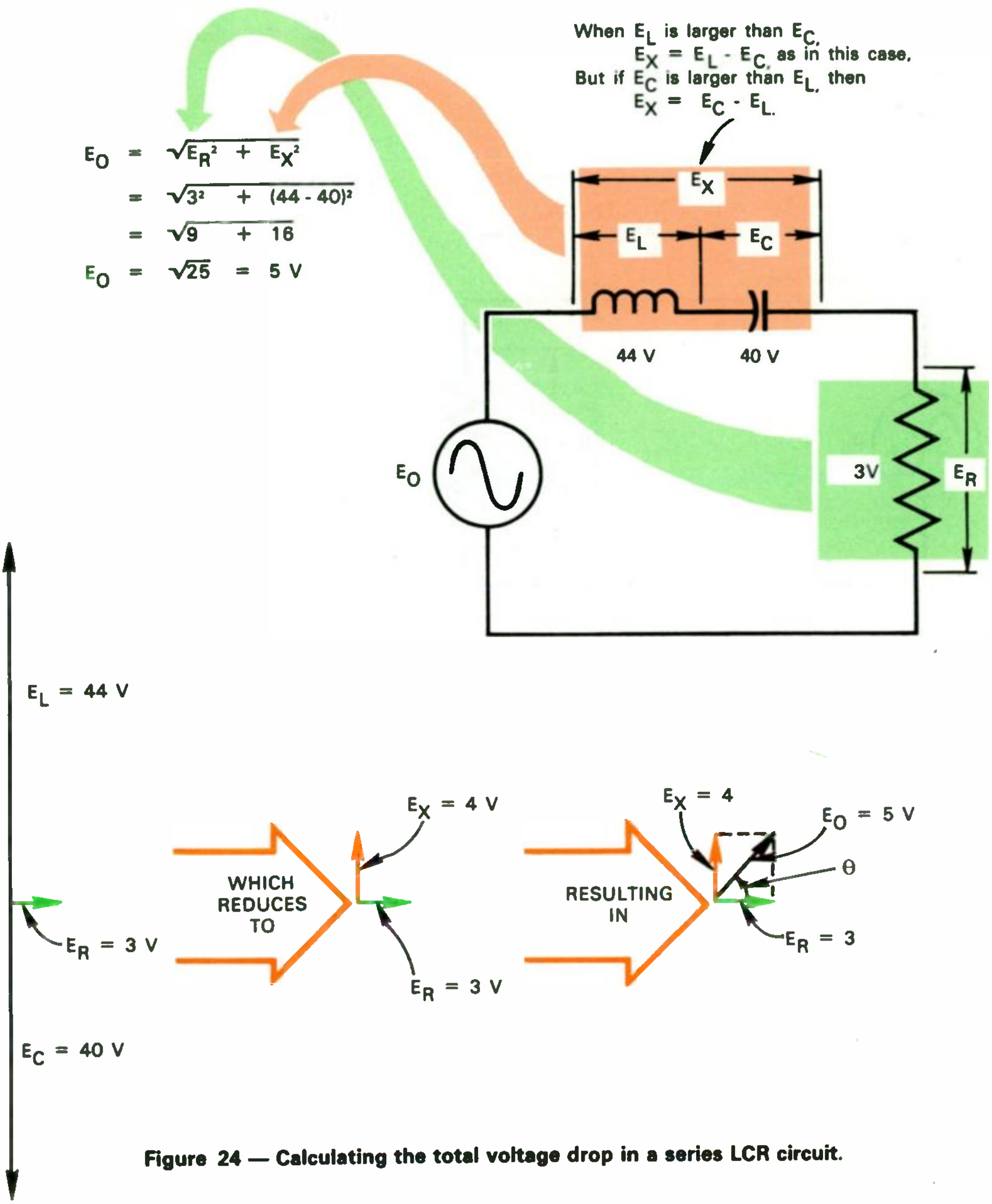
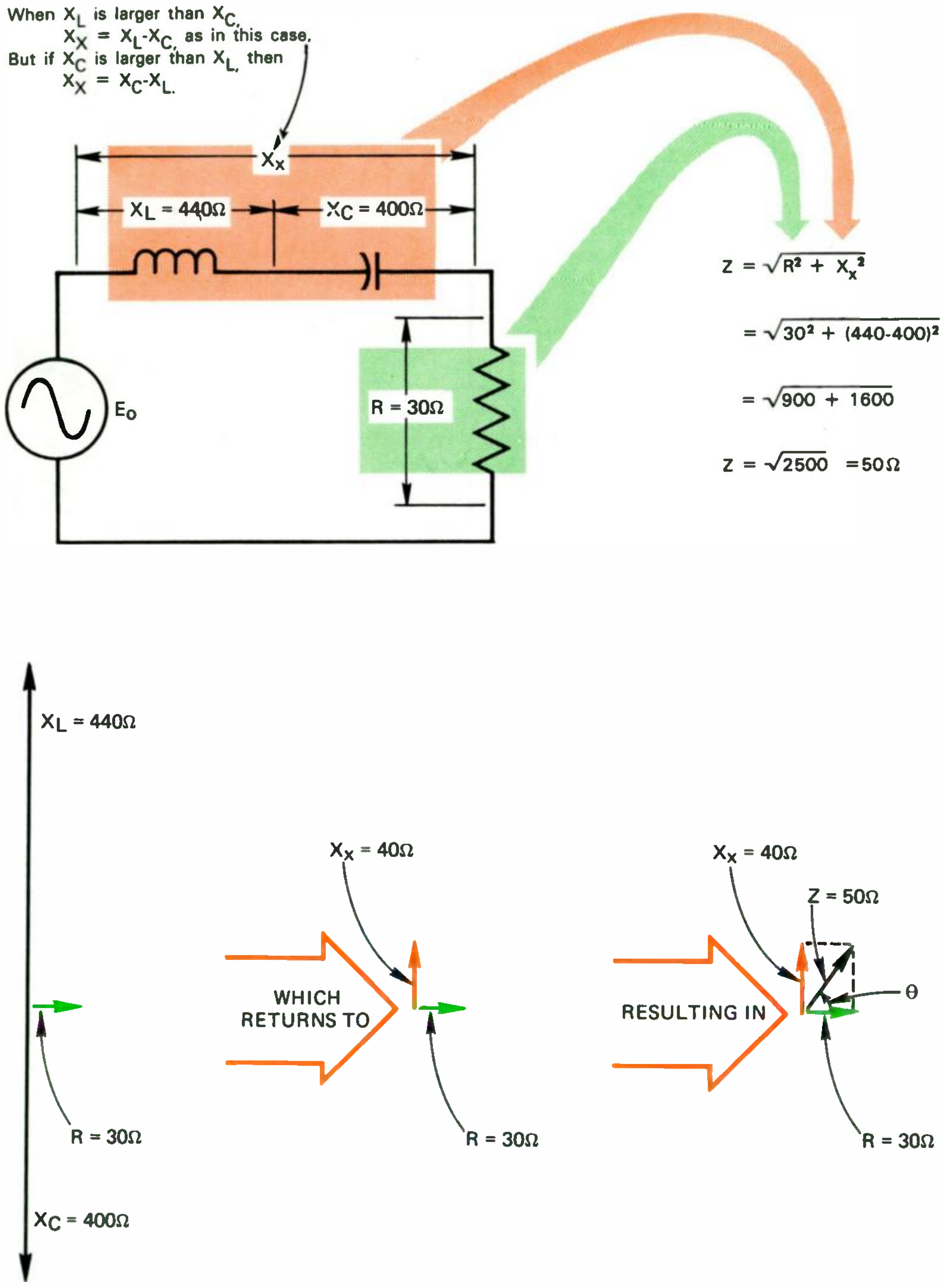


Figure 24 — Calculating the total voltage drop in a series LCR circuit.

and have calculated the voltage drop for E_X, we will, therefore, be able to calculate the applied voltage E_O. This applied voltage E_O again equals the vector sum of the voltage drops. The larger voltage determines the position of the resulting vector of the applied voltage and the phase angle θ.

Calculation of Total Impedance

The impedance of a series LCR circuit is the vector sum of the individual reactances and the resistance (Fig. 25). The vector sum of the two impedances is first determined and then combined with the



$$Z = \sqrt{R^2 + X_x^2}$$
$$= \sqrt{30^2 + (440\text{-}400)^2}$$
$$= \sqrt{900 + 1600}$$
$$Z = \sqrt{2500} = 50\Omega$$

Figure 25 — Calculating the impedance of a series LCR circuit.

resistance vector. The larger reactance again determines the position of the impedance and the phase angle.

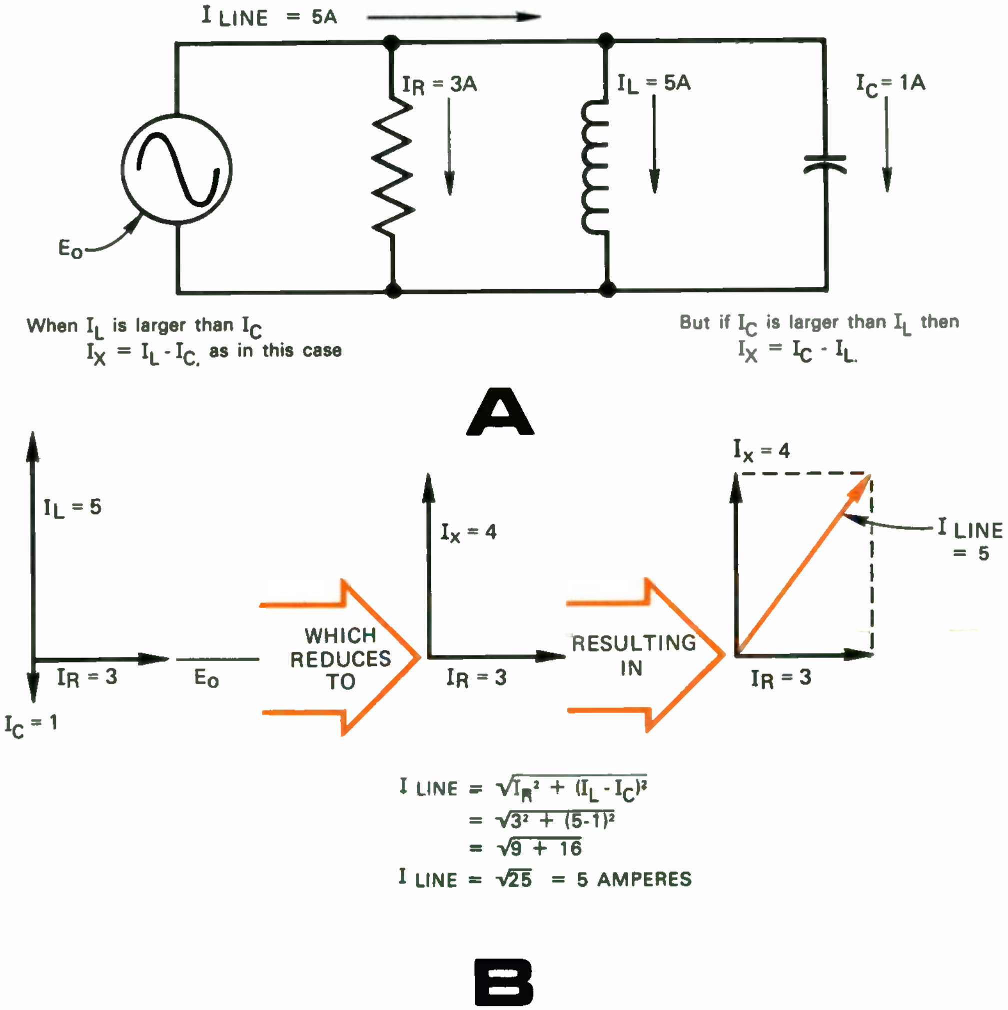
Current and Phase Angle

Ohm's law can be used to determine the current in an LCR circuit:

E is the applied voltage and Z is the total impedance in the circuit. This magnitude of I is the current in the series circuit. The phase angle for each circuit can be found from the triangles in Figures 24 and 25.

PARALLEL LCR CIRCUITS

When we review the relationships between inductance, capacitance and resistance in a parallel



$$
\begin{aligned}
I\ \text{LINE} &= \sqrt{I_R^2 + (I_L - I_C)^2} \\
&= \sqrt{3^2 + (5-1)^2} \\
&= \sqrt{9 + 16} \\
I\ \text{LINE} &= \sqrt{25} = 5\ \text{AMPERES}
\end{aligned}
$$

Figure 26 — Calculating line current in a parallel LCR circuit.

LCR circuit, we can apply many of the facts that we have previously learned. A circuit with inductance and capacitance connected in parallel across the applied voltage, has the same voltage across L and C. Since the voltage E across the inductance L leads the current I (remember ELI), they are 90° out of phase. And since the current I across the capacitance C leads the voltage E (here we use ICE), they are also 90° out of phase. Therefore, the two L and C currents are 180° out of phase (Fig. 26). But as always, the current through the resistance is in phase with the voltage drop across the resistance.

If we combine the two currents that are 180° out of phase (as we have previously done), we can then compute the line current. Again, the larger current value determines whether the circuit is inductive or capacitive. This value will also determine whether the phase angle is leading or lagging (Fig. 26).

Impedance in an LCR Circuit

Determining the impedance in an LCR circuit follows many methods that we have previously studied. Again we must compute the net reactance that exists due to the inductive reactance and the capacitive reactance. This value is then combined with the resistance value (Fig. 27).

After the net reactance is determined, the impedance Z is computed (Fig. 27). It is also possible to use the applied voltage E and the line current I to determine the impedance Z, with Ohm's law:

$$Z = \frac{E}{I}$$

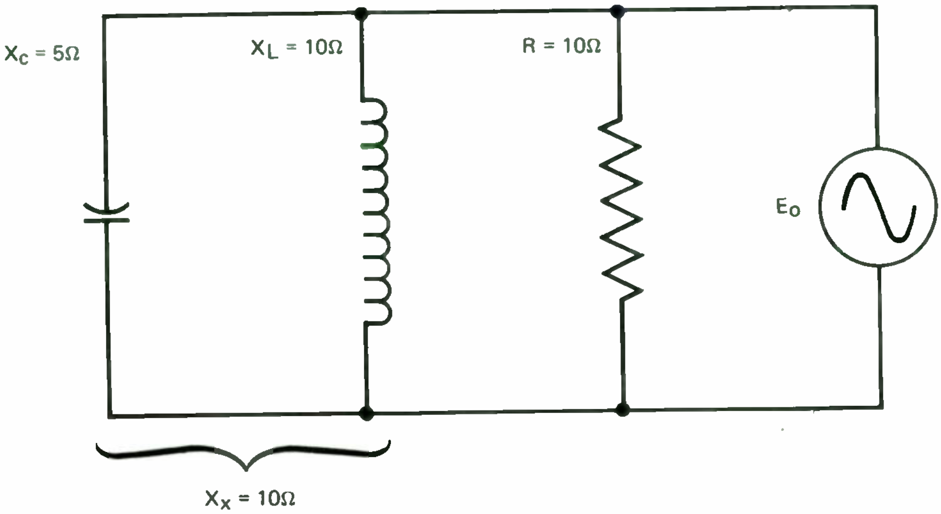
SUMMARY

Inductance and capacitance oppose the flow of current in an AC circuit. Like resistance, this opposition is measured in ohms. Combinations of reactance and resistance are called impedance, which is also measured in ohms. Inductive reactance is designated as X_L, and capacitive reactance is X_C. The symbol for impedance is Z. In the review that follows, refer to the summary charts of all the circuits and the formulas that apply to them (Figs. 28 and 29). These charts will be helpful in reviewing the questions and in understanding both the similarity and the difference between the circuits.

In a series circuit consisting of either RL or RC, the line current is the same and is used as the zero reference vector. Both the applied voltage and the total impedance must be added vectorially.

In a parallel circuit consisting of either RL or RC, the applied voltage is the same across each component and is used as the zero reference vector. The current through each branch is calculated with Ohm's law for AC circuits, but the line current is calculated vectorially. The total impedance is determined from $Z = E_{APP}/I_{LINE}$.

Circuits containing inductance, capacitance and resistance are LCR



1ST CALCULATION

$$X_X = \frac{X_L \times X_C}{X_L + X_C}$$

NOTE:

X_L is considered positive and
X_C is considered negative.
The result will indicate that
the circuit is:
inductive if the answer is positive,
capacitive if the answer is negative.

$$X_X = \frac{10 \times (-5)}{10 + (-5)} = \frac{-50}{5} = -10\ \Omega$$

As the result is negative, the circuit is considered to be capacitive.

2ND CALCULATION

$$Z = \frac{R \times X_X}{\sqrt{R^2 + X_X^2}}$$

$$= \frac{10 \times 10}{\sqrt{100 + 100}} = \frac{100}{\sqrt{200}}$$

$$= \frac{100}{14.14} = 7.07\ \Omega$$

Figure 27 — Calculating impedance in a parallel LCR circuit.

circuits. These components may be in series or in parallel combination. A series LCR circuit is first broken into the LC combination; the current is used as the zero reference vector. The line current is determined from E_{APP}/Z. Voltage drops across L and C are 180° out of phase. Therefore the applied voltage is the arithmetic difference. The larger voltage again determines whether the net reactance is inductive or capacitive.

The series LCR circuit uses the values determined from the simpler LC circuit and combines them with the resistance R. The net reac-

RL SERIES CIRCUIT

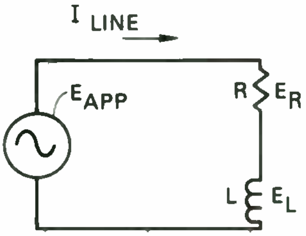
$$E_{APP} = \sqrt{E_R^2 + E_L^2} = I_{LINE}Z$$

where $E_R = I_{LINE}R$

$E_L = I_{LINE}X_L$

$$I_{LINE} = \frac{E_{APP}}{Z}$$

$$Z = \sqrt{R^2 + X_L^2} = \frac{E_{APP}}{I}$$



RC SERIES CIRCUIT

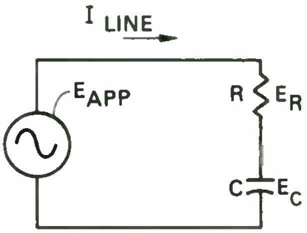
$$E_{APP} = \sqrt{E_R^2 + E_C^2} = I_{LINE}Z$$

where $E_R = I_{LINE}R$

$E_C = I_{LINE}X_C$

$$I_{LINE} = \frac{E_{APP}}{Z}$$

$$Z = \sqrt{R^2 + X_C^2}$$



LC SERIES CIRCUIT

$$E_{APP} = E_X$$

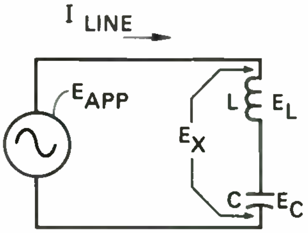
where $E_X = E_L - E_C$, if E_L is larger, or

$E_X = E_C - E_L$, if E_C is larger.

$$I_{LINE} = \frac{E_{APP}}{Z}$$

$Z = X_L - X_C$, if X_L is larger, or

$Z = X_C - X_L$, if X_C is larger



LCR SERIES CIRCUIT

$$E_{APP} = \sqrt{E_R^2 + E_X^2}$$

where $E_X = E_L - E_C$, if E_L is larger, or

$E_X = E_C - E_L$, if E_C is larger.

$$I_{LINE} = \frac{E_{APP}}{Z}$$

$$Z = \sqrt{R^2 + X_X^2}$$

where $X_X = X_L - X_C$, if X_L is larger, or

$X_X = X_C - X_L$, if X_C is larger.

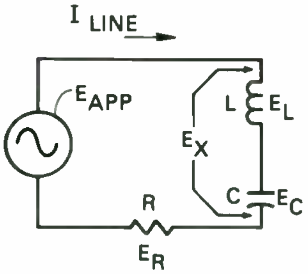
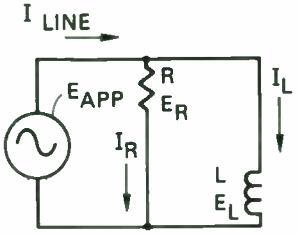


Figure 28 — Summary of series circuit formulas.

RL PARALLEL CIRCUIT



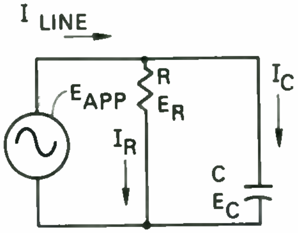
$$E_{APP} = E_R = E_L$$

$$I_{LINE} = \sqrt{I_R^2 + I_L^2} = \frac{E_{APP}}{Z}$$

where $I_R = \frac{E_R}{R}$, $I_L = \frac{E_L}{X_L}$

$$Z = \frac{R \times X_L}{\sqrt{R^2 + X_L^2}} = \frac{E_{APP}}{I_{LINE}}$$

RC PARALLEL CIRCUIT



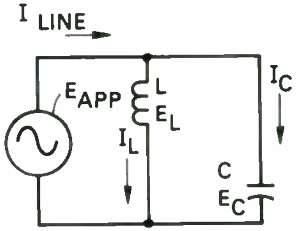
$$E_{APP} = E_R = E_C$$

$$I_{LINE} = \sqrt{I_R^2 + I_C^2} = \frac{E_{APP}}{Z}$$

where $I_R = \frac{E_R}{R}$, $I_C = \frac{E_C}{X_C}$

$$Z = \frac{R \times X_C}{\sqrt{R^2 \times X_C^2}} = \frac{E_{APP}}{I_{LINE}}$$

LC PARALLEL CIRCUIT



$$E_{APP} = E_L = E_C$$

$I_{LINE} = I_L - I_C$, if I_L is larger, or

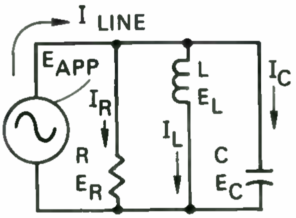
$I_{LINE} = I_C - I_L$, if I_C is larger,

where $I_L = \frac{E_{APP}}{X_L}$, $I_C = \frac{E_{APP}}{X_C}$

$Z = \frac{X_L \times X_C}{X_L - X_C}$, when X_L is larger, or

$Z = \frac{X_L \times X_C}{X_C - X_L}$, when X_C is larger.

LCR PARALLEL CIRCUIT



$$E_{APP} = E_R = E_L = E_C$$

$I_{LINE} = I_R^2 + I_X^2$,

where $I_X = I_L - I_C$, if I_L is larger, or

$I_X = I_C - I_L$, if I_C is larger.

$I_L = \frac{E_{APP}}{X_L}$, $I_C = \frac{E_{APP}}{X_C}$,

$I_R = \frac{E_{APP}}{R}$, $I_{LINE} = \frac{E_{APP}}{Z}$

$Z = \frac{R \times X_X}{\sqrt{R^2 + X_X^2}}$ where $X_X = \frac{X_L \times X_C}{X_L - X_C}$, if X_L is larger, or

$X_X = \frac{X_C \times X_L}{X_C - X_L}$, if X_C is larger.

Figure 29 — Summary of parallel circuit formulas.

tance determines whether the circuit acts like an RL or RC circuit, which also determines the total reactive voltage and its vector direction. The applied voltage is the vector value of the total reactive voltage and resistor voltage. The net reactance and the resistance produces the vector value of the impedance. Line current is E_{APP}/Z. This current either leads or lags the applied voltage, depending upon the net reactance.

The parallel LCR circuit is analyzed by first solving for the LC portion. As in all parallel circuits the voltage across each component is the same and is used as the zero reference vector. Each branch current is $I_L = E_{APP}/X_L$ and $I_C = E_{APP}/X_C$; the line current is the arithmetic difference of the two currents. The larger current determines whether the circuit is inductive or capacitive. The impedance is determined by the product over the sum formula.

The parallel LCR circuit uses the values determined from the simpler LC circuit, and these are combined with the resistance R. Since the net reactance has been determined by the original LC solution, the net reactance of L or C is combined with the resistance R to produce an equivalent RL or RC circuit. The branch currents are solved for independently. Combining vectorially the net reactive current from the LC solution, gives the line current. Depending upon the net reactance, this line current is either leading or lagging. The impedance can be computed by E_{APP}/I_{LINE}.

TEST

Lesson Number 17

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-017-1.

1. Opposition to current flow in AC circuits is measured in

2 [✓ A. ohms.]
B. impedance.
C. reactance.
D. phase angle.

2. Opposition to current flow by an inductance in an AC circuit is known as

A. impedance.
2 [✓ B. inductive reactance.]
C. resultant reactance.
D. line reactance.

3. Opposition to current flow by a capacitance in an AC circuit is known as

A. reactance Z.
20 B. impedance.
[✓ C. capacitive reactance.]
D. line current.

4. Power factor relates the

A. current to the voltage.
16 B. voltage to the current.
C. true power ratio.
[✓ D. true power to the apparent power.]

5. In a circuit containing only inductance, the

[✓ A.] current lags the voltage.
2 B. current and voltage are in phase.
C. voltage must be known first.
D. actual current value has to be checked first.

6. Capacitive reactance X_C is

[✓ A.] cut in half if the frequency is doubled.
22 B. doubled if the frequency is doubled.
C. not changed by frequency variation.
D. independent of frequency.

7. The amount of power dissipated by a resistor is known as

A. apparent power.
B. reactive power.
15 [✓ C.] true power.
D. relative power.

8. In a parallel RL circuit

[✓ A.] $E_O = E_R = E_L$.
19 B. $Z = X_L = R$.
C. $I_{Line} = I_L = I_C$.
D. $Z = X_L + R$.

9. The impedance of a series LCR circuit is

[✓ A.] the vector sum of the individual reactances and the resistance.
33 B. equal to the applied voltage.
C. the algebraic sum of the individual reactance and the resistance.
D. equal to the power factor.

10. In a series LC circuit, the impedance Z is inductive if

A. X_C is larger.
31 [✓ B.] X_L is larger.
C. E_L is smaller.
D. E_C is larger.

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Course Notes - What Do You Think?

One of the most intelligent approaches students can take in relation to mastering their course is to make use of a notebook. There is really no particular size or type that is preferred since this is something that you can decide for yourself. It is strongly recommended that you begin using one, if you have not done so already.

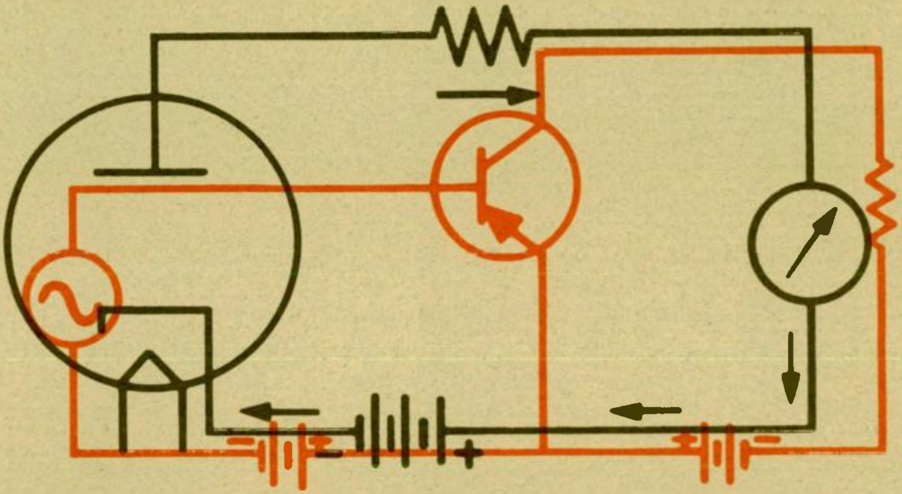
At the start of your course you will come across words and expressions that will seem rather foreign or difficult to you. It will be a great help to write these new sayings or words down along with anything else that might seem difficult. You can then regularly review these problem words and definitions until they are understood.

Your knowledge and familiarity with these terms will serve as a great help in dealing with technical electronic matters.

S. T. Christensen

LESSON NO. 18

YOUR HOME WORKSHOP



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-018

403

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

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Contents

YOUR HOME WORKSHOP

INTRODUCTION

You may be a student who intends to start doing spare time service work early in your training. If you do, you can gain valuable experience and profit by repairing small radios, phonographs, and tape recorders. But before you start to do part-time work, you must decide

1. where you will do the actual work, and
2. at what point in the course you will start.

Even if you do not begin servicing immediately, you will need a work place where you can assemble the kits, perform the experiments and practice wiring and soldering.

The time to start doing repair work is your decision and depends upon your objectives, your financial needs and your initiative. Some students will want to do repair work as soon as possible, while others will wish to progress further with their course before becoming involved with spare time service activity. In either situation, a place to work will be necessary as you pursue your studies and assemble your kits.

Figure 1 — Give thought to the time when you will start service work.

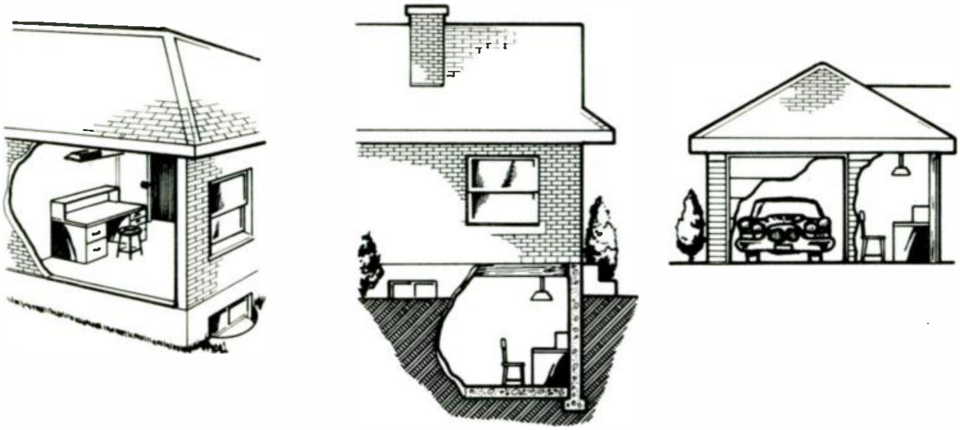


Figure 2 — There are many places that can be used as a work area.

WORK SPACE

Where to do your work will be determined by the space available. You may have the use of a section of a garage or basement, or you may have to use the kitchen table. If you are in cramped quarters, make the most of it. Many of the inconveniences can be overcome with careful planning.

Regardless of the space available, planning is of prime importance. Try to anticipate not only your current need for space, but also the future space you'll need to store tools, equipment, and supplies.

A work space must satisfy five important requirements:

1. It must include an appropriate work surface.
2. It must accommodate a convenient layout of tools and work.
3. There must be storage space for tools, equipment, and parts.
4. Adequate power must be available.
5. Lighting must be adequate.

WORK BENCH

The actual size of a work bench will depend on the space available. It should be from 2-1/2 to 3 feet high; the height selected will, of course, be determined by what is comfortable for you. A bench length of 6 to 8 feet is desirable, but these dimensions may be shortened to fit the available space. Its depth should not be less than two feet, and three feet is recommended whenever possible. A few inches of clearance between the base and the floor provides toe room when standing, while knee room must be provided at some point away from either end to allow you to work sitting down. Any bench design should be planned with both comfort and utility in mind.

A good work bench must be topped with a durable material, such as masonite. In addition, a large square of heavy felt or rug material is recommended to protect the finish on the cabinets of the units you will be working on. Keep this pad brushed free of accumulations of solder, wire clippings, tools,or any material

Figure 3 — One version of a work bench constructed from file cabinets and plywood.

that might scratch the surface of a cabinet.

Figure 3 is a drawing of a home-built bench with a plywood top covered with masonite. The four drawers on the right are from an old dresser, and on the left side the top rests on office file drawers that were purchased from a second hand store for two dollars each. At the center of the bench, two shallow drawers were fastened to the underside of the plywood top, leaving adequate knee clearance below them. This arrangement made a workable bench for one student, but your design may be entirely different and still workable.

If you do not keep your hand tools in a vertical rack, you might want to use the top right hand drawer, as most servicemen do. Little used material and equipment can be stored in the lower drawers. You will undoubtedly rearrange your other parts and equipment in various drawers to suit your needs, keeping in mind accessibility.

Some of the more fortunate students will have access to a suitable area away from their living quarters, or in an area where no one will interfere with their equipment. If this is your case, you will be able to arrange your tools and equipment knowing that no one will disturb them. You will perhaps build or buy a work bench and arrange for storage shelves and parts drawers. If you prefer, your tools can be arranged in holders or wall racks, while your test equipment can be located conveniently and permanently along the rear of the bench. Shelves above the bench are also convenient for holding your test equipment. It is recommended that these shelves be constructed from a perforated material such as pegboard. The free passage of air thru the holes will conduct heat away from the equipment and extend its life. Your stock of parts may be stored in bins and drawers or on shelves.

TEMPORARY WORK AREA

Many will find it necessary to set up shop in the kitchen or in some other room of their home or apartment. If, however, you are unable to use the existing surfaces of tables as a work area, there are alternatives. One solution is to purchase a small folding table, such as a card table, as some of these have mar-proof and scorch resistant surfaces. It is recommended that you avoid metal tables because of the possible shock hazard.

If you must work from a very small surface, there may be insufficient space for both your work and the tools. In this event, you should locate your tools nearby on a chair or foot stool. This leaves the surface free for a soldering iron, a few tools, and your work. It is wise to return a tool to the box immediately after use. Another way to keep the work area uncluttered is to stop frequently, return all tools to the box, wipe the surface free of splashed solder, and then continue.

A desk or table top can and should be protected from the effects of hot solder splashes and tool scratches. Transite, which is a heat resistant building material in flat sheets like plywood, is recommended. Masonite or plywood will serve almost equally as well; even a thick layer of newspaper will do temporarily.

If you work in the living area of a home or apartment, be sure you protect the floors of their coverings and surrounding furnishings from the damaging effects of splashing solder. Use sheets of plastic or painters' drop cloths for this purpose. Layers of newspaper can also serve as a temporary protection.

STORAGE CABINETS

In the case of cramped quarters, all tools and material should be put away after each job. Space in a closet, pantry or the corner of a room can be used as storage. Keep everything in as few boxes as possible for easier and quicker clean-up.

Every imaginable kind of container has been used to store parts. Cigar boxes are excellent for storing your supplies, as they are reasonably strong. Plastic boxes (used by many fishermen) make good storage containers. They have snap lids and dividers that allow you to keep parts separated. As you progress, you may wish to equip yourself with multi-drawer cabinets. These are especially suitable for keeping parts accessible but separated. The entire cabinet unit can be easily stored at the end of a work period.

Tools should be stored separately from parts and material. The box provided with the ASI tool kit makes it possible to keep all your hand tools together. It has adequate space for additional special tools that you may purchase. Arrange it with the most frequently used tools in the top tray and the lesser used ones below.

Additional storage space can be provided by incorporating overhead shelves or cabinets. Hutch cabinets or cabinets with doors or drawers may be installed. Smaller multi-drawer cabinets can also be stacked on the bench top to accommodate frequently used parts, such as assorted resistors, capacitors and hardware.

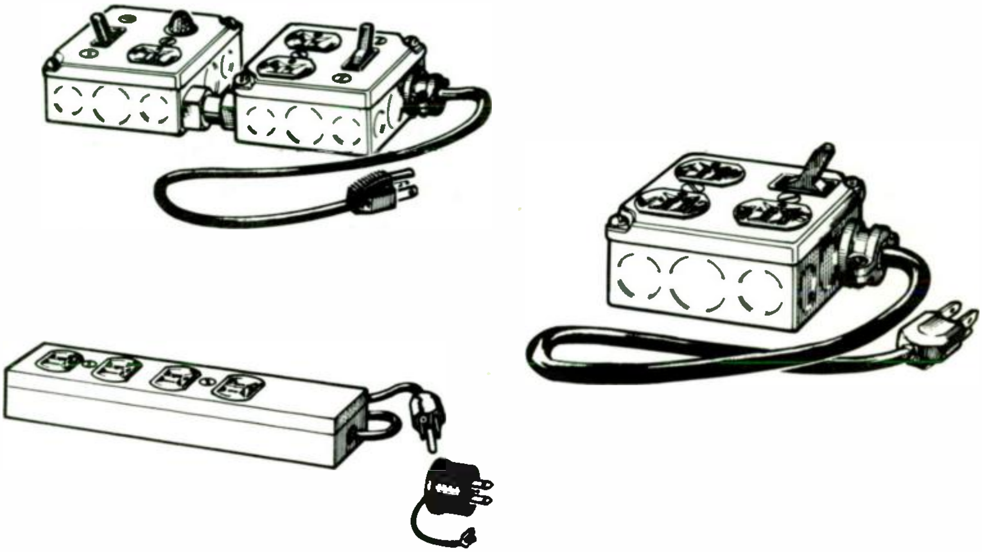


Figure 4 — Electrical outlet boxes may be assembled or purchased.

ELECTRIC POWER

Once the work area and storage space problem has been solved, turn your attention to methods of providing power for your working area. Electric power is essential for your service work and can be provided at your bench in several ways. The bench in Figure 3 has been provided with an electrical outlet strip mounted to an apron across the front of the bench top. There is another outlet strip at the rear, facing upward. The front strip is used to power soldering irons and units under test. The back strip accommodates the test instruments.

An isolation transformer should be utilized in the test instrument power supply. The isolation transformer will prevent a direct short to ground through a test instrument that is connected to the wrong side of the power line. This is extremely important because of the large number of AC/DC power supplies found in radios and televisions that are sold today. The AC/DC power supply does not use a power supply transformer, but is connected directly across the line. The ground or neutral lead of the power cord is connected to the metal chassis. If the power cord is reversed when plugged into an AC outlet, a 115-Volt potential is placed on the chassis and presents a shock hazard. Any unit manufactured today with an AC/DC power supply will have a polarized power cord. A polarized power cord will reduce the possibility of this dangerous shock hazard from occurring. An isolation transformer will also reduce the possibility of damage to test instruments. It effectively isolates test instruments from the line power supply.

The isolation transformer should be connected between the electrical power source and the test instrument receptacle. An isolation transformer has a 1 to 1 turns ratio between the primary and secondary winding. Be sure that the power rating of the isolation transformer is sufficient to supply the required power for the test instruments.

Hardware stores sell multiple outlet cords which are suitable or you may wish to make your own. It is recommended that the unit you buy or make be fused. In addition, you may want it to contain a switch and

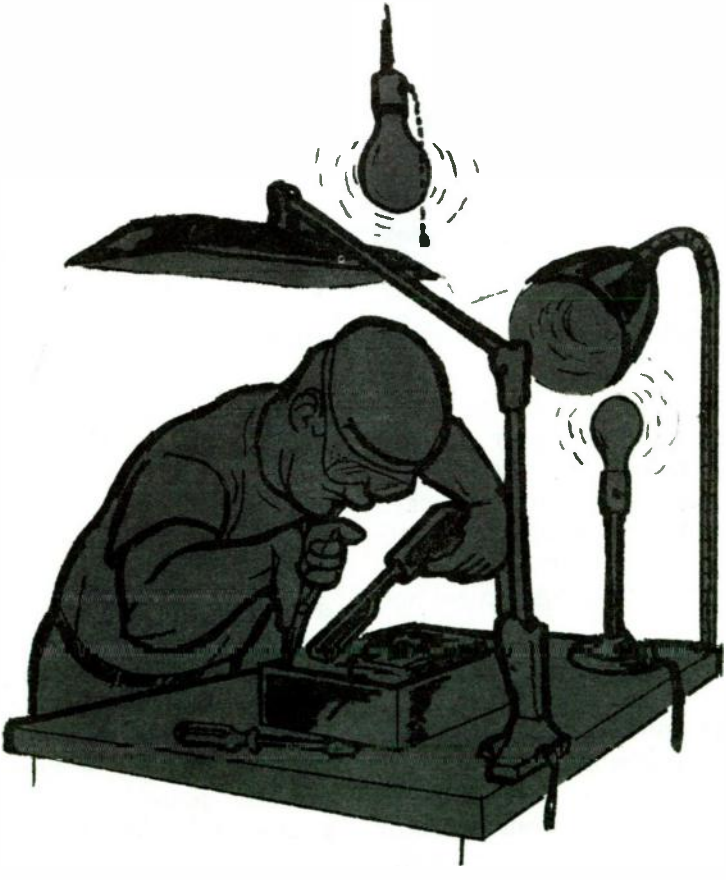


Figure 5 — Good illumination is a must when repairing equipment.

an indicator light. These features are available or can be incorporated.

Each outlet strip on the bench illustrated (Fig. 3) is protected with a ten amp resettable circuit breaker. Standard electrical fuse receptacles and fuses can also be used, and you might want to incorporate a master switch to cut all power to the bench outlets.

ILLUMINATION

Good lighting of your work area is another essential. If present lighting is inadequate, it can be improved with the addition of ceiling fixtures. As a temporary solution, a desk lamp can be used on the bench top, but position it over the work so that it does not produce glare. Incandescent lighting, rather than flourescent fixtures, eliminate any possibility of generating RF interference by the flourescent bulbs.

If you must set up your work area each time you do repairs, a floor lamp may be the easiest to use. Be certain, however, that it gives you an ample amount of light to work by.

SHUT OFF POWER FOR SAFETY

All power should be removed from the bench outlets at the completion of your service work. Removing power from the bench outlets prevents the possibility of inadvertantly leaving a test instrument energized for long periods of time. Although some instruments will operate indefinitely without failure, it is a poor practice to leave equipment unattended when energized. A wall switch will generally suffice as a master power switch depending on the amount of power required. If a large amount of power is required, a circuit breaker is recommended for the protection it affords and the higher current rating of the switch contacts.

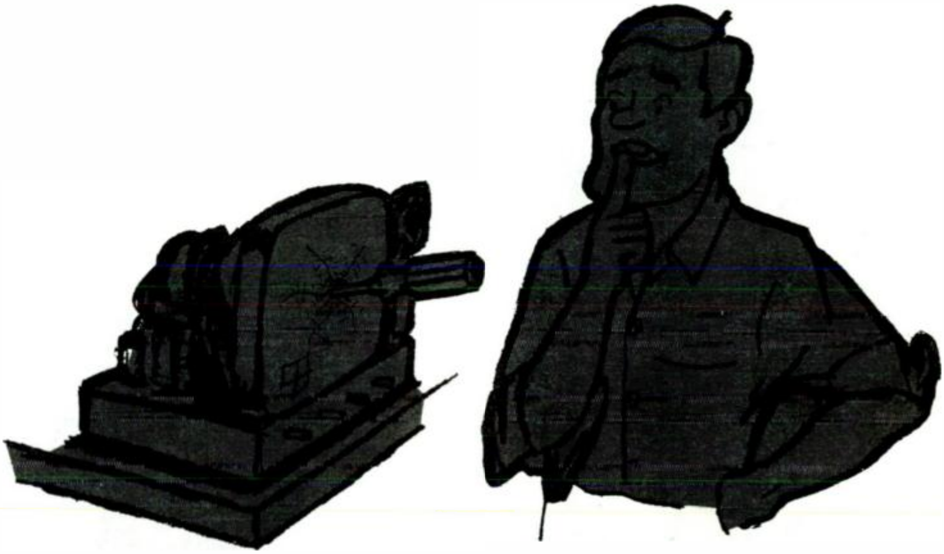


Figure 6 — Don't let the tool slip and damage other components in the equipment being repaired.

SOLDERING IRONS AND HAND TOOLS

Soldering irons can inflict serious burns. You should never grope for the iron while you're looking somewhere else. Follow the same practice when you are using a tool: Look directly at the tool you are picking up and then at the work on which the tool is being used. The instructional material should be carefully studied first. Then complete the work with the tool after you have decided what you need to do. Sidecutters that are designed to easily cut wire can just as easily cut your hand or fingers. A misused screwdriver or knife can easily puncture the skin. Remember that any tool that is being forced when it is being used can slip and injure your hand. Equally as serious, the tool can slip and damage electrical components in the customer's set.

Scrap parts should always be promptly discarded. This is especially true of glass tubes and small objects that can be swallowed or played with by children.

