



SPECIALIZED TELEVISION ENGINEERING

TELEVISION TECHNICAL ASSIGNMENT

ALTERNATING CURRENTS

Copyright 1946 by
Capitol Radio Engineering Institute
Washington, D. C.

7160

ALTERNATING CURRENTS

FOREWORD

This discussion is relatively simple—and purposely so. It deals with fundamental principles and most fundamental principles can be expressed in rather simple terms. Further, no matter how complex the ultimate structure of a problem or a line of reasoning may be, the chances of successful completion are very remote if the foundation of fundamental ideas is not sound.

Further on in the course you will deal with voltages built up in a receiving antenna when the antenna conductor is cut by the radiation field from a distant radio transmitter. You will study the design of coils to meet certain specified conditions. Almost all of your problems in radio-electronics will involve the effects of alternating currents or voltages. By the proper selection of frequency, current amplitude and other factors, the *surface* of a steel bar may be heat treated at high speed without the penetration of heat below the desired surface depth. Even the square and "sawtooth" pulses used in various television applications may be resolved into groups of simple alternating currents and voltages of fundamental and harmonic frequencies. By the application of the proper voltage at the proper frequency high speed bonding of plywood is accomplished. By electronic means developed by a noted radio engineer one of the drying processes in the production of penicillin has been reduced from 24 hours to 30 minutes. (Penicillin is one of the so-called "miracle drugs".)

All of these examples are based on the alternating characteristics of alternating current. This technical discussion starts out with the statement, "The study of radio is the study of alternating currents!" Nothing is more essential to a clear understanding of radio and television circuit phenomena than a clear understanding of the *basic rules* of a.c. theory. Try to visualize what happens in the generation of an alternating voltage—and then what happens when that voltage is applied across a circuit. Then carry that picture with you throughout all your radio career.

As you get into the study of various shaped voltage and

ALTERNATING CURRENTS

current pulses in television, radar and other specialized applications. always remember that in the fundamental circuit theory the concepts of simple alternating currents and voltages, but of a wide frequency band, still prevail.

E. H. Rietzke,
President.

- TABLE OF CONTENTS -

ALTERNATING CURRENTS

	Page
INTRODUCTION	1
DIFFERENCE OF POTENTIAL	3
GENERATOR ACTION	4
FORMULA FOR VOLTAGE GENERATED	6
ELECTRO-MAGNET	7
TWO POLE ALTERNATOR	11
SINE-WAVE DIAGRAM	14
AVERAGE VOLTAGE	16
EFFECTIVE VOLTAGE	17
R.F. METERS	20

ALTERNATING CURRENTS

THE STUDY OF RADIO IS THE STUDY OF ALTERNATING CURRENTS! REGARDLESS OF THE PARTICULAR PHASE OF RADIO IN WHICH THE ENGINEER MAY BE AT THE MOMENT INTERESTED, HIS JOB PRIMARILY INVOLVES DEALING WITH SOME EFFECT OF ALTERNATING CURRENTS. THE WRITER DOES NOT KNOW OF A SINGLE EXCEPTION TO THIS.

A FEW EXAMPLES: RECTIFIERS, FOR EITHER TRANSMITTERS OR RECEIVERS SIMPLY CONVERT A.C. POWER INTO D.C. POWER; THE FILTER USED WITH THE RECTIFIER REMOVES THE A.C. RIPPLE FROM THE D.C. OUTPUT. THE OSCILLATOR, EITHER THAT IN A SUPERHETERODYNE RECEIVER, OR THE CRYSTAL CONTROLLED OSCILLATOR OF A TRANSMITTER, CONVERTS D.C. POWER TO A.C. POWER; EVEN IN AN AMPLIFIER WHERE OSCILLATIONS ARE NOT WANTED, IT IS USUALLY NECESSARY TO TAKE ELABORATE PRECAUTIONS TO PREVENT THEM. THE VACUUM TUBE DESIGN ENGINEER MUST DESIGN THE TUBE FOR USE IN ALTERNATING CURRENT CIRCUITS AT EITHER POWER, AUDIO OR RADIO FREQUENCIES, AND SOME OF THE PRINCIPAL DESIGN PROBLEMS ARISE IN CONNECTION WITH THE ELECTRICAL EFFECTS OF THE TUBE ELEMENTS AT HIGH RADIO FREQUENCIES AT WHICH THE TUBE MAY TEND TO ACT AS A SIMPLE CONDENSER INSTEAD OF AMPLIFYING AS A VACUUM TUBE SHOULD.

THE PRINCIPAL PROBLEM IN THE DESIGN OF INSULATORS MANUFACTURED FOR RADIO PRODUCTS AND USES, ARISES IN CONNECTION WITH THE HIGH A.C. FREQUENCIES OF THE CIRCUITS IN WHICH THEY WILL BE USED. AMONG THE PROBLEMS IN THE DESIGN OF AUDIO AND POWER TRANSFORMERS ARE, MINIMIZING HYSTERESIS LOSS, PREVENTING THE TRANSFORMER WINDINGS FROM ACTING AS CONDENSERS, ETC. ANTENNAS ARE ALTERNATING CURRENT DEVICES, BOTH AT THE TRANSMITTER AND IN THE EFFECT AT THE RECEIVER. THUS IT MAY BE SAFELY STATED THAT A THOROUGH GROUNDWORK OF ALTERNATING CURRENT THEORY IS THE BASIC REQUIREMENT FOR ANYONE WORKING IN ANY BRANCH OF RADIO.

IN DIRECT CURRENT CIRCUITS, THE ONLY FACTORS AFFECTING THE CURRENT FLOW ARE VOLTAGE AND RESISTANCE. IN ALTERNATING CURRENT CIRCUITS THOSE FACTORS ARE STILL EFFECTIVE, BUT TO THEM MUST BE ADDED INDUCTANCE AND CAPACITY. THE STUDY

ALTERNATING CURRENTS

2.

OF ALTERNATING CURRENT THEORY IS SIMPLY THAT OF THE MUTUAL EFFECTS OF VOLTAGE, CURRENT, RESISTANCE, INDUCTANCE AND CAPACITY IN THE ELECTRICAL CIRCUIT. TO THE POWER ENGINEER MANY OF THE PHENOMENA OF RADIO FREQUENCY CIRCUITS SEEM COMPLEX; EQUALLY COMPLEX TO A RADIO ENGINEER SEEMS MUCH OF THE APPARATUS IN A POWER HOUSE. HOWEVER, THE VOLTAGE THAT IS GENERATED ACROSS THE ANTENNA OF A BROADCAST RECEIVER IS GENERATED BY EXACTLY THE SAME PRINCIPLE AS IS THE VOLTAGE ACROSS THE TERMINALS OF A 50,000 KVA GENERATOR. THE OPERATION OF THE ACORN TYPE VACUUM TUBE IN AMPLIFYING A VOLTAGE AT A FREQUENCY OF 300,000,000 CYCLES PER SECOND IS NO DIFFERENT THAN THAT OF THE VACUUM TUBE IN A STUDIO SPEECH AMPLIFIER HANDLING FREQUENCIES OF LESS THAN 10,000 CYCLES PER SECOND.

THE PRINCIPLES OF ALTERNATING CURRENT THEORY THAT APPLY AT 60 CYCLES PER SECOND ALSO APPLY AT 60,000,000 CYCLES PER SECOND--BUT SOME OF THE EFFECTS MAY BE GREATLY MAGNIFIED AT ONE END OF THE FREQUENCY SPECTRUM OR THE OTHER. A FEW EXAMPLES: IN THE FILTER OF A POWER SUPPLY RECTIFIER IT MAY BE NECESSARY TO USE AN INDUCTANCE OF 20 HENRIES CONSISTING OF THOUSANDS OF TURNS OF WIRE ON AN IRON CORE; AT THE ULTRA-HIGH RADIO FREQUENCIES THE INDUCTANCE OF A STRAIGHT PIECE OF WIRE TWO INCHES LONG MAY BE SO PROPORTIONATELY GREAT AS TO CAUSE UNDESIRABLE EFFECTS. IN AN AUDIO AMPLIFIER AT 1000 CYCLES PER SECOND THE INDUCTANCE OF A TRANSFORMER WINDING MAY BE ADEQUATE AND THE AMPLIFIER MAY OPERATE VERY EFFICIENTLY; AT 10,000 CYCLES THE CAPACITY EFFECT OF THE SAME TRANSFORMER WINDINGS MAY BE SO GREAT AS TO ALMOST TOTALLY PREVENT THE AMPLIFIER FROM FUNCTIONING. A HIGH POWER VACUUM TUBE MAY OPERATE PERFECTLY AT BROADCAST FREQUENCIES; AT 50 MEGACYCLES THE INTERELEMENT CAPACITY MAY BE SO GREAT AS TO CAUSE SUFFICIENT CURRENT FLOW IN THE GRID CIRCUIT TO MELT THE WIRE LEADING INTO THE GRID. AN INSULATOR WHICH IS HIGHLY EFFECTIVE AT POWER FREQUENCIES MAY INTRODUCE SO MUCH LOSS AT THE HIGH RADIO FREQUENCIES AS TO RENDER THE EQUIPMENT IN WHICH IT IS INCORPORATED, USELESS AT SUCH FREQUENCIES.

THUS THE RADIO ENGINEER MUST DEVELOP A SENSE OF VALUES. HE MUST LEARN TO KNOW, MORE OR LESS INSTINCTIVELY, WHAT SORT OF CIRCUIT CONSTANTS--INDUCTANCE,

CAPACITY, AND RESISTANCE—SHOULD BE EFFECTIVE IN THE FREQUENCY BAND IN WHICH HE IS WORKING. SUCH A SENSE WILL PROVE INVALUABLE AS A CHECK ON THE PROBABLE ACCURACY OF HIS CALCULATIONS. WITH THESE THOUGHTS IN MIND IT IS LOGICAL TO BEGIN THE STUDY OF ALTERNATING CURRENTS WITH THE GENERATION OF AN ELECTROMOTIVE FORCE.

IN THE STUDY OF ELECTRON PHYSICS IT HAS BEEN SHOWN THAT A CURRENT FLOW IN A CONDUCTOR IS AN ACTUAL MOVEMENT OF ELECTRONS THROUGH THE CONDUCTOR, AND THAT THE FLOW OF ELECTRONS IS CAUSED BY A DIFFERENCE OF POTENTIAL BETWEEN THE TWO ENDS OF THE CONDUCTOR; ALSO, THAT A DIFFERENCE OF POTENTIAL IS ESTABLISHED BY CREATING AN EXCESS OF ELECTRONS AT ONE POINT AND A DEFICIENCY OF ELECTRONS AT ANOTHER POINT. UNDER THESE CONDITIONS THE ELECTRONS WILL DRIFT THROUGH THE CIRCUIT FROM THE POINT OF EXCESS TO THE POINT OF DEFICIENCY. IF AN ORDINARY DIFFERENCE OF POTENTIAL IS ESTABLISHED BETWEEN TWO POINTS AND THE POINTS THEN CONNECTED BY A CONDUCTOR, THE ELECTRONS WILL FLOW THROUGH THE CONDUCTOR UNTIL THERE IS NO LONGER AN EXCESS OR DEFICIENCY AT EITHER END; IN OTHER WORDS, THE DIFFERENCE OF POTENTIAL BETWEEN THE TWO POINTS WILL BE NEUTRALIZED. AN EXAMPLE OF THIS IS A CONDENSER CHARGED TO A GIVEN DIFFERENCE OF POTENTIAL BETWEEN THE PLATES AND THEN, AFTER THE CHARGING SOURCE HAS BEEN REMOVED, THE CONDENSER IS SHORT-CIRCUITED WITH A CONDUCTOR. CURRENT WILL FLOW ONLY SO LONG AS REQUIRED TO NEUTRALIZE THE DIFFERENCE OF POTENTIAL BETWEEN THE PLATES OF THE CONDENSER.

IF, HOWEVER, SOME MEANS ARE AVAILABLE TO MAINTAIN THE DIFFERENCE OF POTENTIAL CONTINUOUSLY, CURRENT WILL FLOW THROUGH THE CONDUCTOR CONTINUOUSLY.

THERE ARE TWO GENERAL METHODS OF MAINTAINING A CONTINUOUS DIFFERENCE OF POTENTIAL BETWEEN TWO POINTS, BY MEANS OF A CHEMICAL ACTION AND BY MEANS OF WHAT MAY BE CALLED GENERATOR ACTION. CHEMICAL ACTION TAKES PLACE IN A BATTERY AND IS A TRUE SOURCE OF A STEADY DIFFERENCE OF POTENTIAL, THE POLARITY OF THE DIFFERENCE OF POTENTIAL REMAINING CONSTANT. SINCE THE CHEMICAL ACTION IS CONTINUOUS OVER A CONSIDERABLE PERIOD OF TIME, THE DIFFERENCE OF POTENTIAL MAY BE CONSIDERED AS A CONTINUOUS FORCE ACTING ON THE ELECTRONS CAUSING THEM TO MOVE.

4.

ALTERNATING CURRENTS

THIS FORCE CAUSING THE MOVEMENT OF ELECTRONS IS THUS CALLED THE ELECTROMOTIVE FORCE AND IS ABBREVIATED EMF.

THE ELECTROMOTIVE FORCE, (EMF), IMPLIES A MOVEMENT OF ELECTRONS, AND ANY DEVICE WHICH CAUSES A CONTINUOUS MOVEMENT OF ELECTRONS, NOT NECESSARILY ALWAYS IN THE SAME DIRECTION, IS SAID TO GENERATE AN EMF. A DIFFERENCE OF POTENTIAL DOES NOT NECESSARILY IMPLY A MOVEMENT OF ELECTRONS; IT MERELY INDICATES THAT AN ELECTRICAL STRAIN EXISTS BETWEEN TWO OPPOSITELY CHARGED BODIES, ONE POSITIVE AND THE OTHER NEGATIVE, AND THAT IF THE TWO CHARGES ARE BROUGHT TOGETHER BY MEANS OF A CONDUCTOR, A CURRENT WILL FLOW LONG ENOUGH TO NEUTRALIZE THE CHARGES.

AN EMF CAN BE DEVELOPED BY BOTH CHEMICAL ACTION AND GENERATOR ACTION. A RATHER DETAILED STUDY OF THE LATTER METHOD WILL BE MADE AS IT IS THE PRINCIPLE UPON WHICH ALL GENERATORS, TRANSFORMERS, RADIO FREQUENCY COUPLED CIRCUITS, AND RECEIVING ANTENNAS OPERATE.

THE TWO BASIC RULES OF GENERATOR ACTION ARE:

1. A MOVING ELECTRIC FIELD CREATES A MAGNETIC FIELD.
2. A MOVING MAGNETIC FIELD CREATES AN ELECTRIC FIELD.

RULE 1 WHICH EXPRESSES THE BASIC PRINCIPLE OF ELECTROMAGNETS HAS BEEN DISCUSSED IN DETAIL IN AN EARLIER LESSON.

FROM RULE 2 IT IS EVIDENT THAT A MOVING MAGNETIC FIELD ALSO HAS VARIOUS PHENOMENA ASSOCIATED WITH IT, THE PRINCIPAL ONE BEING EXPRESSED IN THE RULE ITSELF WHICH STATES, "A MOVING MAGNETIC FIELD CREATES AN ELECTRIC FIELD." IT SHOULD BE PARTICULARLY NOTED IN BOTH RULES THAT MOTION IS ESSENTIAL TO THE CREATION OF EITHER AN ELECTRIC OR A MAGNETIC FIELD.

A MOVING MAGNETIC FIELD MAY BE PRODUCED BY INCREASING OR DECREASING THE CURRENT THROUGH THE WINDINGS OF THE FIELD TURNS, (AS BY AN ALTERNATING CURRENT) THUS CAUSING THE FIELD TO EXPAND OR CONTRACT. IF, AS THIS FIELD MOVES OUTWARD AWAY FROM THE TURNS, IT CUTS ANOTHER CONDUCTOR AT RIGHT ANGLES, THERE WILL BE INDUCED ACROSS THE TERMINALS OF THE SECOND CONDUCTOR A DIFFERENCE OF POTENTIAL.

THE VALUE OF WHICH WILL DEPEND DIRECTLY UPON THE DENSITY OF THE FIELD AND ITS VELOCITY OF EXPANSION. THIS ACTION IS SHOWN IN FIGURE 1. NOTE THAT THE

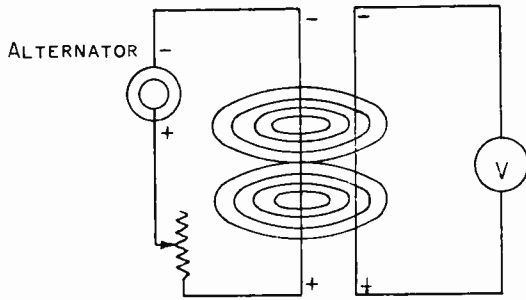


FIG. 1.

POLARITY OF THE INDUCED VOLTAGE IS INDICATED AS OPPOSITE TO THAT OF THE INDUCING VOLTAGE. THIS MAY BE EXPLAINED BY LENZ'S LAW WHICH WILL BE DISCUSSED IN A LATER LESSON. (THE POLARITY OF THE A.C. SOURCE IS OF COURSE FOR A SINGLE ALTERNATION.)

THE PHENOMENON EXPRESSED IN RULE 2, "A MOVING MAGNETIC FIELD CREATES AN ELECTRIC FIELD" IS ALSO ONE WHICH IS NOT DEPENDENT UPON MATTER. IF A MAGNETIC FIELD IS CAUSED TO EXPAND THROUGH EMPTY SPACE IT WILL CREATE AT RIGHT ANGLES TO ITS OWN PLANE AN ELECTRIC FIELD OR STRAIN. THE STRAIN WILL BE SUCH AS TO CAUSE A TENDENCY FOR A MOVEMENT OF ELECTRONS FROM THE NEGATIVE TO THE POSITIVE DIRECTION. IF A SUBSTANCE IS PLACED IN THIS MOVING FIELD IN SUCH A MANNER THAT THE ELECTRIC FIELD OR STRAIN CAUSED BY THE MOVING MAGNETIC FIELD EXISTS BETWEEN THE ENDS OF THE SUBSTANCE, THERE WILL BE A DISPLACEMENT OF THE ELECTRONS IN THE ORBITS OF THEIR RESPECTIVE ATOMS. IF THE SUBSTANCE IS A CONDUCTOR THERE WILL BE AN ACTUAL ELECTRON OR CURRENT FLOW IN THE CONDUCTOR. THE POINT TO REMEMBER, HOWEVER, IS THAT THE ELECTRIC STRAIN EXISTS ACROSS THE SPACE OCCUPIED BY THE CONDUCTOR WHETHER THE CONDUCTOR IS THERE OR NOT. THIS FACT IS OF GREAT IMPORTANCE IN THE PHENOMENON OF RADIATION.

SINCE THE DIFFERENCE OF POTENTIAL IS SET UP ACROSS THE SECOND CONDUCTOR BY VIRTUE OF ITS BEING CUT BY A MOVING MAGNETIC FIELD, IT MAY BE STATED THAT THE ONLY FACTORS NECESSARY IN THE PRODUCTION OF AN EMF ARE A CONDUCTOR, A MAGNETIC FIELD AND MOTION; ALSO THAT IT MAKES NO DIFFERENCE WHETHER THE FIELD MOVES ACROSS THE CONDUCTOR OR THE CONDUCTOR MOVES ACROSS THE FIELD.

ALTERNATING CURRENTS

6.

THIS PRINCIPLE IS MADE USE OF IN THE FOLLOWING GENERAL TYPES OF APPARATUS FOR THE GENERATION OF AN EMF:

1. TRANSFORMER, IN WHICH BOTH THE PRIMARY AND SECONDARY TURNS ARE STATIONARY AND THE MAGNETIC FIELD IS CAUSED TO EXPAND AND CONTRACT, THUS CUTTING THE SECONDARY TURNS AT SOME GIVEN RATE. THE EXPANSION AND CONTRACTION OF THE MAGNETIC FIELD IS CAUSED BY AN INCREASE AND DECREASE OF CURRENT IN THE PRIMARY WINDINGS.
2. THE ROTATING ARMATURE GENERATOR IN WHICH THE MAGNETIC FIELD IS STATIONARY, AND THE SECONDARY CONDUCTORS ARE ROTATED THROUGH THE STATIONARY FIELD.
3. THE ROTATING FIELD GENERATOR IN WHICH THE SECONDARY CONDUCTORS ARE FIXED, AND THE ENTIRE FIELD MAGNETS ARE CAUSED TO ROTATE PAST THE SECONDARY CONDUCTORS.
4. THE INDUCTOR ALTERNATOR IN WHICH BOTH THE PRIMARY AND SECONDARY CONDUCTORS ARE STATIONARY AND THE CURRENT IN THE FIELD WINDING IS STEADY. THE FIELD IS CAUSED TO EXPAND AND CONTRACT BY CHANGING THE PERMEABILITY OF THE FIELD CORE BY ALTERNATELY INSERTING SEGMENTS OF MAGNETIC AND NON-MAGNETIC SUBSTANCES IN THE PATH OF THE MAGNETIC FIELD.

THE ACTUAL VOLTAGE PRODUCED AT THE TERMINALS OF ANY ONE OF THESE DIFFERENT TYPES OF GENERATORS DEPENDS ONLY ON THE NUMBER OF LINES OF INDUCTION CUT IN UNIT TIME, AND IS EQUAL TO:

$$\text{AVERAGE VOLTAGE} = \frac{\text{MAGNETIC LINES OF INDUCTION CUT PER SECOND}}{10^8}$$

THE NUMBER OF LINES CUT PER SECOND IS A FACTOR OF:

1. THE NUMBER OF CONDUCTORS.
2. THE DENSITY AND AREA OF THE MAGNETIC FIELD. (TOTAL NUMBER OF LINES.)
3. THE VELOCITY OF THE MOVING FIELD OR MOVING CONDUCTORS.

A CONSTANT VOLTAGE COULD BE GENERATED IF IT WERE PRACTICAL TO HAVE A GIVEN NUMBER OF CONDUCTORS CUTTING THROUGH A UNIFORM MAGNETIC FIELD AT A CONSTANT SPEED. THAT IS, PRACTICALLY, AN IMPOSSIBILITY. IT IS A SIMPLE MATTER TO CAUSE A GIVEN NUMBER OF CONDUCTORS TO REVOLVE AT A CONSTANT SPEED, BUT THERE IS NO PRACTICAL MEANS OF CREATING A CONSTANT DENSITY OF MAGNETIC FIELD OF A SINGLE POLARITY. WHENEVER A MAGNETIC FIELD IS DEVELOPED IT ALWAYS HAS TWO OPPOSITE POLES, ONE NORTH AND ONE SOUTH, AND THE STRENGTH OF THE MAGNETIC FIELD IN THE MEDIUM BETWEEN THE TWO POLES IS A FUNCTION OF THE DISTANCE BETWEEN THE POLES.