SAFETY

Whether your shop is simple and in your home or is complex and out-

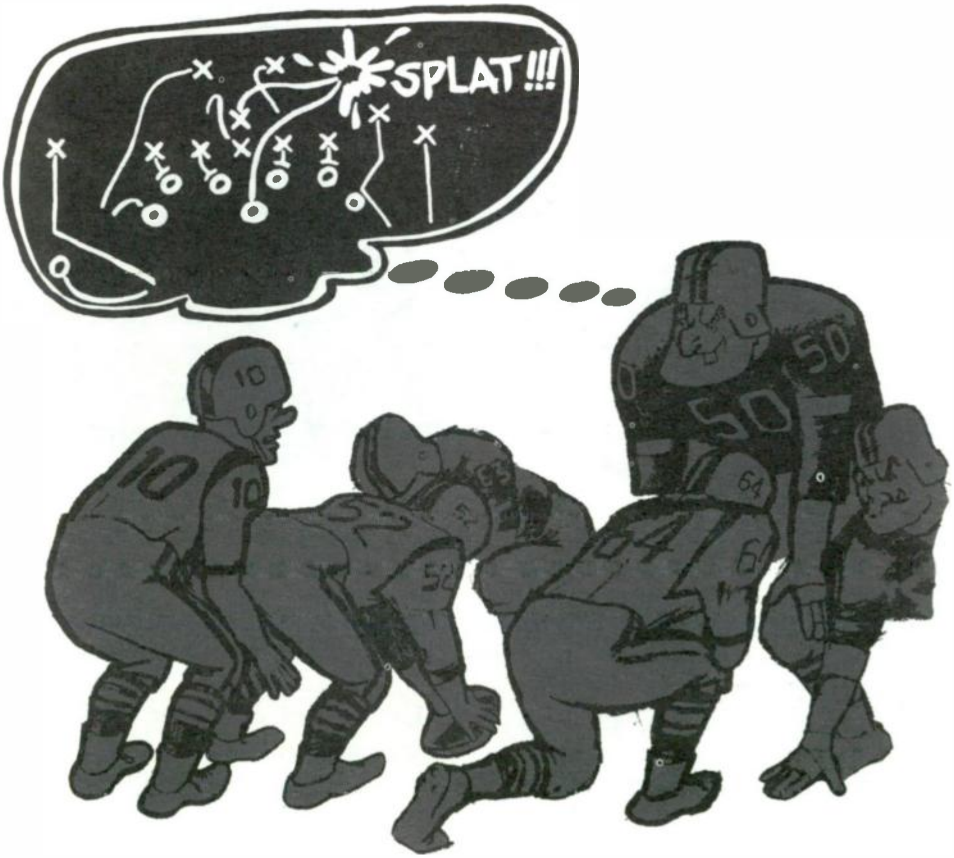


Figure 7 — Plan your work ahead of time.

side your home, it should be arranged with safety in mind. The most important word on safety is THINK BEFORE YOU ACT. If what you are about to do presents any possible hazard to your health or your life, DON'T DO IT.

THINK SAFETY

For your own personal safety, always think before you proceed with a repair job. Remove power from the instrument you are working on before you attempt to replace a part. It is *not* sufficient to just turn off the power switch of the device; unplug it! If it is ever necessary to work on a unit to which power is applied, you might do what some safety directors recommend: "Work with one hand behind your back, and preferably in a rear pocket." By doing this, you will reduce the possibility of the electric current flowing through your body.

It is advocated that you never work alone. Someone nearby should check frequently to see that nothing has happened to you. This is the principle outlined by most state labor departments that establish a minimum of two workmen on any shift. Most homes have posted a list of phone numbers for the fire and police departments and other emergency services. You should also have these phone numbers and a first aid kit with a recommended chart of emergency first aid treatments handy.

Figure 8 — Don't leave equipment around where children can reach it.

Figure 9 — Look before you reach.

If the floor of your area is concrete, there will be the ever-present danger of electrical shock. This hazard can be reduced by using a rubber or plastic mat on the floor in front of your bench. It will insulate you from the earth ground which provides an alternate return path for the electric current.

WORK HAZARDS

A work area that is accessible to children can present innumerable hazards to their safety.

- A hot soldering iron can cause severe burns. Unplug it and allow it to cool before you leave the area.
- An exposed chassis not in its case presents a shock hazard when left plugged in.
- Sharp objects, such as screwdrivers, picks, and soldering aids, can destroy eyesight or inflict other serious wounds. A knife of any kind *can be deadly.*
- Heavy pieces of equipment can be pulled from a bench by the dangling power cord onto the head of a small child and cause injury.
- Slender metal tools, pieces of wire or other metallic objects inserted into electrical outlets can result in shocks which may maim or kill.
- The broken glass of a vacuum tube can easily cut small hands.
- Small objects left lying around can be swallowed by a child or clog his windpipe.
- Electric shock is inherently dangerous, but much bodily injury is done to hands and arms involuntarily when the tool is

physically jerked away from the source of the electrical shock.

The best procedure is to lock the shop when it is unattended. If this is impractical, all tools and material should be kept in locked drawers or boxes.

If it appears that we are strongly emphasizing safety, that is our intention. We believe that safety is the most important aspect of your training and that safe practices should always be uppermost in your mind.

TEST

Lesson Number 18

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-018-1.

1. The time to start spare time service work depends upon
A. your objectives, financial needs, and initiative.
B. your having friends who have radios to repair.
C. your having completed the course.
D. the amount of spare parts you have.

2. A work bench
A. can be made of flimsy materials.
B. can be thrown together from junk lumber.
C. should be made of metal.
D. could be made from second-hand lumber and parts, equipped with a level surface for a top, and having a suitable electrical supply.

3. When you are building a work bench:
A. leave toe room at the bottom.
B. make provision for leveling the bench.
C. provide proper electrical outlets.
D. all of the above.

4. A work area that must be set up each time
A. should be able to be dismantled in five minutes.
B. is the only way to have a home workshop.
C. should have the surrounding floor protected from solder splashes.
D. can be thrown together without much thought being given to protecting the surrounding area.

5. An isolation transformer should be used in the circuit that will supply the test instruments to
A. step up the voltage.
B. step down the voltage.
C. filter out any RF variation.
[✓ D. effectively isolate the test instruments from the line supply.]

6. The best illumination of a work area is provided by
A. overhead lighting.
B. floor lamps.
C. flourescent fixtures.
[✓ D. overhead incandescent lighting.]

7. Hand tools should be
A. left scattered on the bench.
[✓ B. arranged in an orderly manner.]
C. piled together within easy reach.
D. thrown in a drawer after use.

8. Spare parts can be kept
A. in a few cabinets.
B. in a few large boxes.
C. in drawers.
[✓ D. grouped by types and neatly arranged in cabinets.]

9. Your home work area should be
[✓ A. inaccessible to small children.]
B. in a damp location.
C. illuminated by flourescent light.
D. small and compact.

10. The most important factor in your home workshop is
A. proper lighting.
B. proper tools.
[✓ C. safe practices.]
D. proper outlets.

Notes

"School Without Walls"
"Serving America's Needs for Modern Vocational Training"

Complete The Things You Start

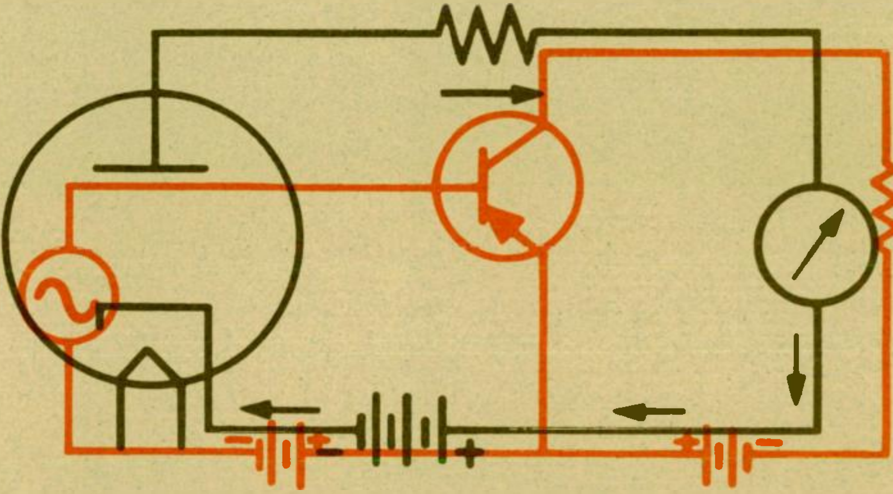
Put some muscle into it! Education requires the utmost patience. As the old saying goes, "Rome wasn't built in a day." Your ASI Training Course is so designed that you can complete it in as short a time as possible, consistent with good study procedures. Good, steady work will produce good results. Strive to do the best you can in every way. Sometimes if you can give that little bit of extra effort it will be enough to get you over-the-hump.

As we all know nothing in life comes easy and we must put forth a professional effort to attain professional results. Be patient enough to complete the things you start and realistic enough to know your strong and weak areas. Remember Rome!

S. T. Christensen

LESSON NO. 19

STARTING YOUR OWN BUSINESS



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-019

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

403

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Contents

STARTING YOUR OWN BUSINESS

INTRODUCTION

It is quite possible that one of the reasons you decided to take this course was your wish to go into business for yourself. This is good. Such thinking is the backbone of our country. Without independent businessmen, and men with the desire and ability to become servicemen, our country would probably not have enjoyed the tremendous rate of industrial growth it has experienced over the past years.

You may be thinking seriously about "becoming your own boss," but you should consider all the pros and cons of such an endeavor. You know, of course, that it isn't easy and, unfortunately, not all students are "cut out" to manage their own business. Actually, there is little doubt you will have the technical ability necessary to make it successful, but important as that is, it is not the sole consideration. You must be emotionally equipped, as well.

Also, in all probability, you are married; if not, you soon may be. A wife deserves your consideration. Maybe she is the kind of woman who prefers her husband to have a steady income and steady hours, rather than a wildly fluctuating income and almost unlimited hours. So, let's face it, starting an independent business is not a trivial matter for you or for your family.

Is it worth it? Only you can decide. If after a few years of working for someone else, you feel you have the skill and ability to operate your own establishment, then you should explore all the possibilities. Good independent repair shops can be very profitable, and their owners enjoy considerably higher earnings than the people working for them. Naturally, the salaried workman doesn't have the "headaches" common to all business operations, but neither does he share in the thrill of building his business and in the profits of a successful business. The very first consideration then is to know yourself. Can you assume responsibility? Can you discipline yourself to get to work on time when there is no time clock for you to punch and no boss to answer to? Can you meet the public, purchase supplies, handle vendors, grasp the fundamental rules of advertising? Are you capable of making your own intelligent decisions? All these questions, and many more like

Figure 1 — After working for others for some time, many students start thinking of owning their own business.

Figure 2 — You're going to have to look inside your own head—and the heads of many others—before you can make a final decision.

them, you should ask yourself frankly and honestly. Don't cheat yourself by dodging the issue. Face up to it squarely and accept nothing less than the truth as you see it. If your answers to these kinds of questions is "Yes," then go further. And how do you go further? By research!

Figure 3 — There's plenty of money to be made in the service business.

DETERMINE THE NEED IN YOUR AREA

Once you are convinced that you can become a successful owner of an independent repair shop, look around you. Is the area in which you live well-supplied with existing service shops? Have any well-established repair shops gone out of business recently? If so, why did they fail? Are there too many shops in your particular area? Are there any "price cutters" who will offer any new service shop tremendous competition in order to force him to close his doors? Are there enough customers in your area to support another service operation, or will you have to depend on "stealing" some of the other fellow's business?

If necessary, "count noses" in your area to see if a business like yours would survive. Consider, too, if your particular area is growing or decreasing in population. There is a definite trend of population shifts away from the heart of the major cities. This means that the population as a whole tends to move to the suburban areas which surround the major cities. Try to determine whether

Figure 4 — The service business, too, can cause plenty of headaches.

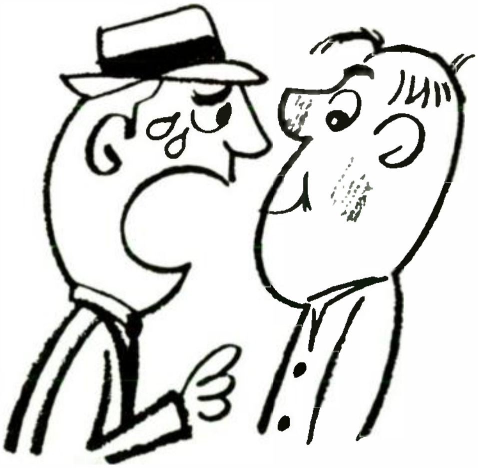

Figure 5 — Irate customers must be met with a smile, even though you would much rather do otherwise.

your particular area is likely to increase or decrease in population over the next few years. Remember, those conditions that exist today are important, but those conditions that will probably exist in the next few years could spell success or failure to any new business.

you will want to spend as little time as possible traveling. Time is money. If you spend a couple of hours traveling each day, you will have less time to work in your shop. The general rule then is to look carefully at your own immediate neighborhood. Be careful to consider all the bad points of moving your entire household to a new and seemingly more promising area. If you don't consider this, your family may resent it. Also, there are considerable costs involved in such a move. And finally, you will have lost one of your biggest assets, the respect of your neighbors for you as a skilled repairman.

Figure 6 — Some salesmen sing such sweet songs that the unwary shop owner may find himself loaded down with unnecessary inventory.

It may be that your immediate area is not a good place in which to start a new service shop. If this is the case, and if you are still determined to become an independent businessman, then look further. Keep in mind, however, that there are definite advantages in starting a new business in your home town. First, people know you, and if they know you as a highly-skilled workman who has worked his way up to going into business for yourself, they will be encouraged to bring their service business to you. Also,

Should your initial research indicate that there just isn't room for another service shop in your immediate area, take a long look at those shops that are currently doing

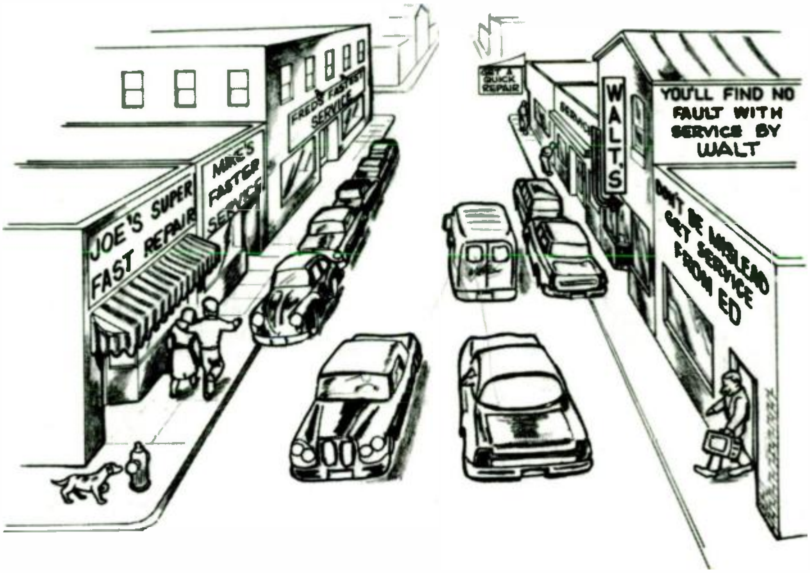

Figure 7 — Are there too many shops now?

business. What are their strong points? What are their weak points? Do they specialize? Do they advertise? Do they appear to know how to maintain their present business and promote new business?

You may find that their facilities are dirty, grubby and low-grade. These are common conditions found in too many independent service shops of all types. It's possible, too, that they are trying "to be all things to all people"; that is, they handle such a wide variety of service jobs that they are bogged down in overhead and paper work. There are many areas of specialization that are available to the alert repairman. Handling all the repair and maintenance work for a local store is one such area. The list is virtually unlimited if you analyze the local needs carefully and then deliberately set out to fill these needs.

The next important point then is to determine what kind of shop you want and will be able to successfully operate.

THE FINANCING BOTTLENECK

Most salaried workers think that money—or the lack of it—is the single outstanding reason why more people are not in business for themselves. They also think that

Figure 8 — Old friends will welcome you in your new business

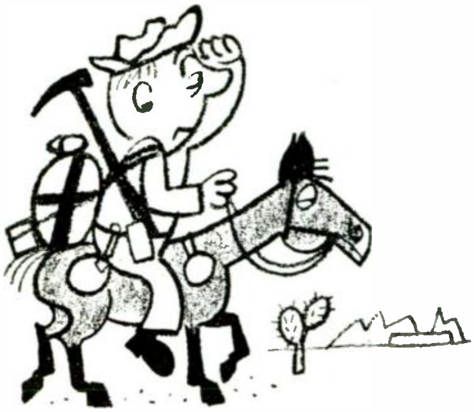

Figure 9 — "Prospecting" for a new business area can be exciting, but it can prove fruitless.

money—or the lack of it—is the reason why most businesses fail. This is not true. Repeated surveys have shown that ability to manage—or lack of ability—is the biggest operating factor of all independent businesses.

But money is important, and you cannot start a business without it. You will need money, but probably not as much as you think. If you have been frugal in handling your own finances, it is likely you may have the funds necessary to start your own business. If so, you are to be congratulated. However, if you do not have all the money for such a venture, don't be discouraged. Money can be obtained; that is, it can be obtained if your plans for a new business are sound.

First you should talk with your local banker. Strange as it may sound, these men are in business primarily to lend money. If people and companies stop coming to them for loans, they would be out of business in a hurry. They want to lend money and welcome serious discussions with those who want to borrow it. But don't go to them with sketchy information. A banker is a shrewd businessman. He will not lend money unless he is very certain he will get it back—with a profit. And if he doesn't get it back, he wants to be able to sell some of the borrower's property until his loan is paid in full. These are the facts of dealing with the moneylenders, but you can't blame them. You, too, would be a poor businessman if you loaned money to all who came asking for it without first determining if they have the ability to repay.

Figure 10 — There are many possible areas for specialization. Often suppliers will help you advertise them.

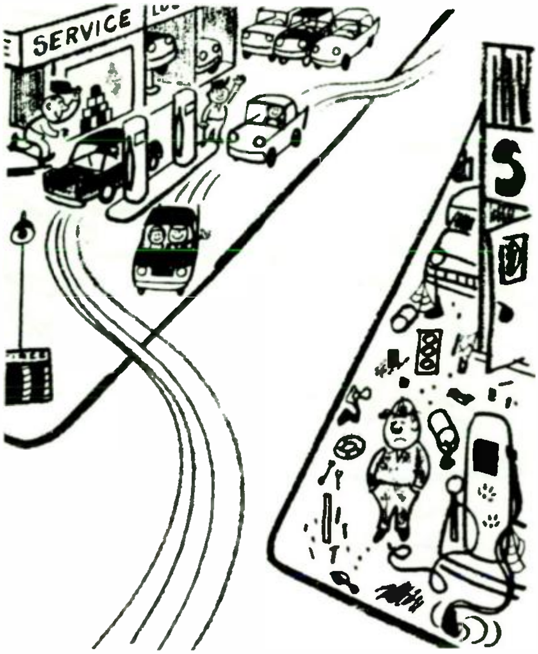

Figure 11 — A clean shop is always more inviting than a dirty shop.

If you don't have cash, then you will have to have security. This may be a home, a car, a boat, or an insurance policy. Don't waste your time seeking a loan unless you have the necessary collateral to back it up. If you have collateral, you most likely will get the loan. If you don't have collateral, in all probability you will not get the loan. But you might not obtain the loan even with collateral, since the lending agency wants to be assured that your new business has a good chance of succeeding and that you will repay their loan promptly.

Other lending agencies that assist in starting new businesses are: small business investment companies, state development departments, leasing agencies, and others, such as the Small Business Administration.

TYPE OF BUSINESS

Partnership

If you don't have the cash, and if you can't get a loan, you should consider taking a partner. A worthy partner may be someone like yourself who thinks the way you do about going into business for himself. By taking in one or more partners, you stand a good chance of raising the money among you. You also stand a good chance of "having two strikes against you" before you start. Partnerships can be difficult. Your closest friend may turn into your worst enemy after a few years as your working partner. The glamor of your own business soon fades if friction develops between the partners, and in too many cases, friction *does* develop.

Figure 12 — You can specialize.

Partnerships are also undesirable from a legal standpoint. For example, partners are generally responsible for their partner's debts, actions, and obligations. If your partner ran up a huge bill and then decided to leave town unexpectedly, you would be held liable for the payment of the bill. The same thing would be true for him.

Also, most partnerships are automatically dissolved when one partner dies. In some cases, the loss of a partner means that his share of the business goes into probate and could cause a forced sale at disaster prices. A successful working partnership can go out of business almost overnight merely with the death of one partner.

Sole Owner

If you decide to be the sole owner and the only boss of your business, you will have many advantages. For example, all the profits will be yours. You will make all the decisions; you will establish prices, hours, etc. Your paper work will be reduced, but your responsibilities will be increased greatly. A sole ownership is usually the most uncomplicated way to start a business. It has definite disadvantages, however. For example, you must be prepared to absorb all losses and creditor claims. In some in-

Figure 13 — Bankers are in business to lend money, but they want adequate collateral.

stances, creditors can and have attached the personal assets of a sole proprietor. This means that if your business runs up bills which cannot be paid, there exists the possibility that the creditor could force you to sell your personal belongings (car, house, etc.) to satisfy his debt.

Corporation

Perhaps the safest form of business ownership is the corporation. Its safety lies in the fact that in the eyes of the law, it is a separate entity. Normally you can lose every dime you have in a corporation, plus accumulated corporative debts, without risk of losing your personal assets. A corporation can go bankrupt, in many cases, without affecting the personal holdings of its officers. This is not an absolute rule, however. If it can be proved that the corporation was set up only to avoid personal liabilities, courts can decide to "pierce the corporate veil" and seek financial satisfaction from the personal assets of the corporate officers.

Another disadvantage of the corporate structure is the complex legalities, which include excessive amounts of paper work and possibly a higher tax bracket. Corporations are regulated very closely by state law. Most private citizens are not qualified to run a corporation or set up a corporation without the constant advice of a qualified attorney. Obviously, this represents an additional expense. Your paper work can be expected to be heavier in a corporation than it ever would be as a sole owner or in a partnership.

On the other hand, corporations can raise working capital through the sale of stock. This is a definite advantage, although it can lead to loss of control of the business by selling too much stock.

Most people who take the plunge into independent business do not feel a corporate structure answers their needs. In the first place, any member or officer of a corporation is legally merely an employee of the corporation. This means that the salary paid to any officers must be

Figure 14 — If your personal cash is limited, don't try to stretch it. Don't proceed without sufficent capital.

Figure 15 — Taking in one or more partners is often a good way to raise capital, but be sure of those with whom you agree to spend years in business.

approved by a Board of Directors or by a vote of all shareholders. Business expenditures, expansions and almost any major decision become a corporate policy. You can, of course, run a "loose" corporation, but nevertheless, you have to conform to specific state laws.

Fundamentally, corporations are an excellent structure for any business. If you feel you can handle the paper work and the "flavor" of a corporation without its becoming annoying to you, you perhaps should consider the corporation structure. On the other hand, if you want to go into business for yourself, and yourself only, the corporation may not be for you.

Corporations cost money to set up. You should employ an attorney, whose services are not cheap. Also, the state charges a fee for corporation registry. This represents another cost. If you feel a corporation is the only logical business structure for you, you must be prepared to spend greater amounts of capital in order to start into business.

BUYING A BUSINESS

Once you have reached your decision and you are assured of adequate financing, you can look seriously toward a profitable site for your business. It may be that you will wish to buy a going business. If so, again consult the real estate brokers in your area. If a service business is for sale, they will know it. Or watch the classified ads in your local paper under the heading "Business for Sale". Some owners prefer to sell their business quickly and without the aid of a realtor. The object of this maneuver obviously is to avoid the broker's selling fee. Unlike houses, however, most businesses do not hand up a "For Sale" sign. The mere fact that the business is for sale is enough to make prospective customers hesitate to use their appliance services. Consequently, you find very few "For Sale" signs in front of a business, even though that business may be on the active market. Another approach if you wish to buy a going business is to talk directly to the business owner. In many instances, owners entertain the thought of selling their business but never quite decide to make a formal announcement. Should you approach such an owner, you may find a welcome ear.

There are advantages in buying a going business. Some of these advantages appear in the business record. If you decide to purchase a going business, you have the right to inspect the books of the business for the past several years of its existence. Careful analysis of these books, especially the tax payment records, will soon tell you whether this business is making money or is unprofitable. Unless you are qualified to interpret fairly complex bookkeeping reports, you should employ the services of a qualified bookkeeper or a certified accountant. These men are trained to interpret figures correctly. With a few hours of intelligent study of prevailing conditions, they can tell you exactly where the business stands monetarily.

Another advantage in buying a going business is that it usually is fairly well equipped. There are many items necessary in any service business that cannot be appreciated by those who have never operated such a business. These include items such as laundry and uniform supplies, heating, taxes, lighting, snow removal, window washing, charitable gifts, uncollectable debts, employee compensations, etc. A going business will have been faced with all the minor details and will have had to pay the bills that they represent over the past few years. If you are starting a brand new business, there is the possibility that you might neglect to recognize a cost of overhead that could spell the difference between profit and loss. With accurate records of a going business, you can spot the cost of overhead more accurately than you could estimate your own potential overhead based on an intelligent evaluation of the overhead you may expect at the start of your new business.

Then, too, a going business often represents "good will." Often the owner of a business may list "good will" as one of the items of the sale. This good will is in addition to the equipment, tools, parts, lease and

Figure 16 — A sole owner of a business keeps all the profit he earns.

any other physical items. It is difficult to assess the actual value of any good will. Basically, it means that the business has been established long enough to be accepted by the community. The owner is recognized as a qualified merchant. In most cases, you can assume that the customers who have been coming to the business will continue to come even though the business changes ownership. These customers are part of the good will and are considered a legitimate item of the sale.

How much is good will worth? Who can say? Some businesses are bought and sold with only a single dollar allocated for the transfer of good will. Other businesses consider good will a major part of the transaction, and consequently thousands of dollars exchange hands for the business' good will.

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142A BUSINESS OPPORTUNITIES
SELL—BUY

143 General

A GOING HARDWARE and Sporting Goods Store — With living quarters and garage in fast growing northern community on main highway and easily accessible to Expressway. Box N-7124. Det. New 31.

AT GIVE AWAY Price—Television service business, $3,000. An ideal location in Ann Arbor on main thoroughfare, no parking problems. Well-equipped with electric cash register, adding machine, desk typewriter, etc. Long lease available at reasonable rent. For further information write P.O. Box 202, Ann Arbor, Mich.

RETIREMENT Deal — Tired of nothing to do, drive to Marine City, small store, 2-flat, excellent ntown location, near St. Clair r, use for used furniture, orking or other purposes, terms. Marine City. RO

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Figure 17 — Many businesses for sale are listed in the classified sections of local newspapers.

As a general statement, you should not consider good will as too important a factor in a small business, because so much of your business activity will center around your personal services and your own business personality. One man may build a good business on the strength of his ability and integrity alone. When he sells the business, the new owner may bring in a different set of rules which may be different from those followed by the previous owner. It can be seen, therefore, that what one man considers good will in one type of service business may not be good will for another man. You will have to face your customers yourself. The good will that you build as an independent businessman reflects you as an individual.

This is not to say that you should ignore good will. There is every reason to believe that you can maintain the customers equally as well, if not better, than the previous owner. However, there is not way that you can be sure this will be true.

Look into the Lease

If you are comtemplating buying a going business, look into the ownership of the building in which you expect to operate. There are many different forms of leases. Also, leases run for different lengths of time. Some are transferable; some are not. If the owner of a business sells to a new owner, the lease may expire automatically and must be renewed by the new owner. In other cases, the lease is transferable, and it may be several years before it is up for renewal. Make sure the lease is

CONDENSED STATEMENT OF PROFIT AND LOSS

	ABC Service Shop		Average Successful Service Shop	
	AMOUNT	% OF SALES	AMOUNT	% OF SALES
NET SALES	$110,000	100.00	$120,000	100.00
LESS COST OF GOODS SOLD	80,300	73.00	87,600	73.00
GROSS PROFIT ON SALES	29,700	27.00	32,400	27.00
LESS EXPENSES:				
EMPLOYEES' WAGES	9,900	9.00	10,800	9.00
OCCUPANCY COSTS	4,800	4.36	4,800	4.00
ADVERTISING	550	.50	600	.50
ALL OTHER EXPENSES	8,855	8.05	6,600	5.50
TOTAL EXPENSE*	*24,105	21.91	*22,800	19.00
NET PROFIT BEFORE TAXES	$ 5,595	5.09	$ 9,600	8.00

Figure 18 — A "quick look at the books" is fine, but it's best to hire an expert to "digest" all areas for accuracy.

transferable and is renewable for a definite length of time at a definite rental figure per month.

Check Inventory

Be especially careful, when buying a going business, to check the actual inventory of parts and supplies. In many instances, the previous owner may not have kept accurate inventory records. He may have bought unwisely and may be "stuck" with much obsolete merchandise. Also, some of his inventory may be on consignment. Consignment means that the parts in question are only paid for when they are sold. Parts that are on consignment should not be considered a saleable part of the business.

Also, you should make sure the inventory is figured on a cost basis. A brand new businessman may find himself buying inventory at the retail figure. For example, if a part sells for $1.30 retail and 80¢ wholesale, you should figure the wholesale price as the inventory figure. Before signing an agreement to purchase, check the inventory very carefully. Then be sure your purchase agreement gives you the right to recheck the inventory before the actual transfer of property. It takes several weeks at least for a business to be bought and sold. During this time, it is possible to deplete an inventory completely. If you agree to buy X dollars worth of inventory two weeks before the transfer of property, the old owner will very likely use his existing inventory during the time it takes to make the actual transfer of sale. You should make allowance for this. Businesses that are on the market for sale characteristically do not order parts for extensive inventory. On the other hand, they try to "live off their inventory" so that they are not putting more money into the business. You can't be too careful

Figure 19 — All inventory should be checked very carefully, ***before and during*** **the closing of a sale.**

when studying inventory during the anticipated purchase of a business.

Check Equipment

Another difficult area to evaluate monetarily is the worth of the equipment. Service equipment is like any other equipment; it depreciates quickly in value. Fortunately, most service equipment enjoys many years of anticipated life; that is, it will serve you well for many years even though it is comparatively old. Nevertheless, you will want to make sure that you are paying only a fair market value price for the equipment involved in the anticipated sale.

To do this, you should make a list of all equipment involved in the sale. Be sure to record the brand name and model number for each individual piece of equipment. It's a good idea also to determine the exact year and month of purchase of each piece of equipment. With this information, you can find out what each piece of equipment is worth. A good place to do this is at the equipment supply houses in your city. Usually the business that sells the equipment new will be able to advise you on the worth of their used equipment. Also there are used equipment dealers who will tell you the market value of the equipment you intend to purchase. Do not accept the owner's appraisal of the worth of his own equipment. As you may suspect, this will quite likely be an inflated figure. Even though it may take you several days to establish the value of each piece of major equipment involved in the sale, this is time well spent. In the long run, such effort can save you a great deal of money.

Equipment Depreciation

A good businessman will maintain an index card on each piece of major equipment in his shop. On this card, he will record the name of the equipment, the date purchased and the purchase price. Each year he will take off the maximum allowable depreciation from his income tax. For example, the Internal Revenue Service may determine that a lathe has an anticipated service life of ten years. The lathe may cost $300.00 when new. This means that the lathe can be depreciated at the rate of $30.00 per year for ten years. At the end of the ten years, the lathe is considered obsolete.

There are other methods of depreciation which allow the owner to take off greater amounts for depreciation per year for the first few years and then lesser amounts as he approaches the end of the anticipated service life of the equipment. When you take the figure obtained by dividing anticipated service life into original cost as a yearly depreciation figure, this is known as the straight line depreciation method. If you prefer to take a greater share of your allowable depreciation off your income tax during the early years of the equipment life, this is known as accelerated depreciation. The manner in which you figure depreciation is your own decision, as long as you comply with the rulings of the Internal Revenue Service.

Too few independent businessmen accurately figure their equipment depreciation. This is one of the areas that separates the businessman from someone who is trying to start a business. Depreciation costs are important and should be carefully analyzed.

As the prospective buyer of a going business, you have a right to demand clarification of the transfer of the business name. You may decide that any purchase of the physical parts of the business be accompanied by full rights to the existing business name. This is a normal business procedure. Also, you should obtain legal agreement from the seller that he will not be involved on any level with the ownership or operation of a similar business within an area of definite radius for a definite period of time.

For example, you may buy a business owned by Mr. Jones. The

Figure 20 — Check equipment thoroughly. Make sure it is listed at fair market value.

name of this business may be Jones Service. It may be a profitable business and a good buy for you. If you do not obtain an agreement from the seller, you may find Mr. Jones staying out of business for a few short months then deciding to return to business. At this point, he may decide to open his business across the street from you and call himself Jones Service again. In doing this, he may destroy your good will and seriously hamper your chances of success, because he will have been established in the area, while you are a new owner fighting for recognition.

An attorney should be consulted to be certain that the former owner of the business cannot legally set up direct competition with you as the new owner of his business for a definite number of years within a definite market area. If the former owner decides he wants to go back into the same service business, you cannot stop him from doing so if he decides to move a number of miles away from you. This is still his right as an American citizen. What you can get, however, is an agreement that will prevent him from reopening under his name or any name within your immediate market area.

Buying an existing business is often a better way to start than to open a new business. It does, however, have disadvantages. We have covered some of these and you can see why they are disadvantages. To review, it's often more expensive to buy an existing business than to build a going business. Also it's quite easy to buy an existing business and then have it "fall apart," because you thought the business would be available to you in the same degree as it was available to the previous owner. This is an assumption you have to make, but you cannot be sure it will be true. And finally, the task of evaluating the actual worth of inventory and equipment is very difficult. If you are new to the business world, there is every possibility you may find yourself being overcharged for equipment. This obviously adds greatly to the cost of your setting up in business. Then, too, the equipment that you may be forced to buy as part of a going business may not be the equipment you really want. You may not wish or plan to do business in the identical manner as the previous owner. All these factors are disadvantages of an existing business. There are, however, many advantages as well.

SOLICIT LOCAL HELP

Fortunately, every community welcomes new business. If you are not aware of it, you may be pleasantly surprised at the reception and help that is available to all prospective new businessmen in any area. For example, your local Chamber of Commerce can be of definite help. They will explain your particular business "climate." They normally keep accurate records on the local business potential. They can show you how your area compares with comparable areas from an industrial standpoint.

You can approach them with the idea that you wish to know how your particular community compares with other communities from a wealth standpoint. If, for example, you are fortunate enough to live in a very wealthy community, it may be unwise to start an independent service garage. Most wealthy families buy only new cars. They may buy a new car at two-year intervals. Your success as an independent repair shop may hinge heavily on the servicing of cars after they are three or four years old. As you can see, if your anticipated market area is saturated with newer cars that are serviced by the selling dealer under the manufacturer's warranty, the chances of your getting business becomes questionable.

Figure 21 — If most people in your area buy new cars every year or two, they do not require much service.

On the other hand, if your anticipated market area is on the low income side, you may find yourself able to get a reasonable amount of service work. Your charges must be extremely modest, however, and they are often difficult to collect.

You should, therefore, know the approximate wealth of your community. If you find it difficult to get figures from any local organization, you can do your own research by driving through the neighborhood. If most of the cars you see are new, you can determine your potential market. If the majority of cars in your area, however, are in the three to five year old group, you can interpret this as an encouraging sign.

If you plan to open a repair shop specializing in radio and TV repair, you should make a thorough canvass of your neighborhood to learn if there are many other shops doing the same kind of work. Repairs of appliances such as radio and TV are sometimes handled by the dealers selling these appliances, and you might talk with them about your prospects of the new repair service you are establishing.

Your local newspaper is another excellent source of information. Editors of these newspapers know their market potential, because they use figures to entice advertisers. They have actual records on the spendable income of the average resident in their area. They may not wish to divulge these figures to everyone, but they are available for prospective new businessmen in the area.

From this review you can see that the prospect of going into business

Figure 22 — Very old cars may require a good deal of service.

for yourself involves much more than skill as a service technician.

OPERATING A BUSINESS

Your main purpose at this time is to make sure you know:

A. Exactly how you will operate;
B. What your service will consist of;
C. How you will set up your promotional program.

How You Will Operate

Will you operate from your basement? Garage? Rented space? Small apartment? These are things you must decide. In addition, you should have some practical experience in repairs before you actually do repair and service work for others. Because of this, it is recommended you locate a source from whom you can obtain used equipment on which to practice.

We suggest you contact local electrical retailers, appliance dealers, used furniture shops, TV and radio shops, and obtain several used pieces of equipment. You can often get these quite reasonable, and they will be ideal for practicing service and repair procedures.

Another important consideration is the local licensing requirements. Most cities, townships, or incorporated areas require a business license for any business operated in the boundaries of the township. A license fee is normally charged and in some instances approval by the city council is required before a business license is issued. Zoning of your area is also a major consideration. If you intend to operate your business in the basement of your home, in an area-zoned for residential structures only, permission of the city council is normally required. Approval of a business license may take one or two months. For this reason an application for a business license should be completed in the early phases of planning your business.

A few states require certification of television and radio service technicians. This generally requires successful completion of a written examination and a certain amount of practical experience in the field. A telephone call or a visit to the city clerk's office will answer all of your questions pertaining to licensing and certification in your area.

It is impossible to stock a complete inventory of repair parts. For this reason you must locate an electronics supply dealer in your area, in order to obtain repair parts. Simply check your telephone book under Television Supplies and Parts, or Electronic Supplies. Once you have located a supplier, a visit to his store is necessary. Browse around the store to get a general idea of his inventory and the parts he will normally maintain in stock. A discussion with the store manager will establish the discount you will receive on parts and the services you may expect him to provide.

Remember—it is best to be conservative at the beginning. If you can save money by using your basement and not paying rent, do so.

What Service You Will Provide

Assuming that you have had no previous experience with service and repair procedures, it will be far better to confine your efforts at the start to making minor repairs. Here is where experience gained from practicing with old radios and TVs will prove valuable.

The most important factor in your service program will be yourself. This cannot be stressed enough. You will be selling yourself, and unless you learn now to use tact and USE it every day, unless you keep yourself neat and trim, you will not last long in business.

One more important point—you must be a *good "Boss."* This applies to yourself more than any employee you may have. You must be able to exercise control over *your own* actions. In other words, you must work for yourself as if you were working for a boss who was watching you every second.

Your ability to develop your own personality, to be honest with customers, and to deal fairly will govern the success you build.

Your Promotional Program

Your promotional program will be governed to a large extent by your capital. If you have ample funds, you can set up an elaborate program. However, if you are like most men, you have little or no capital and can't afford to spend large sums of money on an advertising program. You must get by as reasonably as possible and still do a good job.

It is our feeling that every man, regardless of the amount of money he may have, should start with "Canvassing", as explained later.

Figure 23 — The personal contact developed through canvassing not only is an effective and inexpensive form of advertising but will benefit you greatly in developing your "Customer Personality."

The experience you will gain in meeting and talking to strangers is invaluable and will help shape and develop your "Customer Personality." Also important, *there is no other* system that will produce *as much business* for so little cost as personal canvassing. Personal canvassing, in conjunction with a circular distributing plan, is very effective in getting started. Your promotional campaign must be set up and laid out carefully. We can't stress this too strongly.

BUILDING YOUR BUSINESS

Business building circulars have been used successfully in developing new repair and service businesses. They are economical and do get results.

Any circulars which tell your story to the people and let them know what you can do and are doing will work. They must attract attention and create the interest in the people to keep the circular for future reference. Any local printer should be able to lay out an effective advertising piece for you.

Your first step is to select a name for your business. Next, obtain a telephone number. Getting your service shop in order and in a condition where you can service equipment is your third step.

Using Circulars

The use of circulars in conjunction with a small classified or display advertisement in your local newspaper and personal canvassing is all you should consider at the start.

From actual tests and carefully kept records in all types of neighborhoods, we have found you can expect, on the average, at least five service jobs and as many as 15 from such a program. These jobs will not come all at once. Once your circulars have been distributed, you will keep getting calls for the next three or four weeks and longer. In some actual instances, calls from circulars have been received as long as nine months after they have been distributed. This shows that people will keep them for a long time. The first call from your circulars will generally come in about four or five days after they have been put out. Sometimes the first call will come a little sooner than this, and sometimes it will take a little longer.

Figure 24 — One of the most successful forms of advertising at a low cost is circulars. A local schoolboy can circulate them for a nominal fee.

On a circular campaign, accurate records were kept; 1000 circulars were distributed in one afternoon. Two boys each distributed 500 circulars on opposite sides of the street. It took them four hours for the job. These boys were paid 75¢ per hour or $1.50 for the two of them per hour. This amounted to $6.00 for distributing the 1000 circulars. They could have been mailed, but postage, envelopes and the cost of addressing would have increased the cost. For a three-month period over 17 service calls had been received. This was not too many for 1000 circulars, but these were distributed in a neighborhood of wealthy residences where returns are normally quite low.

It is important at the beginning to start with a smaller amount of circulars. In some localities, instead of 17 jobs, you may receive as many as 40 or more service calls per 1000 circulars.

Figure 25 — Although it is relatively expensive, newspapers are a worthwhile form of advertising.

You are new in this business. The first few service calls you will receive might take longer to service and repair. Perhaps you won't have the repair parts on hand and will have to obtain them from some supply jobber. You may not have a jobber near you and may have to send for their catalogs and order by mail. This takes time. On your first few jobs it may take you longer to discover the trouble and repair it satisfactorily. That is another reason you will only want a few repair jobs at the start.

Circularizing

We are assuming you have your business name, phone number, business cards, circulars and stationery. It may not be necessary to have an address, but it would help if it were on your circulars and ads. If your shop will be where the public can see it, a sign would be all you would want at the start. Let us assume you will have your shop in your basement or garage, or somewhere where the public can't see it. A sign would not be of much help unless it were placed on the street or somewhere where people could see it and be directed by it.

Have a street map of your locality serve as a guide for distributing your circulars. Remember, you should not stop your circular distributing with these first ones. Set up a regular plan. As you finish one block or section of your locality, mark off the date when completed on your map. You may want to recircularize this same section in 30 days.

To start, distribute 200 circulars per week. Mark each section on your map as you complete it with the date. After 30 days, distribute another circular in the same manner over the same section, marking it off on your map. You must remember, this is a continual procedure for the first year of your business if you want a full-time business. It is the continual repetition of your name and your services that will cause your customers to remember you and your company.

Newspaper Advertising

In addition to circulars, insert a small classified or display ad in your local paper. Keep it small, about one inch. If your ad is a classified ad, have it inserted in the proper column of the paper. The publisher of the paper will be more than happy to help you with your copy and may even give you a news write-up about yourself and your new service business.

If he will give you a news article, it will prove to be a valuable source of advertising for you. The way to handle this would be to approach the editor or publisher and tell him you are opening a new service business and are taking training with or have graduated from ADVANCE SCHOOLS. Give him your name, phone number and address. This is news, and because you are also advertising in his paper, he may place this article on the front page. You can write a simple news article similar to the one on page 30 of this lesson, or you can use the one shown. Insert your name, phone number, etc., in the proper spaces. Often the publishers will be willing to insert a picture of you or your shop with the article. Furnish them with a glossy photograph with your news article.

Personal Canvassing

Personal Canvassing should be a "must" for every man who wishes to start a business of his own. If you need money, Personal Canvassing is the best and surest way for you to get started and obtain earnings from spare time service work. The advantage of personal canvassing is that it does not cost you any money except for a small investment in business cards or imprinted circulars.

When personal canvassing is used with a well-planned circularizing and newspaper advertising program, a very successful and profitable service and repair business can be built rapidly.

SERVICE CALLS

The proper handling of your service calls, how much to charge for your repair and service work, or how to handle cases when you do not have the necessary parts on hand, are just a few of the important things you must know.

Before you distribute your circulars, tell your friends and neighbors what you are doing. Many of them will have some kind of service and repair work to be done, which will furnish you with practical experience at the start. Ordinarily, parts and supplies for these jobs can be picked up at a nearby parts dealer, so you should not have a parts problem right away. AFTER you have your "feet wet," you should consider dealing with a wholesale house, thus making a nice profit on the items you install and sell.

After your circulars have been distributed, you should receive calls or, if your community is small, they will bring their repair work to you. On these first jobs, to avoid tension, try to check the equipment when the customer is not around.

After you have found out what is wrong, you are in a better position to judge what to charge your customer for the repair. If the device needs parts which must be ordered from a supply house, you will have to base your estimate accordingly. In these cases, simply inform your customer that you will have to obtain the necessary repair parts from the distributor or factory, and you do not know exactly what they will cost. Tell them that your labor will be so much and the parts will be extra.

If you must send away for parts, you should allow about 10 days for your order to be delivered, and allow about three days for your repair; therefore, you can tell your customer it will take about 10 to 15 days before you will have the unit ready.

Your Fee

You should have a minimum charge. You should not charge less than $3.00 to $5.00 for service work you render in your shop. You have expenses, and if an appliance is worth repairing at all, it is worth at least this amount, plus parts. Base your charges according to the type of equipment being repaired. Unit repair should be figured at $6.00 to $7.00 per hour for labor. In the case of small units, you could charge on a fixed fee basis.

A suggested method is to set a charge of $3.00 for dismantling and assembly of small radios. This could be varied according to the time involved. In all cases, your rates should be set so the labor charge on the job will not be less than $6.00 per hour. To this labor charge you must add the list price of all repair parts used in the repair job. Ordinarily, the list price should allow you about a 40% or more profit on the parts. Increase the price of your parts until you make this much profit.

Learning how and what to charge for your service is one of the most important parts of your education, second only to learning how to repair and service efficiently and properly. You shouldn't charge too little. You MUST charge enough so you will make a fair profit.

Remember, you have fixed expenses which must be met and cannot be charged to any repair cost, but must be taken out of your total income. Some of these are shop rent, power, heat, taxes, gas, oil, car expense, delivery and pickup expenses, tool upkeep, telephone, advertising and miscellaneous shop expenses. These are called "overhead" and should all be considered when basing your estimate. For practical purposes, simply adding a 30% fee or $1.50 to the total price for overhead will generally cover all of these. If 30% is too high, use 15% or 20%. Once you have arrived at what you should get for your labor on a particular job, add to this your parts and materials. Then take 15% or 20% of this total and add this to your labor and parts charge for your final charge to your customer.

Figure 26 — If your books are handled carefully, you will never be surprised by any bill you owe.

Types of Customers

Occasionally, you may have to give service to people who couldn't possibly pay your full fee; you will also find people who can pay your fee without any trouble. So, in summing up, pricing and charging can be "boiled down" to simple facts: type of job, circumstances of your customer, and the locality in which they live. You will find it far better to lower your fee when servicing for people of poorer circumstances, as it is better to collect a small repair bill than to never be able to collect a bill. You should not work a hardship on people if it isn't necessary.

The important thing to remember is that you are entitled to a fair and just profit for your services. This does not give you the right to charge certain people an unfair price, because you think they can pay. This is not the right and fair way to operate.

Fair Dealing

Some service-repairmen have made a practice of taking advantage of repair jobs when the opportunity presents itself. They may receive a call on a washing machine or TV or other appliance which may not operate. The complaint in the case of the washer may be "My machine runs, but the agitator does not work." This is a common complaint on some models of washing machines. When the serviceman arrives, he immediately determines that the trouble is due to a loose coupling. Instead of telling the customer the motor drive coupling was loose, he may tell her that the trouble is in the transmission, and he will have to take the machine away to the shop for transmission repair. He may quote a price of $25.00 or more for the job, and the customer will let him do it. Thus the serviceman will be getting an overcharge for his work, when he should have tightened or replaced the motor drive coupling. This is not the right way, and it certainly shows that this serviceman does not have the right kind of buisness ethics.

It is often very tempting to take advantage of a service job like this, but it very seldom pays off in the long run. You can imagine what the customer's reaction would be if within a week or so the transmission really gave trouble, and the serviceman was called to repair the machine. He could hardly charge the customer for the repair again, because the customer probably would not pay him.

For this reason—*you* want to operate your business in a fair and honest manner—you should refrain from such practices. Eventually, acts of this type will catch up with the one who does them. DON'T LET THIS MAN BE YOU!!

Figure 27 — A neat appearance is essential to a good first impression.

Appearance

Your appearance is very important. You are engaged in a profession, a profession that is equal in respect to any other businessman in your community. You are rendering a specialized, technical service, and you should look the part. Take pride in what you are doing. See that your clothes are clean and that you present a neat appearance when calling on your prospective customer. After you have been doing service work for a while, you should wear a uniform, that is, a shirt and pants, with your name or the name of your service agency on the shirt.

First impressions are very important. A poor appearance fosters lack of confidence, which could limit future service calls from a customer. A good appearance builds confidence in the mind of the customer. The man who presents a professional appearance will get the most service work. Your appearance and the appearance of any of your servicemen should reflect your concern for being a good businessman.

Handling People

One other thing which is very important is learning how to handle people, especially your customers. It is *very important* that you learn all of the details of the service business. Remember, you are spending a great deal of money and time to learn this profession, so make sure you learn all of these fundamentals well! If you follow these fundamental facts and actually put them to work for you, you will find it won't be long before you will have established a list of satisfied customers who will go out of their way to get additional business for you. This is the best form of advertising. See that *YOU* make the most of it!

Time Spent On a Call

After you have acquired the necessary know-how, the time you spend on each service call becomes quite valuable. You are, therefore, entitled to a fair fee for what you know in addition to the mechanical work you perform. You will then be a professional service technician, and you must conduct yourself in a professional manner.

Customers will call you, because you are the expert. Because of the trust your customers are placing in you, it is very important that you conduct yourself in a professional manner that befits your trade.

Only those repairs or adjustments for which the service technician has the equipment, replacement parts, and the knowledge to complete the repairs rapidly and correctly should be done in the home. A good guide to follow on a service call is; if the set is not diagnosed or repaired within 30 minutes, the set should be taken to the shop. This time limit may vary. For example, if the shop is filled with work and there are only a few service calls scheduled for the day, then more time in the home is justified.

Any major repair, major part replacement, alignment, or intermittent condition should be taken to the shop. These repairs require time and elaborate test equipment. An intermittent condition may occur on an erratic basis. This could require time spent in the home waiting for the intermittent to occur. In the shop the set could be set up and monitored while other equipment servicing is taking place. When the intermittent condition occurs, it can be observed and the problem diagnosed.

Behavior In The Customer's Home

The owner or operator of the unit you have been called upon to service is now your customer. He is the buyer of your services. The impression you make on the customer when you first enter his home or office will often decide how successful you will be in selling your services. Your appearance, your manner of speech and the language you use will all have a bearing on the opinion he forms of you. If you clothes are dirty and you express yourself carelessly, you will leave a bad impression on your customer. At first glance, the customer does not think of your technical ability, but is entirely influenced by the impression he receives when you enter.

The knowledge you possess cannot be used to influence the customer's opinion about you at this moment, since this cannot be told in a few words. Even if you tried to tell him about your knowledge, he may not understand you. Therefore, it is of utmost importance to make a good impression, based on your good manners at the first meeting. No doubt, you have judged people in this manner at sometime or other, and know how important first impressions can be.

When your customer called you for service, he may have had a favorable opinion about you. He may have formed this opinion from an advertisement or circular he had seen, or it may be that you were recommended by an acquaintance or a friend. Therefore, it is important that you measure up to this favorable opinion, and try to improve it if possible.

It is important to use so-called "service record cards" when you receive service calls over the phone. These cards should have space on which to write down the name, the make and model of the equipment and the nature of the complaint, the customer's name, address and telephone number. There are also regular Service Record Forms which may be obtained from your parts suppliers.

In some cases, a call for service may have been received by someone else in your home or shop, or you may have been referred to another customer while on a service call, and you could not obtain any information about the set. Ask the customer how the equipment operates. Never ask the customer: "What is the matter with the TV?" That is for you to find out.

What The Customer Wants To Know

The three most frequently asked questions by the customer are: 1. "What is wrong with it?" 2. "How

Figure 28 — You must tell the customer what you think the repair will cost.

much will it cost to fix it?" 3. "How long will it take to fix it?" These are all legitimate questions which deserve an answer. But since you cannot give an exact answer to any of these questions until you have checked the set and found what is wrong, it is best to tell the customer that you are unable to give him an answer until you have had time to make a preliminary examination. After you have made this preliminary examination, you should have an idea of what is required to put it back into operating condition.

You should now be in a position to state the price according to your method of determining the charge for such a repair job. It may be in your favor to charge a flat hourly rate in accordance with your hourly charges and add the retail price for all parts and supplies used, or you may favor a flat price which would include labor, parts, delivery charge and overhead.

In order to be fair, it is sometimes better to state that you will call the customer to give him the price when you have had a chance to thoroughly check it in your shop. If it is necessary to replace some other part, the customer will want to know the cost. This, of course, would only apply when it is necessary to bring the unit to your shop.

When you are using the flat-rate method, you must add in your head the various charges involved. This may be a little difficult in the beginning, but after you have been in the business for a few months, you will have a good idea what to charge in order to get a fair profit for yourself, without overcharging the customer.

While you are settling the price with your customer, it is best to remain standing, even if you have been asked to be seated. You should also avoid smoking and refuse drinks. You are in the customer's house on business and your time is valuable. During the preliminary tests, do not remove your coat or jacket unless it is necessary.

If you get the job, but you have been unable to give the customer a definite price, tell him that you will give him the price over the phone as soon as you know the extent of the needed repair and *before* you start doing any work.

In some cases, another serviceman may have already called on your customer and given him a price. As a rule, the customer will not tell you about this until you have finished your preliminary survey and have given him a price, and then only if your price is higher than that of the other serviceman. There are several ways in which such a case can be handled tactfully.

Stick To Your Price

Once you have stated your price, you should not change it. Your price is based on your cost plus a reasonable profit. Even if you should lose the job, you would be better off than to do the work without any profit. The time spent on a profitless job is wasted.

The Right Reply

The statement by a customer that someone else has quoted a lower price than you on a repair job can be answered in different ways, but you must make sure that it is answered correctly. A good reply would be:

1. "We have found that the only way we can back up our repair work and give a 100% guarantee is to make sure that the job is done properly and that parts of the highest quality are used. Experience has taught us that our customers prefer to pay a little more for our individualized service. They feel that it is less costly in the long run, because they know that their equipment will give satisfactory service for a long time after it has been repaired by us."

2. "We do our work in the shortest time possible and use parts of the highest quality. After the job is done we thoroughly check the operation of the set. During our long experience in this work, we have learned that short cuts can be used in the repair, but we do not believe in short cuts since this results in inferior workmanship."

3. "The price for our work follows a scale that has been carefully determined by taking into consideration all the cost factors. We have found that we cannot operate our business at a lower scale. Our customers have always demanded QUALITY, and that is something we cannot give at a lower price. I would suggest that you call Mr. or Mrs.________whose repair work we have handled since________."

The Wrong Reply

1. "We do not work any cheaper."

2. "We do not turn out cheap work like the __________Company."

3. "I know that__________Company employs young boys who do not know too much about servicing, and often do not know what they are doing."

AN ADDED SERVICE

Upon graduation, as an added service to you, we will upon your request write to your local newspaper advising them of your graduation and your newly acquired abilities, so that your friends will know about your new accomplishments.

SUGGESTED NEWS WRITE-UP

Mr. *(Your name)* of *(Your address)* has just announced the opening of his new *(Type of Business)* Service Company *(Name of your Co.).* At present, his new store is located at *(Shop address and telephone number).* For the past several months, Mr. *(Your name)* has taken specialized training with the Advance Schools, Inc., of Chicago, Illinois. This training has helped him specialize and become an expert *(Type of Technician)* for handling the service and repair of all types of *(Type of repair)*. The *(Name of your Co.)* under the able management of Mr. *(Your name)* is making it a point to give the highest type of service promptly and efficiently. Special services handled by Mr. *(Your name)* include the dependable service and repair of all types of *(List by major categories the types of equipment you will service and repair.).*

Mr. *(Your name)* is firmly convinced that by giving his customers the best in service, quickly and efficiently, his new business should prosper. He cordially invites everyone having a service or repair problem to consider the services offered by his new company.

SERVICE SIGN

You can mount a sign in a prominent place. Some students have found that by placing a sign in the window of a local Hardware Store, Gas Station or Grocery Store, a great deal of repair business can be obtained. Offer the store owner a fee of 50¢ or $1.00 for each job he takes in. Often you can get the cooperation of several stores in this manner and display more than one sign.

OPERATING A TYPICAL BUSINESS

Selling Yourself

A good part of our lives is spent in "selling." On the job, we are constantly selling our ability to our superiors. You may not realize it, but the manner in which you do your work, your knowledge of the work, and the service you give to your employer are all expressions of your ability to "sell" yourself.

While you are a student of Advance Schools, Inc., and after you have completed your training, you should give this matter of selling yourself a great deal of attention. You should also learn to present your skill and your knowledge well to those who are interested in "buying" these commodities.

As a service technician, you have a service to sell. The value of this service is primarily based on your technical knowledge and on the operating principles of the devices you will repair. To this you must add the value of the time spent in repairing at a reasonable but fair rate per hour, plus the value of parts and material used in the repair.

As a service technician, you can place yourself in the same category as your neighborhood barber, dentist and physician, since you are also selling a service based on the knowledge you possess in your trade or profession.

Every time you give an estimate of a repair job to a customer, you are selling your services. Therefore, the more you learn about selling your services successfully, the easier it will be for you to build a profitable servicing business.

As examples of good and poor service, let us suppose that you go to one of your local hardware stores to make a purchase. The clerk or owner goes out of his way to see to it that you are taken care of courteously and quickly. You will go back to this store again, because they gave you good service, and you like the way they are doing business.

Now let us suppose that you enter another store on a similar errand, but the clerk appears surly and makes you wait a long time. In addition, after you arrive home with your purchase, you find a part missing or you have received the wrong part. You return to the store with your complaint, but you do not get satisfaction. Would you go back to this store again? We do not believe you would. We believe you would trade with the first store, even if his prices were higher.

What we are trying to point out is that you as a service technician must learn to sell your services and your skill at a fair profit. At the same

Figure 29 — Everyone likes accurate service.

time you must retain the good-will of your customers. There is no better way of building good-will than to have a list of satisfied customers. Through their recommendations, your clientele will continue to grow. You can also expect to receive a large amount of repeat business.

In summing up, you have two main items to sell:

1. Your knowledge, and
2. Your technical skill.

Together, they spell "service." The parts and material you use on a job are incidentals to the service you render.

You must realize that it is your knowledge of the subject which enables you to locate the trouble and determine what parts are needed. Once this has been done, anyone with a fair amount of mechanical ability or skill can remove the old part and install a new one. It is in locating and diagnosing the trouble that the difference is found between a skilled and an unskilled man. In other words, as a skilled service technician, you get paid for what you KNOW, as well as for what you do.

We are now ready to discuss the various other expenses you must consider in making an estimate, in addition to the value of your services and the price of parts and material you need for the job. This is when so many service technicians fail. They do not take into account the fixed expenses which we commonly refer to as OVERHEAD.

Fixed Expenses

After you have determined what is wrong, it is fairly easy to determine what the parts and material will cost. You can also tell approximately how long it will take you to fix the set, especially after you have had some experience with similar devices.

The "overhead" or the fixed expenses, on the other hand, cannot be figured too accurately for each repair, unless they have been determined beforehand. Let us determine what the overhead or the fixed expenses consist of and what they will amount to per hour on the average. The most important expenses in this category are: rent, electricity, heat, water, insurance, gas and oil, postage, depreciation on tools and test equipment, and bad debts.

Let us assume that you are just starting in business and that you intend to conduct the business from your own home. Your overhead will, of course, be much lower under these circumstances than it would be if the business were conducted from a separate establishment. Nevertheless, you will have a certain amount of overhead regardless of how small your operation is and from where it is conducted.

We will take as an example a case that is based on the records submitted by other students who have already gone through this phase of starting a business. Let us say that you are putting in 15 hours per week in your repair business. It does not make any difference whether you repair one or ten units during this 15-hour period, your overhead or fixed expenses will remain about the same. Therefore, if the total overhead is divided by 15, you will know what your fixed expenses will be per hour.

You may reason that you are just starting and that many of the expenses would have to be paid anyway since you are conducting your business from your home. This may be a good argument, but you are not going to remain working at the kitchen table in your home forever. It is, therefore, a good idea to include these fixed expenses now, so that when the time comes for expansion, these charges will be included automatically in your billing. Furthermore, these fixed charges will help to build capital which you may be needing later in expanding your servicing business.

In order for us to arrive at a fairly accurate fixed charge per hour to cover overhead, let us set up a table like the following. All allowances should be based on one month's operation.

Rent	$70.00
Electricity	5.00
Heat & Water	5.00
Insurance	10.00
Telephone	7.00
Automobile, Gas, Oil & Lic.	30.00
Furnishings	5.00
Stationery & Postage	10.00
Depreciation on Test Equip.	10.00
Bad Debts	10.00
	$162.00

Now let us analyze some of these charges; $70.00 per month is a fair charge for using your own quarters as a repair shop and for the inconvenience it may cause your family.

Your electric bill will increase a certain amount for the power you use in servicing. Therefore, $5.00 per month for electricity is a reasonable amount. The same may be said about heat and water, except perhaps to a lesser degree since neither of these utilities is used very much in the repair of appliances.

Charges for insurance against fire and theft would cover the increase you would have to pay in premiums per month to insure customer units you may have in your possession.

Your monthly telephone bill will also increase a certain amount, depending on how much of your business will be conducted on the phone.

Your automobile expenses in this example have been arbitrarily set at $360.00 per year. If we divide this total by 12, we get $30.00 per month as your car expenses. You may not have these expenses from the beginning. If this is the case, you may exclude this item.

Furnishings include such items as a workbench, chairs, etc. If depreciation and maintenance of the furnishings in your working area are set at $60.00 per year, we get a figure of $5.00 per month for this item, which is quite low.

Stationery and postage would include such items as letterheads, business cards and letters of reminder to your customers. If you were to do a certain amount of advertising, this expense would be carried as a separate item.

Under the heading of "Depreciation of Test Equipment" we have also included the cost of service manuals which you may have to purchase from some manufacturers. In most cases, service manuals are supplied free of charge by the manufacturers.

The required test equipment might cost a total of $360.00. Under normal usage, test instruments will last an average of three years. This will give us a yearly depreciation of $120.00, or a monthly depreciation of $10.00. Service manuals are issued whenever a new model is put on the market. This usually occurs once a year, which means that new manuals have to be added constantly to your reference library.

Sometimes you may not be paid for your services, but if you make it a practice to demand cash on delivery, this should not happen too often. It is, however, a good policy to allow a certain amount each month for "bad" or uncollectable debts.

If we add the various items listed in our fixed-expense or overhead table, we get a total of $162.00. Assuming that you work 15 hours per week, you would be putting in 60 hours of work each month. If we now divide the total of $162.00 by 60, we get approximately $2.75 per hour, which should be added to your labor charge. This would be the hourly charge for your overhead in this particular case.

The next item to consider is the charge for the actual labor. The charge for labor represents a comparatively small part of the total charge. Determining what is wrong and deciding what parts are needed for the repair are the most time-consuming and, therefore, the most costly parts of the job. In order to arrive at a realistic figure for the total labor charge, we must separate the charge for the actual labor per hour from the charge per hour for troubleshooting.

The Final Charge

Thus, the total or final charge for labor consists of three parts:

1. The charge per hour for your know-how.
2. The charge per hour for the actual labor.
3. Your overhead per hour.

A rate of $1.75 per hour may be considered a fair rate for the actual labor, plus $3.00 per hour for your know-how. To this you must add the hourly charge for your overhead, which in our example was $2.75 per hour. If we add the three parts, we get a total of $7.50 per hour, which would be the total charge for labor per hour under the conditions outlined in our example.

The hourly rates for labor will, of course, vary from one part of the country to another. You must establish a rate that is consistent with the rates charges in your neighborhood for similar work. In most parts of the country, the rates we have shown here would be considered low. For this reason, it will not pay you to go any lower. If you were to hire an employee to do the actual work, you would have to pay him from $3.00 to $5.00 per hour, which you should keep in mind when you establish your hourly rates.

Sales or Usage Tax

If you live in a state in which a Sales or Usage Tax is enforced, you must not forget to collect sales tax on the parts and supplies you use on each repair job. This tax must be included in your billing as a separate item.

You must also get a Retail Sales Tax Number before any purchases can be made from wholesale houses. In most states these Sales Tax Numbers are obtained free of charge by writing to the Revenue Department in the state capital. The reason for this stamp is that you as a serviceman become a retailer of those parts you use in your service work. You must, therefore, charge your customer Sales Tax at retail prices on the parts you use and submit this tax to the State Revenue Department at the end of each month, or other period stipulated by the state. The wholesaler in turn does not charge you any Sales Tax on purchases of parts you buy from him, when ordered in the regular manner on your own order form showing the name of your business and your Sales Tax Number.

Pickup And Delivery

When we determined the hourly rate for labor, we did not make provisions for pickup and delivery, except for the $30.00 allowance per month for automobile expenses, but this allowance primarily covers the expense you incur in picking up

Figure 30 — Deliveries take time and must be paid for by the customer.

supplies and parts from jobbers and wholesale houses.

Small sets are quite often brought into the shop by the customers themselves and then picked up when ready, but most often you will have to pick up the heavier units in the customers' homes and then deliver it when repaired (Fig. 30). If you have a car, you could set a flat rate of $1.50 for pickup and delivery. This charge would then be included in the final charge for labor and would not have to be posted as a separate item on the bill.

You can also include the transportation or delivery charge in the labor charge. This has a certain psychological effect. Should your customer complain about the high labor charge when the delivery charge is included, you can easily explain how you arrived at this figure, but this should never be done unless your customer specifically requests it.

Invoice Book

You should purchase an invoice book or sales book with your name, address, zip code and telephone number printed at the top. You can also get a plain sales book from your local dime or stationery store on which space is provided at the top of each sheet for name, address, etc. This information can then be stamped on each sheet with a rubber stamp, which saves the cost of printing.

Always make sure that all bills are made out in duplicate so that you have one copy for your file while the customer gets the original. Thus you are able to keep track of all transactions. You also have a permanent record of what you did on each repair job.

Watch the items carefully in your overhead account, so that you keep close track of your fixed expenses, especially the expense of depreciation. It is a good idea to set this money aside and only use it for the intended purpose. If the depreciation fund is handled in this manner, you will always have sufficient money on hand to replace tools and instruments as the need arises.

Most Important

The most important point to remember when you start in the servicing business is this: If you do not learn how to sell your services, it does not make any difference how good a technician or mechanic you are. Your success will be limited.

TEST

Lesson Number 19

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-019-1.

1. Before going into business for yourself you should first
A. talk to the local hardware dealer.
3 –B. determine the need for your services in your area.
C. ensure that there are many competent servicemen to work for you.
D. buy all the test equipment needed and immediately lease a shop.

2. While a partnership may work out satisfactorily from many angles, it is undesirable from
A. a taxation standpoint.
8 B. business volume potential.
– C. a legal standpoint.
D. the standpoint of social security.

3. The major advantage of being the sole owner of a business is
– A. the profits of the business belong to you.
8 B. the owner is not responsible for debts of the business.
C. reduced insurance rates are available for shops with only one owner.
D. a sole owner does not pay Federal Income Tax.

4. A corporation is able to raise working capital
9 A. through its employees only.
– B. by selling its stock.
C. by appealing to the State.
D. by changing the corporate policy.

5. When you are seriously thinking about buying a going business, you have the right to
11 A. operate it for several days.
B. dictate the day of sale.
– C. inspect the books of the business.
D. remove the books for perusal.

6. **The good will you build up as an independent business man**
   A. is not too important when operating a service and repair shop.
   B. comes about automatically.
   12 – C. reflects you as an individual.
   D. is usually acquired in a few weeks.

7. **In leasing a building to be used for service and repair work,**
   A. you should obtain four copies of the lease.
   12 – B. make sure the lease is transferable and renewable at a definite rental.
   C. try to get a corner location.
   D. check the leases on adjoining buildings.

8. **The purchase agreement of a service business should give you the right to**
   – A. recheck inventory before transfer of property.
   13 B. move in at any time.
   C. a share in the profits.
   D. change the name immediately.

9. **A good guide to follow on service calls is**
   A. always spend 2 hours in the home.
   24 – B. if the set is not diagnosed or repaired within 30 minutes take the set to the shop.
   C. never do any repairs or adjustments in the customer's home.
   D. always replace major parts and do alignment in the customer's home.

10. **There are several different ways to figure equipment depreciation but you must, in all cases**
    A. abide by the equipment maker's advice.
    15 – B. comply with the rulings of the Internal Revenue Service.
    C. use the straightline depreciation method.
    D. use the accelerated depreciation method.

asi

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"Serving America's Needs for Modern Vocational Training"

Take Pride In Your Work

Be A Tiger - No matter what line of work you are in the people who take pride in the quality of their work, are those who are at the top of the ladder. It is this type of person that ASI puts into industry. Always consider yourself to be a professional because that is what you are working for.

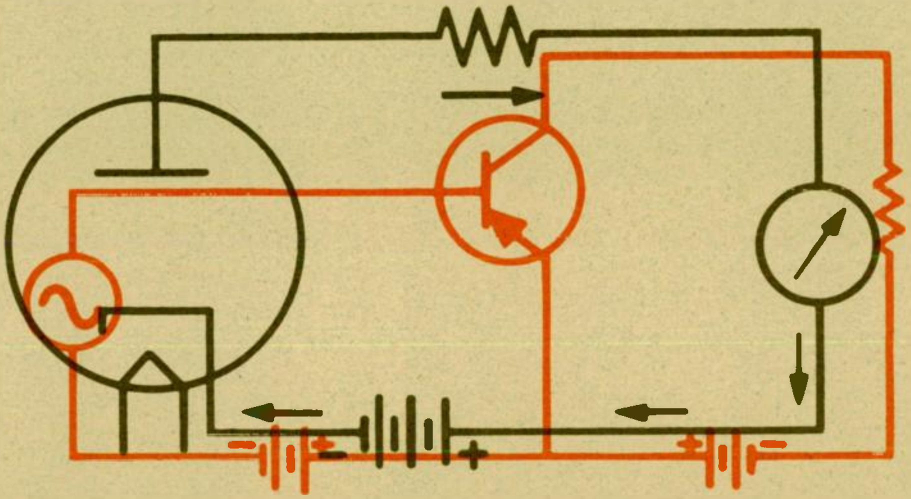
Attack your job in every possible way in order to bring about an efficient end. You are working to ultimately please and service the customer. He is your judge and jury and his decision will shape the possibilities for future customers and success.

Be alert to new ideas, techniques, and procedures as they are introduced into Electronics today and tomorrow. Make an effort to keep aware of progress and changes in your field.

S. T. Christensen

LESSON NO. 20

REVIEW FILM OF LESSONS 16 THROUGH 19



RADIO and TELEVISION SERVICE and REPAIR

LESSON CODE
NO. 52-020
403

ADVANCE SCHOOLS, INC.
5900 NORTHWEST HIGHWAY
CHICAGO, ILL. 60631

Revised 6/73

Reprinted March 1974

REVIEW FILM TEST

Lesson Number 20

The ten questions enclosed are review questions of lessons 16, 17, 18, & 19 which you have just studied.

All ten are multiple choice questions, as in your regular lesson material.

Please rerun your Review Records and film before answering these questions.

You will be graded on your answers, as in the written lessons.

REMEMBER: YOU MUST COMPLETE AND MAIL IN ALL TESTS IN THE PROPER SEQUENCE IN ORDER FOR US TO SHIP YOUR KITS.

REVIEW FILM TEST

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-020-1.

1. An RF carrier is a
A. single frequency.
B. type of transmitter.
C. type of receiver.
D. walkie-talkie.

2. Modulation is a process by which sound is
A. impressed upon an RF carrier.
B. detected.
C. amplified.
D. removed from an RF carrier.

3. In FM the modulating signal varies the ____________________ of the RF carrier.
A. amplitude
B. frequency
C. magnitude
D. impedance

4. Reactance is measured in
A. ohms.
B. farads.
C. henrys.
D. hertz.

5. In a purely capacitive circuit the
A. voltage leads the current by 90 degrees.
[✓ B. current leads the voltage by 90 degrees.]
C. current and voltage are in phase.
D. voltage leads the current by 45 degrees.

6. In your home workshop, after safety, the next most important item is
A. test equipment.
[✓ B. neatness and order.]
C. size.
D. cost.

7. When working on any job, it is important to have
A. the money in advance.
B. all the spare parts on hand.
C. peace and quiet.
[✓ D. the proper tools.]

8. To start your own business,
A. invest all your money in advertising.
B. use a long, hard to spell name.
C. plan an expensive promotion.
[✓ D. begin small and expand carefully.]

9. Your service warranty on repair work should
A. cover at least 1 year.
B. cover at least 2 years.
C. warranty the entire receiver which was repaired.
[✓ D. not exceed the warranty offered by the parts manufacturer.]

10. When preparing a bill for a customer, you should list:
A. all parts installed.
B. all work done.
C. all charges and your guarantee.
[✓ D. all of the above.]

Notes

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First Impressions Can Affect Your Future

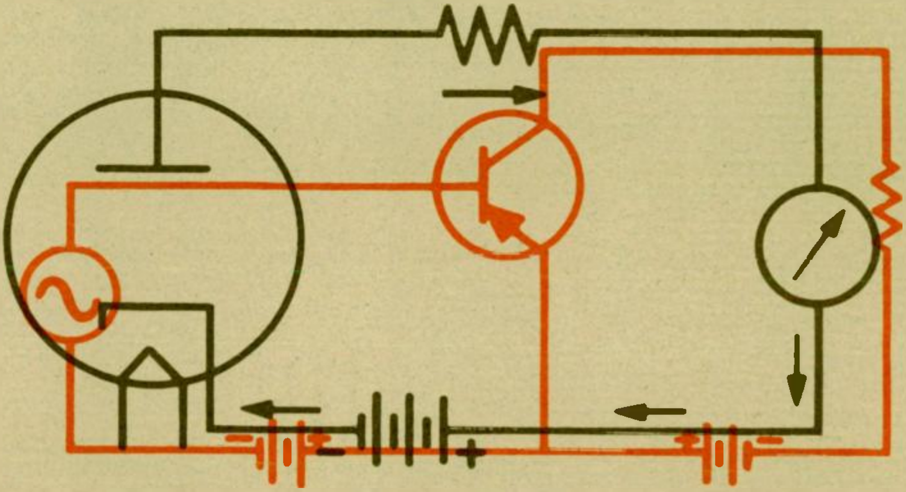
As they say cleanliness is next to Godliness. This little message should hold much truth for every shop owner or small businessman. First impressions are lasting and we all are aware of the fact that no one likes to walk into a sloppy atmosphere whether it be at home or someone's place of business.

Every shop owner wants repeat customers so that he may begin to build his business into a money making operation. One step in that direction is to take pride in your work, your appearance, and the general atmosphere of your shop. Keep things neat and orderly and show your customers you know how to run a business efficiently. If you can do this you shouldn't have any problems.

S. T. Christensen

LESSON NO. 21

TRANSISTORS AND THEIR USES



RADIO and TELEVISION SERVICE and REPAIR

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406

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Contents

TRANSISTORS AND THEIR USES

INTRODUCTION

Semiconductors, also referred to as solid-state devices, are now used in almost all types of electronic equipment. They have even surpassed vacuum tubes in common usage. Practically all new equipment either incorporates some solid-state or uses it exclusively. Semiconductor technology has introduced many new concepts, including new names and symbols. Solid-state devices have not only replaced vacuum tubes; they are able to do things that vacuum tubes cannot.

The transistor appeared in electronic products during the 1950's. Its predecessor, the semiconductor diode, had been used successfully in radar sets during World War II. The transistor was discovered during studies and experiments aimed toward explaining the behavior of diode material. During the experiments, it was discovered that the operation of a diode junction could be controlled by injecting a signal into the material through an electrode placed near the original junction.

Originally, transistors were of the point-contact type. The junction transistor was developed later. For a time, it was believed that point-contact transistors would prove superior in applications such as oscillators, but this thinking proved to be in error. The breakthrough leading to the development of the practical junction transistor came in 1949 when researchers learned how to "grow" a PN junction.

Early semiconductor diodes and point-contact transistors were composed of refined germanium. A small amount of impurity was added to cause a slight excess of electrons in the material. A deficiency of electrons was produced in one section of the crystal by slight contact pressure. A small diameter metallic wire was mounted with its point pressing against the crystal to form this pressure point. These point contact devices were extremely difficult to make. When it was learned how to produce a PN junction without the use of pressure contacts, the junction transistor became commonly available. It soon became available in a number of types for different applications. Since the announcement of the junction transistor, development work has been aimed mainly at improving materials and manufacturing techniques and at formulating new semiconductor de-

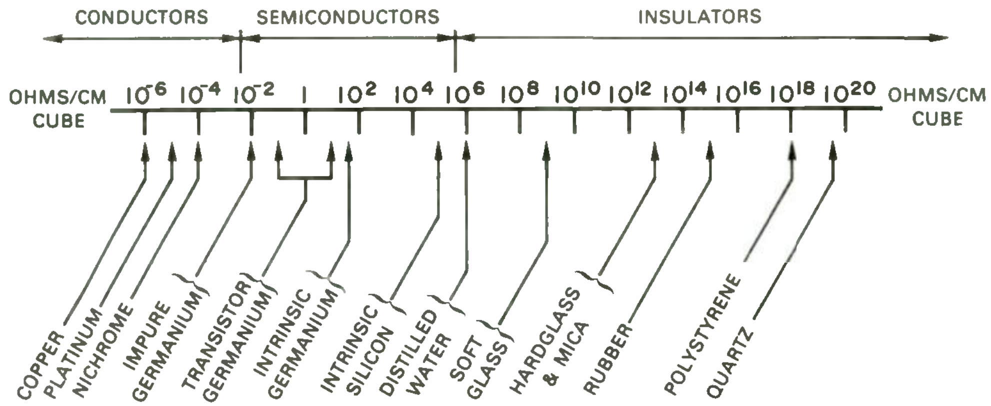


Figure 1 — Resistivity chart of common conductors, semiconductors and insulators at 68°F.

vices. The problem was approached with the idea of combining numerous junctions within a single block of material. These experiments lead toward micro-miniaturization, and to whole new technologies based on integrated circuitry.

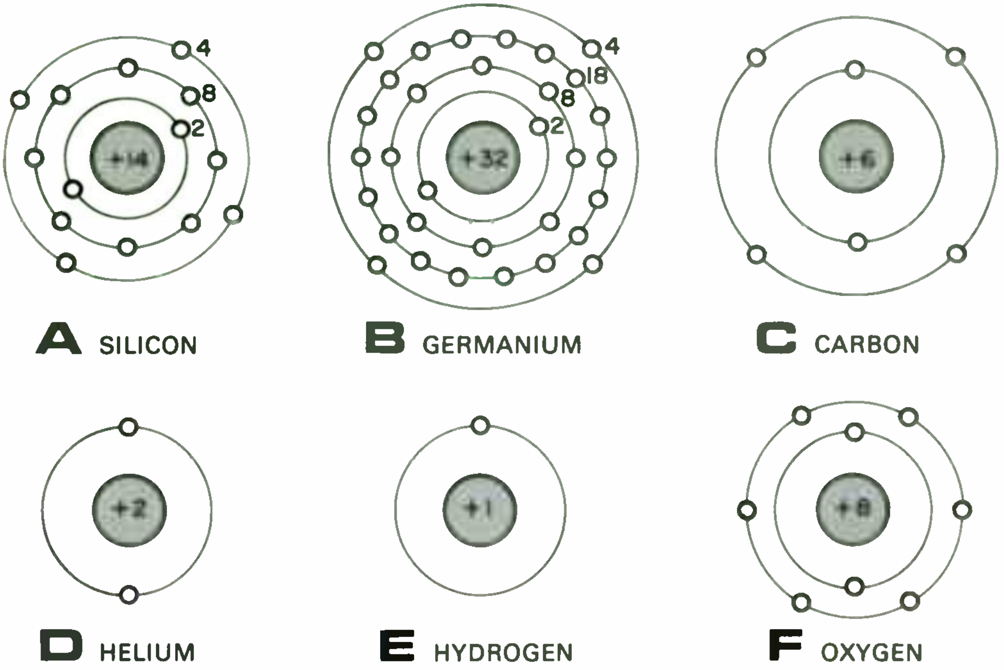
SEMICONDUCTOR PROPERTIES

Semiconductor materials lay between conductors and insulators in resistivity. Elements such as germanium and silicon are prime examples; these are the ones most generally used in solid-state devices. Germanium has a somewhat lower resistivity than silicon, but silicon can work at higher temperatures. See Figure 1 for a comparison of resistivity.

ATOMIC STRUCTURE

An atom consists of a positive nucleus containing a fixed number of protons surrounded by an equal number of electrons, grouped in shells. Each shell can contain not more than a fixed number of electrons. When a shell contains its maximum number of electrons, it is said to be complete. In many atoms the inner shells are complete, whereas, one of the outer shells may not be complete. The innermost (complete) shells, together with the core, form a stable "ionic core" with a net positive charge. The core can be considered completely inactive as far as chemical reactions and electrical phenomena are concerned. Only the outermost shell of electrons determines the chemical and electrical characteristics of the substance.

The orbits of an atom's electrons are grouped with a specified number of electrons in each shell. The shells are numbered 1, 2, 3 and so forth, with number 1 nearest the nucleus. Shell number 1 can contain a maximum of 2 electrons; shell number 2, 8 electrons; shell number 3, 18 electrons; shell number 4, 32 electrons, and so on. As mentioned before, the outer shell of certain atoms does not contain its full complement of electrons.



A SILICON **B** GERMANIUM **C** CARBON

D HELIUM **E** HYDROGEN **F** OXYGEN

Figure 2 — Arrangement of planetary electrons in atoms of various elements.

For example, silicon (Fig. 2A) has an atomic number of 14, that is 14 protons in the nucleus and 14 total planetary electrons distributed in 3 concentric shells around it. Germanium (Fig. 2B) has an atomic number of 32, or 32 protons in the nucleus and 32 total planetary electrons. In both silicon and germanium, the outer shell contains only 4 electrons, instead of the maximum number permitted.

For these atoms and others that have *3 or more shells*, it has been found that if the outermost shell contains 8 electrons, it can be considered to be complete and the atom will be stable. The outermost shell of both *silicon and germanium requires 4* additional electrons to become stable.

The 4 electrons in the outer shell of germanium are the only electrons that can be influenced by external forces. Thus, the germanium atom may be represented by 2 concentric circles; the inner circle will show a net charge of +4 units, and the outer circle will contain 4 electrons that can be affected by external forces (Fig. 3).

CONDUCTORS AND INSULATORS

Substances that permit free movement of a large number of electrons are called conductors; those that do not permit this movement of electrons are called insulators. In insulators, the electrons are bound closely to the nucleus. It is the degree of

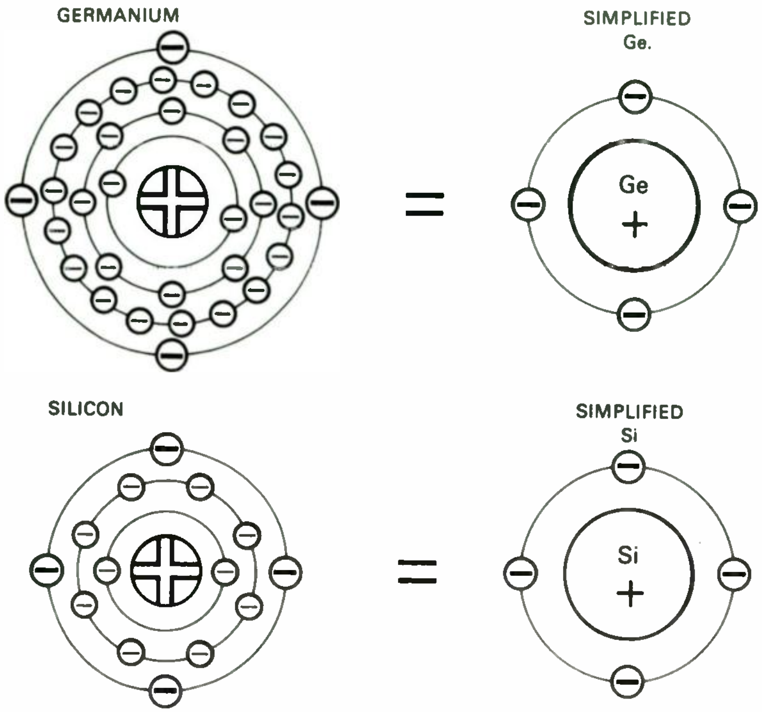


Figure 3 — Germanium and silicon atoms simplified.

difficulty in dislodging planetary electrons which determines whether an element is a conductor, an insulator, or a semiconductor.

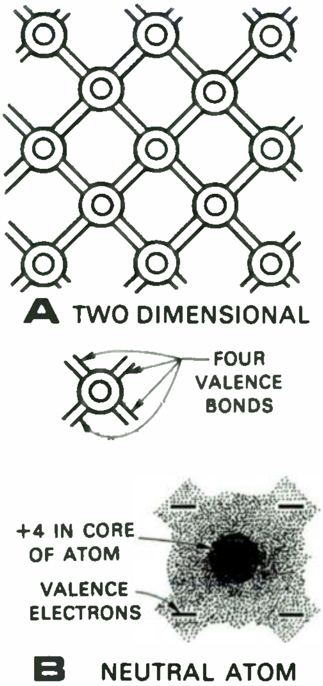
A material that is classified as a semiconductor has characteristics between those of a conductor and those of an insulator. The valence electrons in a semiconductor can be removed when some form of energy is applied. The energy may be in the form of heat, light, an electric field, or nuclear bombardment. When any of these forces is applied to a semiconductor, it will act like a conductor.

Atoms with four valence electrons may be drawn again to show only those *four* electrons. The nucleus and bound electrons can be shown within an inner circle with a positive (+) charge. The four outer or valence electrons can be shown equally spaced around an outer concentric circle. Noteworthy examples are silicon and germanium (Fig. 3).

A crystalline lattice structure is shown in simplified form in Figure 4. The 4 valence bonds appear as 4 pairs of lines extending between circles. The circles represent lattice sites, and each pair of parallel lines represents a covalent bond. Every atom in this illustration has 4 covalent bonds.

ENERGY LEVELS

The valence electrons in an atom can exist in one or more states of charge. This is due to the existence



A TWO DIMENSIONAL

B NEUTRAL ATOM

Figure 4 — Simplified lattice.

of different levels or energy bands around the atom. Ordinarily, the four valence electrons in a germanium atom are at an energy level which confines them to the valence band at a discreet distance from the atom's core. From this band, they can be shared with other atoms to hold the substance together. In this state, they move around the parent atom and transfer smoothly to the valence shells of surrounding atoms.

These electrons at the valence level do not contribute to electron current through the crystal. To become current carriers, they must first move from the valence band to the conduction band. To do so they are compelled to gain enough energy to cross over a forbidden region. This is a region in which electrons cannot exist. Figure 5 illustrates the outer regions of a germanium atom. Once an electron has moved from the valence band to the conduction band, it can then move through the crystal by jumping from the conduction band of one atom to the conduction band of another atom with very little additional energy.

When an electron is missing from the valence band of an atom, a hole or positive charge exists in its place. This hole or positive charge can move from atom to atom within the valence bands and act as a positive current carrier. When a hole attracts a valence electron from a neighboring atom, its positive charge effectively moves to the spot vacated by that electron. Positive current is called conduction by holes or *hole current.*

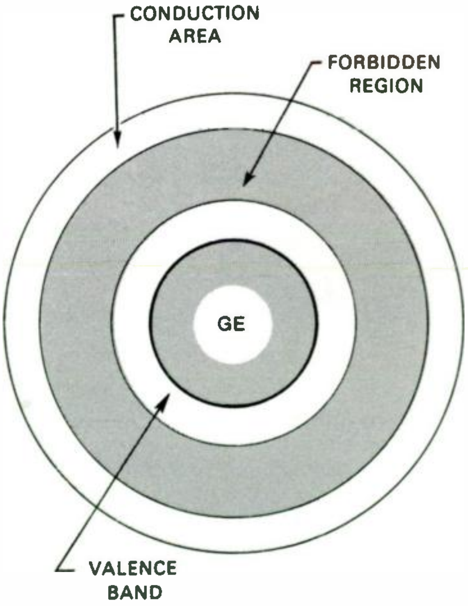


Figure 5 — Energy regions surrounding a germanium atom.