FOR EXAMPLE, IN FIGURE 2, AN ELECTRO-MAGNET IS FORMED BY A BAR OF STEEL

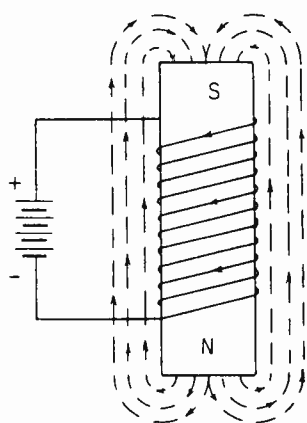


FIG. 2.

WITH A WINDING OF A CERTAIN NUMBER OF TURNS THROUGH WHICH IS PASSING A SPECIFIC ELECTRIC CURRENT. ONE END OF THE BAR BECOMES A NORTH MAGNETIC POLE AND THE OTHER BECOMES A SOUTH MAGNETIC POLE. IN THE AIR SURROUNDING THE MAGNET IS ESTABLISHED A CERTAIN DENSITY OF MAGNETIC FIELD CAUSED BY THE LINES OF FORCE BETWEEN THE OPPOSITE POLES. THIS FIELD IS COMPARATIVELY WEAK DUE TO THE DISTANCE BETWEEN THE POLES AND THE POOR PERMEABILITY OF THE SURROUNDING MEDIUM, AIR. IN FIGURE 3, IS THE SAME

BAR WITH THE SAME NUMBER OF TURNS IN THE WINDING AND THE SAME CURRENT THROUGH THE WINDING, BUT THE SHAPE OF THE BAR HAS BEEN CHANGED SO THAT THE TWO ENDS ARE CLOSER TOGETHER. THE RELUCTANCE OF THE MAGNETIC CIRCUIT IS REDUCED AND THEREFORE A MORE DENSE MAGNETIC FIELD EXISTS IN THE MEDIUM BETWEEN THE TWO POLES.

IN FIGURE 4 THE SHAPE OF THE TWO MAGNETIC POLES HAS BEEN SLIGHTLY CHANGED AND IN THE GAP BETWEEN THE POLES HAS BEEN PLACED A PIECE OF STEEL. THIS GREATLY DECREASES THE RELUCTANCE OF THE MAGNETIC CIRCUIT, AND FOR THE SAME NUMBER OF TURNS ON THE WINDING AND THE SAME CURRENT FLOW THROUGH THOSE TURNS,

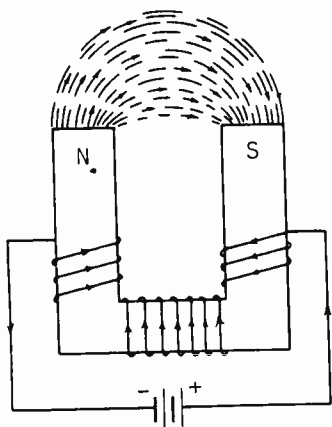


FIG. 3.

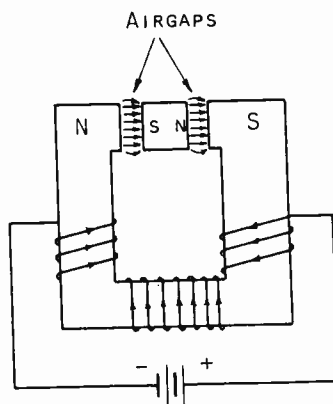


FIG. 4.

(IN OTHER WORDS, THE SAME NUMBER OF AMPERE TURNS), THERE IS DEVELOPED A MUCH STRONGER MAGNETIC FIELD. IT WILL BE NOTED IN FIGURE 4 THAT THERE IS A SMALL AIRGAP BETWEEN THE FACE OF EACH POLE AND THE STEEL CENTER-PIECE BETWEEN THE POLES. THE PERMEABILITY OF THE ENTIRE PATH OF THE FIELD, WITH THE EXCEPTION OF THE TWO NARROW AIRGAPS IS HIGH. THE DENSITY OF THE MAGNETIC FLUX IN THE AIRGAPS IS THEREFORE MUCH GREATER THAN IN EITHER FIGURE 2 OR FIGURE 3.

IF THE AIRGAP WERE ENTIRELY CLOSED AND THE ENTIRE MAGNETIC CIRCUIT OF STEEL, THE FLUX DENSITY WITHIN THE STEEL WOULD BE MUCH GREATER. (THIS HAS BEEN SHOWN IN A PRECEDING LESSON.) FOR THAT REASON, IN THE DESIGN OF POWER TRANSFORMERS THE STEEL CORE IS USUALLY SO CONSTRUCTED AS TO FORM A CLOSED MAGNETIC CIRCUIT, THE ENTIRE PATH BEING OF STEEL. WITH SUCH CONSTRUCTION THE STRONGEST POSSIBLE FIELD WILL BE SET UP FOR A GIVEN NUMBER OF AMPERE TURNS IN THE PRIMARY. HOWEVER, THE PERMEABILITY OF SUCH A CORE WILL NOT BE AT ALL UNIFORM WITH VARIOUS CURRENT AMPLITUDES BECAUSE OF THE SHAPE OF THE BH CURVE DUE TO MAGNETIC SATURATION AT HIGH VALUES OF H .

FOR THIS REASON WHERE IT IS DESIRED TO HAVE A VERY CONSTANT VALUE OF PERMEABILITY WITHIN GIVEN CURRENT LIMITS, AS IN THE FILTER REACTOR OF A RECTIFIER, THE REACTOR CORE IS CONSTRUCTED WITH AN AIRGAP OF DEFINITE LENGTH. AS THE LENGTH OF THE AIRGAP IS INCREASED THE PERMEABILITY OF THE TOTAL MAGNETIC PATH

DECREASES, APPROACHING MORE NEARLY THAT OF UNITY WITH INCREASE OF GAP LENGTH. THIS MEANS THAT, FOR A GIVEN AMOUNT OF INDUCTANCE, (TO BE STUDIED LATER), MORE TURNS WILL BE REQUIRED. HOWEVER, THE PERMEABILITY OF THE MAGNETIC PATH, ALTHOUGH DECREASED IN VALUE, WILL BE MUCH MORE UNIFORM OVER WIDER CURRENT LIMITS AND, SINCE THE INDUCTANCE OF THE REACTOR IS A DIRECT FUNCTION OF THE PERMEABILITY, THE INDUCTANCE ALSO REMAINS CONSTANT OVER WIDER LIMITS OF CURRENT VARIATION. (IN A CERTAIN TYPE OF FILTER REACTOR, CALLED A SWINGING CHOKE, IT IS DESIRED THAT L VARY OVER CERTAIN LIMITS. THIS WILL BE DESCRIBED IN ANOTHER LESSON.)

ON CONSIDERING THE FACT THAT EVERY MAGNET HAS TWO OPPOSITE POLES, AND THAT IN ORDER TO GET A STRONG FIELD IT IS NECESSARY TO BRING THE TWO POLES AS CLOSE TOGETHER AS POSSIBLE, IT WILL BE SEEN THAT TO GET A CONTINUOUS FIELD OF ONLY ONE POLARITY WOULD BE ENTIRELY IMPRACTICAL IN COMMERCIAL APPARATUS. THEREFORE IT IS NOT PRACTICAL, BY GENERATOR ACTION, TO GENERATE AN ELECTROMOTIVE FORCE THAT IS CONTINUOUSLY IN ONE DIRECTION. IT IS NOT DIFFICULT, BY COMMUTATOR ACTION, TO TAKE THE ALTERNATING VOLTAGE WHICH HAS BEEN GENERATED, AND BY CHANGING FROM ONE SET OF CONDUCTORS TO ANOTHER AT EXACTLY THE PROPER INSTANT, GET A CONTINUOUS ELECTROMOTIVE FORCE IN ONE DIRECTION. BUT THE ACTUAL DIFFERENCE OF POTENTIAL BETWEEN THE TWO ENDS OF ANY GIVEN CONDUCTOR REVERSES PERIODICALLY. THIS WILL BE SHOWN AS FOLLOWS:

CONSIDER THE CASE OF A NUMBER OF CONDUCTORS IN THE FORM OF A COIL CUTTING ACROSS A MAGNETIC FIELD, AT THE NORTH POLE OF A MAGNET. (SEE FIGURE 5.) ASSUME THE DIRECTION OF CUTTING OF THE FIELD IS FROM RIGHT TO LEFT. IF THERE IS CONNECTED ACROSS THE TWO ENDS OF THE COIL A VOLTMETER HAVING A DOUBLE SCALE, INDICATING EACH SIDE OF CENTER WHICH IS ZERO, WHILE THE CONDUCTORS ARE MOVING ACROSS THIS POLE THE INDICATOR ON THE VOLTMETER WILL DEFLECT IN ONE DIRECTION, SHOWING THAT AN ELECTROMOTIVE FORCE HAS BEEN GENERATED BY THE CONDUCTORS CUTTING THE MAGNETIC FIELD. IF THE DIRECTION OF MOTION OF THE CONDUCTORS IS NOW REVERSED AND THE FIELD CUT FROM LEFT TO RIGHT, THE VOLTMETER DEFLECTION WILL

10.

ALTERNATING CURRENTS

BE OPPOSITE IN DIRECTION TO THE PREVIOUS DEFLECTION. THIS PROVES THAT THE POLARITY OF THE GENERATED EMF DEPENDS UPON THE DIRECTION OF CUTTING OF THE FIELD.

SUPPOSE, INSTEAD OF REVERSING THE DIRECTION OF MOVEMENT OF THE CONDUCTORS, THE POLARITY OF THE MAGNET IS REVERSED, AS IN FIGURE 6.

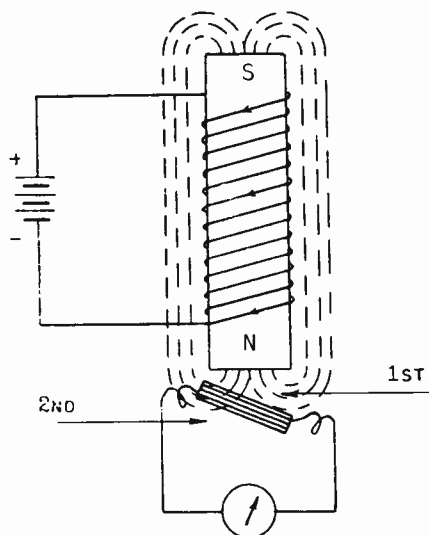


FIG. 5.

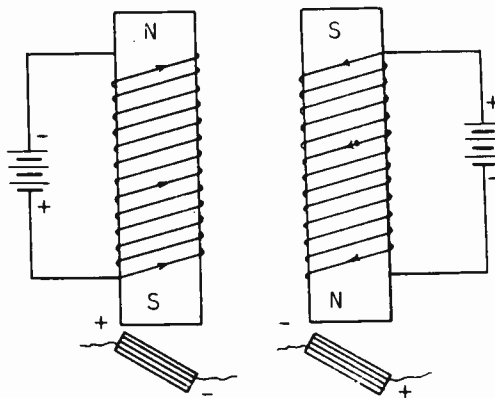


FIG. 6.

AS THE CONDUCTORS PASS UNDER THE NORTH MAGNETIC POLE A CERTAIN DIFFERENCE OF POTENTIAL IS CREATED BETWEEN THE TWO ENDS OF THE COIL. AS THE COIL CONTINUES THE MOVEMENT IN THE SAME DIRECTION UNDER THE SOUTH POLE A DIFFERENCE OF POTENTIAL OF OPPOSITE POLARITY IS GENERATED.

IT IS THEREFORE POSSIBLE TO GENERATE AN EMF THAT PERIODICALLY REVERSES, EITHER BY MOVING CONDUCTORS BACK AND FORTH UNDER THE SAME MAGNETIC POLE AT REGULAR INTERVALS, OR BY MOVING THE CONDUCTORS IN THE SAME DIRECTION UNDER OPPOSITE MAGNETIC POLES AS IN FIGURE 6.