Electrons and holes do not move at the same rate of speed. Electron current flows in a region of little opposition, the conduction band; holes move in the valence region where more resistance is encountered.

An illustration of relative widths of the forbidden bands of insulators, semiconductors, and conductors is shown in Figure 6. You will notice that insulators have a very wide forbidden band. They require large amounts of additional energy to force an electron into the conduction region. Because of this wide gap, insulators can withstand large voltage potentials without conducting. Conductors have very narrow or nonexistent forbidden regions which permit electrons to cross over readily and support current flow. The forbidden regions of semiconductor materials are between insulators and conductors in width.

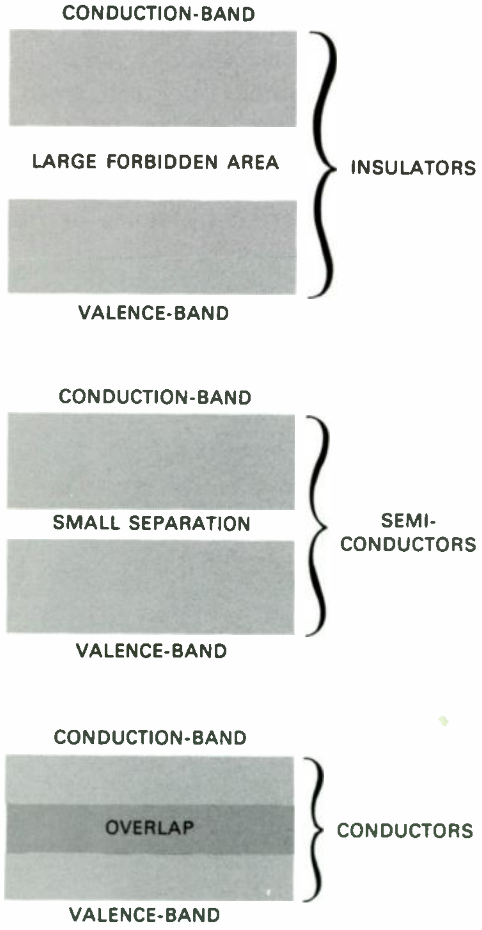


Figure 6 — Forbidden regions in three classes of material.

INTRINSIC AND EXTRINSIC SEMICONDUCTOR MATERIAL

A pure piece of semiconductor material will have an equal number of free electrons and holes. This number depends on the temperature of the material, its type and size. Such a specimen is called an *intrinsic* semiconductor; the current, which is borne equally by hole conduction and electron conduction, is called intrinsic conduction.

If a suitable "impurity" is added to the semiconductor, the resulting material can be made to have either an excess of electrons or an excess of holes. An "impure" specimen of semiconductor material is known as an *extrinsic* semiconductor.

IMPURITY DONORS AND ACCEPTORS

In pure form, semiconductor materials are of no use as semiconductor devices. When a certain amount of impurity is added, however, the material will contain more (or less) free electrons than holes. Both forms of conduction will be present, but the majority carriers will be dominant. The kind of majority current carriers will depend upon whether the impurity is positive (with excess holes) or negative (with excess electrons). The type and amount of impurity added is carefully controlled by a process known as "doping."

The impurities that are important in semiconductor materials are those that align themselves in the regular lattice structure. They have either one valence electron too many, or one valence electron too few. The first type loses its extra electron easily and, in so doing, increases the negative conductivity of the material by contributing a free electron. This type of impurity has 5 valence electrons. *Arsenic, antimony, bismuth, and phosphorus* are some examples of impurities that have 5 valence electrons. Because these materials give up or donate one electron to the material, they are called donor impurities.

The second type of impurity has only three valence electrons, and tends to compensate for its deficiency by acquiring an electron from its neighbor. Impurities of this type are called *trivalent* impurities. *Indium, aluminum, gallium, and boron* are trivalent impurities. Because these materials accept an electron from the material, they are called acceptor impurities.

N-TYPE GERMANIUM

When an impurity such as arsenic is added to germanium, it forms covalent bonds with the germanium atoms. Figure 7A illustrates an arsenic atom (As) in a germanium lattice structure. The arsenic atom has 5 valence electrons in its outer shell, but can use only 4 of these electrons to form covalent bonds in the germanium structure; this leaves an electron free to travel. Because this type of material conducts by electron movement, it is called a negative-carrier type or N-type material. Pure germanium may be converted into an N-type semiconductor by "doping" it with any donor impurity.

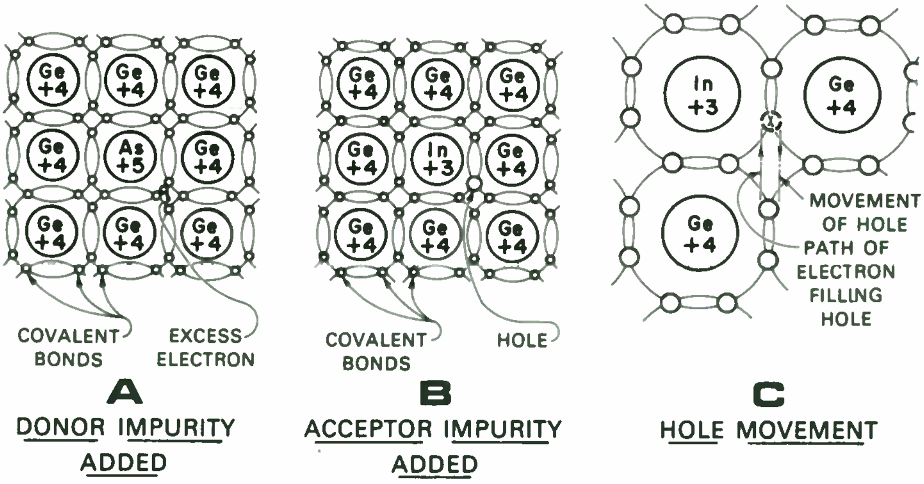


Figure 7 — Germanium lattice with impurities added.

P-TYPE GERMANIUM

An impurity with 3 valence electrons can also be added to pure germanium to dope it. In this case, the impurity has 1 less electron than is needed to establish covalent bonds with 4 neighboring atoms. Thus, in one covalent bond there will be only 1 electron instead of 2. This arrangement leaves a hole or positive charge in that covalent bond (Fig. 7B). When an electron moves in to fill this hole, the hole appears to move to the spot that the electron just vacated (Fig. 7C).

As stated previously, both holes and electrons are involved in conduction. In N-type material, the electrons are the majority carriers; in P-type material, holes act as the majority carriers.

SEMICONDUCTOR DIODES

When P and N type materials are combined in manufacture, the result is a semiconductor diode. If properly biased with an external voltage, the diode will conduct heavily in one direction. Reversing the polarity of the external bias voltage results in very little current in the reverse direction. A diode is a one-way current device.

Figure 8 shows the schematic representation of a semiconductor diode. In normal applications, this diode conducts current in one direction. Current flows from the cathode to the anode. Another method used to determine the direction of current flow through a diode is to simply notice the direction of the arrow in the schematic symbol. Current flow occurs in the direction opposite the direction the arrow is pointing. In normal rectifier applications, the cathode is connected to the negative potential while the anode is connected to the positive potential.

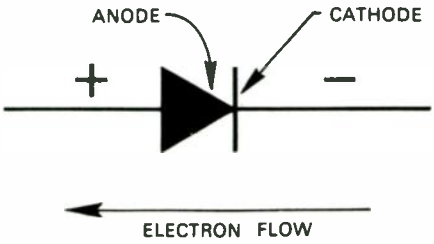


Figure 8 — Schematic representation of a semiconductor diode.

Semiconductor diodes are used for rectification and detection. In addition, they have special properties which make them useful in other applications, such as voltage regulation and switching in logic circuits. Semiconductor diodes vary in size from microminiatures, with current ratings of less than one milliampere, to very large 500 amp units.

Semiconductor diodes can be classified according to construction. The names "junction" and "point contact" represent two different methods of making semiconductor diodes.

JUNCTION DIODE

A junction diode is made by taking a single germanium or silicon crystal, and adding a donor impurity to one region and an acceptor impurity to another. This produces a single crystal with an N and a P section. Contacts are then fastened to each end. The end (ohmic) contacts are large surfaces that make a good connection with the crystal.

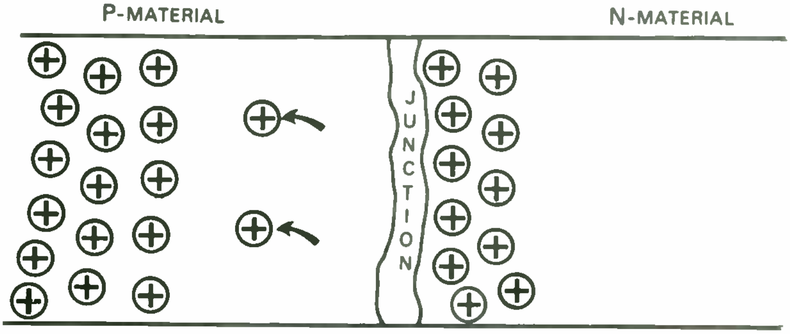


Figure 9A — Junction charges in N-region repel charges in P-material.

The two impurities filter into their respective sections of the crystal and meet at a point called the junction. These impurities do not just meet at the junction; they intermingle. P-type impurities appear near the N region (Fig. 9A), and N-type impurities appear near the P region (Fig. 9B). Immediately at the junction, the opposite charges of the two impurities neutralize. Away from the junction, other conditions exist.

As previously stated, conduction in N material is negative electron current and takes place between conduction bands of the atoms. This occurs because the donor impurity has extra electrons. The acceptor atoms in the P region near the junction attract these free electrons across the junction and lock them into the crystal's lattice structure. Two noteworthy conditions now exist.

1. The once unattached electron is no longer free to support negative current flow.
2. A hole is now present at a point where the electron previously existed.

A strongly charged P region appears in the N material near the junction. Since this area is both highly positive and near the junction, it repels any additional positive charges which attempt to cross the junction. A barrier now exists to positive current.

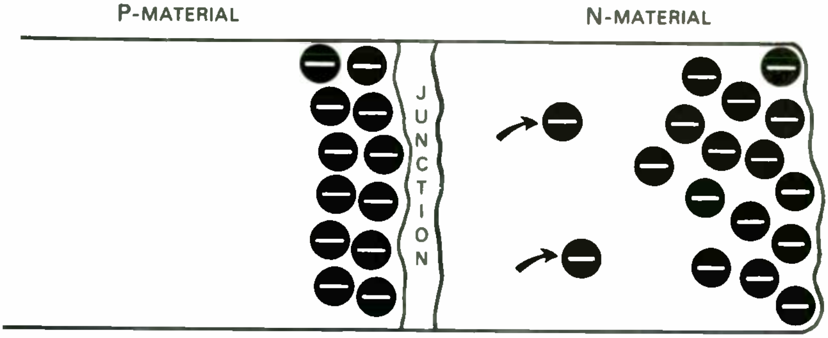


Figure 9B — Junction charges in P-region repel charges in N-material.

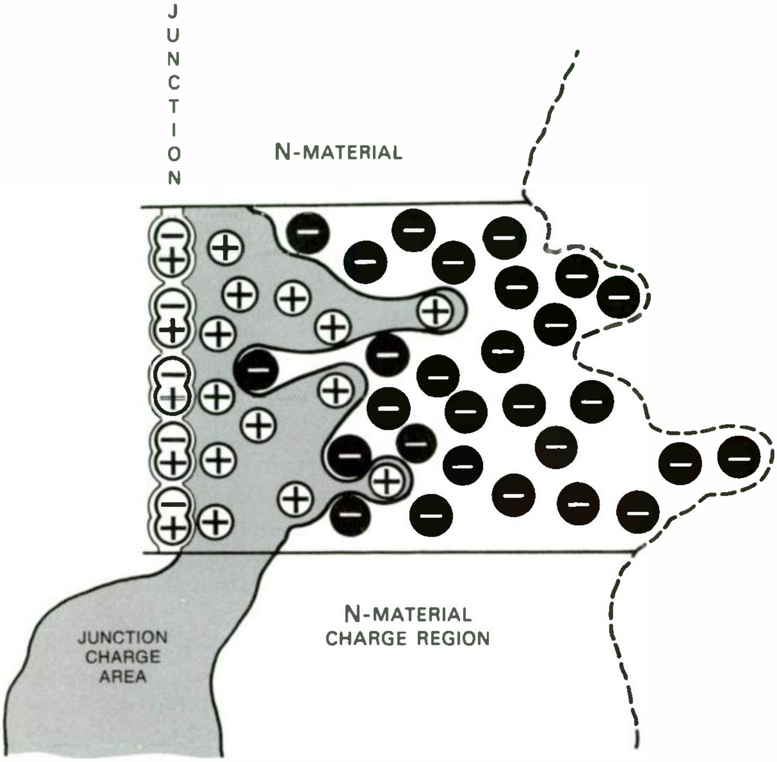


Figure 10 — Junction charge on N side of junction.

To complete the barrier, an opposite set of charge conditions exists near the junction in the P material. Due to a concentration of N ions, a strong negative force field exists. The presence of this negative field prevents any other negative charges from crossing the junction.

The forces established on either side of the junction are called *junction charges*. Figures 9A and 9B show how they each repel "like" charges from the opposite sides of the junction, and establish a barrier to either kind of current flow in one direction.

Figures 10 and 11 illustrate both the junction charges and the charges in the P and N material. In these illustrations, you see how the junction charges infiltrate the material's charge regions. Figure 12 is a composite of the two previous illustrations. It shows a positive charge on the side of the junction composed of the N-material and a negative charge on the side of the junction composed of the P-material. The two areas on either side constitute oppositely charged poles similar to the opposite poles of a battery. The force that exists between these two charges is frequently referred to as a *potential hill battery*. A potential exists in the order of a few tenths of a volt. This potential must be opposed and neutralized by an external force in order for current to flow through the junction.

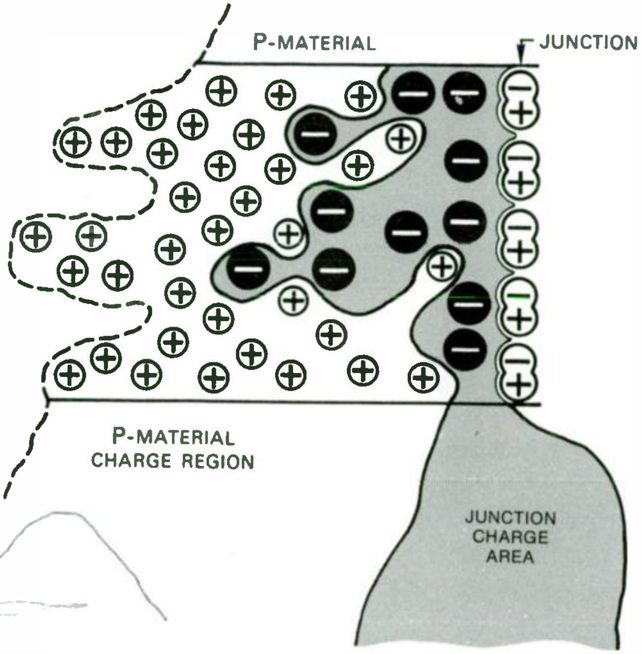


Figure 11 — Junction charge on P side of junction.

The two charges on opposite sides of the junction are of opposite polarity from the material in which they exist. They are also opposite to each other. It seems that they should combine and neutralize; they do not, however, because of the following two conditions:

1. The particles (holes and electrons) which are normally free have been captured by atoms and are no longer free to move.
2. The atoms or ions which hold them captive are themselves held stationary in the crystal's structure.

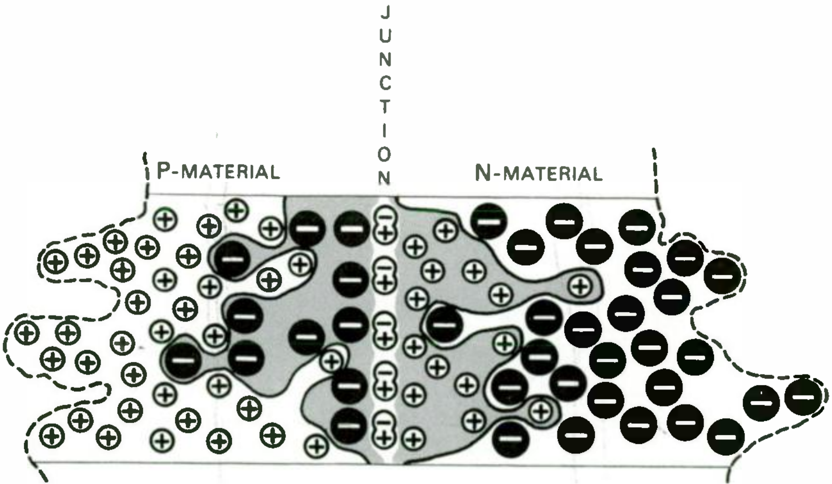


Figure 12 — PN junction and junction charges.

Therefore, charges exist with no free particles available to neutralize them. One way that free particles can be induced is by proper application of an external force. This force is usually provided by a DC power source.

FORWARD BIAS

If an external battery is connected across a semiconductor diode, the diode is said to be biased. It will be forward biased when the battery is connected to supply electrons to the N material and extract electrons from the P material (Fig. 13).

Electrons entering the N material from the battery's negative terminal first neutralize the positive force field at the junction and then cross the junction. The positive terminal of the battery attracts electrons from the negative force field near the junction in the P material. This allows electrons from the N material to cross the junction in a steady stream. Current flows almost as if the diode were a conductor (Fig. 13).

REVERSE OR BACK BIAS

Reversing the external battery causes quite a different effect from the forward bias condition. In this case, the battery's positive terminal is connected to the N material. The battery's positive force opposes and is opposed by the positive force field near the junction in the N material. Also the batteries negative potential opposes and is opposed by the negative force field near the junction in the P material. This condition is called back bias and acts to reinforce the junction potential, making the junction more stubbornly resistive. Practically no current will be allowed to flow through this back biased junction.

AVALANCHE EFFECT

If, however, the battery voltage is increased above a critical value

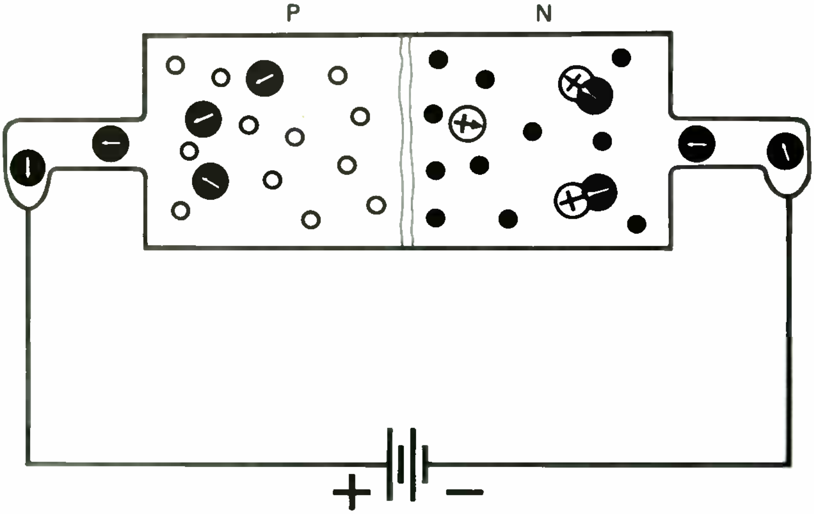


Figure 13 — Forward bias of a PN junction.

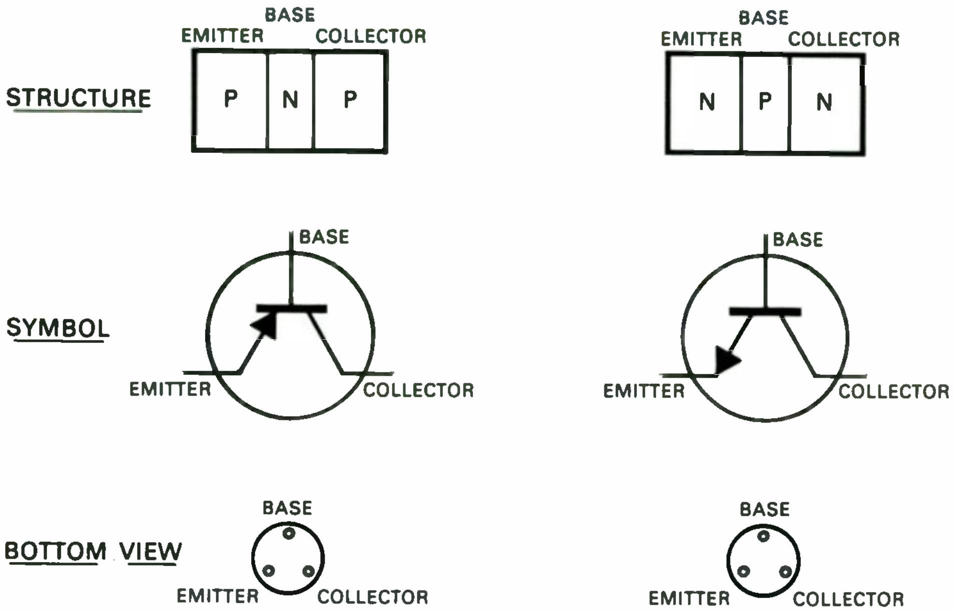


Figure 14 — Material arrangement with symbol and lead locations of the PNP and NPN transistor.

in the back direction, a breakdown occurs and current avalanches through the junction. A special device, the Zener (breakdown) diode, utilizes this effect for voltage regulation in DC power supplies. Zener's effect will be discussed later in this lesson.

TRANSISTOR ACTION

The transistor is both a derivative and an extension of the semiconductor diode; but it can do more than just pass current in one direction and oppose its passage in the opposite direction. Transistors have the ability to act as a current valve. A small amount of injected current can regulate a much larger volume of current. For example, a changing signal of less than one thousandth of an amp can produce much larger changes in a current that is ten, fifty or a hundred times stronger. This ability to increase the strength of a signal many times is called amplification.

A transistor is like two diodes placed end to end. However, connecting two individual diodes in series will not result in a transistor. To be a transistor the two junctions must be formed within the same crystal. Transistors are in reality three layer devices with two junctions. The layers may be arranged in either a P-N-P sequence or an N-P-N sequence. The only basic difference between the two is that the polarity requirements of the external bias voltages and the input signals to NPN transistors require opposite polarities from PNP types.

Figure 14 shows the material arrangement of both a PNP and an NPN transistor. Also shown are their associated schematic symbols and a bottom view of the lead arrangements for popular TO-5 cased transistors and several other small sizes.

Figure 15 pictures the PNP and NPN transistor with bias batteries connected in correct polarity for each type. In each case, the base-emitter bias polarity forward biases both the emitter junction and the collector junction. The small amount of base current flowing in the base-emitter circuit conditions the junctions, and allows a much larger current to flow from the collector to the emitter. This is forced to do so by the larger collector potential supplied by a collector bias battery. The ratio of base current to collector current is the measure of current gain for a transistor and has been termed "Beta." A transistor's Beta determines how many times an input signal is amplified or increased in strength.

How can a small current effect a much larger current movement? This can be explained relative to the charge levels of majority current carriers. Carriers exist at an elevated energy level within the semiconductor materials. Only a small amount of additional energy is required to displace them. One unit of positive charge can supply sufficient energy to attract several high energy electrons. Also, the repelling force of one moving electron from a battery can supply enough force to cause several high energy electrons within the material to move.

INPUT AND OUTPUT

Transistors are associated with resistors, capacitors, diodes, and inductors or transformers to receive,

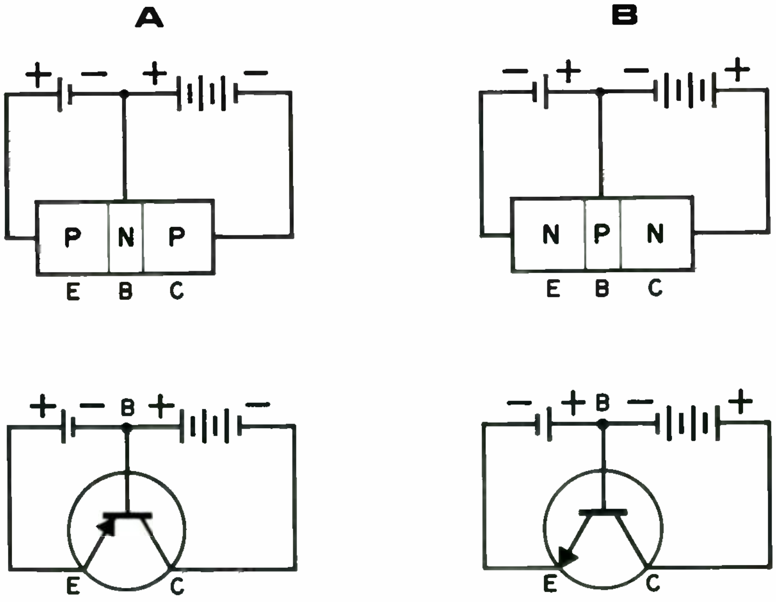


Figure 15 — Forward bias polarities.

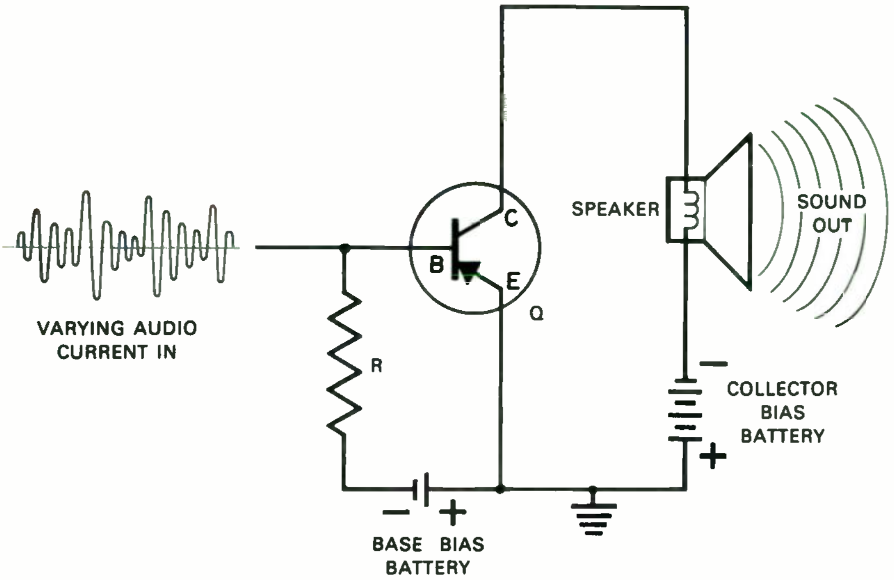


Figure 16 — Basic audio amplifier.

modify, and pass on signals. This association of components is called a circuit. A transistorized circuit must include two very important provisions: there must be a way to inject the signal current into the device, and a way to extract an output signal.

Figure 16 schematically represents a basic audio amplifier. The small input signal of varying audio current is injected directly into the base (B) of transistor "Q." R is included to prevent the base bias battery from affecting the input signal. In this case, the *base* is the input element.

The collector is connected directly to a speaker with the other side of the speaker connected to the collector's bias battery. The *collector* is the output element. A large output current flows through the transistor and battery, and operates the speaker in the collector's current path.

The *emitter* (E) is connected to both batteries and is, therefore, called the common element. The *emitter* is common in another sense; both the input (base) current and the output (collector) current flow through it.

TRANSISTOR CONFIGURATIONS

A signal may be inserted into either the base or the emitter of a transistor. The amplified output can be taken from either the emitter or the collector. The position of a transistor relative to input and output signals is called the *configuration* of a transistor.

The configuration used to perform a function with transistors is frequently determined by one of two important requirements: the amount of current gain required, or the amount of voltage gain required. A

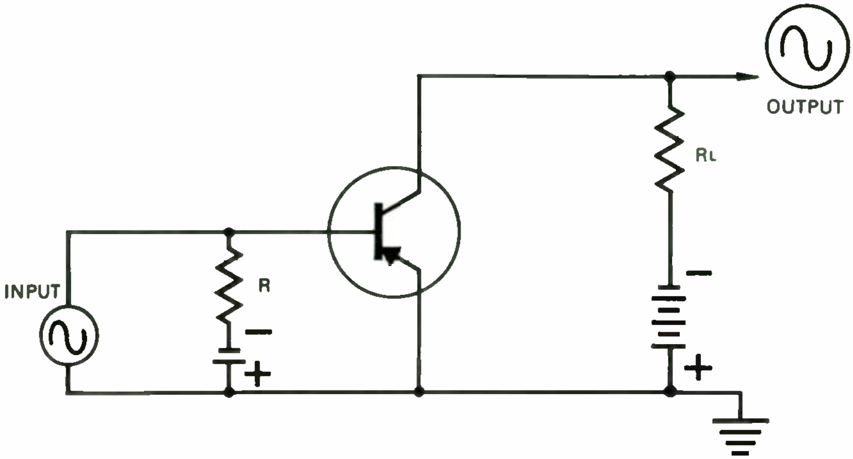


Figure 17 — Common emitter amplifier.

combination of the two results in a power gain, which may also be a prime consideration.

The transistor in the basic audio amplifier of Figure 16 is in a *common emitter configuration*. This is the most widely used arrangement. It is also referred to as a grounded emitter circuit. The output load (speaker, in this case) is in the collector's circuit. Another version of the configuration is shown in Figure 17.

Common emitter amplifiers owe their popularity to their desirable gain feature. These features are relatively high current, voltage, and power gain in one circuit. Common emitter amplifiers also have a relatively high input impedance and absorb only a moderate amount of power from the signal source.

A *common collector configuration* (also known as an emitter follower) is shown schematically in Figure 18. Like the common emitter circuit, the

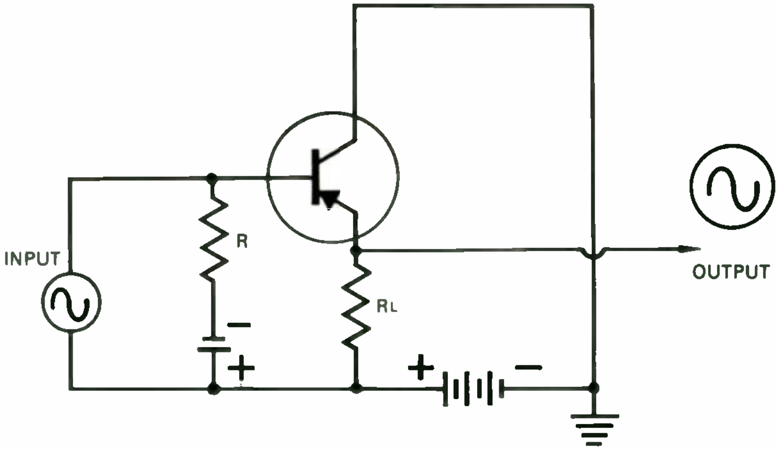


Figure 18 — Common collector (emitter follower) amplifier.

input signal is also injected into the base. The output, however, is taken across a load resistor R_L that appears in the emitter's current path.

Common collector amplifiers have exceptionally high current gain. This means that a current input signal will be boosted many times. The output voltage, however, will be less than that of the input signal; therefore, the voltage gain will be less than one to one, which is less than unity voltage. The common collector amplifier has the highest input impedance of all configurations.

Common base configurations were the earliest used arrangements for amplifiers (Fig. 19). The input signal is injected into the emitter instead of the base, and the output is taken across R_L in the collector circuit. Common base amplifiers have phenomenal voltage gains, but their current gains are less than unity. They also have very low input impedances.

BIASING METHODS

The circuits shown thus far use two individual batteries to supply junction biases. A small battery forward biases the emitter-base junction, and a larger one provides bias voltage to the collector-base junction. The necessity for two DC sources has been eliminated by the use of one of many alternate methods.

In the common emitter circuit of Figure 20, a resistive divider network has replaced the emitter-base bias battery. This network consists of resistor R_B from the base to common (ground) and R_S. R_S is connected from the base to the collector. A small amount of current is shunted around the collector through R_S. This current then divides; a portion flows through R_B and provides a small voltage at the base. This voltage is great enough to overcome the emitter-base junction potential. If the resistors R_S and R_B are chosen correctly, the voltage established at

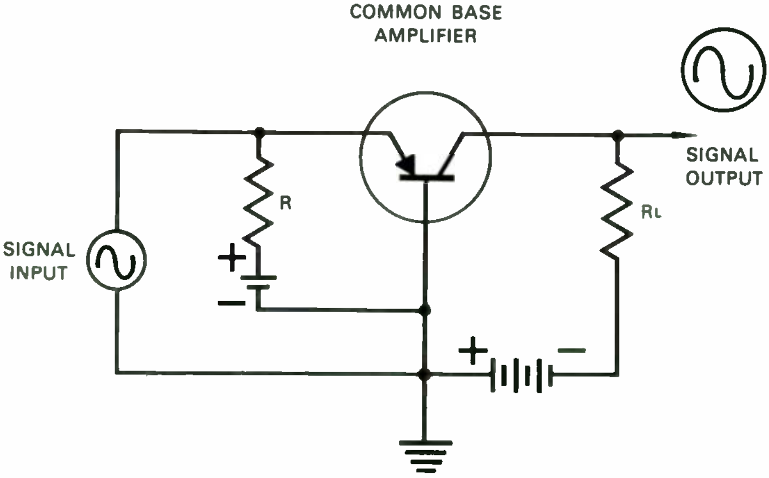


Figure 19 — Common base (grounded base) amplifier.

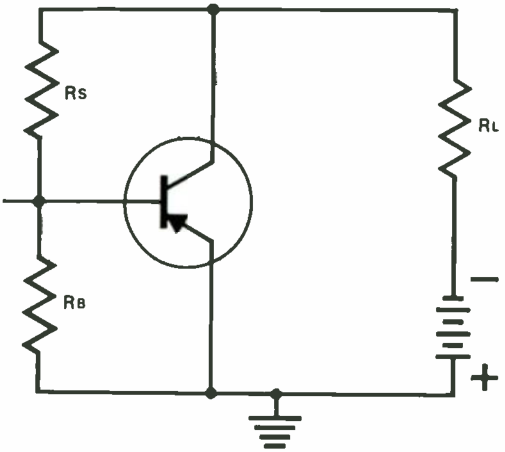


Figure 20 — Resistive divider R_s and R_b replaced base bias battery.

the base will partially forward bias the emitter-base junction. The balance of the current through R_S will then flow through the base-emitter junction and keep the junction partially forward biased.

Current flows from the battery through the collector and the collector-base junction. It continues through the base area, across the base-emitter junction, and back to the bias battery. Because the junctions are only partially forward biased, there will be resistance in each junction. These resistances in a properly balanced amplifier will equal the value of load resistor R_L. In this case, an equal amount of voltage will be dropped across the transistor and across R_L. Each of these voltages will be one half the bias battery voltage. Once this condition is established, the collector voltage can increase or decrease as the base input signal current becomes greater or less, respectively. Thus, the affected collector current and the voltage appearing across R_L will be an amplified duplicate of the input signal.

THE TRANSISTOR IS A SWITCH

Transistors are probably most often used as logic elements in industrial electronics systems and computers. A simple logic element performs the same function as a mechanical switch. It is either open and passes no current, or it is solidly closed and allows current to pass freely. The advantage of using transistors rather than mechanical devices are their small size and speed. Many transistors can be switched on or off in less than a millionth of a second.

Figure 21 pictures a simple transistor switch that can operate a low voltage lamp. With "O" volts applied, no current is flowing into the base to forward bias the junctions. Practically no current flows from emitter to collector, and the bulb is extinguished.

In Figure 22, the same circuit is shown with +12 volts applied to the base of the NPN transistor through a current limiting resistor R_1. The resulting current into the base forward biases the junctions and reduces their resistances to a negligible value. Practically all the voltage is dropped across the bulb. The bulb will illuminate until the input is once again reduced to nearly "O" volts. The condition described in which a transistor's junction resistances are reduced to their minimum value is called *saturation.* Additional input current cannot further reduce this resistance or allow the transistor to conduct more current.

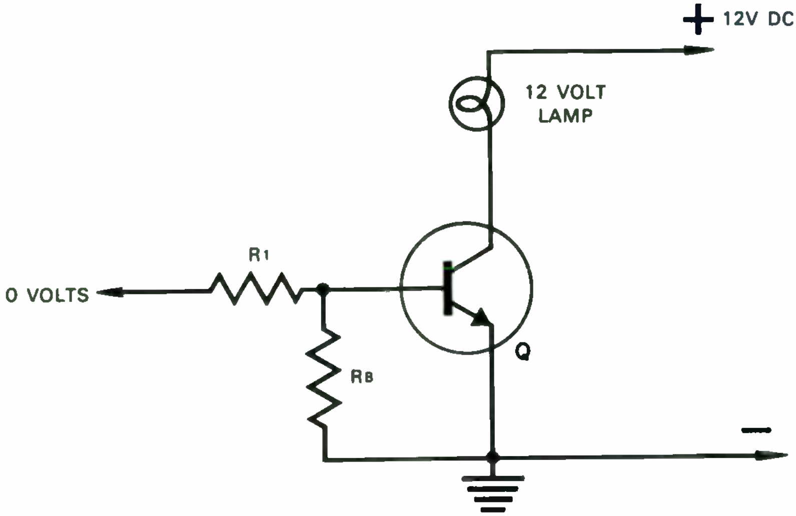


Figure 21 — A transistor arranged to switch current to a lamp.

SOME OTHER SOLID-STATE DEVICES

Tunnel diodes are two terminal devices that can operate as amplifiers or oscillators at frequencies far above the capability of transistors. They are smaller than a transistor and are less affected by temperature extremes or radiation.

The tunnel diode relies on a highly doped PN junction for its operation. Majority carriers tunnel through the junction at speeds approaching the speed of light. At some point the voltage-current relationship is such that current is increasing, even though the applied voltage is decreasing. This is called the *negative resistance* region of the curve of the

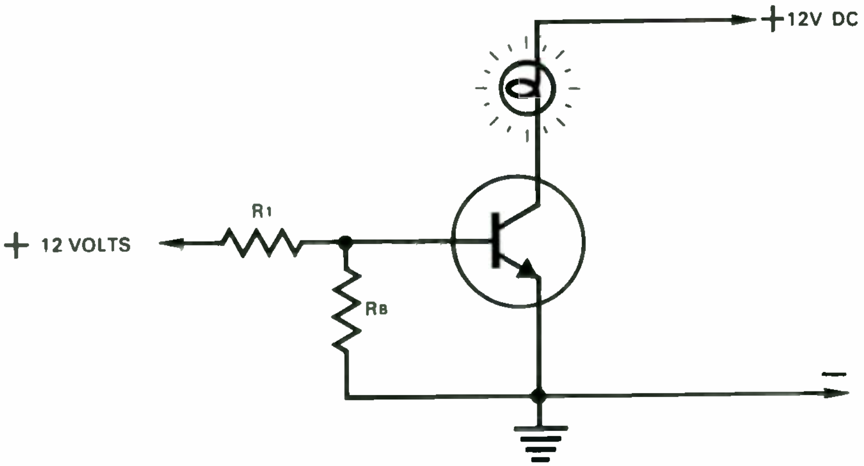


Figure 22 — A lamp illuminated from a voltage controlled transistor switch.

device. When a tunnel diode is operated in this region, it amplifies, because a small change in the input signal produces a large change in current through the device.

Zener diodes are operated in a back-biased condition as voltage regulators. The junction of these devices is formed by special doping methods. Careful selection of the type and quantity of impurity assures a predetermined breakdown voltage. Zener diodes are commonly available in a series of breakdown voltages with power capabilities ranging from a fraction of a watt to greater than 50 watts. A selection of breakdown voltages is available beginning at less than 2 volts and extending to over 200 volts.

Figure 23 illustrates a zener diode used in a shunt regulator circuit. A small value of resistance (R) is inserted between the DC source and the load. The zener is connected from the output side of R to common. Two different currents flow through R to produce a voltage drop. The current through the zener will vary with requirements to maintain a constant voltage at the output of R, point B. If the input voltage increases, the zener will conduct more current through R. This results in more voltage drop across R and prevents the voltage at point B from rising. Also if the load begins to draw less current (which also flows through R), the zener current will increase and hold the output voltage constant.

The shunt regulator circuit is the simplest voltage control circuit in common use. Other more sophisticated versions make use of components such as transistors, capacitors and additional regulating elements to accomplish more precise control.

Other solid-state diodes are the *constant current diode, avalanche rectifier diode,* and the more recently developed *light emitting diode.*

Constant current devices maintain the same value of current flow over a wide range of voltage fluctuations.

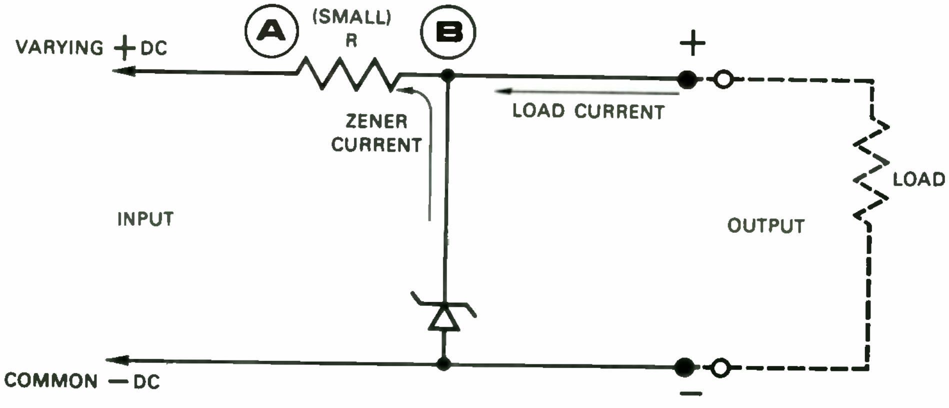


Figure 23 — A zener diode used to supply regulated DC.

Avalanche rectifier diodes are useful in equipment power supplies that are subjected to brief high potential voltage spikes. They do not ordinarily conduct in the reverse direction, but can be induced to do so when the reverse voltage rises to their avalanche value. At this point, the transient is conducted into the supply's filter section where its energy is dissipated. This prevents short duration, high voltage pulses from destroying solid-state components in the supply or in the equipment it powers.

Light Emitting Diodes or LEDs are recently developed devices that emit light when they are properly biased. Their advantages over conventional bulbs are long life and low heat dissipation.

OTHER MULTI-LAYER DEVICES

A number of solid-state devices have been developed since the transistor. These include transistors with more than one control element:

> *Silicon controlled rectifiers* (SCRs) that latch in an "on" or "conducting" state when triggered by a small momentary gate current;
>
> *Silicon controlled switches* (SCSs) can be latched on or turned off by injecting a small current pulse into them.

A more recent four layer device is the *triac*. It is a bidirectional device that can be made to conduct in either direction by the selection of specific circuit component values. Since it is bidirectional, it is useful for switching and controlling AC power.

FIELD EFFECT TRANSISTOR

A conventional transistor is known as *bipolar*, because it makes use of both positive and negative current carriers. The field effect transistor or FET is unipolar; it uses only one polarity current. Whether the current is positive or negative depends upon whether the device is of P-channel construction or N-channel construction.

Unlike bipolar transistors, FETs use a controlling voltage instead of a controlling current. FETs are available in two types, as determined by their gate construction. These are the JFET and the IGFET. Each of these is available with either N-material (N-channel) or P-material (P-channel). In addition, they may have only one gate or dual gates. Figure 24 shows a pictorial view of both the N-channel and P-channel JFET with a single gate.