CONSIDER THE VOLTAGE GENERATED IN ONE CONDUCTOR OF THE SIMPLE TWO POLE ALTERNATOR. SEE FIGURE 7. FOUR POSITIONS OF THE CONDUCTOR ARE SHOWN AS IT MOVES IN A COUNTER-CLOCKWISE DIRECTION THROUGH THE 360 DEGREES OF THE CIRCLE

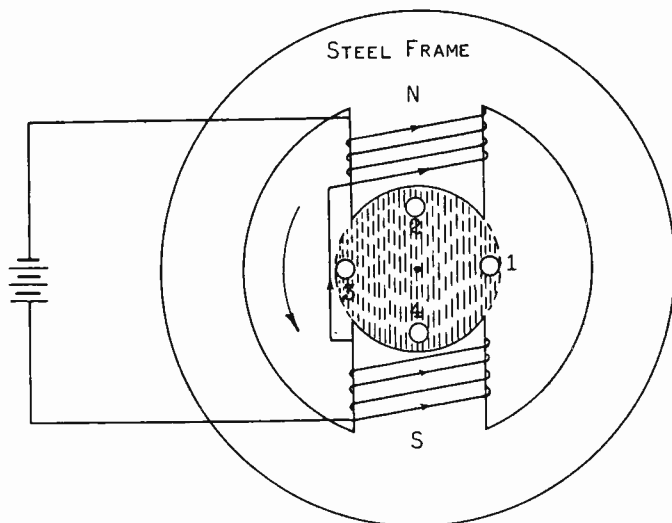


FIG. 7.

NECESSARY IN COMPLETELY PASSING UNDER THE TWO POLES.

IN POSITION 1 THE CONDUCTOR IS MOVING VERTICALLY UPWARD PARALLEL TO THE LINES OF FORCE IN THE MAGNETIC FIELD. AS IT IS MOVING PARALLEL TO THE LINES OF FORCE IT IS NOT CUTTING THE FIELD AND NO

VOLTAGE IS GENERATED AT THIS PARTICULAR INSTANT. AS THE CONDUCTOR MOVES UP FROM POSITION 1 IT IS MOVING IN A CIRCLE, AND THE INSTANT IT LEAVES POSITION 1 IT IS NO LONGER MOVING EXACTLY PARALLEL TO THE MAGNETIC FIELD AND IS THEREFORE CUTTING THE FIELD, GENERATING A DIFFERENCE OF POTENTIAL ACROSS THE TWO ENDS OF THE CONDUCTOR.

THE VOLTAGE GENERATED AT ANY INSTANT DEPENDS UPON THE NUMBER OF LINES OF FORCE CUT PER SECOND, THAT IS, THE RATE OF CUTTING. THIS DEPENDS UPON THE DENSITY OF THE FIELD, THE VELOCITY WITH WHICH THE CONDUCTORS ARE MOVING ACROSS THE FIELD, AND THE NUMBER OF CONDUCTORS. IN FIGURE 7 THERE IS A COMPARATIVELY CONSTANT FLUX DENSITY, A CONSTANT VELOCITY OF ROTATION, AND A SINGLE CONDUCTOR, BUT ANOTHER FACTOR NOW ENTERS INTO THE EQUATION. THAT ELEMENT IS THE ANGLE AT WHICH THE CONDUCTOR CUTS THE FIELD. REGARDLESS OF THE DENSITY OF THE FIELD, NO VOLTAGE IS GENERATED AT POSITION 1 BECAUSE, EVEN THOUGH THE CONDUCTOR IS MOVING IN THE FIELD, IT IS MOVING PARALLEL TO THE LINES OF FORCE, THEREFORE CUTTING NONE OF THEM. AT POSITION 2 THE CONDUCTOR IS MOVING WITH THE SAME VELOCITY IN THE SAME FIELD, BUT IT IS MOVING DIRECTLY ACROSS THE FIELD CUTTING THE GREATEST POSSIBLE NUMBER OF LINES OF FORCE PER UNIT TIME. AT THIS POINT, THEREFORE, THE

12.

ALTERNATING CURRENTS

MAXIMUM VOLTAGE IS GENERATED AND THE DIRECTION OF MOTION OF THE CONDUCTOR IS AT NINETY DEGREES TO THE DIRECTION OF THE MAGNETIC FIELD. IT MAY BE STATED THAT WHEN THE DIRECTION OF MOTION OF THE CONDUCTOR IS ZERO DEGREES FROM THE DIRECTION OF THE FIELD, ZERO VOLTAGE IS GENERATED, AND WHEN THE CONDUCTOR IS MOVING PERPENDICULAR TO THE DIRECTION OF THE FIELD, MAXIMUM VOLTAGE IS GENERATED. AT ANY POINT BETWEEN THESE LIMITS THE VOLTAGE WILL HAVE SOME AMPLITUDE BETWEEN ZERO AND MAXIMUM, AND THE AMPLITUDE WILL DEPEND UPON THE ANGLE OF CUTTING. AS WILL BE SHOWN LATER, THE ACTUAL VOLTAGE AMPLITUDE AT ANY INSTANT IS A DIRECT FUNCTION OF THE SINE OF THE ANGLE WHICH THE INSTANTANEOUS DIRECTION OF THE CONDUCTOR MAKES WITH THE MAGNETIC LINES OF FORCE.

AS THE CONDUCTOR LEAVES POSITION 2 AND MOVES TOWARD POSITION 3, THE ANGLE OF CUTTING GRADUALLY DECREASES UNTIL AT POSITION 3 THE CONDUCTOR IS AGAIN MOVING PARALLEL TO THE LINES OF FORCE AND THE VOLTAGE GENERATED IS ZERO. THE VOLTAGE HAS NOW FALLEN OFF IN THE SAME FORM AS IT INCREASED BETWEEN POSITIONS 1 AND 2. ALSO, THE POLARITY OF THE DIFFERENCE OF POTENTIAL ACROSS THE CONDUCTOR IS THE SAME DURING THE ENTIRE 180 DEGREES BETWEEN POSITIONS 1 AND 3. DURING THE SECOND 90 DEGREES THE VOLTAGE DECREASES, BUT THE POLARITY IS UNCHANGED.

AS THE CONDUCTOR PASSES POSITION 3, HOWEVER, A DECIDED CHANGE TAKES PLACE. DURING THE FIRST 180 DEGREES THE CONDUCTOR WAS PASSING UNDER A NORTH POLE. THE CONDUCTOR NOW BEGINS TO CUT THE MAGNETIC FIELD UNDER A SOUTH POLE. THE CONDUCTOR IS STILL MOVING IN A COUNTER-CLOCKWISE DIRECTION BUT THE MAGNETIC FIELD THROUGH WHICH IT IS PASSING IS OF THE REVERSE POLARITY, THEREFORE, THE GENERATED VOLTAGE HAS ALSO BEEN REVERSED IN POLARITY. (SEE FIGURE 6).

(SINCE THE CONDUCTOR IS MOVING, UNDER BOTH POLES, IN A FIELD WHICH IS CONTINUOUS BETWEEN THE POLES, THE EFFECT AS DESCRIBED IN THE PRECEDING PARAGRAPH COULD ALSO BE THOUGHT OF AS A REVERSAL OF THE DIRECTION OF CUTTING ACROSS THE SAME FIELD. HOWEVER, IN VIEW OF THE FACT THAT THE ROTARY MOTION IS CONTINUOUS, AND THAT ON THE SECOND HALF-CYCLE THE CONDUCTOR ACTUALLY PASSES UNDER A MAGNETIC POLE OF OPPOSITE POLARITY TO THAT OF THE FIRST HALF-CYCLE, IT IS BELIEVED THAT

THE EXPLANATION AS GIVEN IN THE PRECEDING PARAGRAPH WILL ALLOW A CLEARER CONCEPTION OF A.C. GENERATOR ACTION, PARTICULARLY AS IT RELATES TO OTHER GENERATING DEVICES.)

THE REVERSED VOLTAGE GOES THROUGH THE SAME CHANGES, REACHING MAXIMUM AT POSITION 4 AND IS BACK TO ZERO AT POSITION 1. THE CONDUCTOR HAS THEN COMPLETED 360 MECHANICAL DEGREES AND THE VOLTAGE HAS GONE THROUGH TWO COMPLETE ALTERNATIONS OR REVERSALS, CHANGING FROM ZERO TO MAXIMUM AND BACK TO ZERO IN ONE DIRECTION, THEN REVERSING AS THE CONDUCTOR BEGINS TO PASS UNDER THE OPPOSITE POLE AND GOING THROUGH THE SAME CHANGES IN THE OPPOSITE DIRECTION.

TWO COMPLETE ALTERNATIONS REPRESENT ONE ELECTRICAL CYCLE AND ONE CYCLE IS COMPLETED EACH TIME THE CONDUCTOR PASSES ENTIRELY UNDER TWO OPPOSITE MAGNETIC POLES. IN A 24 POLE MACHINE TWELVE CYCLES WILL BE COMPLETED IN ONE COMPLETE MECHANICAL REVOLUTION OF THE CONDUCTOR. EACH ELECTRICAL CYCLE CONSISTS OF 360 ELECTRICAL DEGREES WHICH MAKE UP TWO ALTERNATIONS, EACH ALTERNATION BEING A COMPLETE VARIATION OF VOLTAGE FROM ZERO TO MAXIMUM AND BACK TO ZERO. DURING EACH CYCLE THE VOLTAGE REACHES MAXIMUM TWICE AND ZERO TWICE, THE TWO MAXIMUM VALUES BEING IN THE OPPOSITE DIRECTION.

NOW CONSIDER THE VALUES REACHED AT DIFFERENT POINTS ALONG THE CYCLE. THESE VALUES VARY WITH THE ANGLE THAT THE DIRECTION OF MOTION OF THE CONDUCTOR MAKES WITH THE DIRECTION OF THE LINES OF FORCE IN THE MAGNETIC FIELD. IT HAS BEEN SHOWN THAT THE CONDUCTOR MOVES IN A PERFECT CIRCLE THROUGH A PRACTICALLY UNIFORM FIELD, COMPLETING IN THAT CIRCLE 360 ELECTRICAL DEGREES.

IN FIGURE 8 ARE PLOTTED THE POSITIONS OF THE CONDUCTOR AS IT MOVES IN A CIRCLE COMPLETING 360 ELECTRICAL DEGREES. THE RADIUS OF THE CIRCLE REPRESENTS THE MAXIMUM AMPLITUDE OF THE VOLTAGE GENERATED DURING THE CYCLE.

THE AMPLITUDE OF THE VOLTAGE AT ANY INSTANT DURING THE CYCLE IS EQUAL TO THE DISTANCE THE EXTREME END OF THE RADIUS VECTOR EXTENDS ABOVE OR BELOW THE HORIZONTAL LINE BETWEEN POINTS 1 AND 9 WHICH REPRESENTS THE TIME AXIS. FOR EXAMPLE, IF FIGURE 8 IS DRAWN TO SCALE, THE RADIUS BEING EQUAL TO THE MAXIMUM

VOLTAGE GENERATED DURING THE CYCLE, THEN THE AMPLITUDE OF THE VOLTAGE AT POSITION 3 IS EQUAL TO THE LENGTH OF (B) DRAWN TO THE SAME SCALE. LIKewise AT POSITION 11, THE AMPLITUDE OF THE VOLTAGE IS EQUAL TO THE LENGTH OF (B₁), BUT THE POLARITY OF THE VOLTAGE IS OPPOSITE TO THAT OF THE VOLTAGE AT POSITION 3. IF Φ_1 EQUALS Φ THEN (B₁) EQUALS (B), AND THE AMPLITUDES OF THE TWO VOLTAGES ARE EQUAL BUT OPPOSITE IN POLARITY.

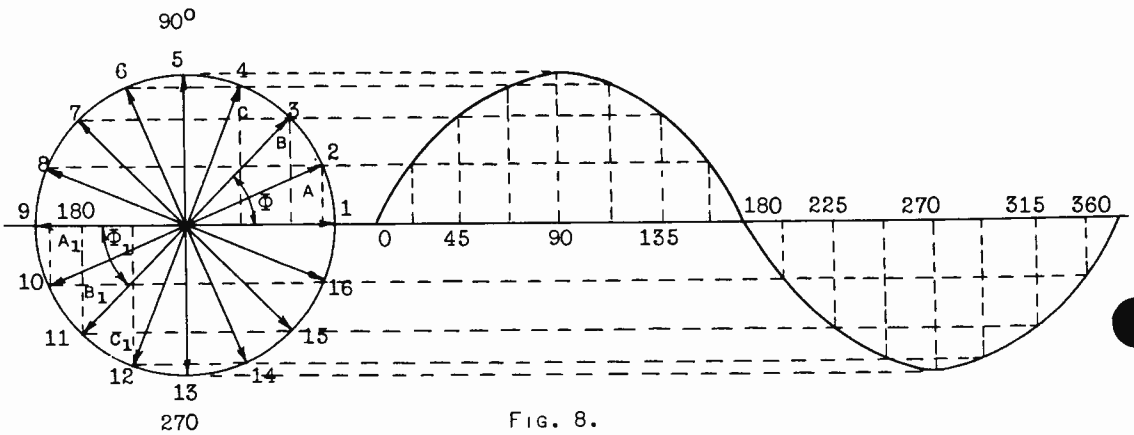


FIG. 8.

ON STUDYING THIS DIAGRAM IT IS SEEN THAT THE RADII OF THE CIRCLE, IN CONJUNCTION WITH THE PERPENDICULARS DROPPED FROM THEIR EXTREMES TO THE HORIZONTAL AXIS BETWEEN 0° AND 180° , FORM RIGHT TRIANGLES, THE ADJACENT SIDES OF WHICH ARE FORMED BY THE HORIZONTAL AXIS. THE OPPOSITE SIDES OF THE RIGHT TRIANGLES ARE FORMED BY PERPENDICULARS DROPPED FROM THE EXTREMES OF RESPECTIVE HYPOTENUSES WHICH ALL EQUAL THE RADIUS OF THE CIRCLE.

BY TRIGONOMETRY, THE OPPOSITE SIDE OF ANY RIGHT TRIANGLE IS EQUAL TO THE HYPOTENUSE TIMES THE SINE OF THE ANGLE. IN THIS CASE THE HYPOTENUSE IS EQUAL TO THE MAXIMUM AMPLITUDE OF VOLTAGE DURING A CYCLE. THE ANGLE IS THE ANGLE BETWEEN THE RADIUS AND THE NEAREST HORIZONTAL AXIS. THUS THERE ARE FOUR POSITIONS DURING THE CYCLE IN WHICH THE ANGLES TO THE NEAREST HORIZONTAL AXIS WILL EQUAL ANY GIVEN ANGLE BETWEEN 0° AND 90° .

FROM THIS MAY BE STATED,

INSTANTANEOUS VOLTAGE = MAXIMUM VOLTAGE TIMES THE SINE OF THE ANGLE TO THE NEAREST HORIZONTAL AXIS.

THE HORIZONTAL AXIS IS REPRESENTED IN AN ELECTRICAL CYCLE AS PASSING THROUGH 0° , 180° AND 360° . IN CALCULATIONS, FOR ANY ANGLE BETWEEN 0° AND 90° USE THE ANGLE SPECIFIED. FOR ANY ANGLE BETWEEN 90° AND 180° USE THE ANGLE FOUND BY SUBTRACTING THE GIVEN ANGLE FROM 180° . EXAMPLE, 138° .

$$\text{ANGLE TO USE} = 180^{\circ} - 138^{\circ} = 42^{\circ}.$$

FOR ANY ANGLE BETWEEN 180° AND 270° USE THE ANGLE FOUND BY SUBTRACTING 180° FROM THE GIVEN ANGLE. EXAMPLE, 256° .

$$\text{ANGLE TO USE} = 256^{\circ} - 180^{\circ} = 76^{\circ}.$$

FOR ANY ANGLE BETWEEN 270° AND 360° USE THE ANGLE FOUND BY SUBTRACTING THE GIVEN ANGLE FROM 360° . EXAMPLE, 310° .

$$\text{ANGLE TO USE} = 360^{\circ} - 310^{\circ} = 50^{\circ}.$$

THE ANGLES AS DETERMINED ABOVE ARE THE ANGLES TO THE NEAREST HORIZONTAL AXIS AND ARE THE ANGLES USED IN CALCULATING THE INSTANTANEOUS AMPLITUDES OF VOLTAGE OR CURRENT WHICH ARE FUNCTIONS OF THE SINES OF THE RESPECTIVE ANGLES. THE CURVE ON THE RIGHT OF FIGURE 8 IS A SINE CURVE, SO CALLED BECAUSE IT IS PLOTTED FROM THE SINE VALUES OF THE VOLTAGE, THAT IS, FROM THE INSTANTANEOUS VALUES WHICH ARE FOUND BY MULTIPLYING THE MAXIMUM VALUE BY THE SINES OF THE RESPECTIVE ANGLES. A PERFECT SINE CURVE OF VOLTAGE IS PRODUCED WHEN A CONDUCTOR CUTS A UNIFORM MAGNETIC FIELD IN A PERFECT CIRCLE AT A CONSTANT SPEED. THE VOLTAGE GENERATED BY MOST ALTERNATORS IS VERY NEARLY IN THE FORM OF A SINE CURVE, ALTHOUGH THE ACTUAL SHAPE OF THE CURVE MAY BE DISTORTED BY DISTORTION OF THE FIELD DISTRIBUTION, WHICH MAY BE DUE TO THE MECHANICAL ARRANGEMENT OF THE POLES AND OTHER FACTORS.

THE CURRENT IN A LOW RESISTANCE RADIO FREQUENCY CIRCUIT WHICH IS FREE TO OSCILLATE AT ITS OWN PERIOD WITHOUT INTERFERENCE FROM OTHER CIRCUITS, IS ALSO PRACTICALLY SINUSOIDAL. ON A SINE CURVE, PLOTTED ACCURATELY TO SCALE, THE INSTANTANEOUS AMPLITUDE AT ANY GIVEN ANGLE DURING THE CYCLE MAY BE DETERMINED BY MEASURING THE HEIGHT ABOVE OR BELOW THE HORIZONTAL TIME AXIS AT THAT PARTIC-

ALTERNATING CURRENTS

ULAR ANGLE. IT WILL BE OBSERVED THAT THE TIME AXIS IS CALIBRATED IN DEGREES OF THE COMPLETE CYCLE, FROM ZERO TO THREE HUNDRED SIXTY DEGREES INCLUSIVE. THE VOLTAGE WILL REACH A ZERO VALUE AT 0° , 180° AND 360° ; AND WILL REACH MAXIMUM VALUE AT 90° AND 270° .

SINCE AT EVERY INSTANT DURING THE CYCLE THE ALTERNATOR DELIVERS A DIFFERENT VOLTAGE, IT WILL BE SEEN THAT THE EQUATION FOR A GENERATED VOLTAGE AS PREVIOUSLY GIVEN MUST APPLY TO THE AVERAGE VOLTAGE, AND THE EQUATION IS,

$$\text{AVERAGE VOLTAGE} = \frac{\text{NUMBER OF LINES OF FORCE CUT PER SECOND}}{10^8}$$

THIS IS FROM THE FACT THAT A MAGNETIC FIELD MUST BE CUT AT THE RATE OF 10^8 LINES OF FORCE PER SECOND TO GENERATE A DIFFERENCE OF POTENTIAL OF ONE VOLT.

THE FACTORS WHICH DETERMINE THE SHAPE OF A SINE CURVE DO NOT INCLUDE THE AMPLITUDE OF THE VOLTAGE OR CURRENT. ALL SINE CURVES HAVE THE SAME SHAPE REGARDLESS OF THE VALUE OF VOLTAGE OR CURRENT REPRESENTED BY THE MAXIMUM POINT ON THE CURVE. THEREFORE, IF ONE WERE TO DETERMINE ALL THE INSTANTANEOUS VALUES DURING AN ALTERNATION, AVERAGE THOSE VALUES AND COMPARE THE AVERAGE AMPLITUDE WITH THE MAXIMUM AMPLITUDE, THE COMPARATIVE FACTOR OBTAINED WOULD HOLD TRUE FOR ALL ALTERNATING VOLTAGES AND CURRENTS WHICH VARY IN THE FORM OF A SINE CURVE. THIS COMPARATIVE FACTOR HAS BEEN FOUND TO BE .636 MAXIMUM AMPLITUDE.

$$\frac{\text{AVERAGE (VOLTAGE)}}{\text{(CURRENT)}} = .636 \frac{\text{MAXIMUM (VOLTAGE)}}{\text{(CURRENT)}}$$

IF THE AVERAGE VOLTAGE IS KNOWN, THE EQUATION MAY BE REARRANGED TO INDICATE THE MAXIMUM. IT THEN BECOMES,

$$\text{MAXIMUM VOLTAGE} = \frac{\text{AVERAGE VOLTAGE}}{.636} = 1.57 E_{\text{AVE}}$$

THE AVERAGE VALUE IS USED EXTENSIVELY IN DESIGN WORK WHERE A GENERATOR IS TO BE DESIGNED TO PRODUCE A GIVEN VOLTAGE. IN RADIO WORK THE AVERAGE VALUE OF CURRENT IS USED LARGELY IN DEALING WITH THE OUTPUTS OF RECTIFIERS WHERE A DIRECT CURRENT AMMETER IS EMPLOYED TO INDICATE THE LOAD CURRENT. THE D.C. AMMETER IN A CIRCUIT CARRYING A PULSATING OR FLUCTUATING CURRENT WHICH VARIES TOO RAPIDLY FOR INDICATOR TO FOLLOW, WILL INDICATE THE "AVERAGE" CURRENT IN THE CIRCUIT. A.C.

METERS INDICATE THE EFFECTIVE OR R.M.S. VALUES. FROM THE EFFECTIVE VOLTAGE CAN BE CALCULATED THE MAXIMUM VOLTAGE, AND FROM THE MAXIMUM THE AVERAGE IS OBTAINED BY MULTIPLYING BY .636. THEN USING THE FOLLOWING GENERATOR EQUATION ONE MAY SO PROPORTION THE VARIOUS FACTORS IN THE EQUATION AS TO OBTAIN ANY DESIRED VOLTAGE:

$$\text{AVERAGE VOLTAGE} = \frac{\text{No. OF CONDUCTORS} \times \text{No.}^* \text{ OF MAGNETIC LINES OF FORCE IN FIELD} \times \text{No. OF POLES} \times \text{REVOLUTIONS PER SECOND}}{10^8}$$

*THIS IS THE NUMBER OF LINES PER POLE.

MULTIPLICATION OF ALL THE FACTORS IN THE NUMERATOR GIVES THE NUMBER OF LINES OF FORCE CUT PER SECOND. THAT NUMBER DIVIDED BY 10^8 GIVES THE AVERAGE VOLTAGE GENERATED.