The JFET is a small thin wafer of silicon doped with either an N or a P impurity. A contact is provided at each end. One end is called the *source* (S) and the other is the *drain* (D). A gate (G) is formed by doping a thin strip on each face with an impurity that is opposite in polarity to that of the material. Gate contacts are attached to each of these strips and then tied together.

Figure 25 illustrates an N-channel JFET with a bias battery attached between the drain and source in series with R_L. Current flows freely

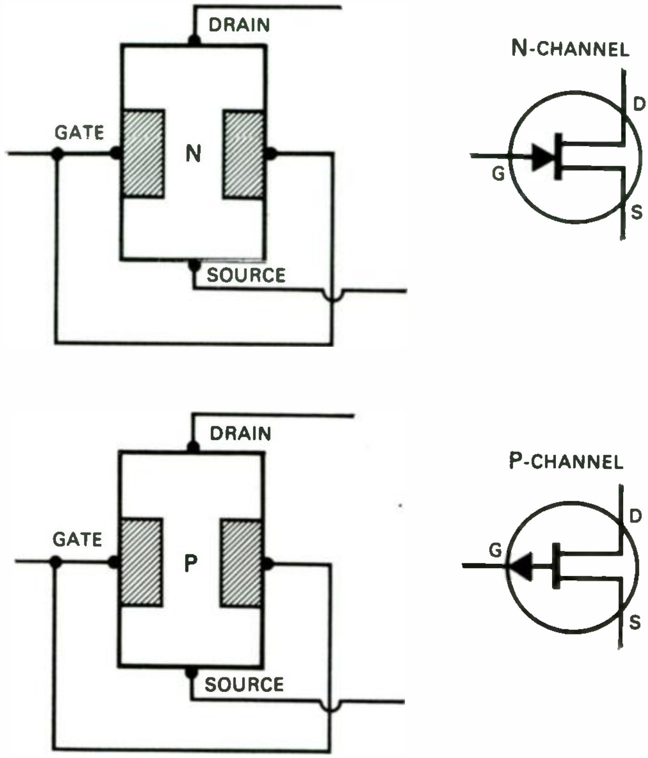


Figure 24 — Element arrangements of JFETs.

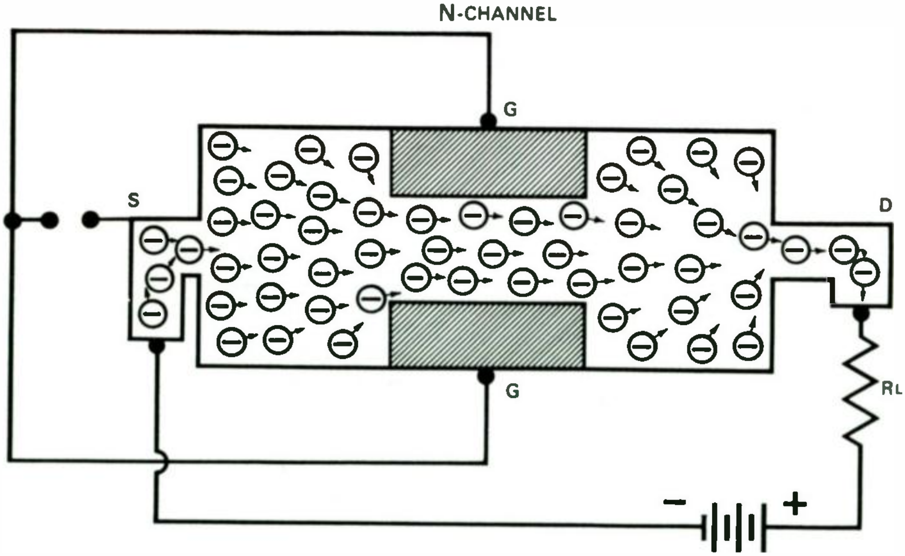


Figure 25 — Channel current in a JFET without gate bias.

through R_L, the battery, and through the device from the source to the drain.

In Figure 26 we have added a gate bias battery between the gate and the source with its negative pole to the gate. A powerful negative charge extends into the N-material and prevents electrons from flowing through the material between the gate elements. If this charge is great enough, current will cease to flow between the source and the drain; the device is then said to be in a "pinch-off" condition. The gate potential required to accomplish this is called the pinch-off voltage.

Figure 27 illustrates two JFET amplifiers. One uses an N-channel JFET and the other a P-channel JFET. A steady drain-source current flows in each of these circuits, even with no signal applied. The amount of source-drain current flowing in this static or no-signal state is established by the value of R_2, in series with the source. A voltage drop occurs across R_2. Therefore, the source is either more positive (in the N-channel circuit) or more negative (in the P-channel circuit) than the gate. Effectively, the gate is reverse biased. Its field potential will somewhat impede drain-source current flow.

This mode of operation is called the depletion mode, because the gate-source potential is polarized to restrict or deplete the devices charge carriers. Nearly all JFETs operate in the depletion mode.

If a changing voltage is applied to the inputs of the amplifiers (Fig. 27), its changes will affect the depletion charges of the gate area. These charges will become either more or less negative and will permit more or less drain-source current to flow. The drain-source current, therefore, reflects the change (direction and amplitude) of the input signal. The drain-source change is much

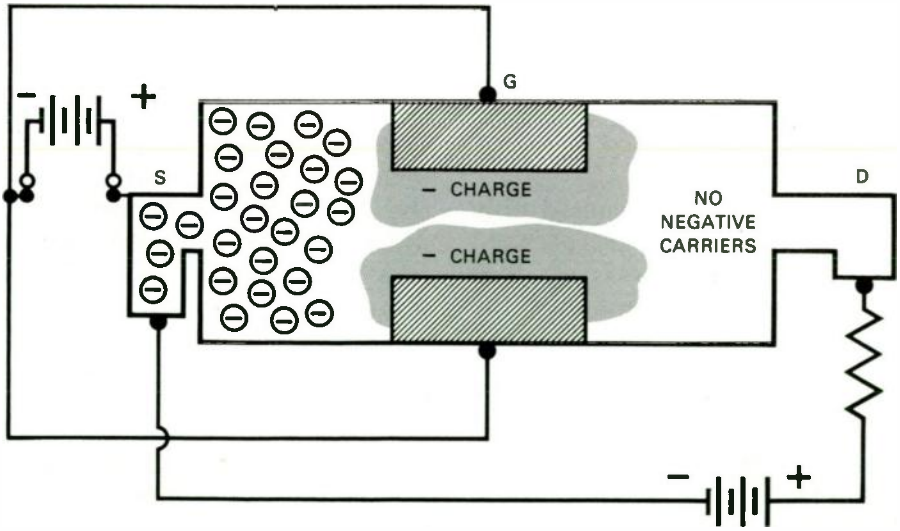


Figure 26 — Pinch-off condition of a FET.

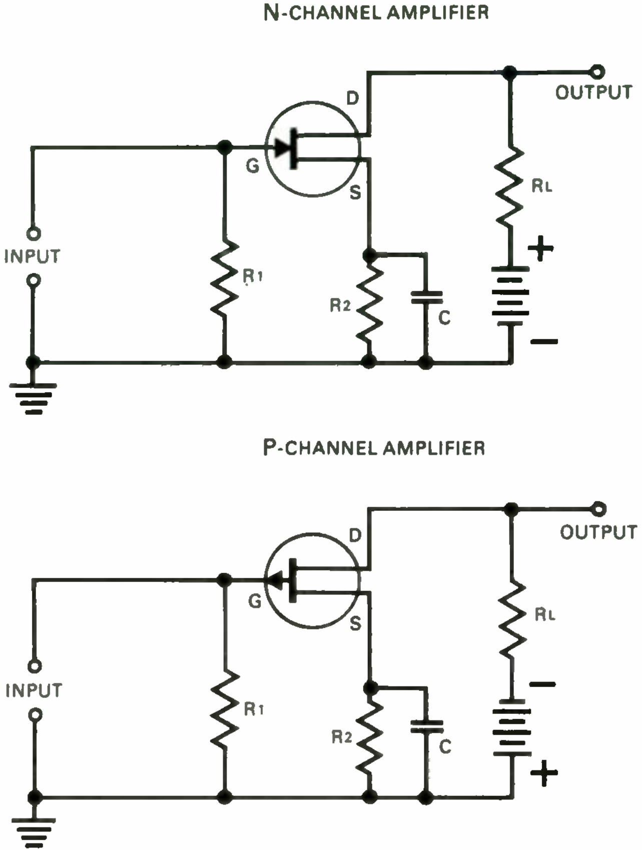


Figure 27 — Common source JFET amplifiers.

greater in magnitude than the input signal. The output signal will be an amplified duplicate of the input.

MOSFET (IGFET)

Thus far we have discussed only the JFET. Another type of field effect device is now available that has numerous advantages over the JFET. This is the MOSFET or *insulated gate field effect transistor,* sometimes abbreviated IGFET. It is called an insulated gate device, because the gate is a metal strip insulated from the source and drain. MOS is interpreted as metal-oxide-semiconductor.

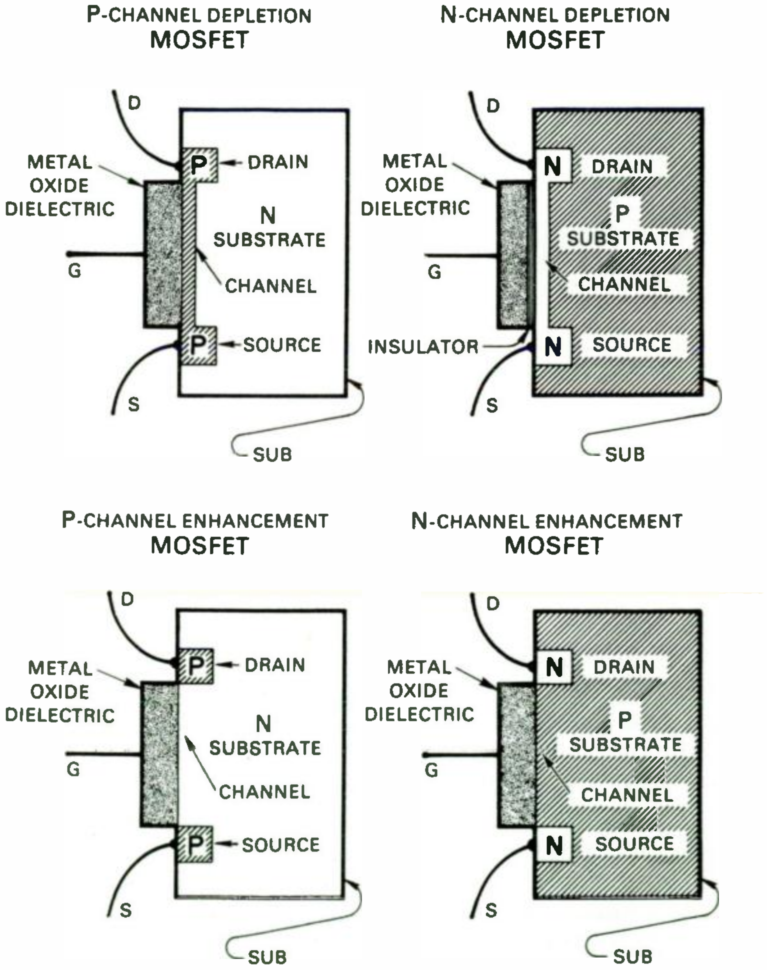
MOSFETS are available as either a P-channel or an N-channel device. They are also available as *depletion* or *enhancement* devices. The depletion MOSFET operates with a reverse bias voltage on its gate, like the JFET. The enhancement type, unlike the JFET, needs a forward bias voltage on its gate to conduct drain-source current.

Since the gate is insulated from the other elements, for all practical purposes it draws no current from the signal source. MOSFETS have the highest input impedances of any of the amplifying devices. Their input requirements are strictly voltage. Since they require no current from the signal source, they absorb no power in the input.

Figure 28 shows the construction of both the enhancement MOSFET and the depletion MOSFET. Notice that the drain-source areas are in a substrate of opposite polarity material. The depletion MOSFET contains a channel for the drain-source current, while the enhancement MOSFET uses the substrate for drain-source current.

Figure 29 shows the schematic symbols for MOSFETS. Study this carefully, so that you will be able to identify them whenever they are encountered on drawings.

Many other solid-state devices are in current usage, and new devices become available almost daily. The modern technician can keep abreast of this rapidly changing technology by subscribing to publications devoted to the latest advancements.


P-CHANNEL DEPLETION MOSFET

N-CHANNEL DEPLETION MOSFET

P-CHANNEL ENHANCEMENT MOSFET

N-CHANNEL ENHANCEMENT MOSFET

Figure 28 — Structure of MOSFETs (IGFETs).

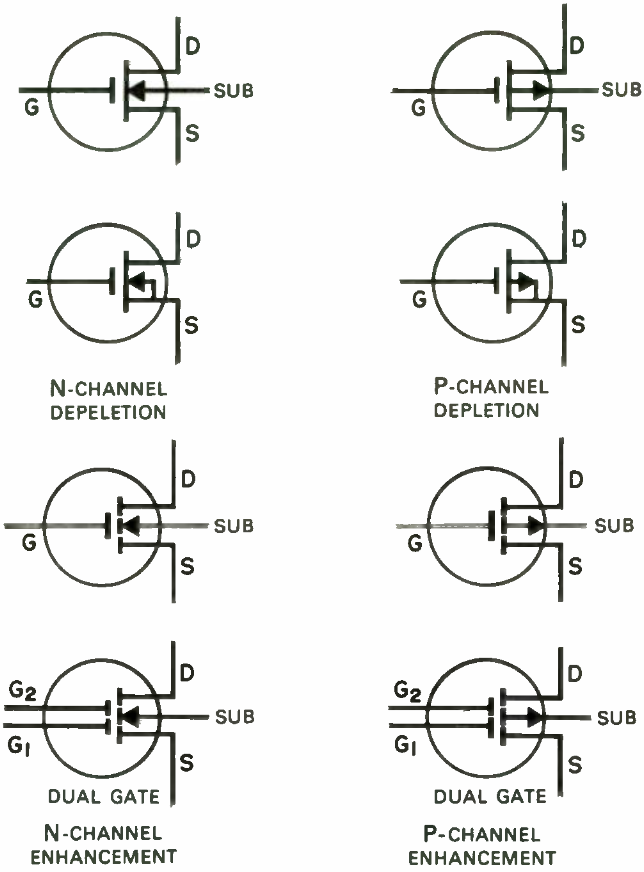


Figure 29 — MOSFET symbols.

SUMMARY

Semiconductor devices have not only replaced vacuum tubes but have surpassed the vacuum tube in the number of applications that they may be used in. Semiconductors have reduced the power requirements of equipment, reduced the physical size, and the amount of heat generated by a given unit. In addition, the life expectancy of transistorized equipment far exceeds that of equipment containing vacuum tubes. Semiconductor devices include a large variety of integrated circuits.

The transistor is a current amplifier. Used in an amplifier configuration, a small input current signal can control a large output current; thereby, producing a current gain. The measure of a transistor's current gain is known as *Beta*.

Another solid-state device, the field effect transistor, has added its unique characteristics to the ever increasing family of solid-state devices. Unlike bipolar transistors, the FET is a voltage amplifying device. The FET also has a very high input impedance.

TEST

Lesson Number 21

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-021-1.

1. **The transistor was discovered during experiments with**
   A. vacuum tube triodes.
   1 [✓ B. diode material.]
   C. space charges.
   D. hole flow.

2. **Two common semiconductor materials are**
   A. copper and aluminum.
   2 [✓ B. germanium and silicon.]
   C. hydrogen and oxygen.
   D. holes and electrons.

3. **When an impurity with 5 valence electrons is added to germanium**
   [✓ A. N-type material is formed.]
   7 B. P-type material is formed.
   C. a PN junction is formed.
   D. a PNP transistor is formed.

4. **When an impurity with 3 valence electrons is added to germanium**
   A. a plus-3 germanium is formed.
   8 B. N-type material is formed.
   C. a plus-5 germanium is formed.
   [✓ D. P-type material is formed.]

5. **Holes travel**
   A. faster than electrons.
   7 [✓ B. slower than electrons.]
   C. at the same rate as electrons.
   D. faster than light.

6. A semiconductor diode
A. conducts in both directions.
8 B. conducts in only one direction.
C. does not conduct.
D. conducts when reverse biased.

7. The charges on opposite sides of a junction
A. are of the same polarity.
B. do not exist in N-material.
10 C. are of opposite polarity.
D. do not exist in P-material.

8. The measure of a transistor's current gain is
A. Mu.
26 B. Delta.
C. Omega.
D. Beta.

9. A very common transistor configuration is the
A. cathode follower.
16 B. common emitter.
C. common battery.
D. common drain.

10. The three elements of a FET are
A. source, drain, and cathode.
21 B. emitter, drain, and gate.
C. gate, source, and drain.
D. gate, source, and collector.

Notes

Notes

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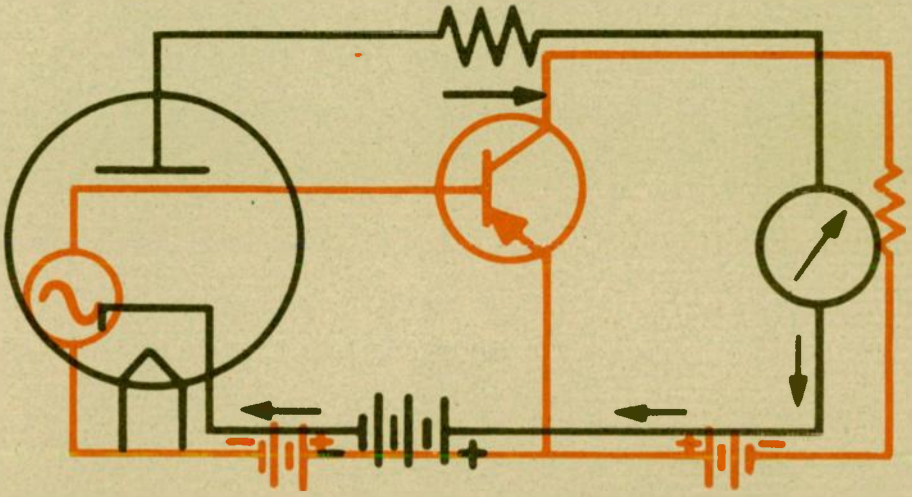
LESSON NO. 22

VACUUM TUBES



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LESSON TWENTY-TWO

VACUUM TUBES

Contents

Revised 1973

INTRODUCTION

Thomas Edison discovered the basic principle of the vacuum tube in 1883 while performing experiments with his incandescent light bulb. He inserted a metal plate into the bulb near the hot filament, and connected a battery from the filament to the metal plate, with the positive terminal to the plate. Edison was surprised to find that a current was flowing through what he considered to be an open circuit. He did not understand the reason for this current flow; nor did he realize the importance of a discovery which came to be known as the Edison Effect.

The first practical use of the Edison effect was discovered by Sir John Fleming who constructed and used the first vacuum tube diode. For many years this diode was known as the *Fleming Valve.*

A short time after Edison's discovery, Sir J. J. Thompson theorized that electrons were emitted by the hot wire filament, and were being attracted toward and collected by the positively charged metal plate.

ELECTRON EMISSION

Most metals have a large number of free electrons. Although they are called free electrons, they are free only in the sense that they can wander about within the lattice structure of the metal. The free electrons cannot normally escape from the surface of the metal. Electron emission occurs when an electron leaves the surface of the material and escapes into space.

When the surface of a solid material is placed in contact with a liquid or a gas (air, etc.), a thin film develops on the surface of the solid. Theory predicts that in a perfect vacuum this film would not exist. Since it is impossible to obtain a perfect vacuum some amount of surface film is always present. The extremely thin surface film which develops on exposed surfaces of metals acts to confine the atoms and free electrons within the metal. This thin film thus forms a *Surface Barrier* through which the free electrons cannot pass.

It is possible for a free electron to escape if enough additional energy is added. The energy required to produce emission of an electron can be supplied in any of the following forms:

heat energy (thermionic emission)
electrical energy (high field emission)
light energy (photo emission)
collision with a high energy particle
(secondary emission)

One or more of these forms of emission are utilized in the operation of any electron tube. The image orthicon TV camera for example, uses thermionic, photo, and secondary emission to produce a TV picture signal.

THERMIONIC EMISSION

Thermionic emission, as the name implies, is the process by which electrons gain enough energy by application of heat to escape from the surface of the emitting material. This is the most common type of emission employed in electron tubes. Thermionic emission is produced by heating the cathode or emitter of the tube with an electric current. Sometimes this is done directly by permitting the filament to be the emitter (cathode); frequently a separate emitter is employed which in turn is indirectly heated by a filament which is then called a heater. In other words, the power dissipated by the heater raises the temperature of the emitter to the point where electrons will be boiled from the surface of the emitting material.

HIGH FIELD EMISSION

High field emission is one of the less frequently used types of emission. This is accomplished by placing a concentration of positive charges near the surface of the emitter. The intense electrostatic field developed between the emitter and the positive charge literally rips electrons from the surface of the material.

PHOTO EMISSION

When light rays strike certain materials, the energy of the light rays is imparted to electrons near the surface. If the energy acquired by the electrons is sufficient, the kinetic energy thus gained will enable electrons to overcome the surface barrier and the electrons will escape from the substance. This type of emission is called Photo Emission. The velocity with which electrons are emitted depends upon the frequency of the light energy striking the material. The higher the light frequency (shorter the wavelength), the greater is the velocity of the emitted electrons. The quantity of electrons emitted is directly related to the intensity of the light.

Only certain specific materials can be used as photo emitters because light contains relatively little energy. Materials such as cesium, selenium, zinc, and potassium are frequently used as photo emitters. Television camera tubes and photoelectric cells are common examples of the use of photo emission.

SECONDARY EMISSION

If a stream of electrons flowing at high velocity strikes a material, the force may be great enough to dislodge other electrons from the surface of the material. The dislodged electrons are called secondary electrons and this type of emission is called secondary emission. Although secondary emission occurs to some extent in most tubes, it is used as a source of electrons in only a few specialized types. The photomultiplier tube which is beyond the scope of this course is a good example of the use of secondary emission. The X-Ray tube is another example of the use of this type of emission. In the latter case, a stream of high velocity electrons is directed against a target plate and as a result the secondary particles or X-Rays are emitted.

CONSTRUCTION

Physical Shape

The electron tube is made up of a highly evacuated glass or metal shell, which encloses several elements. The elements consist of the cathode which emits the electrons, the plate and sometimes one or more grids. Another element of importance in many tubes is the heater, sometimes called the filament, which serves to heat the emitter.

Cathode Construction

Cathodes are both directly and indirectly heated. A directly heated cathode is one

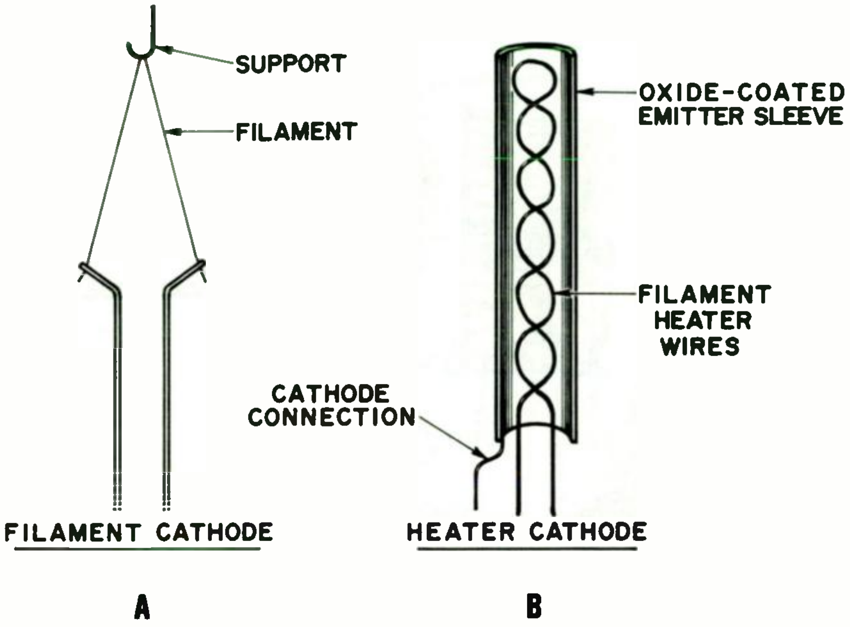


Figure 1 — Methods of heating the cathodes of electron tubes.

in which the current, used to supply the heat, flows directly through the cathode emitting material, (Fig. 1A).

The thin wire filament is suspended on an insulated support in the manner shown in the illustration. The filament can be made of tungsten, thoriated tungsten, or oxide coated nickel. When the current from a battery or other source heats the filament it will act as a cathode and emit electrons. Alternating current is not a good source for heating directly heated cathodes, because the small mass of the filament wire permits the filament temperature to rise and fall in step with the AC heating current. This causes small periodic fluctuations in the number of electrons being emitted. In most types of circuits, this can introduce an undesirable hum in the signal.

Figure 1B shows a typical indirectly heated cathode. A relatively constant rate of emission is obtained by using an AC heater due to the mass of the nickel cylinder and the fact that the heating current does not flow through the emitting material.

Most of the modern low power vacuum tubes use an indirectly heated cathode similar to the type shown. The cathode consists of a thin nickel cylinder which is coated on the outside with barium and strontium oxides. A tungsten or tungsten alloy wire, called a Heater, is placed inside the nickel cylinder. This wire is used only as a heating element and does not contribute to the emission of the tube. Some types of indirectly heated cathodes use a ceramic material surrounding the filament to electrically insulate it from the cylindrical cathode.

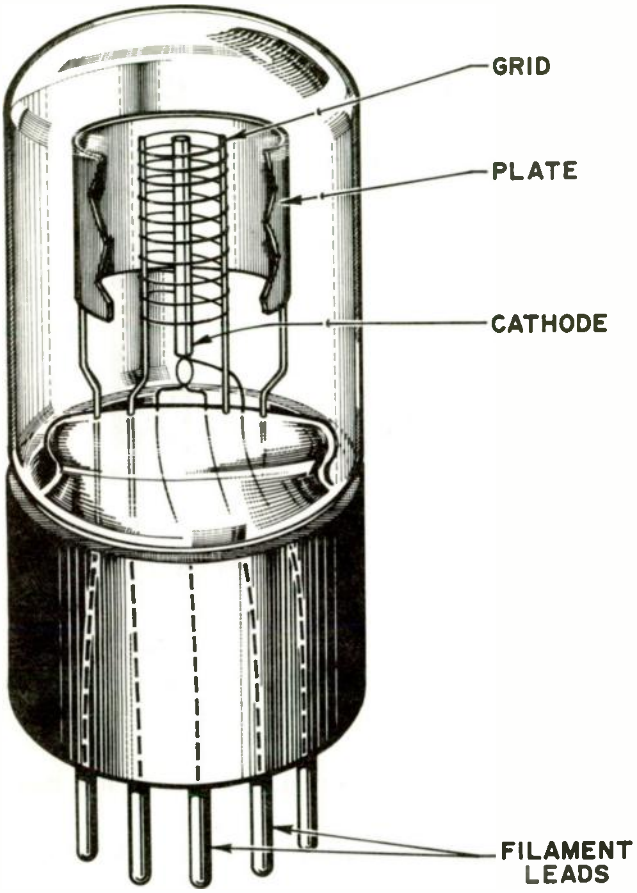


Figure 2 — Cut-away view of a triode vacuum tube.

Plate and Grid

The anode (plate) is made of materials that will not emit electrons thermionically at normal tube operating temperatures. Metals used as plates include iron, nickel, carbon, and tantalum. The plate is mounted externally, with respect to the cathode. It is electrically insulated from the cathode and usually surrounds it in order to receive all of the cathode field of emission. The plate usually has a dark surface to radiate the heat caused by the plate current.

The grid is physically located between the cathode and the plate and usually consists of a continuous spiral ring of small sized wire. This spacing between the wires allows some of the electrons to pass through the mesh formed by the grid wires (Fig. 2). The exact uses of the grid and its ability to control the electron flow between the cathode and the plate are described later under the individual tube types.

External Connections

The external leads from the tube are electrically welded to the tube elements. They are brought out at the bottom through a special glass-metal fusion to make the envelope airtight. In metal tubes a glass button is used at the base to provide electrical insulation. The materials selected for the external leads have nearly the same coefficient of expansion as that of glass. Thus during heating and cooling periods, the glass expands and contracts the same amount as the metal, and the vacuum seals are maintained.

Metal tubes are an outgrowth of the competitive field in tube manufacturing. They are designed to act as a shielded unit (the same as a glass tube with an external shield placed over it). The shield on a tube acts primarily to prevent the introduction of stray fields within the envelope where induced voltages might be amplified many times, thus causing distortion in the output stages. There are a few circuits in electronic equipment in which metal and glass tubes cannot be interchanged, even though the operating characteristics might be identical.

Getter

Like any incandescent lamp, the air in a vacuum tube must be removed to prevent oxidation and destruction of the filament. The presence of air would also tend to oxidize or contaminate the emitting surface of the cathode. In addition, the electrons would collide with the molecules of the air.

A small quantity of magnesium or barium, called a "getter," is placed inside the tube to remove any gas that may be left after evacuation. The getter is ignited by eddy currents, which are produced by means of a high frequency coil placed around the glass envelope of the tube. The high frequency field induces eddy currents which heat up a small metal cap containing the getter material and a small charge of gunpowder. This heat fires the getter which combines with the air left in the tube to form a silvery deposit on the inner walls of the glass envelope.

Tube Identification

Electron tubes are identified by symbols printed on the tube. The symbols consist of a series of numbers and letters called the tube number. The first symbol in the tube number is a number which tells the approximate filament or heater voltage. The second symbol is a letter which designates the function of the tube. Rectifier tubes, for example, are usually assigned letters near the end of the alphabet (U, V, W, X, Y, and Z).

The third symbol is a number which indicates how many of the total base pins must be connected for proper base pin operation of the tube. As an example, the tube number 5U4 indicates that the filament requires 5 volts, the U indicates that the tube is a rectifier, and the 4 indicates that 4 of the 8 base pins are actually needed to operate the tube (Fig. 4).

The relationship of an actual tube, the tube base diagram, and the tube base as seen from the chassis side is illustrated in Figure 3.

Although some electron tubes adhere to this system, some exceptions do exist. To obtain specific information on any given type of tube, a tube manual should be consulted.

There are a number of different tube bases used in electronics (Fig. 4). All vacuum tubes use one of these standard configurations. Attempts have been made to use the same

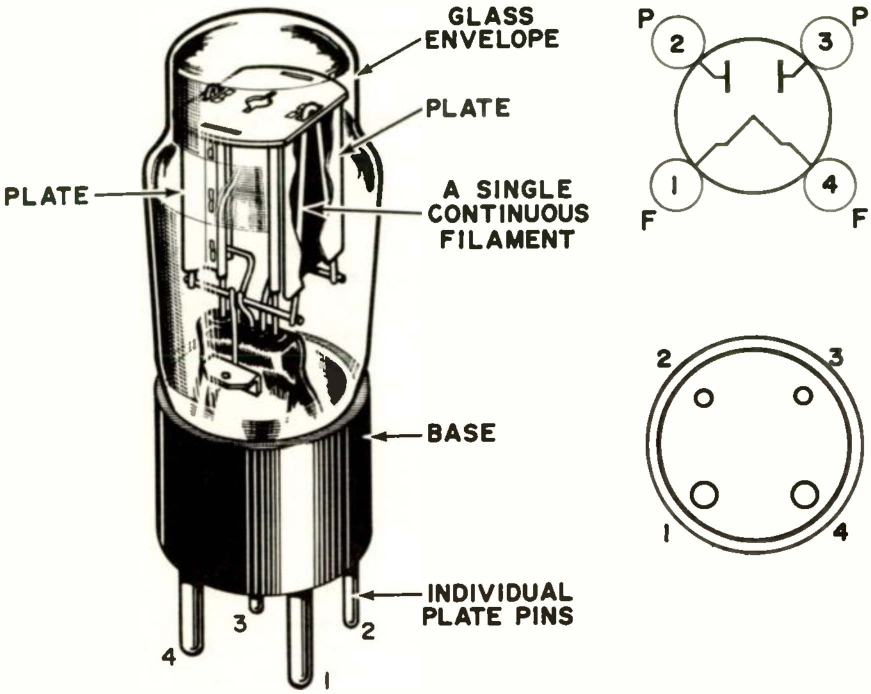


Figure 3 — Views showing how tube elements are identified.

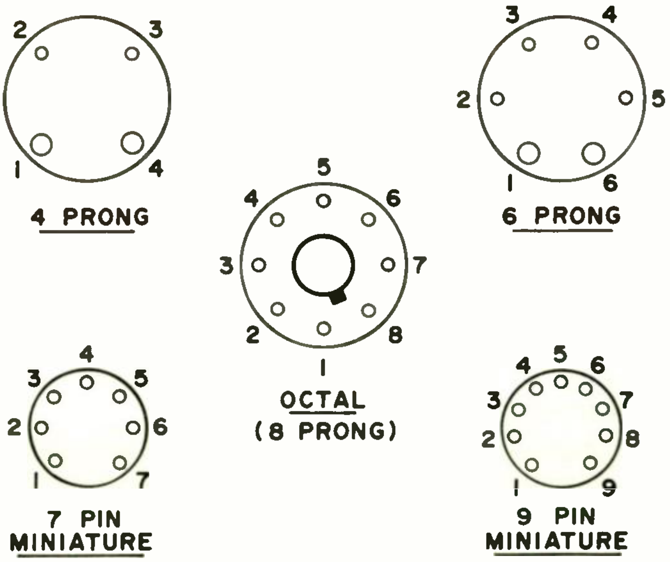


Figure 4 — Five tube base types showing how the tube connecting pins are numbered. These end views also indicate how the tube sockets are numbered on the underneath side, to correspond to the pin numbers

pin numbers for the same elements, like using the same numbers for the heaters. But tubes have certain operating characterisics designed into them, which makes it necessary to place the internal leads in a definite relationship to other elements.

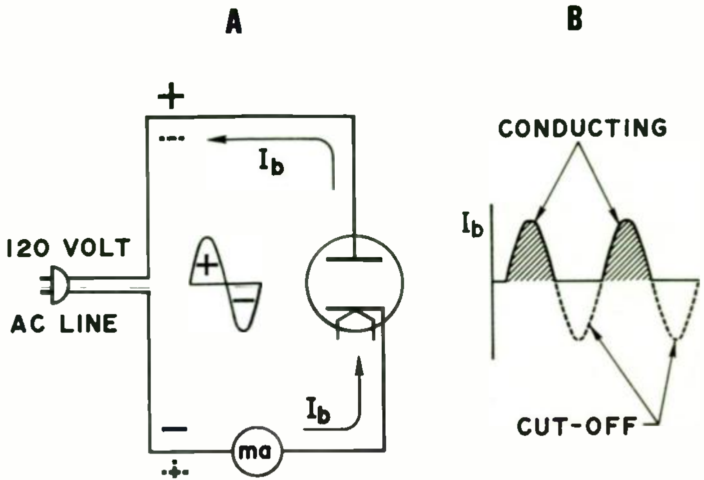


Figure 5 — Simple diode rectifier.

PRINCIPLES OF OPERATION

Rectification

Rectification is the removal of one half of a sinusoidal or other symmetrical wave. One of the widely used devices for accomplishing this is the electron tube diode. Another is the semiconductor diode. Rectification is accomplished because of the one-direction conduction characteristic of diodes. When a sinusoidal voltage is applied between the plate and cathode, conduction occurs only during alternate half cycles.

The schematic diagram in Figure 5A shows a vacuum tube diode connected across a 120 volt AC line. During the positive alternation of source voltage, the sine wave applied to the tube makes the plate positive with respect to the cathode, causing the diode to conduct. During the entire time that the plate is positive with respect to the cathode, current will flow from the negative supply lead, through the milliammeter and tube, to the positive supply lead.

The dotted lines represent the negative portion of the sine wave, during which time the plate of the tube is negative with respect to the cathode, and the tube cannot conduct. During this period, the tube is said to be cut off.

During each cycle of input voltage, the tube will conduct for 180° and will be cut off for the other 180° of the sine wave. The circuit current will, therefore, have the appearance of a series of positive half cycles as shown by the shaded portion of Figure 5B. These unidirectional pulses are called pulsating DC.

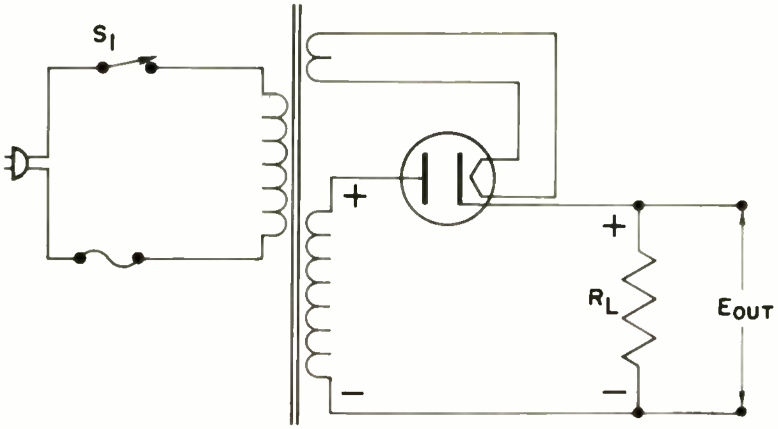


Figure 6 — Half-wave rectifier circuit.

Practical Rectifier Circuit A practical tube rectifier circuit is shown in Figure 6. Notice that a separate winding is provided on the transformer to supply current to heat the cathode. This particular tube uses an indirectly heated cathode, so the heater filament is electrically isolated from the electron emitting element.

In this half wave rectifier circuit, the diode is connected to the secondary winding through a load resistor R_L. The other terminal of the transformer winding connects to the plate of the diode. Any current flowing through the diode must also flow through the load resistor R_L and, of course, the output voltage is the drop across resistor R_L. The voltage drop across R_L, E_{OUT}, is directly proportional to the current flowing through it.

When switch S_1 is closed, the primary of the transformer is energized, and voltage will be induced into both secondary windings. The heater (current) will heat the filament and cause the cathode temperature to rise. Emission temperature will be reached a few seconds after the voltage has been applied. The alternating voltage induced in the high voltage secondary will cause the plate of the diode to be positive with respect to cathode on one alternation and negative with respect to cathode on the opposite alternation.

The schematic diagram in Figure 7 is the same as that in Figure 6. Figure 7, however has been drawn again to emphasize the fact that the rectifier tube and the load resistor form a simple series circuit connected across the transformer high voltage secondary. The heater winding has been omitted from the drawing for simplicity.

At zero degrees on the sine wave of secondary voltage, the applied voltage is zero. An instant later, the top end of the secondary winding becomes slightly positive, and current begins to flow in the circuit. Since the diode tube and the load resistor form a series circuit, the same current flows through both the tube and the resistor. This current will produce voltage drops across the load resistor (R_L) and tube which have the polarities shown in Figure 7. Since the resistance of the diode is very low, about 95 percent of the applied voltage will be dropped across the load resistor and only about 5 percent will be dropped across the tube.

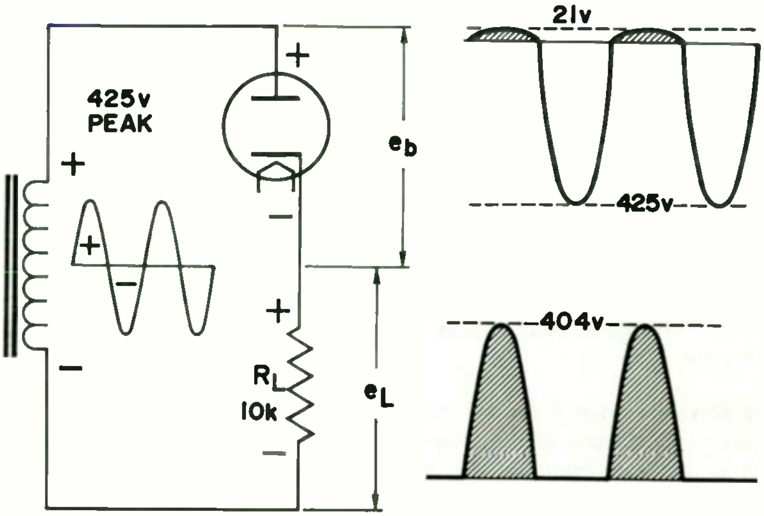


Figure 7 — Rectifier circuit and voltage waveforms.

At 90° the applied sine wave reaches its peak value, and the voltage applied to the circuit is 425 volts. Of this total, about 404 volts are dropped across R_L, and 21 volts are dropped across the tube. From 90° to 180° the voltage applied to the circuit decreases from 425 volts to zero volts, causing the tube and load voltages to drop to zero.

During the negative alternation of applied voltage, the tube cannot conduct and no current flows in the circuit. Since there is no current flow through R_L the load voltage remains at zero volts throughout the negative alternation. During this time the entire negative alternation is dropped across the tube.

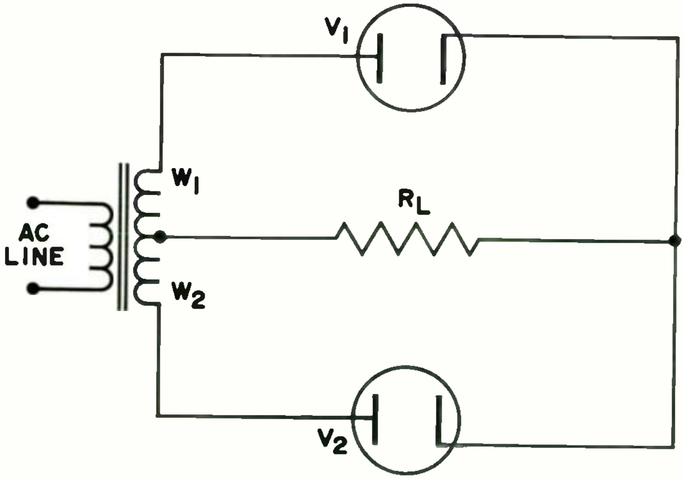


Figure 8 — Basic full-wave rectifier circuit.

The half wave rectifier (Fig. 7) draws power from the transformer during only half of the input cycle. Thus, for a given size of transformer, less power can be delivered than if the transformer were utilized on both halves of the cycle. For this reason, half wave rectifiers are used mostly in applications that require relatively small current drains.

Another disadvantage of the half-wave rectifier is that the DC current flow in the power transformer is always in the same direction. This results in a considerable amount of *core saturation* in the iron of the transformer, thereby reducing the transformer's efficiency. Core saturation will be fully explained in a later lesson.

One of the principal disadvantages of the half wave rectifier is the fact that the individual output pulses are relatively widely spaced with periods of no output voltage between them. This condition requires additional filtering if the ripple in the DC output is to be kept low.

Basic Full Wave Rectifier Circuit The disadvantages of the half-wave rectifier can be largely overcome by using a full-wave rectifier. In this type of circuit, two diodes are connected so that each conducts during alternate half cycles of the AC input. The two diodes have a common load, and the current flow through this load is always in the same direction.

The schematic diagram in Figure 8 illustrates a simple full-wave rectifier circuit. The rectifier tubes are the indirectly heated type, and the diagram does not show the tubes filament's, or the heater secondary winding on the transformer. The high voltage secondary winding is center tapped forming the two sections W_1 and W_2 which act as the source for diodes V_1 and V_2, respectively. The connections to the diodes are arranged, so that the diodes will conduct on alternate half-cycles.

Figure 9 shows the polarities of the various parts of the circuit during one alternation of the secondary voltage. The source for diode V_2 is the voltage induced in the lower half of the transformer secondary W_2. At the instant of time shown, the plate voltage on V_2 is negative and V_2 cannot conduct.