THE FREQUENCY OF THE VOLTAGE GENERATED IS FOUND IN AN EQUALLY SIMPLE MANNER. THE FREQUENCY IN CYCLES PER SECOND IS EQUAL TO THE NUMBER OF PAIRS OF POLES PASSING THE CONDUCTOR PER SECOND. THUS,

$$F = \frac{\text{POLES} \times \text{R.P.M.}}{2 \times 60}$$

FOR A 36 POLE ALTERNATOR ROTATING AT 1800 REVOLUTIONS PER MINUTE,

$$F = \frac{36 \times 1800}{2 \times 60} = 540 \text{ CYCLES PER SECOND.}$$

THE EFFECTIVE VALUE OF A VOLTAGE OR CURRENT MAY BE DEFINED AS THE VALUE OF ALTERNATING VOLTAGE OR CURRENT THAT WILL PERFORM THE SAME AMOUNT OF WORK AS AN EQUIVALENT AMOUNT OF DIRECT CURRENT. THE ORDINARY UNITS OF CURRENT AND VOLTAGE ARE PRIMARILY D.C. UNITS. THE UNIT OF CURRENT, THE AMPERE, IS DEFINED AS THE AMOUNT OF CURRENT THAT WILL DEPOSIT A CERTAIN AMOUNT OF SILVER ON AN ELECTRODE IN A STANDARD SOLUTION IN A GIVEN LENGTH OF TIME. THAT DEFINITION CERTAINLY CANNOT APPLY TO AN ALTERNATING CURRENT, BECAUSE AS THE CURRENT REVERSED ON THE SECOND ALTERNATION IT WOULD REMOVE THE SILVER DEPOSITED ON THE FIRST ALTERNATION, AND THE TOTAL DEPOSIT AFTER ANY NUMBER OF COMPLETE CYCLES WOULD BE ZERO. BUT THE UNIT OF CURRENT FOR BOTH D.C. AND A.C. IS THE AMPERE. IT IS THEREFORE NECESSARY TO FIND SOME WAY OF COMPARING THE WORK DONE BY ALTERNATING AND DIRECT CURRENTS.

ALTERNATING CURRENTS

THE DIRECT COMPARISON IS IN THE HEATING EFFECT OF THE TWO CURRENTS. THE HEAT PRODUCED IS NOT A FUNCTION OF THE DIRECTION OF CURRENT FLOW. THE HEAT PRODUCED IN A GIVEN CIRCUIT DEPENDS ONLY UPON THE AMPLITUDE OF THE CURRENT.

IN A D.C. CIRCUIT THE CURRENT MAINTAINS A STEADY AMPLITUDE, THEREFORE, THE HEAT PRODUCED IS STEADY. IN AN A.C. CIRCUIT THE CURRENT IS CONTINUOUSLY VARYING, SOMETIMES HIGH, SOMETIMES LOW OR ZERO. TO PRODUCE THE SAME AMOUNT OF HEAT AS AN EQUIVALENT FLOW OF DIRECT CURRENT, THE INSTANTANEOUS VALUES OF A.C. MUST AT TIMES EXCEED THE D.C. LEVEL TO COMPENSATE FOR THE LOSS OF HEAT WHEN THE ALTERNATING CURRENT IS AT A LOW OR ZERO VALUE. IN OTHER WORDS, TO PRODUCE THE SAME AMOUNT OF HEAT IN A GIVEN CIRCUIT AS 1 AMPERE OF DIRECT CURRENT, THE MAXIMUM VALUE OF A.C. MUST BE CONSIDERABLY HIGHER THAN ONE AMPERE.

BY AVERAGING THE HEATING EFFECTS OF ALL THE INSTANTANEOUS VALUES DURING A CYCLE IT IS POSSIBLE TO OBTAIN THE AVERAGE HEAT PRODUCED DURING THE CYCLE. THEN THE AMOUNT OF DIRECT CURRENT IN AMPERES REQUIRED TO PRODUCE THAT HEAT WILL BE THE EFFECTIVE VALUE OF THE ALTERNATING CURRENT.

THE HEATING EFFECT OF A CURRENT VARIES AS THE SQUARE OF THE CURRENT. THAT IS, IF THE CURRENT IS DOUBLED THERE WILL BE PRODUCED FOUR TIMES AS MUCH HEAT. IF THE CURRENT IS INCREASED TEN TIMES, THE HEAT PRODUCED WILL BE ONE HUNDRED TIMES AS GREAT. FROM THE SHAPE OF THE SINE CURVE IT IS SEEN THAT THE AVERAGE CURRENT IS GREATER THAN ONE-HALF THE MAXIMUM. IN A SIMILAR MANNER, THE EFFECTIVE VALUE IS GREATER THAN THE AVERAGE. THIS IS BECAUSE OF THE FACT THAT THE HEAT PRODUCED VARIES AS THE SQUARE OF THE CURRENT AND THEREFORE THE HIGH VALUES HAVE A GREATER PROPORTIONATE EFFECT FOR THE SAME LENGTH OF TIME THAN THE LOWER VALUES. IN OTHER WORDS, THE SQUARE ROOT OF THE AVERAGE OF THE INSTANTANEOUS VALUES SQUARED IS GREATER THAN THE AVERAGE OF THE INSTANTANEOUS VALUES TO THE FIRST POWER.

IF THE INSTANTANEOUS VALUE IS DETERMINED FOR EACH DEGREE DURING THE CYCLE, INCLUDING ZERO, AND EACH VALUE IS THEN SQUARED, THE RESULT WILL BE THE HEATING EFFECT FOR EACH DEGREE DURING THE CYCLE. BY ADDING THE SQUARED VALUES AND DI-

VIDING BY THE TOTAL NUMBER OF VALUES TAKEN, ONE MAY OBTAIN THE AVERAGE HEATING EFFECT OVER THE CYCLE.

SINCE THE HEATING EFFECT VARIES AS THE SQUARE OF THE CURRENT, THEN THE CURRENT MUST VARY AS THE SQUARE ROOT OF THE HEATING EFFECT. THE SQUARE ROOT OF THE AVERAGE HEATING EFFECT, AS FOUND IN THE PRECEDING PARAGRAPH, IS EQUAL TO THE EFFECTIVE VALUE OF CURRENT NECESSARY TO PRODUCE THAT HEATING EFFECT. THIS IS ALSO COMMONLY CALLED THE R.M.S. (ROOT-MEAN-SQUARE) VALUE FROM THE METHOD USED IN ITS DETERMINATION. (SINCE E_i IS A DIRECT FUNCTION OF THE SINE OF THE ANGLE, THE FACTOR FOR EFFECTIVE VOLTAGE CAN BE FOUND BY DETERMINING THE R.M.S. VALUES OF THE SINES OF THE ANGLES OVER 360° .)

IF A MAXIMUM VALUE OF ONE AMPERE A.C. IS TAKEN AS A BASIS FOR THESE CALCULATIONS, THE EFFECTIVE OR R.M.S. CURRENT WILL BE .707 AMPERE.

THE EFFECTIVE (R.M.S.) VALUE OF AN ALTERNATING CURRENT MAY BE DEFINED AS:

$$\begin{aligned} \text{EFFECTIVE (CURRENT)} &= .707 \text{ MAXIMUM (CURRENT)} \\ \text{EFFECTIVE (VOLTAGE)} &= .707 \text{ MAXIMUM (VOLTAGE)} \\ \text{MAXIMUM} &= \frac{\text{EFFECTIVE}}{.707} = 1.414 \text{ EFFECTIVE (CURRENT OR VOLTAGE)}. \end{aligned}$$

THE EFFECTIVE VALUE IS THE VALUE INDICATED BY ALL A.C. AMMETERS AND VOLTMETERS.

THE HEAT PRODUCED BY AN ELECTRIC CURRENT VARIES AS THE SQUARE OF THE CURRENT. THIS FACT IS SHOWN VERY CLEARLY IN HIGH FREQUENCY A.C. AMMETERS, THAT IS, RADIO FREQUENCY AMMETERS. AN AMMETER WHICH DEPENDS FOR ITS OPERATION ON THE HEAT PRODUCED BY THE CURRENT PASSING THROUGH A THERMOELEMENT INTRODUCES A NEGLIGIBLE AMOUNT OF INDUCTANCE AND CAPACITY INTO THE CIRCUIT. IF AN AMMETER OPERATING ON THE PRINCIPLE OF OPPOSING MAGNETIC FIELDS WERE PLACED IN A RADIO FREQUENCY CIRCUIT, THE DETUNING EFFECT ON THE CIRCUIT WOULD BE LARGE DUE TO THE INDUCTANCE OF THE METER COIL. ALSO SUCH AN AMMETER COULD NOT BE USED AT HIGH RADIO FREQUENCIES BECAUSE THE CAPACITY OF THE WINDING WOULD SIMPLY BYPASS A VERY LARGE PROPORTION OF THE HIGH FREQUENCY CURRENTS.

THERE ARE TWO GENERAL TYPES OF THERMO-AMMETERS, THE HOT-WIRE AMMETER AND THE THERMOCOUPLE TYPE AMMETER. THE HOT WIRE AMMETER HAS BEEN ALMOST ENTIRELY

ALTERNATING CURRENTS

20.

REPLACED IN GENERAL USE BY THE THERMOCOUPLE TYPE. THE HOT WIRE METER DEPENDS FOR ITS OPERATION UPON THE ABILITY OF A LONG PIECE OF PLATINUM WIRE TO STRETCH WHEN HEATED.

THE EXPLANATIONS OF THE OPERATION OF THE TWO TYPES OF METERS ARE GIVEN, NOT AS A DETAILED STUDY OF THE METERS THEMSELVES, BUT RATHER TO SHOW THE MANNER IN WHICH THE WORK DONE BY AN ALTERNATING CURRENT, OR IN FACT ANY CURRENT, VARIES FOR AN INCREASE OR DECREASE OF CURRENT IN THE CIRCUIT, AND THE MANNER IN WHICH RADIO FREQUENCY CURRENTS ARE MEASURED. THE OPERATION OF BOTH METERS SHOWS VERY CLEARLY THAT THE TEMPERATURE, AND THEREFORE THE POWER EXPENDED, VARIES AS THE SQUARE OF THE CURRENT.

FIGURES 9(A) AND 9(B) SHOW THE PRINCIPLE OF THE OPERATION OF A TYPICAL HOT-WIRE AMMETER. THE WIRE STRETCHED BETWEEN 1 AND 2 IS THE PLATINUM WIRE CONSTITUTING THE HEATING ELEMENT. FROM THE CENTER POINT OF THIS WIRE A FLEXIBLE WIRE RUNS TO THE DRUM ON THE INDICATOR SHAFT. THERE IS A CONSTANT SPRING TENSION TENDING TO MOVE THE INDICATOR TO THE RIGHT BUT WITH THE PLATINUM WIRE STRETCHED TIGHT, (COLD), THE INDICATOR IS HELD AT THE ZERO POSITION. HOWEVER, WHEN A CURRENT IS PASSED THROUGH THE WIRE THE WIRE IS HEATED, THEREFORE EXPANDING: SEE FIGURE 9(B). AS THE WIRE EXPANDS THE INDICATOR IS NO LONGER HELD IN

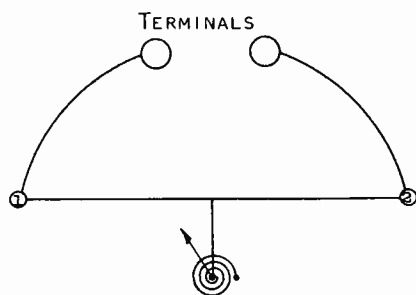


FIG. 9(A).

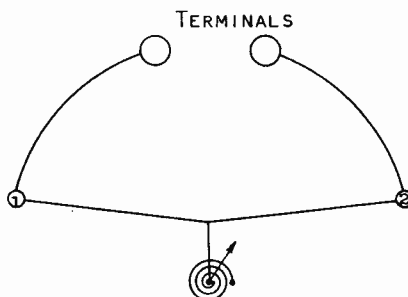


FIG. 9(B).

THE PREVIOUS POSITION, THE TENSION OF THE SPRING NOW PULLING IT TO THE RIGHT. HOW FAR THE INDICATOR MOVES TO THE RIGHT DEPENDS UPON HOW FAR THE WIRE EXPANDS. THE EXPANSION OF THE WIRE DEPENDS DIRECTLY UPON THE HEAT WHICH VARIES AS THE

SQUARE OF THE CURRENT. WITH A CURRENT OF ONE AMPERE THE WIRE WILL EXPAND A CERTAIN DEFINITE AMOUNT. WITH TWO AMPERES THE EXPANSION WILL BE FOUR TIMES AS GREAT. WITH THREE AMPERES, THERE WILL BE NINE TIMES AS MUCH EXPANSION AS WITH ONE AMPERE, ETC. SINCE THE MOVEMENT OF THE INDICATOR OVER THE DIAL DEPENDS DIRECTLY UPON THE EXPANSION OF THE WIRE, THE SCALE WILL BE AS SHOWN IN FIGURE 10. ALL DIRECT READING THERMO-AMMETERS HAVE THIS TYPE OF DIAL.

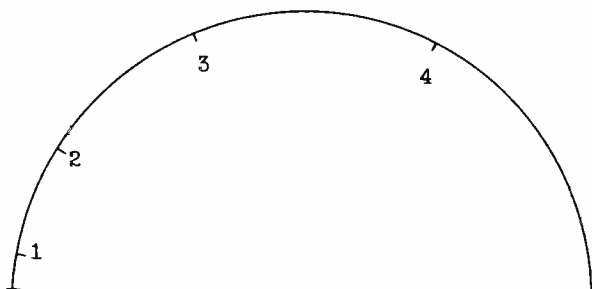


FIG. 10.

THE THERMOCOUPLE AMMETER HAS PRACTICALLY REPLACED THE HOT-WIRE TYPE OF METER. THE OPERATION OF THE THERMOCOUPLE METER DEPENDS UPON THE FACT THAT WHEN A CONTACT IS MADE BETWEEN TWO DISSIMILAR METALS

AND THE JUNCTION IS HEATED, A DIFFERENCE OF POTENTIAL IS BUILT UP BETWEEN THE TWO SIDES OF THE JUNCTION, AND THE EXTENT OF THE DIFFERENCE OF POTENTIAL IS A DIRECT FUNCTION OF TEMPERATURE. IF A SENSITIVE MILLIVOLTMETER IS USED TO ACCURATELY MEASURE THE VOLTAGE PRODUCED BY THE JUNCTION, (CALLED THE THERMOCOUPLE), THE SCALE OF THE VOLTMETER MAY BE CALIBRATED DIRECTLY IN DEGREES OF TEMPERATURE REQUIRED TO PRODUCE CERTAIN DIFFERENCES OF POTENTIAL. THIS IS DONE IN THE ELECTRICAL PYROMETER WHICH IS USED TO MEASURE THE HIGH TEMPERATURES IN FURNACES, ETC.

IF, HOWEVER, THE HEAT IS CAUSED BY THE PASSAGE OF CURRENT THROUGH THE THERMOCOUPLE ITSELF, OR THROUGH A SEPARATE ELEMENT WHICH HEATS THE THERMOCOUPLE, THE SCALE OF THE MILLIVOLTMETER MAY BE CALIBRATED DIRECTLY IN AMPERES REQUIRED TO PRODUCE THE HEAT, WHICH IN TURN CREATES THE DIFFERENCE OF POTENTIAL ACROSS THE COUPLE.

THE ARRANGEMENT AS SHOWN IN FIGURE 11 IS EMPLOYED IN MOST THERMOCOUPLE METERS IN USE TODAY. A VERY SMALL HEATER WIRE IS EXTENDED BETWEEN THE METER TERMINALS. THE R. F. CIRCUIT CURRENT FLOWS THROUGH THIS WIRE AND THE TEMPER-

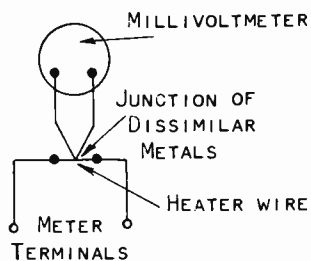


FIG. 11.

ATURE OF THE WIRE VARIES AS THE SQUARE OF THE CURRENT. THE JUNCTION OF THE DISSIMILAR METALS IN WHICH THE THERMOVOLTAGE IS GENERATED IS SOLDERED OR WELDED TO THE HEATER WIRE SO THAT THE HEAT DEVELOPED BY THE CIRCUIT CURRENT IS TRANSFERRED BY CONDUCTION TO THE JUNCTION. THIS HEAT DEVELOPES A D.C. VOLTAGE ACROSS THE COUPLE

WHICH IN TURN IS INDICATED BY THE MILLIVOLTMETER.

IT IS ONLY NECESSARY TO USE A VERY DELICATE MILLIVOLTMETER OR MICROVOLT-METER, A MINUTE COUPLE, AND A VERY SMALL HEATER WIRE, TO MEASURE THE SMALLEST AMOUNTS OF RADIO FREQUENCY CURRENT. SUCH METERS MAY BE CALIBRATED IN MICRO-AMPERES TO READ VERY SMALL CURRENTS FLOWING THROUGH THE HEATING ELEMENT. R.F. MICROAMMETERS ARE OF CONSIDERABLE VALUE IN MAKING PRECISION MEASUREMENTS IN THE LABORATORY. THE VARIOUS METHODS OF USING R.F. METERS WILL BE DISCUSSED IN GREATER DETAIL WHEN VARIOUS PRECISION MEASUREMENTS ARE STUDIED.

SINCE THE THERMOCOUPLE AMMETER DEPENDS UPON TEMPERATURE VARIATION FOR ITS OPERATION, ITS SCALE IS SIMILAR TO THAT OF THE HOT-WIRE AMMETER. BOTH TYPES OF METERS MAY BE USED FOR MEASURING DIRECT CURRENTS AS WELL AS RADIO FREQUENCY CURRENTS.

A TYPE OF METER COMMONLY USED IN RADIO FREQUENCY CIRCUITS, PARTICULARLY AS INDICATORS IN WAVEMETERS, ETC., IS THE CURRENT-SQUARED METER. THIS IS USUALLY OF THE THERMOCOUPLE TYPE AND ITS OPERATION DIFFERS IN NO WAY FROM THAT OF THE THERMO-AMMETER. THE ONLY DIFFERENCE IS IN THE CALIBRATION OF THE SCALE. REMEMBERING THAT THE TEMPERATURE INCREASE VARIES AS THE SQUARE OF THE CURRENT, IT CAN EASILY BE SEEN THAT TO MOVE THE INDICATOR TO THE FOUR AMPERE POSITION, (FIGURE 10), REQUIRES SIXTEEN TIMES AS GREAT A TEMPERATURE INCREASE AS IS REQUIRED TO MOVE IT TO THE ONE AMPERE POSITION. IF THE SCALE WERE CALIBRATED IN HEAT UNITS THE POINT OF FOUR AMPERES WOULD BE MARKED SIXTEEN. LIKewise, THE TWO AMPERE POSITION WOULD BE MARKED FOUR, AND THE THREE AMPERE POSITION WOULD BE MARKED

NINE. IT SHOULD BE NOTED THAT EACH READING WOULD THEN BE NOT THE CURRENT ITSELF BUT THE CURRENT SQUARED. ANY RADIO FREQUENCY CURRENT INDICATING INSTRUMENT HAVING A SCALE MARKED OFF IN EVENLY SPACED DIVISIONS IS A CURRENT-SQUARED METER. IN A CIRCUIT EMPLOYING SUCH A METER, IF IT IS DESIRED TO DECREASE THE CURRENT BY ONE-HALF IT WILL BE NECESSARY TO BRING THE INDICATOR BACK TO ONE-FOURTH OF THE PREVIOUS READING. THIS TYPE OF METER IS USUALLY EMPLOYED WHERE IT IS DESIRED TO ACCURATELY REGISTER VERY SMALL CHANGES OF CURRENT, AS IN FREQUENCY METER INDICATORS, AND WHERE THE ACTUAL VALUE OF THE CURRENT IS NOT IMPORTANT. A COMMONLY USED R.F. GALVANOMETER IS ONE HAVING A FULL SCALE DEFLECTION OF 115 MILLIAMPERES, A SCALE MARKED OFF IN 100 DIVISIONS, AND A RESISTANCE OF 4.5 OHMS.

ONE DECIDED ADVANTAGE OF THE THERMOCOUPLE AMMETER FOR MEASURING LARGE CURRENTS IN RADIO FREQUENCY CIRCUITS IS THAT, IF THE PART OF THE CIRCUIT WHERE IT IS DESIRED TO MEASURE THE CURRENT IS INACCESSIBLE, THE THERMOCOUPLE MAY BE PLACED IN THE CIRCUIT AT THAT POINT AND THE INDICATING METER CONVENIENTLY LOCATED ON THE SWITCHBOARD. AN EXAMPLE OF WHERE THIS MAY BE PARTICULARLY DESIRABLE IS WHERE IT IS NECESSARY TO USE A TRANSMISSION LINE IN TRANSFERRING POWER FROM A TRANSMITTER TO AN ANTENNA LOCATED AT SOME DISTANCE FROM THE TRANSMITTER. IN SUCH EVENT THE THERMOCOUPLE MAY BE INSERTED IN THE BASE OF THE ANTENNA AND THE INDICATING INSTRUMENT MOUNTED ON THE TRANSMITTER PANEL, POSSIBLY SEVERAL HUNDRED FEET DISTANT. (AS EXPLAINED IN AN EARLIER DISCUSSION OF METER SHUNTS, THE RESISTANCE OF THE LONG LEADS MUST BE CAREFULLY CONSIDERED IN THE METER CALIBRATION.)

BY THE USE OF A SMALL, CAREFULLY CONSTRUCTED THERMOCOUPLE AND A VERY SENSITIVE MICRO-VOLTMETER, IT IS POSSIBLE TO MEASURE EXTREMELY SMALL CURRENTS AT RADIO FREQUENCIES. METERS TO MEASURE THESE SMALL CURRENTS ARE RADIO FREQUENCY MILLIAMMETERS OR MICROAMMETERS. RADIO FREQUENCY METERS MAY BE DISTINGUISHED FROM THE DIRECT CURRENT METERS BY THE ARRANGEMENT OF THE SCALE AS EXPLAINED ABOVE.

SOME OF THE METALS USED IN THERMOCOUPLES ARE: BISMUTH, PLATINUM, COPPER, LEAD, SILVER, ANTIMONY. ANY TWO OF THE ABOVE METALS MAY BE USED TO FORM THE

ALTERNATING CURRENTS

THERMOCOUPLE. THE MOST SENSITIVE COUPLE WOULD BE FORMED BY BISMUTH AND ANTIMONY. A COMMONLY USED COMBINATION IS STEEL AND CONSTANTIN.

ONE POINT SHOULD PARTICULARLY BE REMEMBERED IN WORKING WITH THERMO-AMMETERS. THEY WILL NOT STAND OVERLOADS. ORDINARY A.C. AND D.C. METERS MAY BE SUBJECTED TO QUITE LARGE INSTANTANEOUS OVERLOADS--POSSIBLY ONE HUNDRED PER CENT OR GREATER--WITHOUT NECESSARILY DAMAGING THE METER. THIS IS NOT TRUE OF THERMOCOUPLE METERS WHICH MAY BE BURNED OUT WITH AN OVERLOAD OF ONLY FIFTEEN OR TWENTY PER CENT. IF THE OVERLOAD IS SUFFICIENTLY GREAT THE SMALL HEATER WIRE MAY BE BURNED OUT SO QUICKLY THAT THERE IS NOT SUFFICIENT TIME TO TRANSFER HEAT TO THE THERMOCOUPLE AND NO DEFLECTION OF THE INDICATOR MAY BE NOTICED. THUS, IN MEASURING RADIO FREQUENCY CURRENTS BE VERY CAREFUL THAT THE CURRENT IS NOT GREATER THAN THAT INDICATED BY THE FULL SCALE RATING OF THE METER.