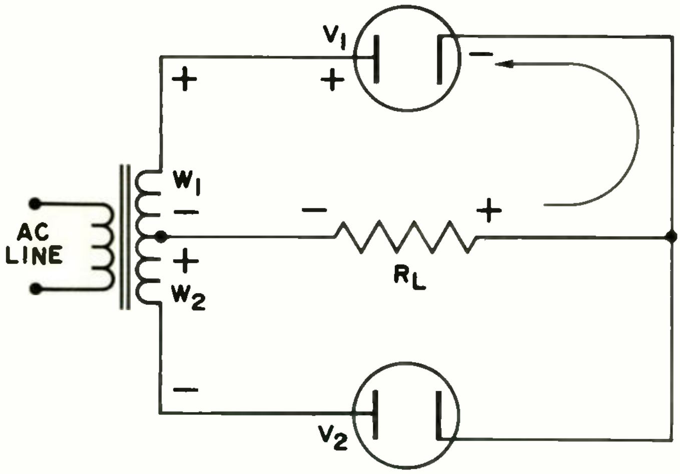


Figure 9 — Simple full-wave rectifier circuit showing polarities on the positive half cycle.

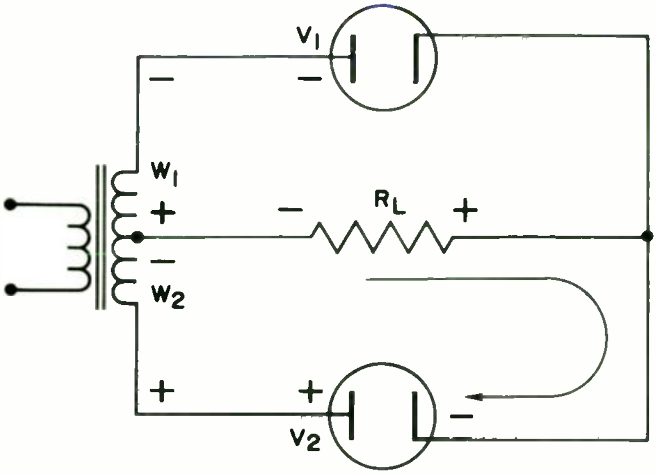


Figure 10 – Simple full-wave rectifier circuit showing polarities on the negative half cycle.

When the plate of V_2 is negative, the plate of V_1 is positive, as shown by the polarity signs in the illustration. Since the plate of V_1 is positive, it will conduct, causing current flow through the load resistor in the direction shown.

On the next half cycle of secondary voltage, the polarities across W_1 and W_2 will reverse (Fig. 10). During this alternation, the plate of V_1 is driven negative, and V_1 cannot conduct.

When the plate of V_1 is negative, the plate of V_2 is positive, as shown by the polarity signs in the illustration. Since the plate of V_2 is positive, it will conduct, causing current to flow through the load resistor in the same direction as during the previous half cycle.

Practical Full Wave Rectifier Circuit The schematic diagram in Figure 11 illustrates a typical full-wave rectifier circuit using a twin diode rectifier. Two separate diode plates and a common directly heated cathode are sealed in a single glass envelope in order to conserve space and material. The load resistor R_L is connected between the center tap of the high voltage secondary and the filament type cathode. Notice that the metal chassis is used to complete the circuit between the load resistor and the center tap. This use of the chassis to form a common ground connection is frequently used in many types of electronic equipment in order to simplify the wiring. The additional secondary winding (X, X) on the power transformer is intended to supply heater voltage to other tubes in the equipment served by the power supply.

During the positive alternation which we shall call number 1, the top end of the secondary is positive with respect to ground, and the bottom end of the secondary is negative with respect to ground. Only the upper diode has the necessary positive plate voltage required for conduction. Current will flow from ground, up through the load resistor (solid arrows) to the cathode, from the cathode to the upper diode plate, down through the top half of the transformer secondary to the center-tap, and back to the bottom of the load resistor by way of the metal chassis. This current develops a pulse of voltage across the load resistor which makes the top of the resistor positive with respect

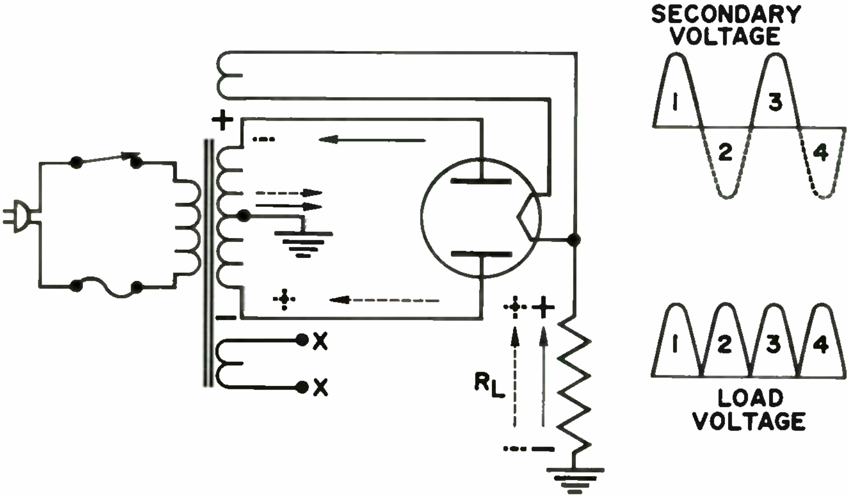


Figure 11 – Complete full-wave rectifier.

to ground. The waveform across the resistor is shown by the load voltage alternation marked "1" in the diagram.

Upon completion of the positive alternation, the polarities across the secondary winding reverse. This makes the plate of the top diode negative causing it to cut off. The bottom diode plate becomes positive, and conduction occurs over the path marked by the dotted arrows. The important fact to note about the circuit arrangement is that current flows through the load resistance in the same direction for both positive and negative alternations of the applied wave.

The output waveform of the full-wave rectifier consists of two pulses of current or voltage for each cycle of input voltage. The ripple frequency at the output is, therefore, twice the line frequency. The advantages of this higher frequency will become apparent when we study filter circuits for power supplies in a later lesson.

Control Elements

Although the Fleming valve (the diode) was developed for the purpose of detecting radio waves, it did not prove to be very satisfactory until, in 1906, Lee De Forest invented the Audion. The Audion was merely a Fleming valve with a third element or grid inserted between the plate and the filament (cathode).

Lee De Forest's invention proved to be the birth of a new age in the history of man's technical advancement. By placing a small wire mesh or grid into the diode, he discovered that the electron flow from the cathode to the plate could be controlled by varying the relative potential between the grid and cathode. This new vacuum tube now had three active elements so it was called a Triode.

The manner in which the triode grid controlled the electron flow was compared with the action of a valve controlling the flow of water in a pipe; therefore, the first triode vacuum tubes were called valves. This term is still used in England to describe what we call an electron tube.

Just as a slight pressure on the handle of a valve or faucet controls enormous water pressures, a small potential on the grid of the triode can control a much larger plate potential by its ability to control current flow. In other words, a small amount of power or energy can control a much larger amount of power or energy. This process is commonly called *amplification.*

When heater voltage is applied to a vacuum tube, emission begins and electrons are thrown out of the emitting material into the evacuated space surrounding the cathode. These electrons form an invisible but dense cloud which hovers around the cathode. This cloud of negative electrons is called the *space charge.*

Most of the electrons have low velocities and do not travel far from the cathode surface. A few of the more violently expelled electrons have velocities sufficient to carry them beyond the space charge to the plate electrode.

Negative Plate Voltage Condition The schematic diagram in Figure 12 shows the B– voltage connected to the plate or anode, and the B+ voltage connected to the cathode. It is common practice to omit the connections to the heater in order to simplify the diagram.

The negative voltage on the plate of the tube causes an electrostatic field to exist between the plate and cathode. Since the plate is negative with respect to the cathode, the direction of this field is such as to repel electons away from the plate and toward the cathode. Due to the plates inability to emit electrons, no current can flow through the tube. In other words, when the plate of a diode is negative with respect to its cathode, the diode acts as an open circuit.

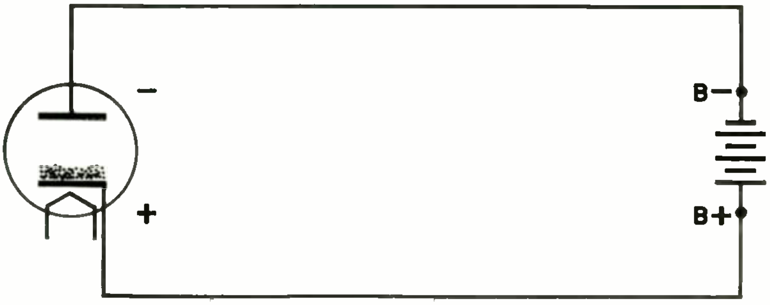


Figure 12 — Diode with a negative plate voltage.

Positive Plate Voltage Conditions The schematic diagram in Figure 13 shows the B+ voltage connected to the plate, and the B– voltage connected to the cathode. The direction of the electrostatic field between the plate and cathode will be such as to accelerate the electrons near the outer edge of the space charge and attract them to the plate. Upon striking the plate the electrons are attracted to the positive terminal of the battery. This flow of electrons from the plate of the tube to the positive terminal of the battery is called *plate current* (i_p).

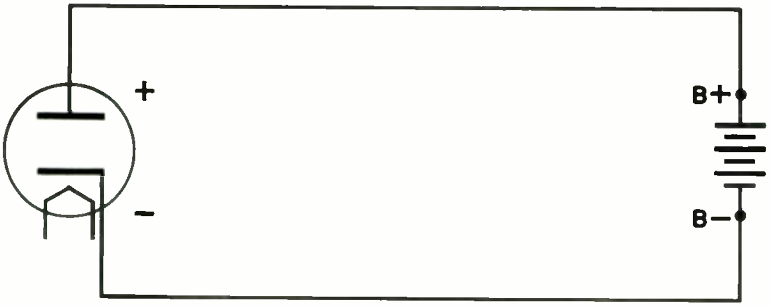


Figure 13 — Diode with a positive plate voltage

For each electron removed from the space charge by the plate, one electron is supplied to the space charge by the cathode. The space charge thus acts as a reservoir from which the plate can draw electrons.

Since the number of electrons entering the plate is the same as the number of electrons leaving the cathode, the plate and cathode currents are identical. The tube and battery, therefore, constitute a simple series circuit in which the tube acts as a resistance and the current is the same in all parts of the circuit.

As long as the space charge reservoir of electrons exists around the cathode, the amount of plate current depends entirely on the amount of positive voltage applied to the plate. If the plate voltage is increased, the plate current will increase.

Amplification

The electrons flowing from cathode to plate in a vacuum tube must pass between the grid wires; therefore, the potentials of both grid and plate are effective in controlling the plate current. The grid, however, is closer to the cathode and has more control over the plate current than does the plate. As stated before, it is this feature which produces amplification in a triode vacuum tube.

The behavior of electrons within the tube depends upon the various electrostatic fields existing between the tube's elements. The direction and intensity of these fields are governed entirely by the difference of potential between the elements of the tube.

The voltage between grid and cathode produces an electrostatic field between them. If the bias voltage is negative, the direction of the electrostatic field is opposite to the field created by a positive plate. Thus, while the cathode-to-plate field is attracting electrons from the space charge to the plate, the cathode to grid field is opposing the movement. For a positive bias voltage, the conditions are reversed. The two fields are in the same direction, and both cause electrons to be attracted to the plate. The spacing between the grid wires allows practically all of the electrons to pass through the grid on their way to the plate. Very few electrons are intercepted by the grid itself (Fig. 14).

Increase the positive potential on the plate of the triode in Figure 2 and it attracts more electrons. The same can be accomplished by decreasing the minus potential applied to its control grid. The important difference is that a much smaller change is required at the grid than at the plate to cause *a like change in plate current.* The ratio between these two voltage changes is the amplification factor μ or Mu, of a vacuum tube.

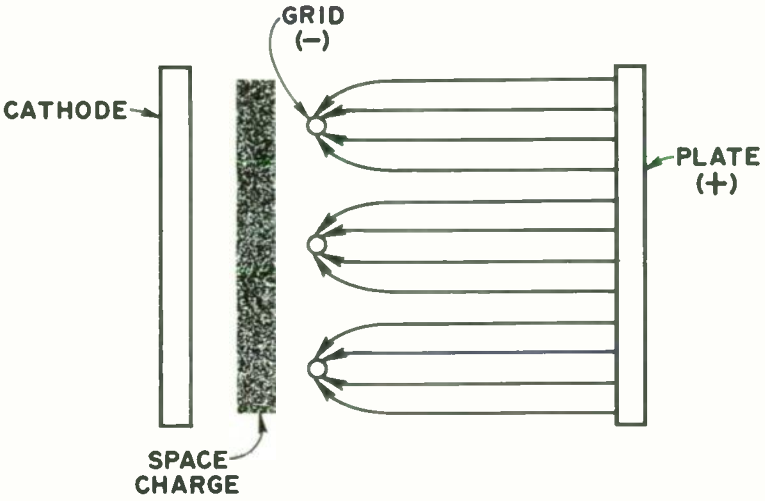


Figure 14 — Electrostatic field at or beyond cut-off.

TYPES OF VACUUM TUBES

Diode

Design The vacuum tube diode consists of two electrodes or elements called the cathode and plate. The cathode is always placed in the center of the tube, and the plate is positioned around it (Fig. 15). Figure 15A illustrates a diode with a directly heated cathode, and Figure 15B illustrates a diode with an indirectly heated cathode. Since the function of the plate is to collect electrons, it is made of a material which does not

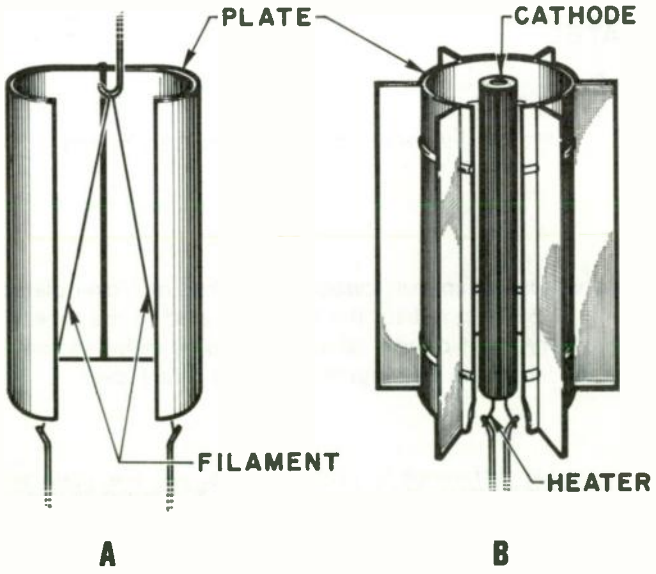


Figure 15 — Typical construction of directly and indirectly heated diodes.

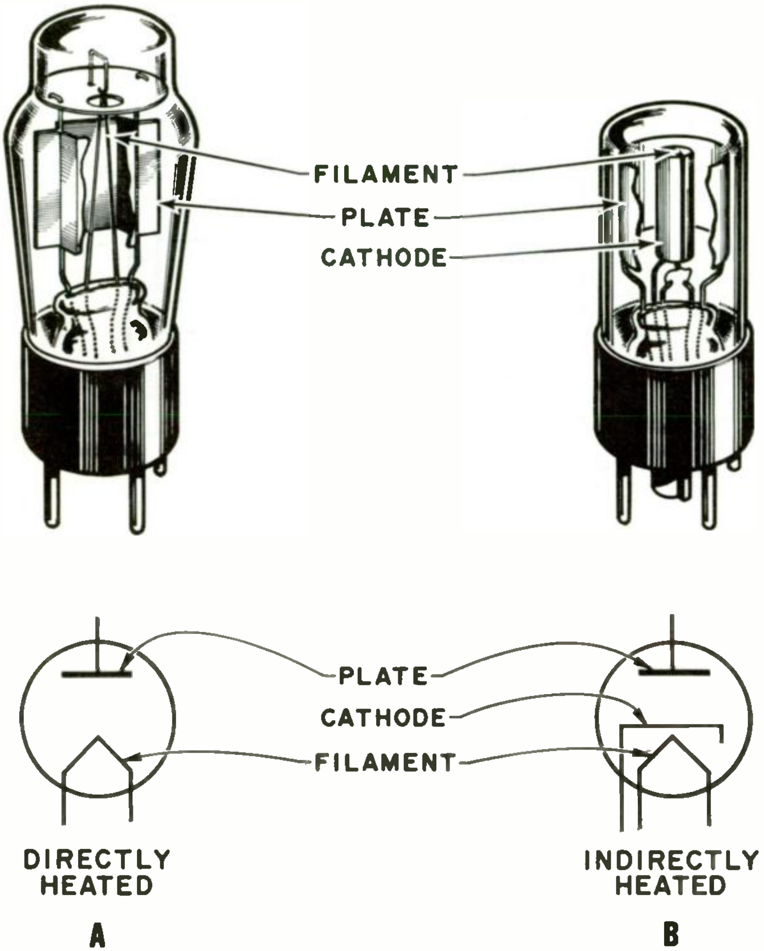


Figure 16 — Cutaway views of two types of diode tubes.

readily emit electrons, such as copper, carbonized nickel, or nickel plated steel. The fins on the plate in Figure 15B help radiate the heat generated in the tube. Figure 16 shows cut away views of two types of diodes, which can also be called vacuum tube rectifiers. Also illustrated are the schematic drawings of these two tube types.

Operation If a potential difference is produced between the plate terminal and the cathode terminal so that the plate is positive with respect to the cathode (Fig. 17A), electrons flow from the cathode to the plate inside the tube envelope. These electrons return to the cathode via the plate circuit battery. This flow of electrons, known as plate current, can be measured by a milliammeter.

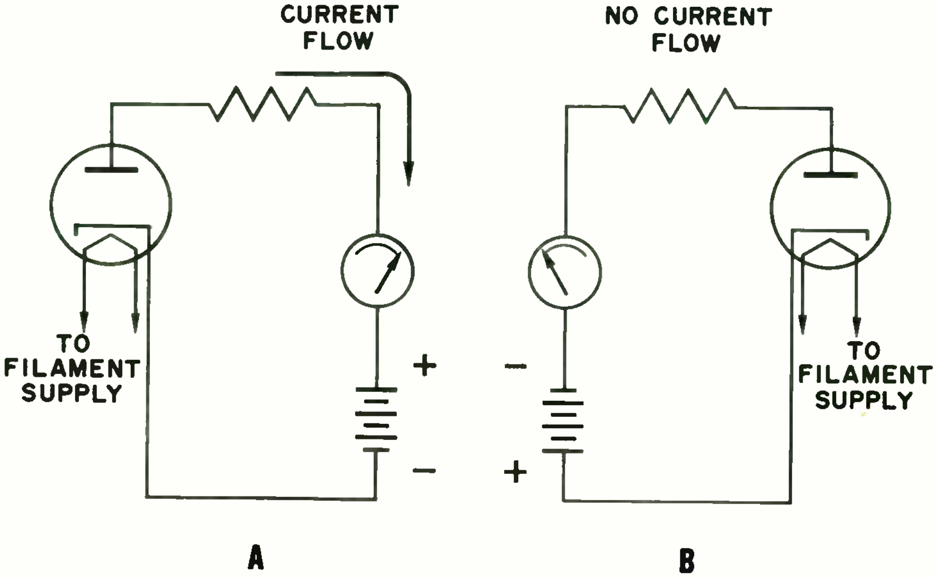


Figure 17 — Current flows in a diode only when the plate is positive.

However, if the plate is made negative with respect to the cathode (Fig. 17B), no plate current flows, because the emitted electrons are repelled instead of attracted (since like charges repel). This unidirectional characteristic of the diode permits electrons to flow from the cathode to the plate only when the plate is positive with respect to the cathode.

Space Charge The total number of electrons emitted by the cathode, at a given operating temperature, is always the same regardless of the plate voltage. The electrons in the interelectrode space constitute a negative space charge which tends to repel, *back into the cathode,* the electrons just being emitted. At low plate voltages, only those electrons nearest the plate are attracted to it, constituting a low plate current. However, as the plate voltage is increased, greater numbers of the electrons are attracted to the plate, and correspondingly fewer of those being emitted are repelled back into the cathode. Eventually a high enough plate voltage is reached at which all the electrons being emitted cross over to the plate, and none are repelled back to the cathode. Any further increase in plate voltage can cause no increase in the plate current flowing through the tube. The relation between the increase in plate current i_p in a diode as the plate voltage e_p is increased is illustrated in Figure 18.

Application Since current can flow in only one direction through a diode, one of its applications in electronics is its use as a rectifier. An alternating current potential applied in series with the circuits of Figure 17 causes a current to flow through the resistance load only during alternate half-cycles (Fig. 19). The flow takes place only when the plate is positive with respect to the emitter. This unidirectional characteristic of the diode is also used in principle when the tube is used as a detector.

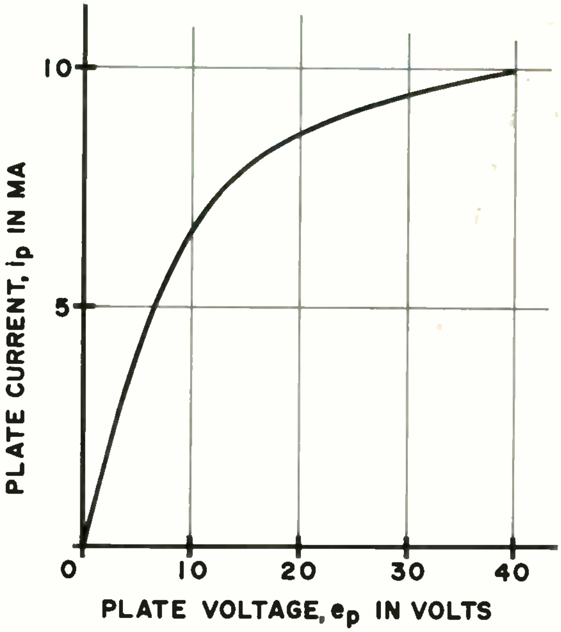


Figure 18 — Plate current i_p increases as the plate voltage e_p increases.

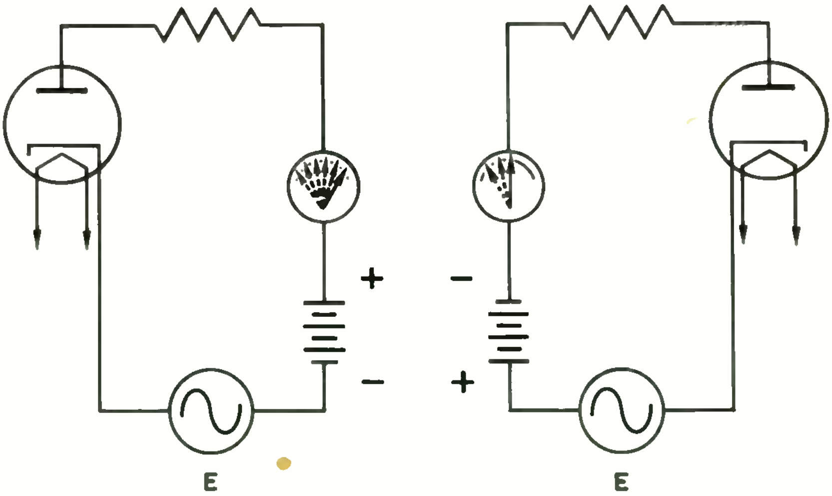


Figure 19 — An alternating current in series with a battery produces current flow in a diode only when the plate is positive.

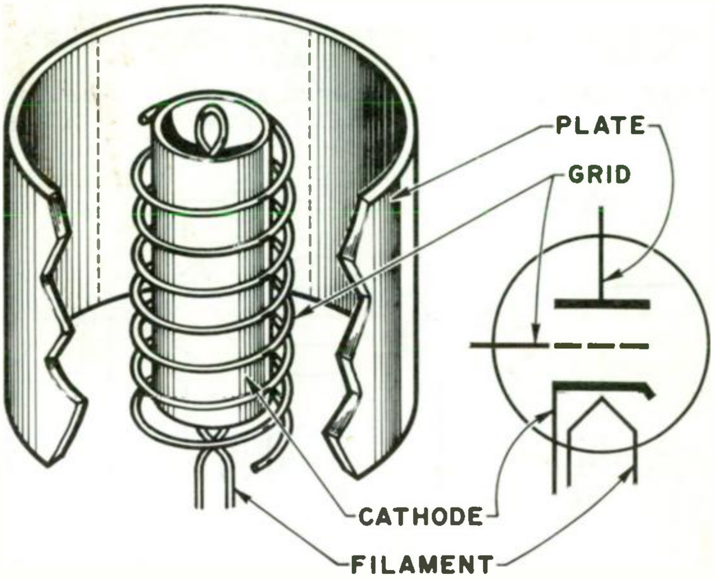


Figure 20 — Physical structure and schematic symbol of a triode vacuum tube.

Triode

Grid Bias When a third electrode, a control grid or *grid,* is placed between the cathode and the plate, the vacuum tube is known as a triode (Fig. 20). The grid itself does not present an obstacle to the electron flow, because it is an open helix or mesh of fine wires. But a varying potential on this electrode has an important controlling effect on the plate-current output of the tube.

If the grid is made sufficiently negative with respect to the cathode, all electrons are repelled by it and are forced back to the cathode. No electrons reach the plate and so the plate current is zero. The smallest negative voltage between grid and cathode which causes the tube to cease conducting is called the *cut-off bias* (Fig. 21A). There is no plate current flowing, as indicated by the zero position of the milliammeter in the plate circuit.

If the grid is made slightly less negative with respect to the cathode, some electrons get past the grid and move to the plate, producing a small plate current. Further decrease in the negative grid voltage allows further increase in plate current. As long as the grid is negative with respect to the cathode, no electrons are attracted to the grid, and no current can flow through the grid circuit (Fig. 21B).

At zero grid potential, with respect to the cathode, no retarding influence is exerted on the electrons, and the action is very similar to that of a diode. (Fig. 21C). When the grid is positive, an accelerating influence is exerted on the electrons; some of them are attracted to the grid, causing an appreciable grid current to flow. Under these conditions power is dissipated in the grid circuit. To avoid power consumption by the grid circuit, vacuum tubes are generally operated with a grid voltage varying in a negative direction from zero with respect to the cathode.

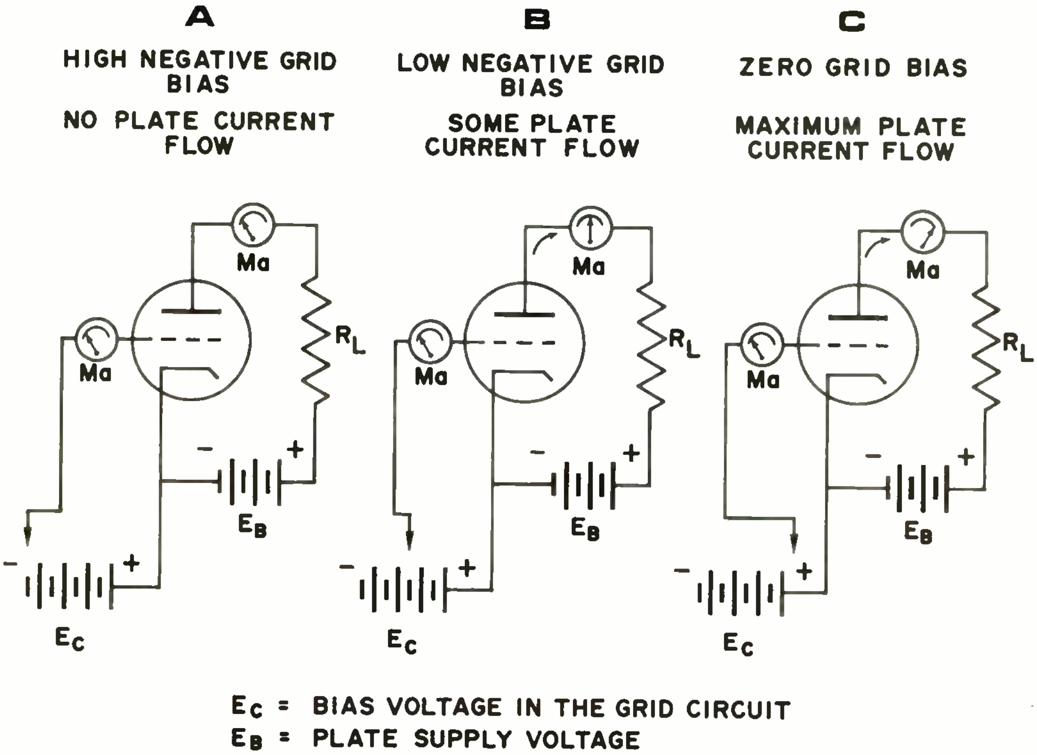
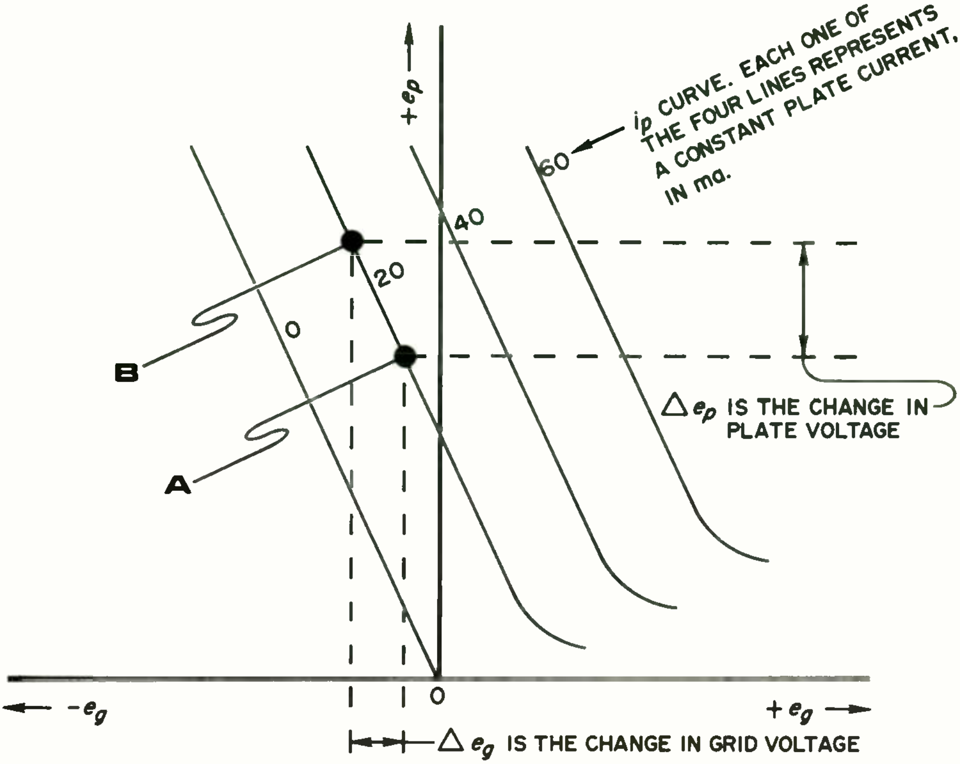


Figure 21 – The plate current increases as the bias voltage on the grid is made less negative.

Tube Characteristics The grid may act as a valve to control the plate current since the voltage variation on the grid has a much greater effect on the plate current than do changes in plate voltage. When a resistance or impedance load R_L (Fig. 21) is placed in series in the plate circuit, the voltage drop across it, which is a function of the plate current flowing through it, is controlled by the grid voltage. Thus, a small change in grid voltage causes a large change in voltage across the load. In other words, the grid voltage is *amplified* in the plate circuit.

Amplification Factor The characteristics of vacuum tubes with cathode, grid, and plate elements involve the relationships between grid voltage, plate current, and plate voltage. The measure of the amplification of which a tube is capable is known as its *amplification factor,* designated μ, and is the ratio of

plate voltage change required for
a given change in plate current
to
the grid voltage change necessary to
produce the same change in plate current.



AMPLIFICATION FACTOR, $\mu = \frac{\Delta e_p\text{, PLATE VOLTAGE CHANGE}}{\Delta e_g\text{, GRID VOLTAGE CHANGE}}$ adjusted

Figure 22 — Plate voltage to grid voltage curves.

An e_p vs. e_g characteristic for a typical triode is shown in Figure 22. A value of plate voltage e_p is selected, and the grid voltage e_g is adjusted to operate the tube at point A on the 20 milliampere curve. The value of e_p is raised a specific amount; and e_g is made more negative to hold the plate current at 20 milliamperes, so that the tube operates at point B. The amplification factor is determined by the ratio of the small change in plate voltage, called Δe_p, to the small change in grid voltage Δe_g, and becomes

$$\mu = -\frac{\Delta e_p}{\Delta e_g} \text{ when } i_p \text{ is held constant}$$

The minus sign simply indicates that the changes in plate voltage and grid voltage are in opposite directions. Triodes have amplification factors varying from 10 to 100 times the input signal.

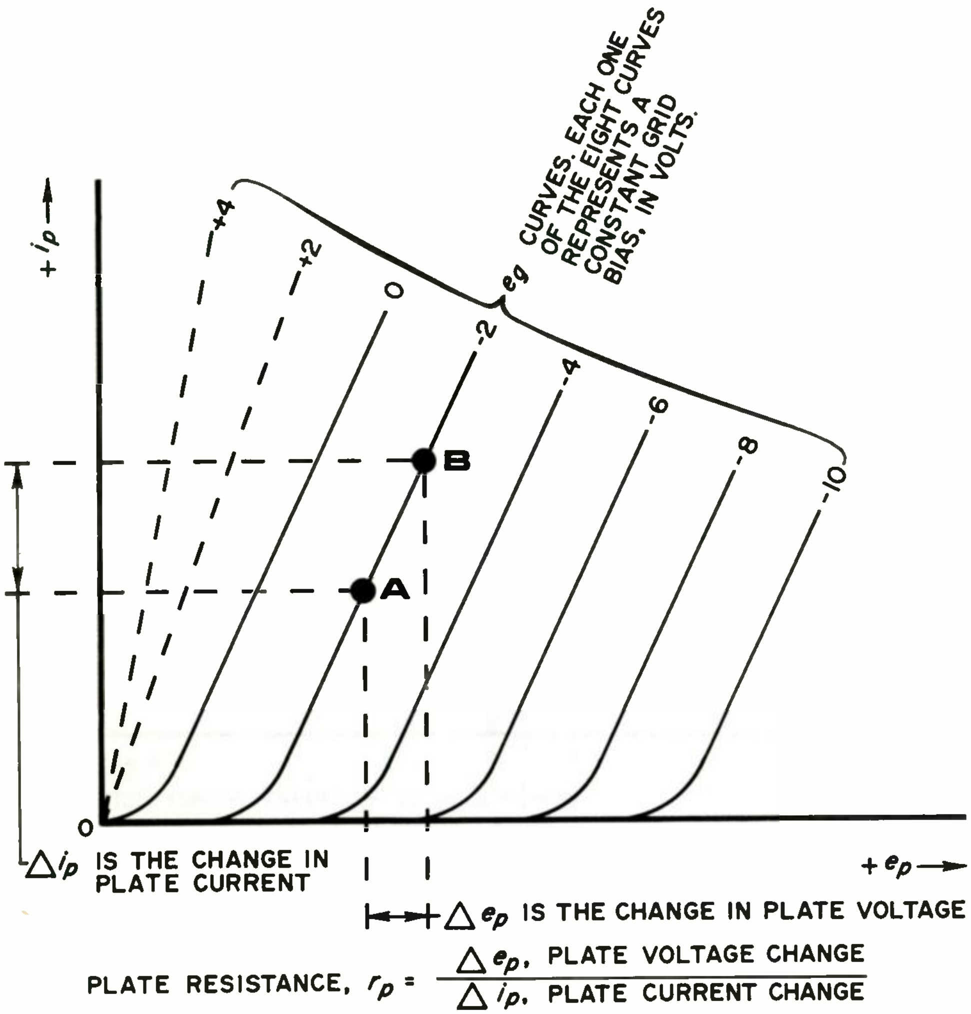


Figure 23 — Plate voltage to plate current curves.

Plate Resistance Another important characteristic is the *AC plate resistance,* designated by r_p. It is the ratio for a constant grid voltage of

the small change in plate voltage
to
the small change in plate current

that it produces, and is expressed in ohms.

An i_p vs. e_p characteristic for a typical triode is shown in Figure 23. A grid bias of -2 volts is maintained constant, and the plate voltage is raised from a value which places the operation of the tube at point A to a value which places the operation at point B. The ratio of this small change in plate voltage Δe_p, to the small change in plate current Δi_p, which it produces, indicates the plate resistance.

$$r_p = \frac{\Delta e_p}{\Delta i_p}, \text{ where } e_g \text{ is held constant.}$$

The value of Δe_p is in volts, Δi_p is in amperes, and r_p is in ohms.

Transconductance A third characteristic used in describing the properties of vacuum tubes is the grid to plate *transconductance* g_m. It is defined as the ratio with plate voltage held constant of

the small change in plate current
to
the small change in grid voltage

which causes the change of plate current. The transconductance is a rough indication of the design merit of the tube, and the value is usually expressed in micromhos.

The i_p vs. e_g characteristic for a typical triode is shown in Figure 24. The voltage at the plate is held constant at 300 volts, and the grid voltage is reduced from the value which places the operation at point A to the value which places the operation at point B. The ratio of the resulting small change of plate current Δi_p to the small change in grid voltage Δe_g indicates the transconductance $g_m = \Delta i_p$, where e_p is held constant.

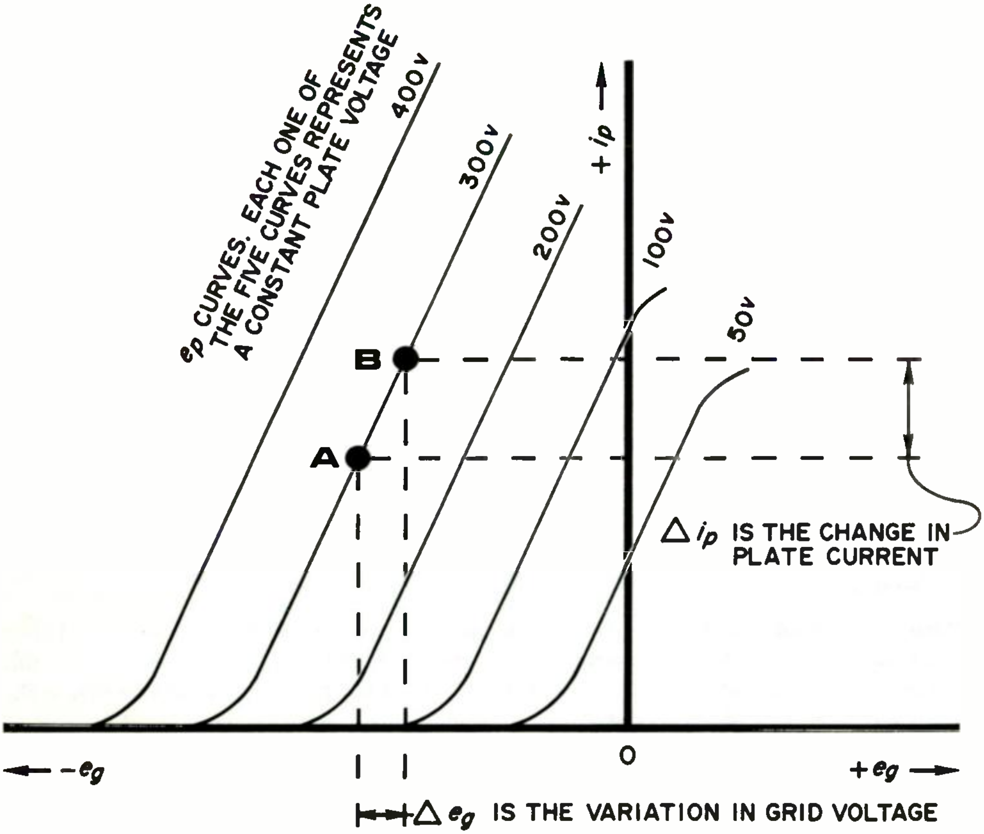
$$g_m = \frac{\Delta i_p \;\; A}{\Delta e_g \;\; V} \text{ where } e_p \text{ is held constant.}$$

When ip is in amps and eg is in volts, gm must be multiplied by 1,000,000 to be expressed in micromhos.

Polarity Reversal When the signal voltage applied to the grid has its maximum positive instantaneous value the plate current is also maximum (Fig. 25). It can be seen that this maximum plate current flows through the plate load R_L producing a maximum $i_p \times R_L$ drop across it. The lower end of R_L is connected to the positive terminal of E_B and is, therefore, held at a constant value of 200 volts. With a maximum $i_p \times R_L$ drop across the load, the upper end of R_L is at a minimum instantaneous voltage. The plate of the tube is connected to this end of R_L and is at the same minimum instantaneous potential.

This polarity reversal between grid and plate voltages is further clarified by a consideration of Kirchoff's law as it appliers to series resistors. The sum of the IR drops around the plate curcuit must at all times equal the supply voltage E_B. Thus, when the instantaneous voltage drop across R_L is maximum, the voltage drop across the tube E_p is minimum, but their sum remains at 200 volts. The variations of grid voltage, plate current, and plate voltage about their steady state values is illustrated in Figure 26.

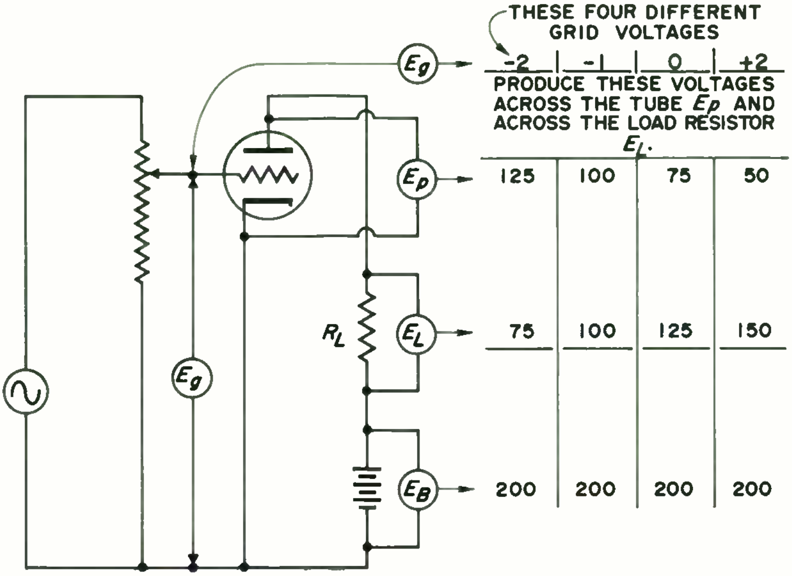
Grid Biasing Methods The difference of potential between *grid and cathode* is called the *grid bias* of a vacuum tube. There are three general methods of providing this bias voltage. In each of these methods the purpose is to establish the grid at a potential with respect to the cathode which will place the tube in the desired operating condition, as determined by its characteristics.



$$\text{TRANSCONDUCTANCE } g_m = \frac{\Delta i_p, \text{ PLATE CURRENT CHANGE}}{\Delta e_g, \text{ GRID VOLTAGE CHANGE}}$$

Figure 24 – Plate current to grid voltage curves.

AC rp
plate



E_g	-2	-1	0	+2
E_p	125	100	75	50
E_L	75	100	125	150
E_B	200	200	200	200

Figure 25 – The voltage drop Ep across the tube plus the voltage drop E_L across the load R_L always totals the voltage E_B of the plate battery.

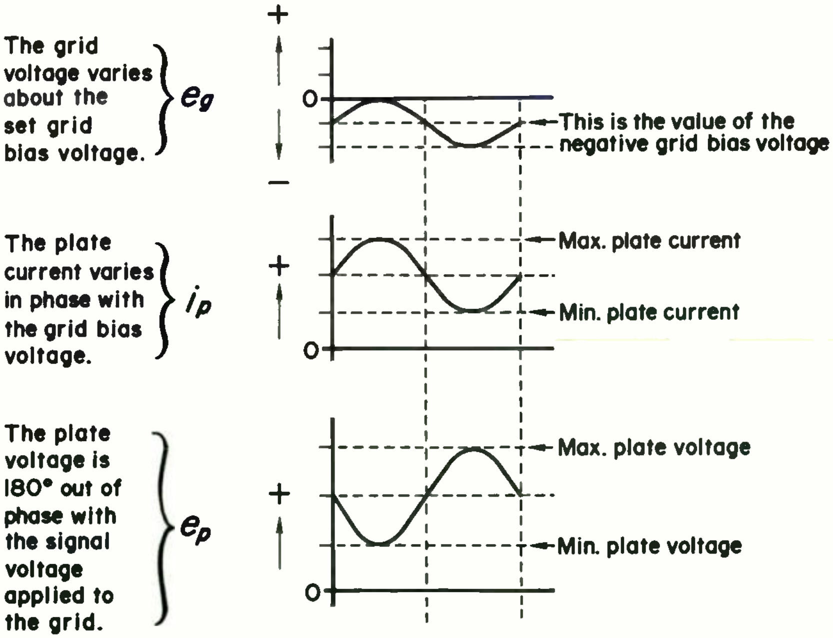
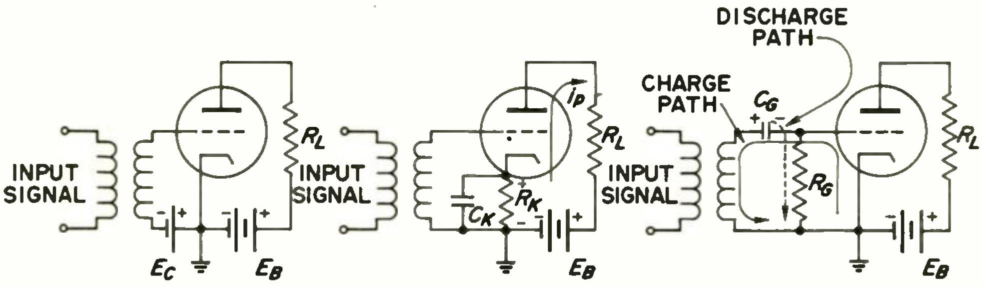


Figure 26 – The polarity of the plate voltage is 180° out of phase with the grid voltage.



A FIXED BIAS **B** CATHODE BIAS **C** GRID LEAK BIAS

Figure 27 — Methods of obtaining grid bias.

FIXED BIAS Grid bias may be obtained from a source of voltage especially provided for the purpose, such as a battery or other DC power supply. This method is known as *fixed bias* (Fig. 27A).

CATHODE BIAS A second biasing method (Fig. 27B) utilizes a cathode resistor, and an IR drop is developed as a result of plate current flow through it. The cathode of the tube is held at a positive potential, with respect to ground, by the $i_p x R_k$ drop. This voltage drop effectively places the grid negative, with respect to the cathode, by the amount of the $i_p x R_k$ drop, because the grid is at ground potential.

Since the biasing voltage depends upon the flow of plate current, the tube cannot be held in a cut-off condition by means of the *cathode* bias voltage developed across R_k. The value of the cathode resistor is determined by the bias required and the plate current, which flows at the value of bias as found from the tube characteristic curves.

The capacitor C_k is shunted across R_k to provide a low-impedance path to ground for the AC component of the plate current which results from an AC input signal on the grid. If C_k is large enough to offer negligible reactance for the lowest frequency signal placed on the grid, then only the DC component of the plate current flows through R_k, and the DC bias voltage remains constant.

GRID LEAK BIAS The third method of providing a biasing voltage is illustrated in Figure 27C and is called *grid-leak bias.* During the portion of the input cycle which causes the grid to be positive with respect to the cathode, grid current flows from cathode to grid, charging capacitor C_g. When the grid draws current, the grid-to-cathode resistance of the tube drops from an infinite value to a very low value, on the order of 1,000 ohms, making the charging time constant of the capacitor very short. This enables C_g to charge up to essentially the full value of the positive input voltage. This action results in the grid, which is connected to the low potential plate of the capacitor, being held essentially at ground potential.

During the negative swing of the input signal, no grid current flows, and the discharge path of C_g is through R_g which has a value on the order of 500,000 ohms. The discharge time constant for C_g is, therefore, long in comparison to the period of the input signal, and only a very small part of the charge on C_g is lost. Thus, the bias voltage developed by the discharge of C_g is substantially constant, and the grid is not permitted to follow the positive portions of the input signal.

Interelectrode Capacitance Capacitance exists between any two pieces of metal separated by a dielectric. The amount of capacitance depends upon the size of the metal pieces, the distance between them, and the type of dielectric. The electrodes of a vacuum tube have a similar characteristic known as the interelectrode capacitance, illustrated schematically in the triode (Fig. 28). The direct capacitances that exist in a triode are

the grid-to-cathode capacitance, C_{kg};
the grid-to-plate capacitance, C_{pg}; and Limit High Freq
the plate-to-cathode capacitance, C_{pk}.

The effective capacitance of a tube, measured when the electrodes are disconnected from a circuit, are not as great as when the electrodes are connected. This is due to the shunting effects of the circuit wiring, tube bases, and sockets.

Interelectrode capacitance, though very small, has a coupling effect and often can unbalance a circuit with which it is associated. In this respect, the grid-to-plate capacitance generally causes the greatest trouble. At high frequencies, the grid-to-plate capacitance can feed back some of the plate voltage in phase with the grid voltage, and thus cause undesirable oscillations. This internal feedback can be neutralized by feeding back a voltage of equal magnitude and opposite polarity from the plate to the grid circuit.

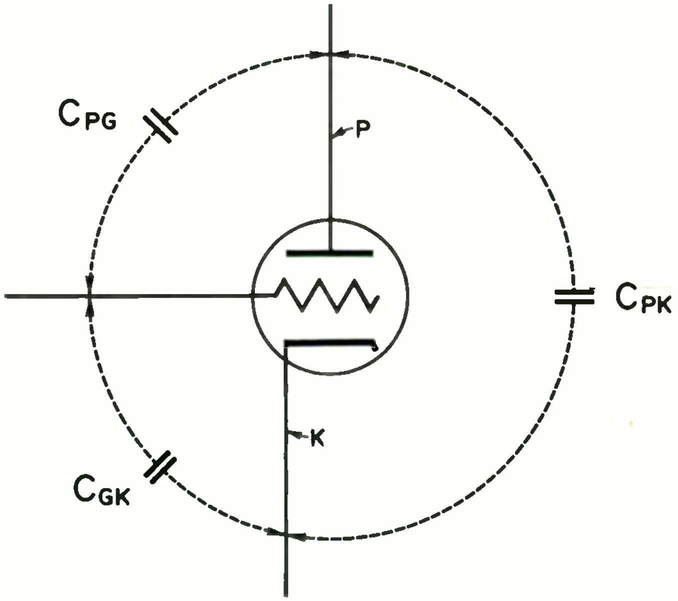


Figure 28 — Representation of interelectrode capacitance in a triode.

Such an external capacitance is known as a neutralizing capacitor. It usually is variable to permit adjustment for precise cancellation of the objectionable internal feedback voltage.

At ultra-high frequencies (uhf), interelectrode capacitance becomes very objectionable and prevents the use of ordinary vacuum tubes. Special uhf tubes are used at such operating frequencies. These tubes are characterized by very small physical dimensions and closely spaced electrodes and often do not have conventional tube bases. These tubes are discussed later in the lesson.

Tetrode

The large values of the interelectrode capacitances of the triode, particularly the plate-to-grid capacitance, impose a serious limitation on the tube as an amplifier at high frequencies. In order to reduce the plate-to-grid capacitance a second grid, called a screen grid, is inserted between grid and plate of the tube (Fig. 29A). It is connected to a positive potential somewhat less positive than that of the plate. The positive voltage on the screen grid accelerates the electrons moving from the cathode. Some of these electrons strike the screen and produce a screen current which, as a rule, serves no useful purpose. The larger portion, however, pass through the open-mesh screen grid to the plate.

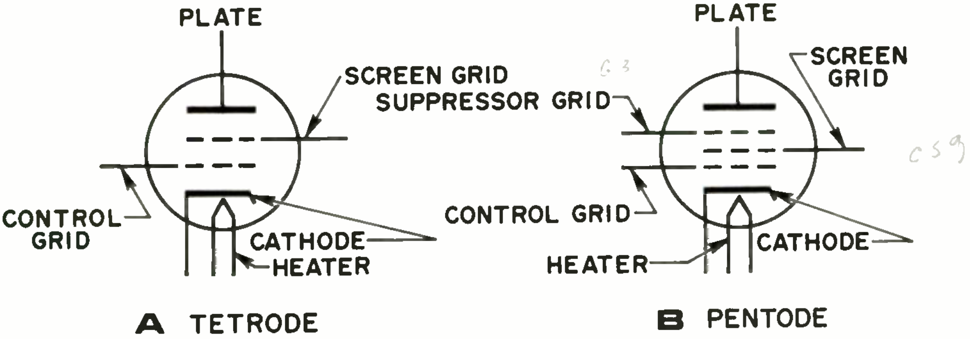


Figure 29 — Schematic diagrams of the tetrode and the pentode vacuum tubes.

Because of the presence of the screen grid, a variation of plate voltage has little effect on the flow of plate current; while the control grid, on the other hand, retains its control over the plate current. The tetrode has high plate resistance and amplification factors ranging up to 800. By proper design, the transconductance can also be made high.

In the application of tetrodes, it is necessary to operate the plate at a somewhat higher voltage in order to overcome the effects of secondary emission from the plate.

Pentode

The addition of a third grid, called the *suppressor* grid, between the plate and the screen eliminate the effect of secondary emission of the tetrode. Introduction of the fifth electrode produces a pentode (Fig. 29B). In this tube, the suppressor grid, usually connected to the cathode, serves to repel or suppress secondary electrons, driving them

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back into the plate from which they were ejected. This permits a smooth rise of plate current from zero up to its saturation point as the plate voltage is increased.

The pentode can be used to produce an increased power output for a given input of grid voltage. The amplification factor of pentodes is high, ranging from 100 to 1,500. The plate resistance and transconductance of pentodes are both fairly high.

rf pentode

Beam Power Tubes

A special type of tetrode, which functions in the manner of a power pentode, is called a beam-power tube (Fig, 30). Instead of using a suppressor grid to control the secondary emission from the plate, this tube obtains the same effect by shaping the tube electrodes in a manner that controls the space charge near the plate. A beam-forming plate, connected internally to the cathode, causes a concentration of electrons in the vicinity of the plate, thereby producing a region of minimum potential. As long as the plate potential is greater than the minimum potential because of the electron concentration, secondary electrons are returned to the plate. A beam-power tube operated at the same voltages as a normal tetrode provides more power output for a given signal voltage. This is accomplished without an increase in internal tube capacitances.

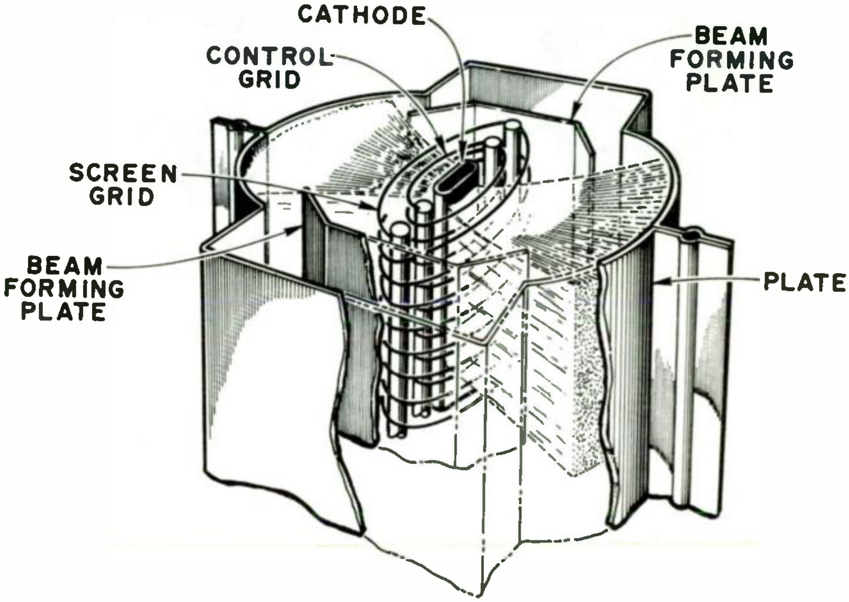


Figure 30 – Internal design of a beam power tube.

UHF Tubes

The amount of interelectrode capacitance, the effect of electron transit time, and other objectionable features of ordinary vacuum times are minimized considerably in the construction of special tubes for use at ultra-high frequencies. These uhf tubes have very small electrodes placed close together and often have no socket base. By a reduction in all physical dimensions of a tube by the same scale, the interelectrode capacities are decreased without affecting the transconductance or the amplification factor. Transit time likewise is reduced, as is the power-handling capacity of a tube of small dimensions.

The "Acorn" types of vacuum tubes (Fig. 31) were developed especially for uhf operation and are available as diodes, triodes, or rf pentodes. Acorns are very small physically, have closely spaced electrodes, and have no base; the tube connections are brought out to short wire pins sealed in the glass envelope. An enlarged version of the Acorn type is known as the "door-knob" tube, which operates at considerably higher powers and at frequencies as high as 600 megacycles.

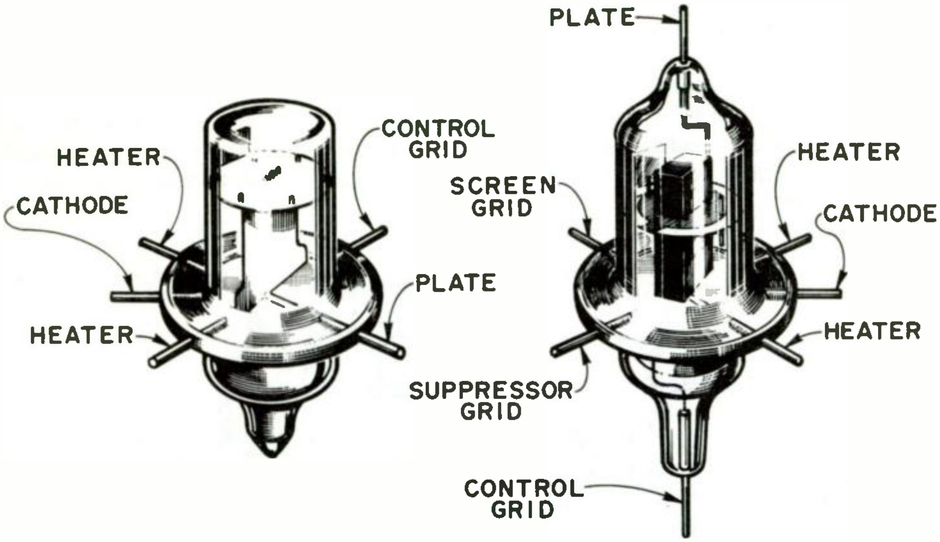


Figure 31 — Acorn tubes.

Multiunit Tubes

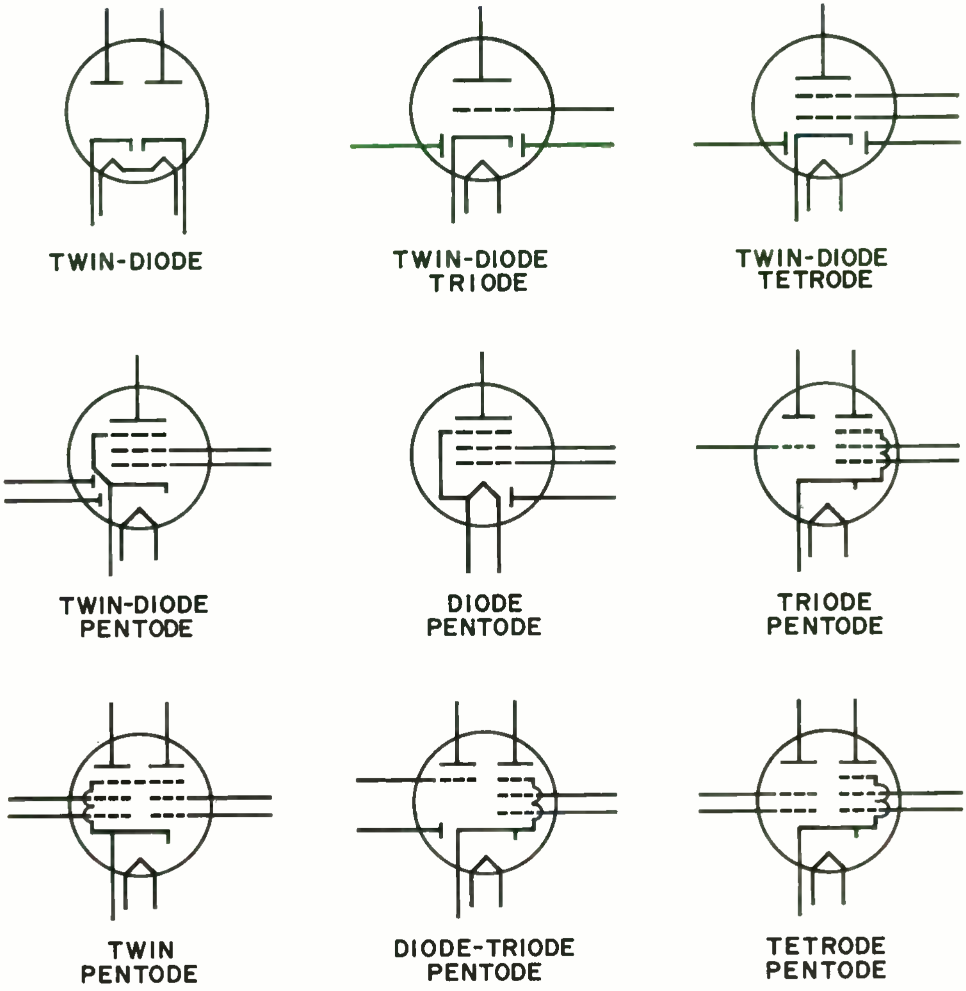
To reduce the number of tubes in radio circuits, the electrodes of two or more tubes frequently are placed within one envelope. Multiunit tubes generally are identified according to the way the individual types contained in the envelope would be identified if they were made as separate units. Thus, a multiunit tube may be identified as a twin-diode (also called duo-diode), a diode-pentode, triode-pentode, twin-pentode, etc. A number of multiunit tubes are shown in Figure 32.

There are other combinations of the so-called basic types of diodes, triodes, tetrodes, etc., just as there are many tubes that have the same operating characteristics but different filament voltages.

CATHODE RAY TUBE (CRT)

Solid state is replacing vacuum tubes at an accelerated rate. One type of tube, however, seems destined for continued usage. Currently, an available solid state replacement for the cathode ray tube (CRT) is not commercially available.

6AL5



TWIN-DIODE

TWIN-DIODE TRIODE

TWIN-DIODE TETRODE

TWIN-DIODE PENTODE

DIODE PENTODE

TRIODE PENTODE

TWIN PENTODE

DIODE-TRIODE PENTODE

TETRODE PENTODE

Figure 32 – Schematic diagrams of multiunit tubes.

The cathode ray tube (CRT) is familiar to all who have viewed an image on the face of a TV set. In addition to television, CRTs are used in test equipment and industrial monitoring equipment. Light is produced on the face of a CRT when accelerated electrons strike a coated surface or screen. This surface is coated with phosphors which give off light when struck by high velocity electrons. The electrons originate in and are accelerated by that part of the tube called *an electron gun.* The electron gun contains a filament, a cathode and various grids which accelerate, control, and focus the beam of particles.

At some point both near and surrounding the gun are beam deflecting plates or coils which determine the point on the screen that will be struck and energized by the electron beam. By supplying the proper signal to these coils or plates, an image can be traced across the screen. By supplying a signal to a control grid or to the cathode, the intensity of the beam will be controlled. These actions reproduce the desired light and dark areas which make the image recognizable.

TUBE MANUALS

Imagine that the TV you are servicing in a customer's home has a defective 1B3, high voltage rectifier tube. The last tube of this type in your caddy went into a previous customer's set. Is a return trip inevitable? Not necessarily. As a wise repairman you would equip your service kit with up-to-date substitution manuals. You could leaf through your substitution guide book and discover that a 1B3 has a number of replacements. Some of these are the 1G3, 1J3 and 1K3. You would use one of these, collect your fee and then proceed to the next customer relieved that a return trip is not necessary.

In the event that a replacement for an out of stock tube is not listed in the substitution guide, all is not lost. Occasionally, a temporary replacement can be found by comparing specifications and basing arrangements of similar tubes in a good tube manual. Figure 34 lists specifications for three different tubes. Above the chart, you will notice a basing diagram which shows the pin numbers for each of the tube elements. In checking for a replacement, this is the first consideration. Next would be plate current, plate voltage, and grid bias. Amplification factor, Gm, and Rp are of secondary concern; however, do not completely ignore their importance. A substitute tube selected with considerable variations should be replaced with the correct tube the next time you call in the neighborhood.

Manuals become outdated whenever new or improved tubes become available. Check with your supplier frequently for new editions of manuals, or arrange to have each new manual sent to your shop as it becomes available.

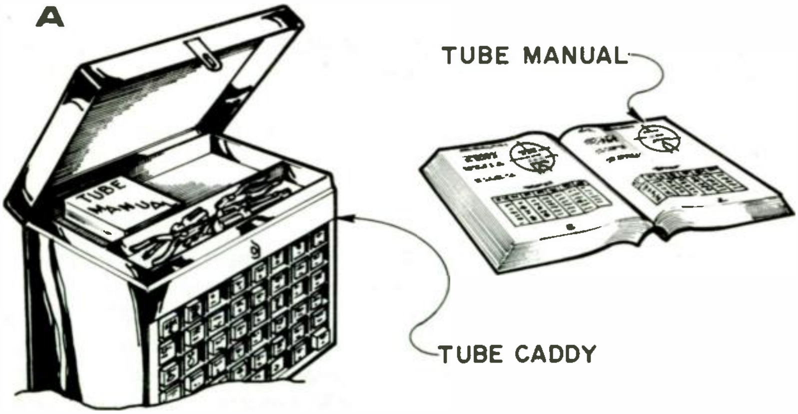
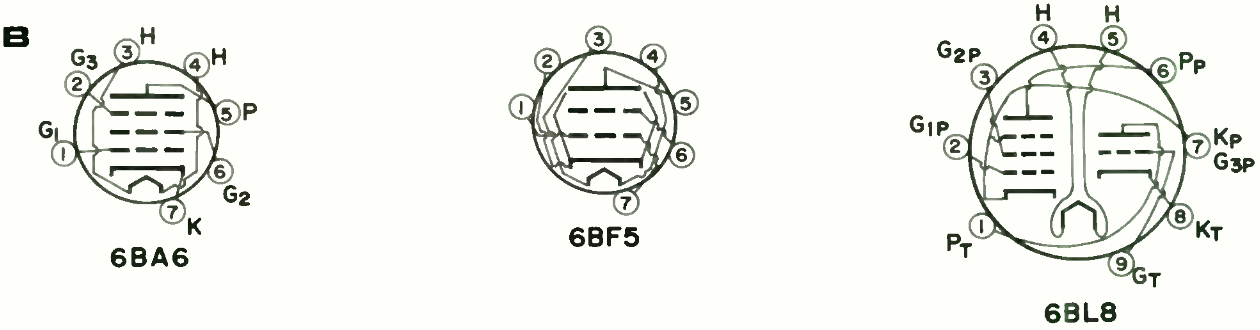


Figure 33 – Illustration of the tube manual.



	Filament		Plate		Screen		Grid Bias	RP	Gm	Amp Fact.	Output
	V	Amp.	V	Ma.	V	Ma.	V	Ohms	Mho	Mu	Watts
6BA6 Remote Cut-off Pentode	6.3	0.3	250	11	100	4.2	68*	1 Meg.	4400	–	–
6BF5 Beam Power Amp.	6.3	1.2	110	39	110	10.5	–7.5	12k	7500	36	1.9
6BL8 Triode			250	14	–	–	–1.3	–	5000	20	–
Pentode	6.3	0.43	250	10	175	2.8	–1.3	400k	6200	47	–

*Cathode bias resistor in ohms

Figure 34 – Illustration of the type of information presented in tube manuals.

LESSON TWENTY-TWO
VACUUM TUBES

TEST

1. Electron emission in a vacuum tube provides

A. a positive current.
B. a varying voltage.
1 [✓ C.] a source of electrons.
D. a source of protons.

2. The type of vacuum tube used for rectifications is a

7 [✓ A.] diode.
B. pentode.
C. triode.
D. tetrode.

3. Three vacuum tubes generally used as amplifiers are

19 A. diode, triode, and pentode.
\+ [✓ B.] triode, tetrode, and pentode.
C. triode, diode, and pentode.
28 D. diode, tetrode, and pentode.

4. In order for a vacuum tube to be conductive, the plate potential, with respect to the cathode, must be

16 A. neutral.
\+ B. negative.
17 [✓ C.] positive.
D. alternating.

5. The voltage applied to the grid of a vacuum tube to establish the operating point is called the

A. space charge.
22 [✓ B.] bias voltage.
C. heater voltage.
D. plate voltage.

6. The suppressor grid was included to suppress

28 [✓ A.] secondary emission.
B. thermionic emission.
C. high field emission.
D. photo emission.

7. The three kinds of grid bias are

A. grid leak, cathode, and variable.
26 [✓ B.] grid leak, cathode, and fixed.
C. grid leak, space charge, and fixed.
D. grid leak, plate load, and fixed.

8. The grid bias voltage applied to a vacuum tube is generally

A. negative.
B. positive.
C. pulsating.
D. alternating.

9. A triode vacuum tube consists of this number of basic elements

A. 2 elements.
19 B. 3 elements.
C. 4 elements.
D. none of the above.

10. The transconductance of a vacuum tube is the ratio of a small change of

A. plate current to grid voltage.
23 B. filament voltage to plate current.
C. grid current to plate voltage.
D. plate voltage to grid current.

NOTES

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"School Without Walls"
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The Customer Is Always Right

As you progress in your business there are going to be days that you wish you had never gotten out of bed. No matter what you try to do, it just doesn't seem to work out. We all suffer from those kind of days; but the challenge is not to let it get you down.

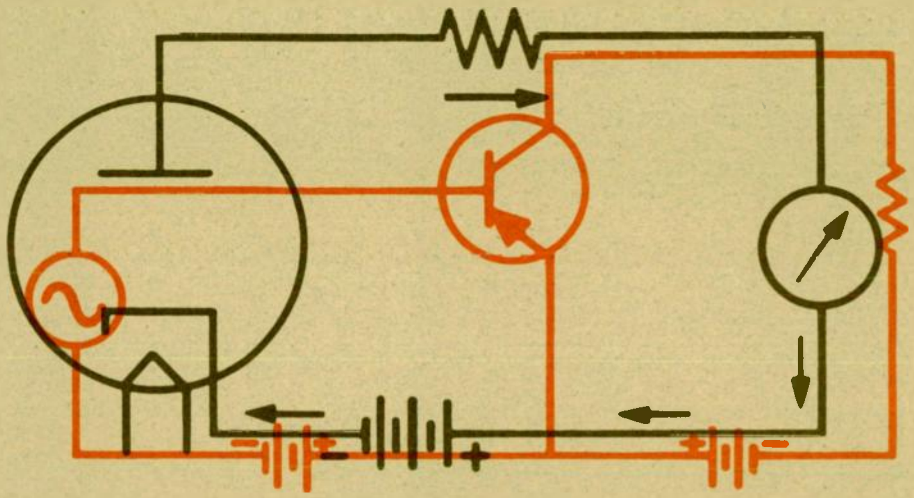
Try and be as patient as you can when dealing with an angry customer who has a problem. You have to remember that customers are the people who are paying your salary so treat them with respect and above all get the job done.

Always be aware of the fact that when you answer a service call you will be "on the spot". How well you handle the job can mean the difference between gaining a new customer or losing an old one. Keep your cool!

S. T Christensen

LESSON NO. 23

SYMBOLS AND SCHEMATIC DRAWINGS



RADIO and TELEVISION SERVICE and REPAIR

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Contents

SYMBOLS AND SCHEMATIC DRAWINGS

INTRODUCTION TO SYMBOLS

Symbols on circuit diagrams are best understood when one considers that they actually represent a physical component and indicate the action of that component. Resistors have previously been represented by Figure 1A which really indicates a compressed long wire of resistance. The symbol in Figure 1B represents a condenser and shows the break in the DC circuit. Let us review the symbols shown in Figure 1.

The units in Figure 1 are joined on the electronic chassis and must be identified. It is quite convenient for us to have these symbols laid out on paper and thereby be able to identify the hook-up or circuit. The same functional circuit will have many varieties of hook-ups, and it is impossible for anyone to know them all. But the basic knowledge of the units and the schematic layout will help identify the circuit and pinpoint any trouble. The schematic diagram is the "scheme" of the designer's layout. This universal language of electronics parallels the notes of music to the instrumentalist, or a road map to the truck driver.

Since we have established that symbols represent function, it should be noted that the symbols in Figure 1 are standard American symbols. Some foreign and industrial symbols are shown in Figure 4.

RESISTORS

Resistance components are varied and have many shapes and uses. The values are indicated either by being stamped or color coded. The color code is stamped only on simple or fixed resistors (Fig. 2).

This coding is on the physical unit and not on the schematic diagram. The schematic or circuit diagram usually shows the actual numerical value. (It should be noted that prior to the present coding system, resistors were constructed differently and used the same color code but were read "body-end-dot." The entire resistor was coated a color; the end had a color, and a dot was in the center.)

Shown in Figure 3 are the symbols associated with variable resistors. Variable resistors may be of two types; carbon composition or wire wound.

CAPACITORS OR CONDENSERS

In Figure 5 there are fixed and variable types of capacitors. Whether the capacitor is ceramic, paper tubular, disc, mica, or any other material, the fact that it is fixed and has a given value is shown by the symbol. Electrolytics are fixed capacitors and are polarized. Condenser is the obsolete term for capacitor.

INDUCTORS

Figure 6 shows the various symbols for inductors. The symbol for an inductor represents a coil of wire. It is important to note that the number of turns in the symbols do not necessarily designate the actual physical turns nor their ratio. It's only a symbol.

TRANSFORMERS

Place one coil near another and they react on each other, forming a transformer (Fig. 7).

VACUUM TUBES

Figures 8 and 9 illustrate the schematic symbols for vacuum tubes. Figure 9 shows multi-unit tubes where two or more functions are accomplished in one tube envelope.

At this point it should be noted that while symbols are fairly well standardized, they do not all look exactly alike. It is emphasized again that the function and representation are all important.

SEMICONDUCTORS

The trend in the electronic industry is toward semiconductor devices. Figure 10 shows the schematic symbols for some semiconductor devices. The placement and direction of the arrow indicates the transistor type. Electron flow is always against the arrow. FETs (field effect transistors) are also shown. An FET is a voltage controlled device and operates similar to a vacuum tube.

SWITCHES

Many circuits need complex switching. Some are simple. Switches are designated by the number of poles and circuits involved, as shown in Figure 11.

RELAYS

A relay is merely a switch that is electrically, instead of mechanically, operated. An electromagnetic relay contains an electromagnet and switching contacts. It should be remembered that the two sections are generally electrically isolated from each other. When the circuit is complete to the electromagnet, a switching action takes place as the movable arm is attracted by the coil. This either opens or closes the switch contacts. Schematic symbols for relays are shown in Figure 12.

JACKS

Jacks may be used to connect only compatible parts or to hook-up units, such as chassis speakers, headphones, or earphones. The inserting of the compatible jack plug can activate switches combined with the jack.

The jacks shown in Figure 13 are female jacks and may be of many shapes and sizes. In fact, a jack may be a connector or plug of varied shapes and openings.

Figure 14 shows a combination jack that performs several switching actions as well as the connecting function.

CIRCUIT BREAKS

On schematics, jumpers are placed in the circuit to facilitate circuit measurements. These are generally test points and allow the technician to open the circuit for meter insertion without unsoldering components.

These are considered circuit breaks as shown in Figure 15. Also shown are the symbols for connectors which contain a male and female connector, such as the usual house plug. There is really no particular standardization. Careful study of any schematic makes junctions that disconnect obvious.

POWER SOURCES

Figure 16 shows the schematic symbols for some power sources. The amount of voltage and the polarity of the connection are usually designated on the schematic.

CONNECTIONS

Figure 17 shows a few of the symbols used by manufacturers to represent wiring connections. These will vary with the manufacturer, but will be similar to the symbols shown.

The previous explanations are by no means complete. And it is impossible to publish a complete and comprehensive table of symbols. More are added each day, and vary from diagram to diagram.

SUPPLEMENTARY INFORMATION

It is important to assemble as much supplementary information as possible, such as:

voltage charts
resistance charts
parts lists and values
special schematic designations.

While much of this is available on the schematic diagram, supplementary information is usually supplied. Look for letters and/or numbered designations, as well as values. Make special note of additional information on numbered or lettered designations, such as a transformer and the information of the physical form. There may also be supplied the information as to the function of a particular stage, as well as an additional layout when components are physically laid out on the chassis. Photos or drawings of control placements may also be available.

CIRCUIT TRACING

One of the simplest electronic circuits is the phono or audio amplifier. However, even the simplest electronic circuit has its own engineering specialties. Our sample circuit (Fig. 18) is a functional phonograph. The principles of circuit tracing laid down here are by no means the only way tracing is done. In time, you will discover the method best suited for you. What we will do now, however, is take an in-depth look at the amplifier, and in so doing, you should develop a circuit tracing pattern.

Tube Type Amplifier

The easiest place to begin is where the circuit begins, the power supply. This unit has no power transformer. This means that the chassis has a 50-50 chance of having 110 Volts on it. This is called a "HOT" chassis. If you touch one of these when you are grounded, you will know exactly why it is called "HOT". The symbol after the AC plug is the motor for the phonograph. The switch, shown going to ground, turns on both the phono motor and the amplifier. Switches are generally shown open. Assuming that the switch is closed, we continue. A voltmeter with the minus lead at ground is placed on pin 8 of our rectifier. The meter should read between 104 and 125 volts of DC. The first DC path goes from the first filter to the bottom of the output transformer (the red lead) and capacitor C6. C6 stops the DC from going on to R2. R2 is across the output transformer; varying R2 changes the tone heard in the speakers. The DC continues through T1 to the plate of V2. C5, C1-C (C1 is a three section capacitor), and R7 form the cathode bias network. That is the entire DC path, from the starting point of the first filter. The second DC path (and the last) begins at the end of the power supply filter. The voltage measured at this point will be a few volts less than at the first section of the filter network. The 4700 ohm resistor (R6) accounts for this. The second DC path splits, with one leg going to the screen of V2. The voltage at the screen is the same as the starting voltage of path 2. Path 2 goes on through R4 to the plate of V1. The voltage at the plate of V1 is 60 volts. R4 "dropped" 40 volts. This is the plate voltage the design engineer wanted at the plate. That is the end of the DC paths in this amplifier.

Looking at the bottom of the schematic diagram once more, we see that the tube heaters are in a "series string". When the set is turned off and the AC cord is UNPLUGGED, an ohmmeter can be placed across the "string" to check for an open filament or an open dropping resistor. You must NOT disconnect the phono motor. Place one lead of the ohmmeter at pin 7 of V3 and the other lead to ground. The resistance chart tells you the meter should read *about* 220 ohms.

We have checked the filaments and the DC paths. Now all that is left to check is the signal path. The signal path in this schematic diagram begins at point "A". It is marked PHONO INPUT. R1 is a load for the input signal. C2 is a tone equalizer and C3 is the coupling capacitor. The signal is fropped across R3, the grid resistor. The amplified signal appears at the plate of V1. This amplified signal is coupled to the output stage through C4. T1 with R2 and C6 act as the load for the output stage. The signal is coupled through the transformer to the speakers.

At the left, all by itself, is C7. The purpose of this capacitor is to connect the chassis to ground capacitively. Except in rare cases, the insertion of a capacitor automatically means the circuit is broken to DC.

The symbols on the schematic diagram are representative and not necessarily any indication of their construction. T1 shows more turns on the primary than on the secondary. This only emphasizes that there are more turns on the primary. Although the DC resistance (not to be confused with AC impedance) is 145 ohms, we don't know the impedance of the voice coils of the speakers, and what the effect would be if one of the speakers were disconnected. However, with the schematic diagram, the manufacturers usually supply a parts list with more complete information. Our diagram has sufficient information to let us know what the circuit is and where to locate problems. If the unit will not light up, it is obvious that any one of three tubes with an open filament would cause this. But a careful look will also show that R9, a dropping resistor, could also be open. All units added together must equal the input voltage of 115 volts. A tube manual will reveal how much current the filament draws, and the process of Ohm's law will supply the necessary dropping resistor, 120 ohms.

Carefully observe that when the schematic diagram is drawn, it presents a path that can be followed. Sometimes it becomes necessary to cross lines. Note how those lines not connected on the physical unit are designated, and those intended to touch have the added emphasis of a dot joining them.

Attention should be made to the polarity of the electrolytics. The negative polarity is always to ground or B-. There are cases in other circuits where it is not obvious.

This diagram, therefore, gives additional information not expected or not actually concerning wiring. Most diagrams have additional hints. Of particular interest is that the chassis is "hot". Notice the method of bias on V1. The technician is not expected to be an engineer, but he should be able to follow the engineer's layout and discover some of the ideas the engineer had in mind. Only the diagram can give this information.

Supplementary information, such as voltage charts and resistance charts, should not be expected. True, they are of tremendous help when supplied, but the technician should be able to find much of this information merely by simple computations of resistor arrangements, condenser hook-ups, current paths, and voltage dividing arrangements. Even in the simple amplifier of the phonograph, the function of DC components should be separated from AC components.

Let us examine T1. It is an iron core transformer and supplies the load resistance for tube V2. It is connected to the DC power at the beginning of the powr supply filter; therefore, the designer does not need a highly filtered or perfectly smooth DC. The tone control is merely a matter of the designer juggling by-pass circuitry. A shorted C6 or C5 would both stop T1 from functioning, but for different reasons. C5 would short out V2 and the entire power supply, whereas C6 would only short out the transformer. In reality, even if we did not know the purpose of either condenser, we would know what damaged units could do, because we are able to READ THE SCHEMATIC DIAGRAM.

Transistor Type Amplifier

Transistors present entirely different problems and symptoms than tubes, and, in fact are not even related in operational aspect. The functions, however, are similar. For example, an amplifier is an amplifier whether it is a transistor or tube type. Here we have a transistor amplifier (Fig. 19). Its function is to amplify the signal picked up by the phono cartridge enough to be heard by the human ear.

The phono cartridge M1 is loaded by R2 and R1, each effectively coupled to ground. The desired portion of the signal is then fed to transistor Q1, which in turn feeds the output transistors Q2 and Q3. There is no output transformer; yet the two separate DC components are separated from each other by C3, which stores the charges to operate the speaker. By virtue of the hook-up, it should be obvious that although an AC audio signal is being amplified, the circuit is designed to pass pulsating DC at the audio rate.

When you read this circuit diagram, it should be noted that there is no need for any of the draftsman's lines to cross. The diagram is further simplified by identifying the 12.6 V source and resultant connections. The arrows and the source are actually one physical connection. We should also note that the entire circuit is isolated by transformer T1, an iron core power transformer that reduces voltage. Reducing the amplitude of the pulsating DC is accomplished by inserting a 1000 mfd filter capacitor (C1).

The circuitry of most equipment is built around the capability of a transistor or tube. Diagrams show how to properly hook them up; as well as trace their associated circuits.

SUMMARY

Regardless of the type of circuit being dealt with, you should be able to trace the path of the signal. The methods that cause this signal to move must be arranged and physically hooked-up to the devices used. If there is a question of what the physical unit is, as compared to the schematic diagram, a drawing can be made and compared to the information on the diagram. There may be portions of the circuit printed, obscured, or even contained in another unit. These are usually designated on the diagram but may be difficult to recognize.

It is also important to remember that most of the servicing of electronic equipment is done with various meters, and must be metered at the point of supplying information to be compared with given information. If the plate of a tube calls for 250 volts and only reads 50 volts, something is wrong. Perhaps the diagram calls for a plate resistor of 20,000 ohms, and the ohmmeter reveals that it has changed to 2 megohms. Although the circuit is designated in the diagram, the value does not agree with that shown on the diagram. It should, therefore, be apparent that the schematic diagram is valuable beyond just the hook-up information. If the plate of a previous stage feeds the next stage through a condenser, and both have the same voltage reading, apparently the condenser is shorted. If the voltages do not properly relate, or if they are correct but the signal will not pass, the technician must read the diagram. He should look for the path of the signal, conclude that the condenser is open, and then measure it to verify. The pin numbers for the connections and the values to be checked should be available on the schematic diagram.

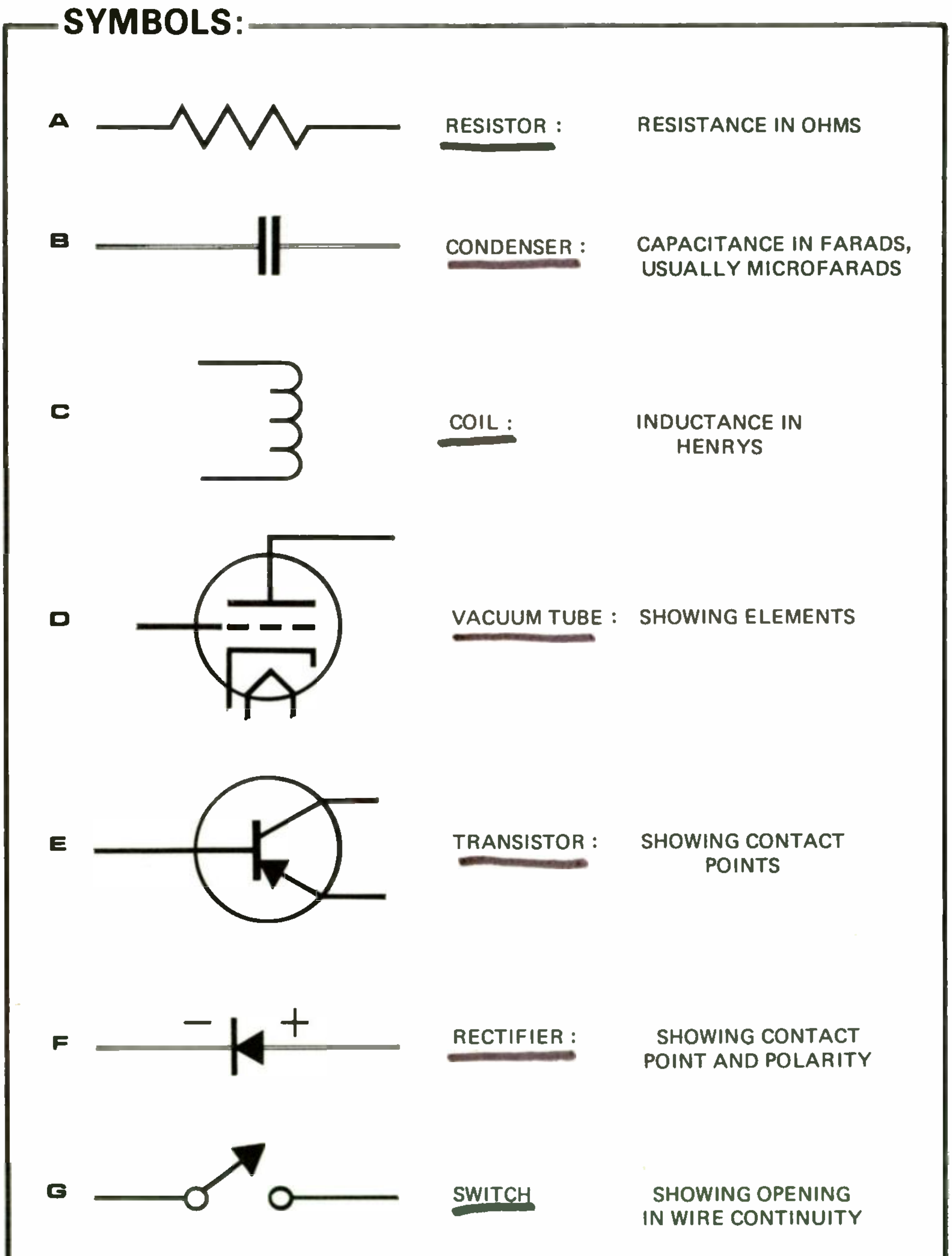


Figure 1 — Common schematic symbols.

RESISTORS:

Black = 0
Brown = 1
Red = 2
Orange = 3
Yellow = 4

Green = 5
Blue = 6
Violet = 7
Gray = 8
White = 9

Always read the bands from edge to middle.
For example,

red / red / yellow
= 2 2 + 4 zeros = 220,000 ohms

or

brown / black / orange
= 1 0 + 3 zeros = 10,000 ohms.

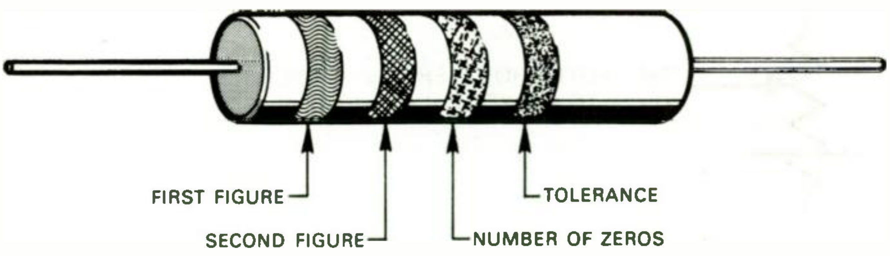
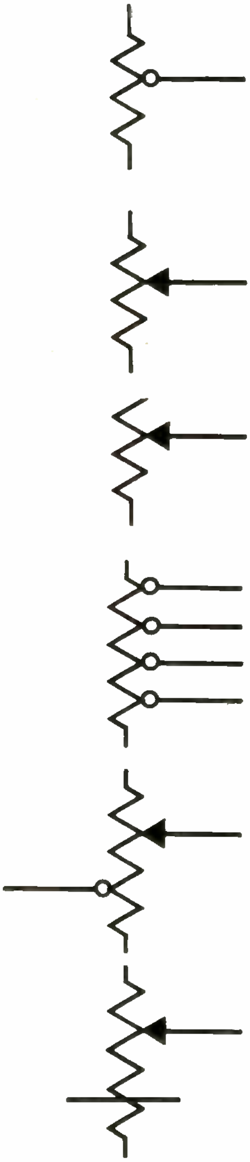


Figure 2 — Resistor color code.

RESISTORS (contd.):

BUT WE HAVE MANY TYPES OF RESISTORS



THIS IS A TAP

SINCE AN ARROW *ALWAYS* INDICATES "MOVING," THIS WOULD BE A VARIABLE TAP.

THIS IS A RHEOSTAT. NOTICE THERE ARE ONLY TWO CONNECTION POINTS.

THERE ARE PRIMARILY TWO TYPES OF RESISTORS. ONE IS A POTENTIOMETER * KNOWN AS "POT." THE OTHER IS A VARIABLE TAP USUALLY OF HIGH WATTAGE VALUE AND USUALLY FIXED AFTER BEING SET. THEY ARE ADJUSTABLE TO OBTAIN DESIRED VOLTAGES.

THIS IS A MULTI-TAP WITH MANY PERMANENT VOLTAGE DROPS AVAILABLE.

THIS IS A COMBINATION OF VARIABLE AND FIXED POTENTIOMETER.

THIS POTENTIOMETER IS VARIABLE ONLY TO A FIXED POINT.

THESE SYMBOLS ARE USED REGARDLESS OF THE MATERIAL FROM WHICH THEY ARE MADE. THE HIGHER WATTAGE RESISTORS ARE WIRE-WOUND, WHILE THE LOWER WATTAGE UNITS ARE CARBON COMPOSITION.

* POTENTIAL IS THE VOLTAGE, AND METER IS TO CONTROL OR MEASURE. THEREFORE, POTENTIOMETER MEANS TO CONTROL THE VOLTAGE.

Figure 3 — Variable resistors.

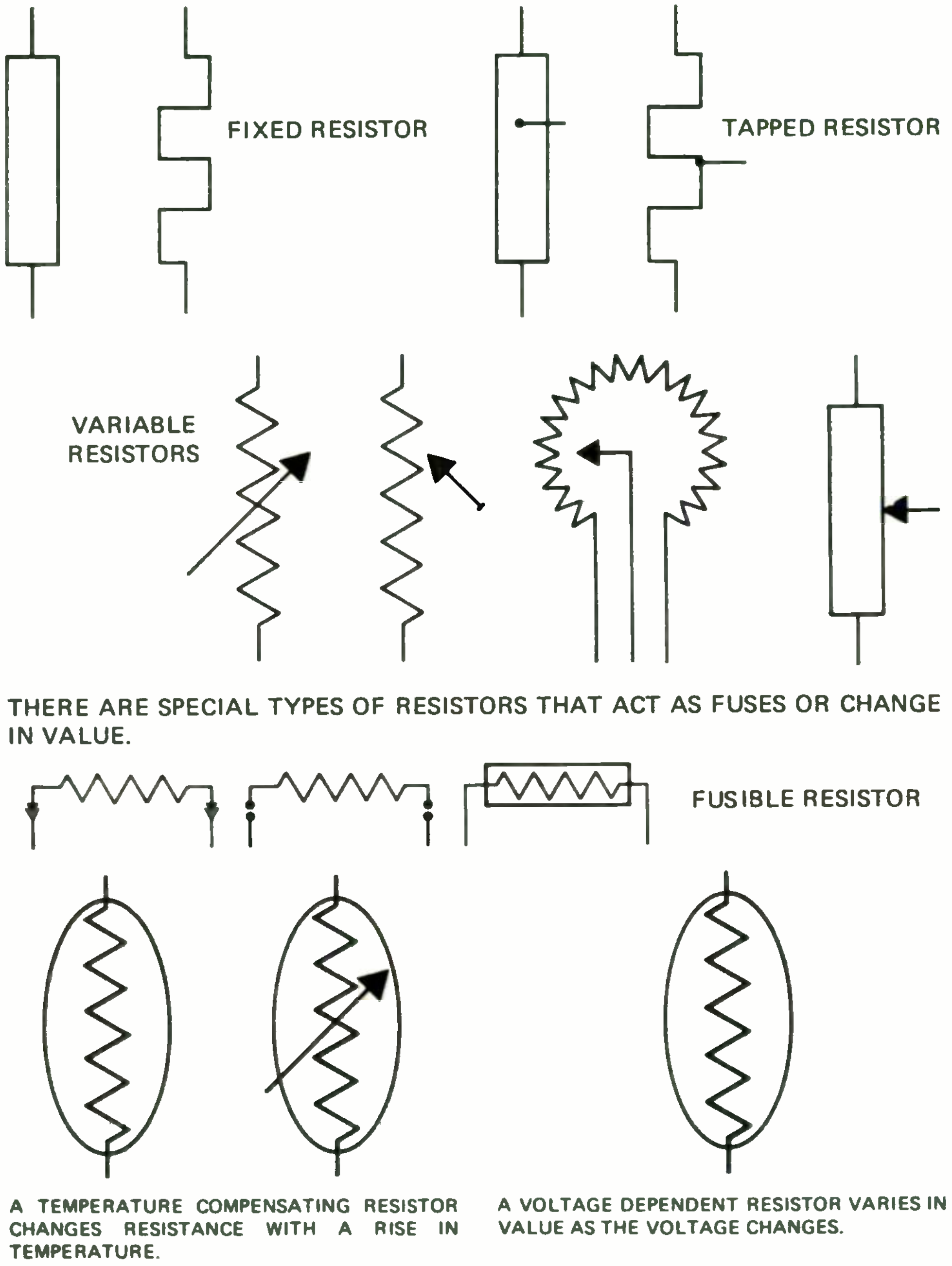
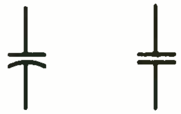
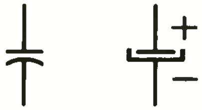


Figure 4 — Foreign and industrial symbols for resistors.

CAPACITORS:

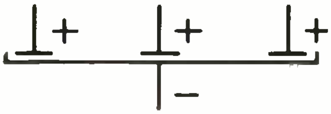


FIXED CAPACITOR



ELECTROLYTIC

(NOTE POLARITY: ELECTROLYTICS MUST BE CONNECTED CORRECTLY, AND CANNOT BE USED FOR AC APPLICATIONS.)



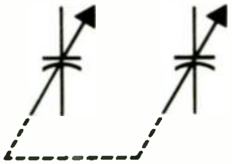
MULTIPLE UNIT
ELECTROLYTIC WITH
COMMON NEGATIVE

SPECIAL TYPE ELECTROLYTIC, NON-POLARIZED, USED IN CHARGING.

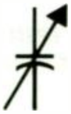
VARIABLE CAPACITORS ARE ALSO MADE OF MANY DIFFERENT MATERIALS.

VARIABLE CAPACITOR

(USUALLY USED AS A PADDER OR TRIMMER, IN ADDITION TO A LARGER VARIABLE)



TWO SUCH VARIABLES "GANGED" OR OPERATING TOGETHER BY ONE CONTROL (GANGING NUMBERS ARE UNLIMITED)



TUNING VARIABLE
CAPACITOR

Figure 5 — Schematic symbols for capacitors.

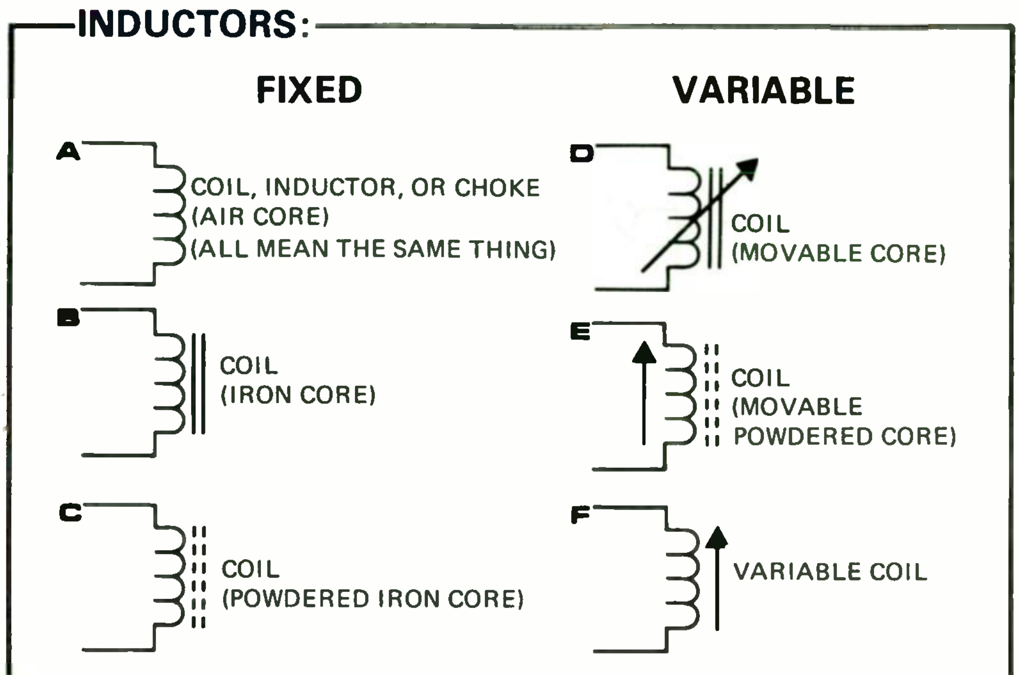


Figure 6 — Schematic symbols for inductors.

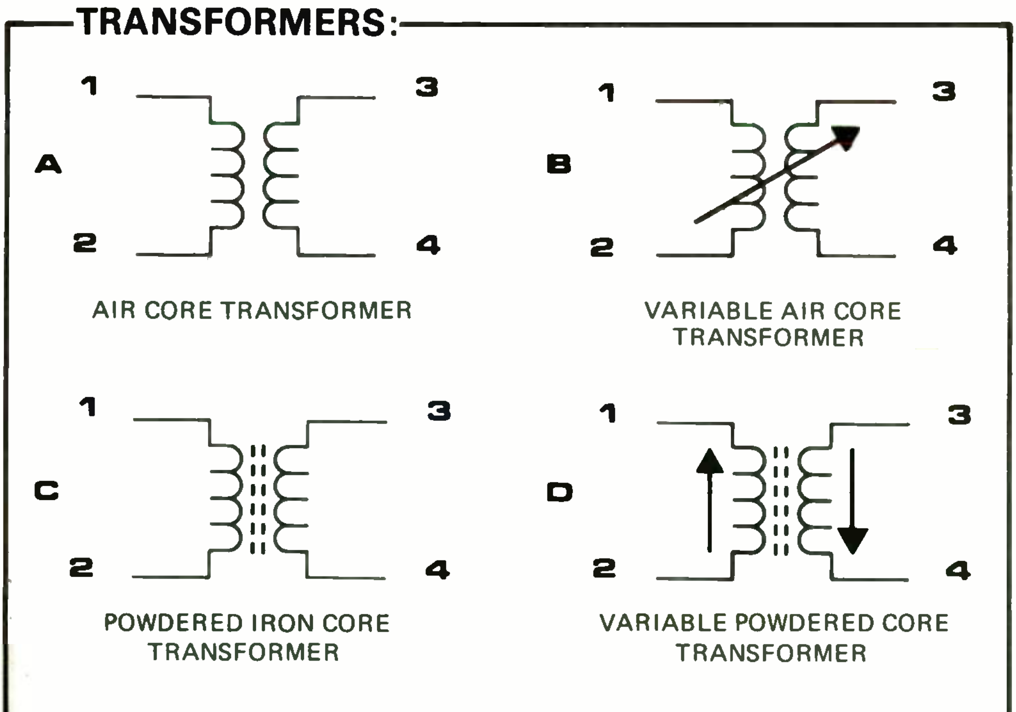
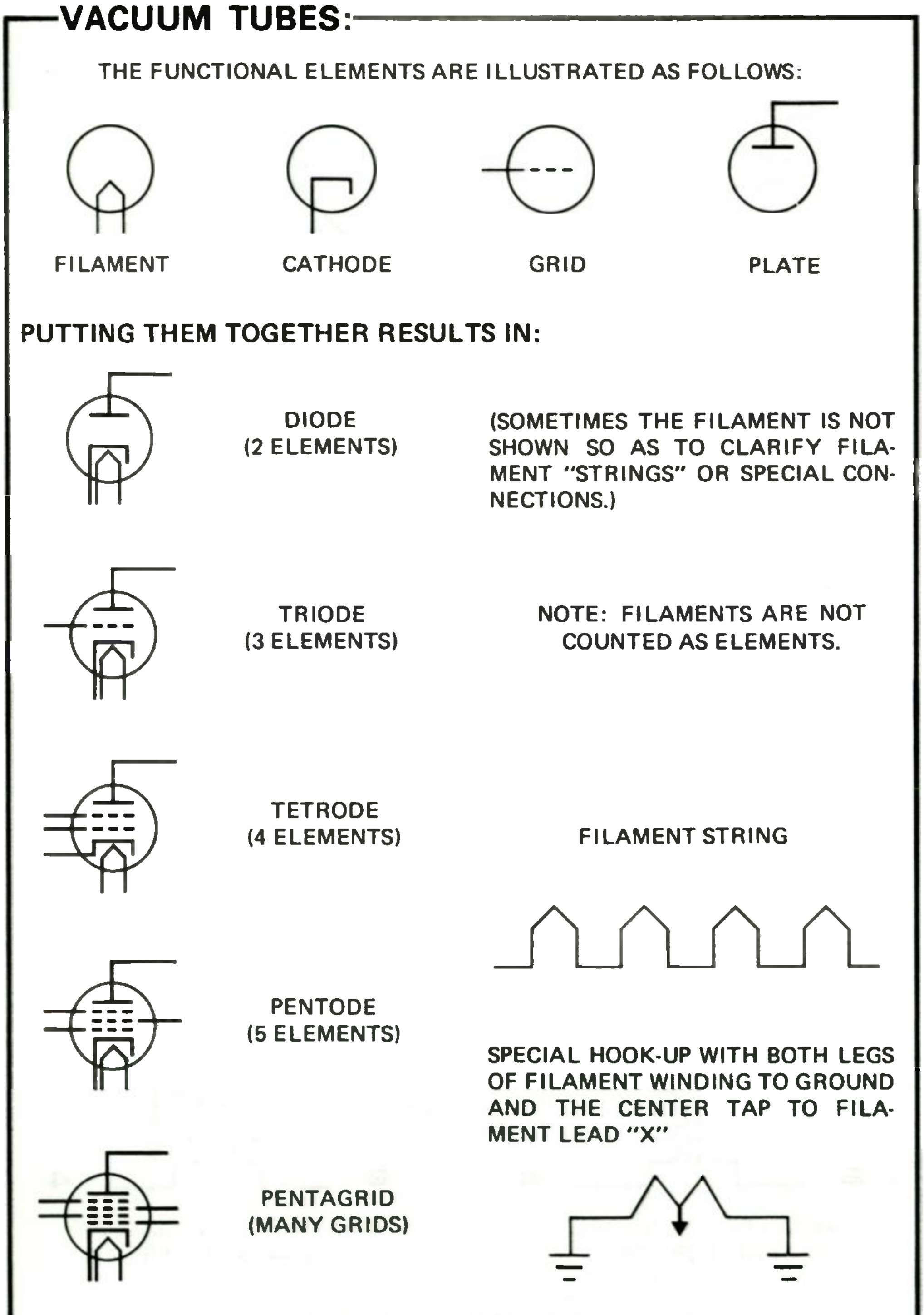


Figure 7 — Schematic symbols for transformers.



(SOMETIMES THE FILAMENT IS NOT SHOWN SO AS TO CLARIFY FILAMENT "STRINGS" OR SPECIAL CONNECTIONS.)

NOTE: FILAMENTS ARE NOT COUNTED AS ELEMENTS.

SPECIAL HOOK-UP WITH BOTH LEGS OF FILAMENT WINDING TO GROUND AND THE CENTER TAP TO FILAMENT LEAD "X"

Figure 8 — Schematic symbols for vacuum tubes.

VACUUM TUBES (contd.):

THERE ARE ALSO COMBINATIONS IN ONE ENVELOPE OR TUBE.

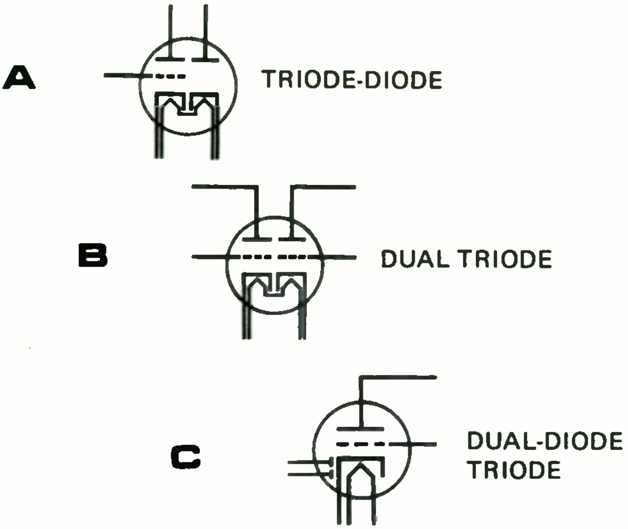


Figure 9 — Multi-unit tube symbols.

SEMICONDUCTORS:

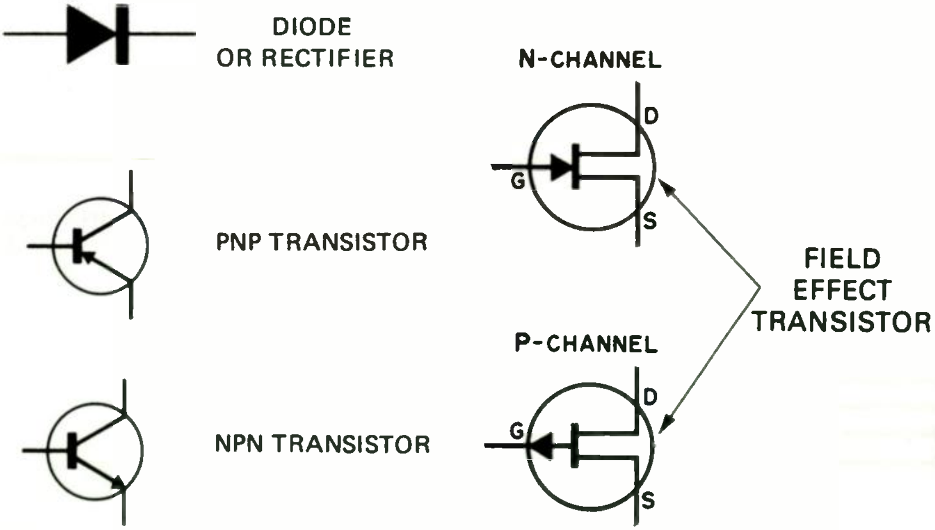
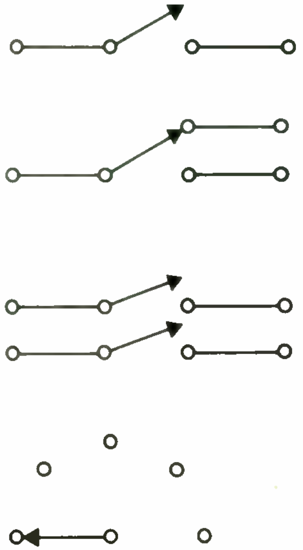


Figure 10 — Schematic symbols for semiconductors.

SWITCHES:



SINGLE POLE, SINGLE THROW (SPST)

SINGLE POLE, DOUBLE THROW (SPDT)

(NOTE THE 2 SEPARATE POSITIONS BY SWITCHING EITHER POLE.)

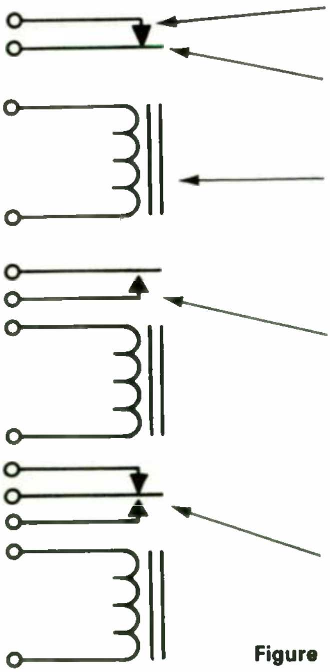
DOUBLE POLE, SINGLE THROW (DPST)

(ONLY MAKE OR BREAK 2 SEPARATE UNITS GANGED TOGETHER, OPERATING SIMULTANEOUSLY.)

ROTARY 1 POLE, 5 THROW

Figure 11 — Schematic symbols for switches.

RELAYS:



SWITCH CONTACT FOR OTHER CIRCUIT TO BE SWITCHED

MOVING ARM

IRON CORE ELECTROMAGNETIC COIL TO ACTIVATE SWITCH

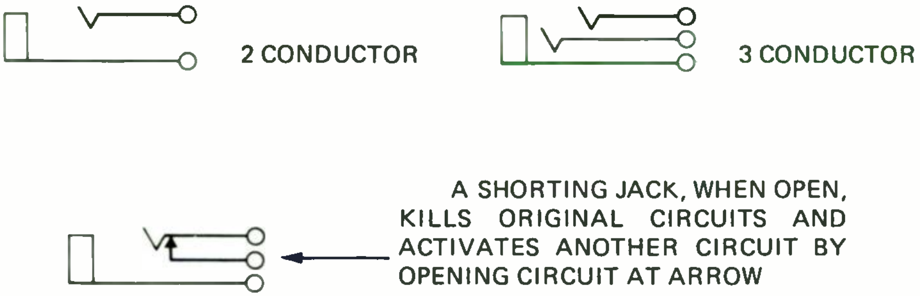
RELAY SPST

ANY NUMBER OF COMBINATIONS OF "MAKE" AND "BREAK" MAY BE INCORPORATED.

RELAY SPDT

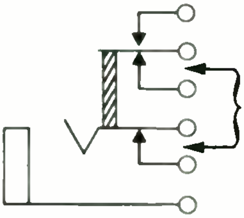
Figure 12 — Schematic symbols for relays.

JACKS:



A SHORTING JACK, WHEN OPEN, KILLS ORIGINAL CIRCUITS AND ACTIVATES ANOTHER CIRCUIT BY OPENING CIRCUIT AT ARROW

Figure 13 — Schematic symbols for jacks.



INSERTION OPENS THIS FUNCTION.

Figure 14 — Schematic symbols for combination jacks.

CIRCUIT BREAKS:

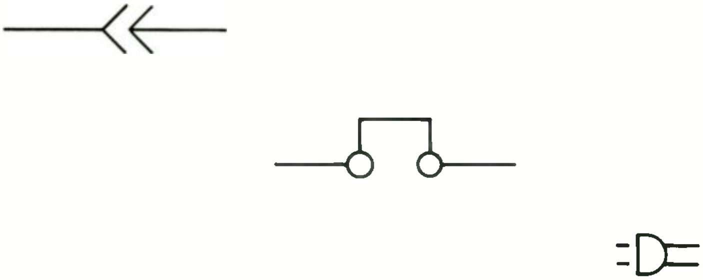
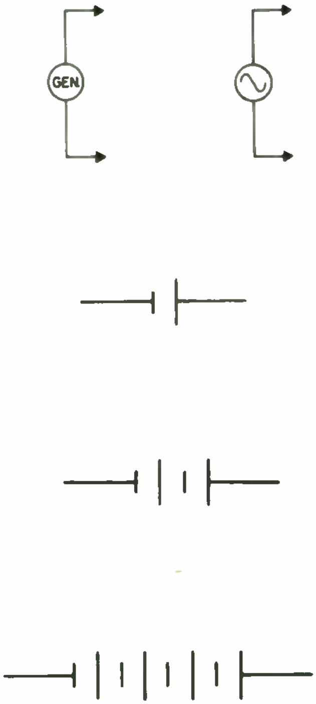


Figure 15 — Schematic symbols for connectors and circuit breaks.

POWER SOURCES:



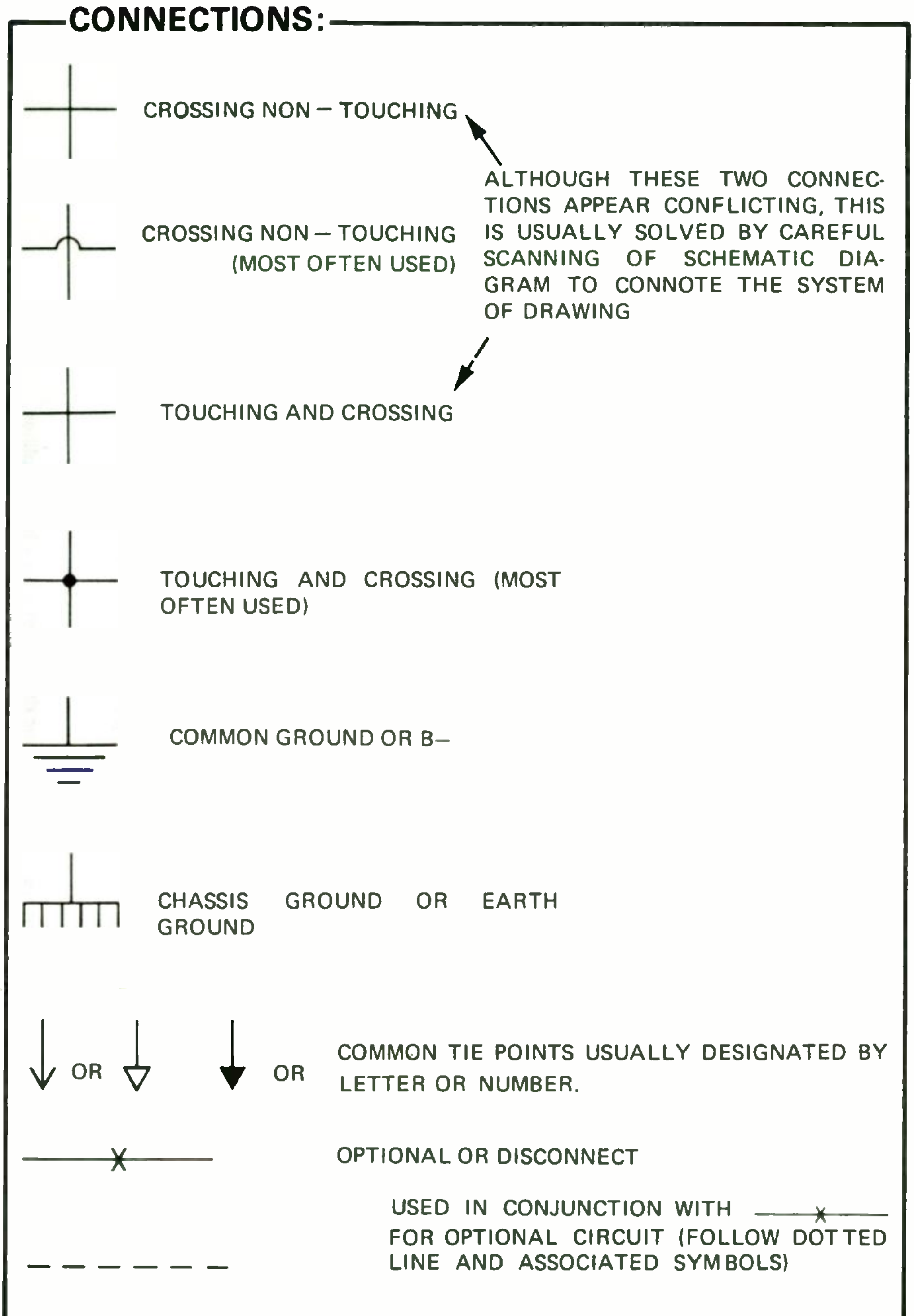
SINE WAVE DESIGNATES AN AC SOURCE

USUALLY DESIGNATES 1 CELL BATTERY; VOLTAGE IS USUALLY INDICATED.

USUALLY DESIGNATES 2 CELL BATTERY; VOLTAGE IS USUALLY INDICATED.

MAY BE A 4 CELL BATTERY OR JUST AN EMPHASIZED SOURCE OF DC VOLTAGE.

Figure 16 — Schematic symbols for batteries and other voltage sources.



CONNECTIONS:

CROSSING NON – TOUCHING

CROSSING NON – TOUCHING (MOST OFTEN USED)

ALTHOUGH THESE TWO CONNECTIONS APPEAR CONFLICTING, THIS IS USUALLY SOLVED BY CAREFUL SCANNING OF SCHEMATIC DIAGRAM TO CONNOTE THE SYSTEM OF DRAWING

TOUCHING AND CROSSING

TOUCHING AND CROSSING (MOST OFTEN USED)

COMMON GROUND OR B–

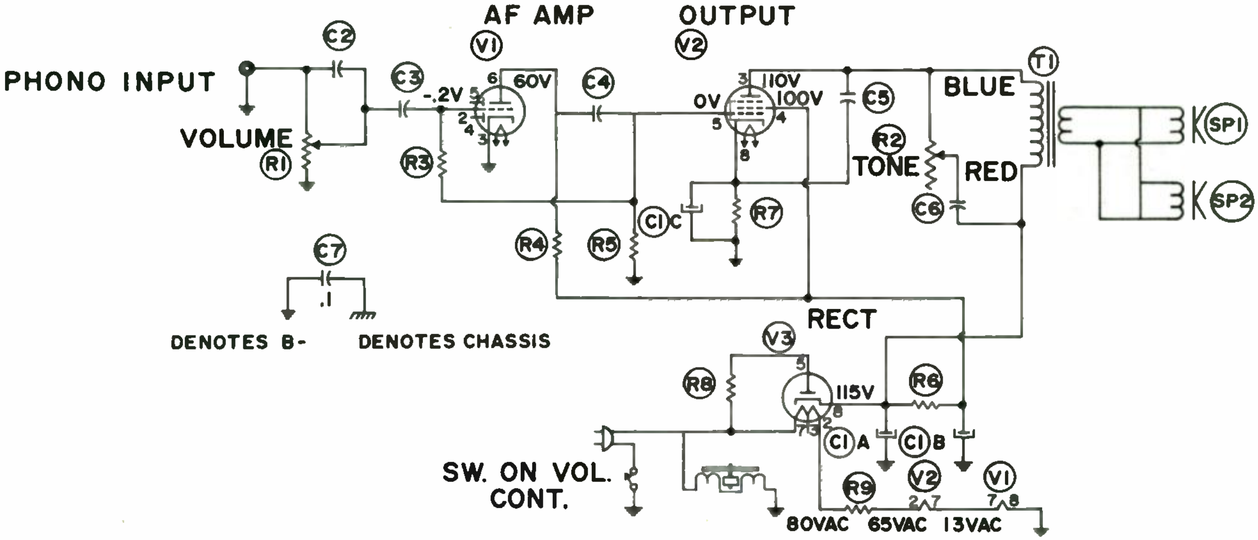
CHASSIS GROUND OR EARTH GROUND

OR OR COMMON TIE POINTS USUALLY DESIGNATED BY LETTER OR NUMBER.

OPTIONAL OR DISCONNECT

USED IN CONJUNCTION WITH FOR OPTIONAL CIRCUIT (FOLLOW DOTTED LINE AND ASSOCIATED SYMBOLS)

Figure 17 — Connections.



ITEM	Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7	Pin 8
V1	NC	6 Meg	0Ω	NC	NC	*275K	15Ω	0
V2	NC	65Ω	*145Ω	*4700Ω	470K	NC	15Ω	150Ω
V3	NC	185Ω	200Ω	NC	260Ω	NC	220Ω	20K(min)

*measured from Pin 8 of V3

NC No Connection

Figure 18 — Schematic drawing of a tube type amplifier.

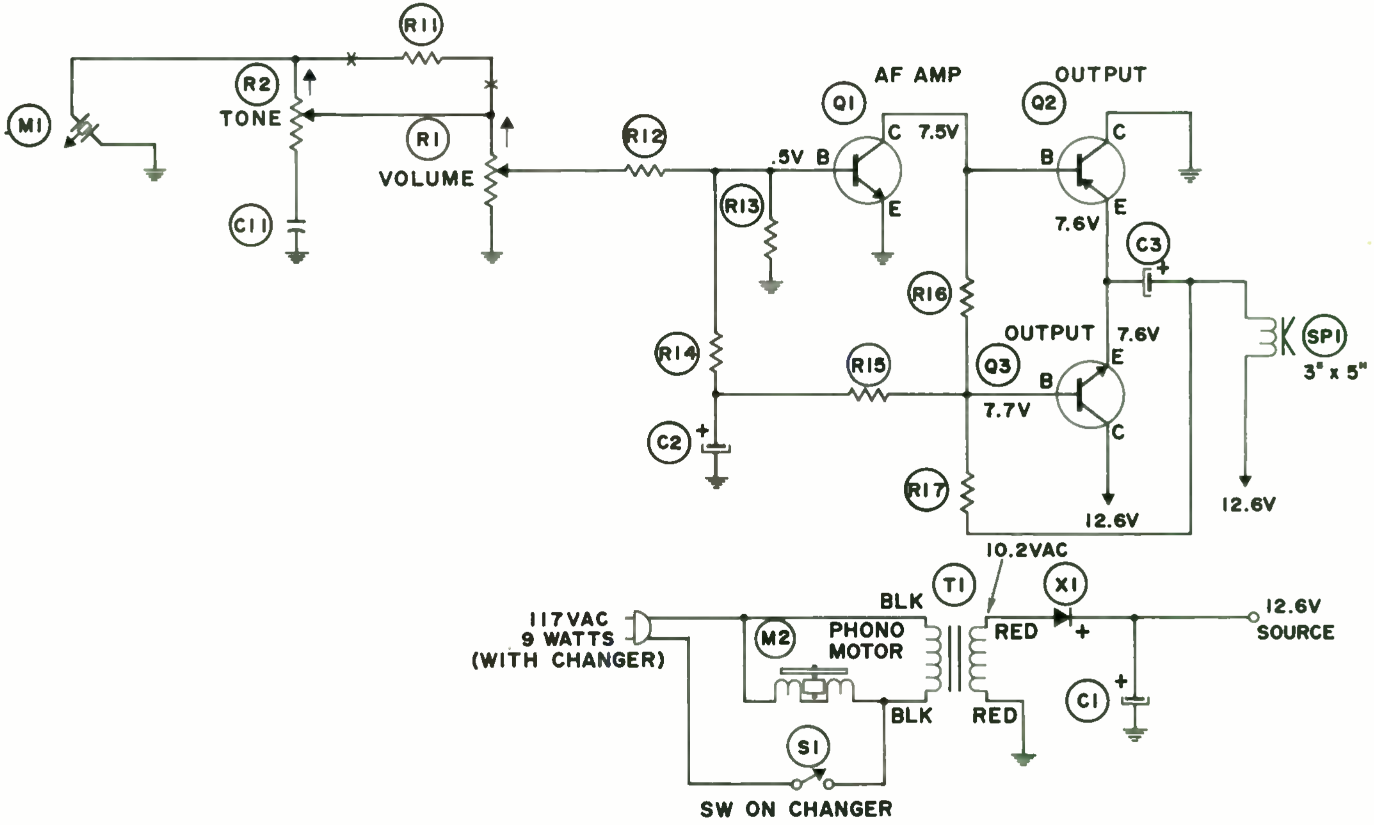


Figure 19 — Schematic drawing of a transistor type amplifier.

TEST

Lesson Number 23

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-023-1.

1. **Symbols rather than pictures, are used for drawing schematic diagrams, because**
   - A. symbols give a clearer understanding of the circuit.
   - B. schematic diagrams can be drawn before the unit is manufactured.
   - C. different manufacturers make the same component in different ways, yet the symbols remain the same.
   - [✓ D.] All of the above.

2. **An important point to remember when working with elec-**
1 **trolytic capacitors is that electrolytic capacitors are**
   - A. useless above 50V DC.
   - 2 [✓ B.] polarized.
   - C. used only in RF application.
   - D. never used as filter capacitors.

3. **Figure 1A is a**
   - A. diode.
   - 8 B. transformer.
   - C. capacitor.
   - [✓ D.] resistor.

4. **Figure 1C is a**
   A. transistor.
   [✓ B.] coil.
   C. tube.
   D. resistor.

5. **Figure 1F is a**
   A. resistor.
   B. tube.
   [✓ C.] rectifier.
   D. switch.

8

6. **Figure 1B is a**
   A. resistor.
   [✓ B.] capacitor.
   C. coil.
   D. tube.

7. **Figure 1D is a**
   A. resistor.
   B. coil.
   [✓ C.] tube.
   D. rectifier.

8. **Figure 1E is a**
   A. resistor.
   B. coil.
   [✓ C.] transistor
   D. switch.

9. **Figure 1G is a**
   A. coil.
   B. resistor.
   [✓ C.] switch.
   D. transistor.

10. **In Figure 2, the value of a resistor with bands colored red-violet-orange-silver is**
   A. 2700 10%.
   [✓ B.] 27,000 10%.
   C. 270 10%.
   D. 26,000 5%.

9

Notes

Notes

Notes

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Serviceman And Customer Both Must Profit

Profitable applications of fair rate pricing of repair work is linked inseparably with craftsmanship. Once the customer has authorized a repair job, then the serviceman whether he owns the shop or not, is accountable.

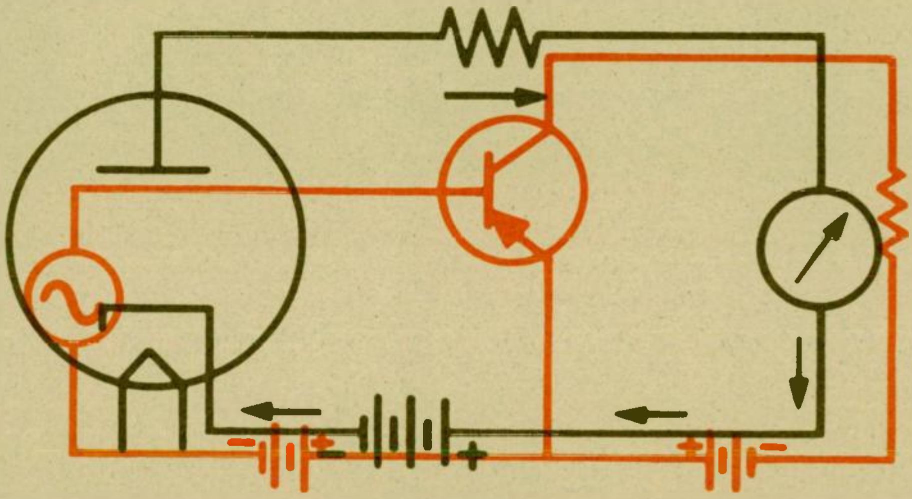
The presence or absence of craftsmanship will determine if the diagnosis was on the beam and if the serviceman will get his "labor's worth" along with a fair profit.

Each step in shop work must be based on authentic trade knowledge. To that must be added the full and fair use of the knowledge to the benefit of both the shop and the customer. These add up to repair work that is correctly priced, correctly done, and correctly sold.

S. T. Christensen

LESSON NO. 24

REVIEW FILM OF LESSONS 21 THROUGH 23



RADIO and TELEVISION SERVICE and REPAIR

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LESSON CODE
NO. 52-024
406

ADVANCE SCHOOLS, INC.
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CHICAGO, ILL. 60631

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REVIEW FILM TEST

Lesson Number 24

The ten questions enclosed are review questions of lessons 21, 22, &23 which you have just studied.

All ten are multiple choice questions, as in your regular lesson material.

Please rerun your Review Records and film before answering these questions.

You will be graded on your answers, as in the written lessons.

REMEMBER YOU MUST COMPLETE AND MAIL IN ALL TESTS IN THE PROPER SEQUENCE IN ORDER FOR US TO SHIP YOUR KITS.

REVIEW FILM TEST

IMPORTANT

Carefully study each question listed here. Indicate your answer to each of these questions in the correct column of the Answer Card having Test Code Number 52-024-1.

1. A transistor is
- A. a voltage controlling device.
- B. a kind of radio.
- [✓ C.] a current controlling device.
- D. only a PNP.

2. An advantage of a transistor, when compared to a vacuum tube, is that transistors
- A. have filaments or heaters.
- B. are very fragile.
- C. have a short life.
- [✓ D.] have a long life.

3. Some vacuum tubes
- A. have been replaced by transistors.
- B. are obsolete.
- C. are still needed for some applications.
- [✓ D.] all of the above.

4. A vacuum tube with three elements is called a
- [✓ A.] triode.
- B. diode.
- C. tetrode.
- D. pentode.

5. A vacuum tube with five elements is called a
A. triode.
B. diode.
C. tetrode.
[✓ D. pentode.]

6. The term Common Emitter means the
A. base is common to both the input and output.
[✓ B. emitter is common to both the input and output.]
C. collector is common to both the input and output.
D. base and collector are shorted to ground.

7. An amplifier has a gain of 50. With 1 volt on the grid, the output will be
[✓ A. 50 volts.]
B. 5 volts.
C. 500 volts.
D. 25 volts.

8. Transistors are replacing vacuum tubes because:
A. transistors are cheaper.
B. transistors make equipment more portable.
C. transistors are more durable.
[✓ D. all of the above.]

9. One tube envelope containing two identical triode units is called a
A. dual-diode.
[✓ B. twin triode.]
C. dual purpose tube.
D. nine pin tube.

10. The screen grid is inserted into a vacuum tube to
[✓ A. reduce the plate to grid interelectrode capacitance.]
B. reduce the plate resistance.
C. suppress secondary electron emission.
D. form a beam-power tube.

Notes

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Knowledge - Care - Craftsmanship

Knowledge, care, and craftsmanship are vitally essential to the success of the electronic repairman. Knowledge is the foundation whereupon we begin. For example, a thorough understanding of the fundamentals of the many circuits contained in a modern electronic set is basic. This knowledge can then be applied to any make or model, old or new.

Care is also vital to good servicing techniques. Many a service job has proved a waste of time and money because the serviceman was careless. Careful attention to the job at hand and all the details involved creates satisfied customers.

Good craftsmanship is in short supply. ASI training plus your own concentrated efforts will enable you to become a highly-skilled serviceman. Your services will be in great demand and you will be able to enjoy the excellent profits you deserve.

It's almost that easy. In a nutshell, we again say, you control your future.

S. T. Christensen