THE CONNECTION IN A RADIO FREQUENCY CIRCUIT IS CLEARLY SHOWN IN FIGURE 12.

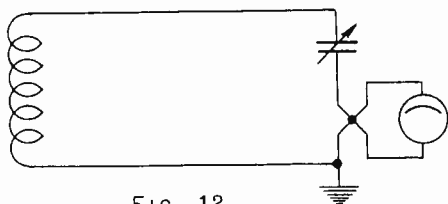


FIG. 12.

THE POINT OF INTERSECTION OF THE TWO CROSSED WIRES REPRESENTS THE THERMOCOUPLE.

IN ORDER THAT THE COUPLE MAY BE MECHANICALLY STRONG AND ABLE TO STAND

UP UNDER SERVICE IT IS USUALLY SPOT WELDED. THIS DOES NOT AFFECT THE ELECTRICAL ACTION OF THE THERMOCOUPLE.

IN CONNECTION WITH THE STUDY OF ALTERNATING CURRENTS, ONE POINT SHOULD PARTICULARLY BE MADE CLEAR. IN RADIO AND AUDIO FREQUENCY WORK ONE VERY OFTEN ENCOUNTERS A CIRCUIT IN WHICH THE TOTAL CURRENT IS MADE UP OF A COMBINATION OF A DIRECT CURRENT AND A SUPERIMPOSED ALTERNATING CURRENT. IN A SIMILAR MANNER BOTH A D.C. VOLTAGE AND AN A.C. VOLTAGE MAY BE APPLIED ACROSS THE SAME POINTS IN A CIRCUIT. IN FACT THIS IS THE CONDITION IN MOST CIRCUITS USED IN RADIO. A FEW TYPICAL EXAMPLES OF SUCH CURRENTS AND VOLTAGES ARE SHOWN IN FIGURES 13, 14, AND 15.

IN FIGURE 13 IS THE OUTPUT CURRENT OF A RECTIFIER WHEN ONLY PARTLY FILT-

ERED. IT IS ESSENTIALLY A DIRECT CURRENT, NEVER ACTUALLY REVERSING IN DIRECTION, BUT CONTAINING SINUSOIDAL VARIATIONS WHICH AFFECT A CIRCUIT CONTAINING

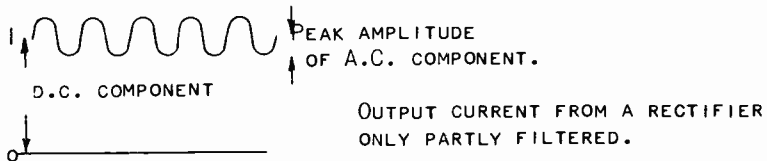


FIG. 13.

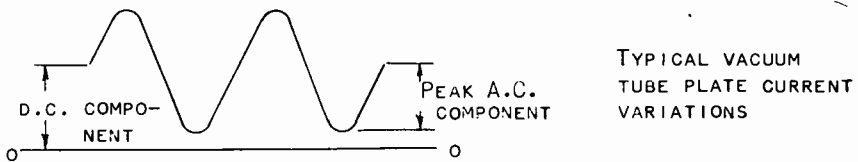


FIG. 14.

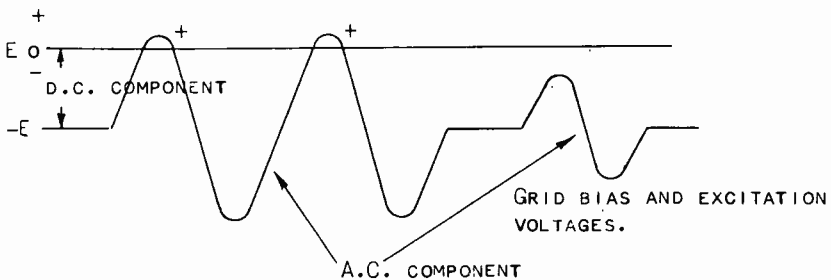


FIG. 15.

AN INDUCTANCE JUST AS DOES AN ALTERNATING CURRENT, BECAUSE THE MAGNETIC FIELD AROUND A COIL CAUSED BY THIS CURRENT WILL RISE AND FALL IN ACCORDANCE WITH THE ALTERNATING COMPONENT OF THE CURRENT.

IN FIGURE 14 IS SHOWN A TYPICAL VACUUM TUBE PLATE CURRENT WHEN THE TUBE IS IN OPERATION. THE ACTUAL DIRECTION OF CURRENT THROUGH THE TUBE CANNOT REVERSE BUT THE EFFECT OF THE CURRENT VARIATIONS IN THE OUTPUT LOAD CIRCUIT IS EXACTLY THE SAME AS IF THE CURRENT WERE AN ACTUAL ALTERNATING CURRENT.

IN FIGURE 15 ARE SHOWN TYPICAL VOLTAGES APPLIED TO THE GRID OF A VACUUM

ALTERNATING CURRENTS

TUBE. THE D.C. COMPONENT E IS THE NEGATIVE GRID BIAS. THE A.C. COMPONENT IS THE SUPERIMPOSED A.C. GRID EXCITATION VOLTAGE. THE FIRST TWO CYCLES ARE OF SUCH AMPLITUDE THAT THE PEAK A.C. VOLTAGE ACTUALLY EXCEEDS THE D.C. COMPONENT SO THAT ON THE TWO + PEAKS THE ACTUAL VOLTAGE APPLIED TO THE GRID IS POSITIVE. EXCEPT FOR THE SHORT DURATION OF THE + PEAKS, THE ACTUAL VOLTAGE IS NEGATIVE REGARDLESS OF WHICH DIRECTION IT IS VARYING. ON THE THIRD A.C. VOLTAGE CYCLE THE AMPLITUDE IS LESS AND THE SUM OF THE D.C. AND A.C. COMPONENTS IS NEVER POSITIVE.

IT MUST BE REMEMBERED THAT IN A CIRCUIT HAVING BOTH D.C. AND A.C. COMPONENTS, EVEN THOUGH THE CURRENT NEVER REVERSES OR THE APPLIED VOLTAGE IS NEVER POSITIVE, THE EFFECTS ON THE CIRCUIT ARE EXACTLY THE SAME AS IF THE CURRENT OR VOLTAGE ACTUALLY REVERSED. THIS WILL BE DISCUSSED IN DETAIL IN LATER LESSONS.

ALTERNATING CURRENTS

EXAMINATION

Indicate the answer by underlining and filling in gaps for the problems where work must be shown.

1. (A) In a magnetic circuit, a decrease in the distance between the poles will (decrease, not change, increase) the flux density. ✓
- (B) For a constant permeability over a wide range of current variations a large air gap in the magnetic circuit (is, is not) desirable. ✓
- (C) The field magnet of a generator is preferably operated (above, below) the knee of the magnetic curve in order that small fluctuations in the field current do not produce corresponding fluctuations in the magnetic field and hence in the generated voltage. ✓
- (D) The iron core of an audio transformer is preferably operated (above, below) the knee of the magnetic curve in order that the magnetizing current be as small and as nearly sinusoidal as possible. ✓
2. (A) If the polarity of the magnetic pole and the direction of motion of the conductor are reversed simultaneously, the polarity of the potential generated will (remain the same, be reversed, alternate rapidly). ✓
- (B) The EMF induced in a conductor is proportional only to:
 - (a) The material of the conductor.
 - (b) The angle of cutting the lines of flux.
 - (c) The intensity of the magnetic field.
 - ← (d) The rate of cutting the lines of flux.
- (C) An "Electrical Cycle" contains 360 electrical degrees. ✓
- (D) The armature of an alternator is rotated through 360 mechanical degrees. The alternator must have 12 ✓

ALTERNATING CURRENTS

EXAMINATIONS, Page 2.

2. (D) (Continued)

magnetic poles in order to go through six electrical cycles during this single revolution.

3. A 24-pole alternator is running at 2,000 RPM. What is the frequency of the generated voltage? Show work.

$$\begin{aligned}
 F &= \frac{\text{Poles} \times \text{RPM}}{2 \times 60} \\
 &= \frac{24 \times 2000}{2 \times 60} = 400 \text{ cps}
 \end{aligned}$$

4. (A) The voltage generated by a four-pole alternator goes through two "Electrical Cycles" during each complete revolution of the armature. ✓

(B) There are no alternators in present day use having (both north and south magnetic poles, north magnetic poles only, south magnetic poles only, no magnetic poles at all). Underline all correct answers. ✗

(C) If E_{\max} is reached when the armature has rotated 45 mechanical degrees from the starting position, the E_{\max} of the opposite polarity will be reached when the armature is rotated 225 electrical degrees in the same direction. ✗

5. (A) The sine of the angle which the instantaneous position of the conductor makes with the magnetic lines of force 180 or 270

ALTERNATING CURRENTS

EXAMINATION, Page 3.

5. (A) (Continued)

is directly related to:

- (a) The polarity of the instantaneous voltage.
- (b) The frequency of the generated EMF.
- (c) The amplitude of the instantaneous voltage. ✓

(B) $E_{inst} = 60$ volts at 15 degrees. Find E_{inst} at 30, 160, 270 degrees and E_{avo} .

NOTE: The electrical cycle moves first in a positive direction. Show polarity of instantaneous voltages. Show work.

$$E_{max} = \frac{E_{inst}}{\sin \phi} = \frac{60}{\sin 15^\circ} = \frac{60}{.25982} = 231.8 \text{ V.}$$

$$E_{inst} \text{ at } 30^\circ = 231.8 \times \sin 30 = 231.8 \times .5 = 115.9 \text{ ✓ +}$$

$$\begin{aligned} \dots \dots 160^\circ &= 231.8 \times \sin(180^\circ - 160^\circ) = 231.8 \times \sin 20^\circ \\ &= 231.8 \times .34202 = 79.29 \text{ ✓ +} \end{aligned}$$

$$\dots \dots 270^\circ = E_{max} \text{ Neg} = -231.8 \text{ V ✓}$$

$$E_{av} = E_{max} \times \frac{.606}{.636} = \frac{147.42}{.636} \text{ Volts ✓}$$

(C) $E_{avo} = 500$ volts. Find E_{max} . Show work. ✓

$$E_{max} = \frac{E_{av}}{.606} = \frac{500}{.606} = \frac{784.6}{.636} \text{ Volts}$$

ALTERNATING CURRENTS

EXAMINATION, Page 4.

6. (A) The average voltage is (.301, .707, .636, .866) times the maximum voltage. ✓
- (B) The effective voltage is (.301, .707, .636, .866) times the maximum voltage. ✓
- (C) RMS voltage is the same term as (effective, maximum, average, instantaneous) voltage. ✓
- (D) The frequency of a given voltage (does, does not) affect the average and effective values. ✓

7. (A) Given the effective voltage of a power supply transformer in a cathode ray oscilloscope is $E_{eff} = 1,000$ volts. Find E_{max} , E_{RMS} . Show work. ✓

$$E_{max} = E_{eff} \times 1.414 = 1000 \times 1.414 = \underline{\underline{1414 \text{ Volts}}}$$

$$E_{rms} = E_{eff} = \underline{\underline{1000 \text{ Volts}}}$$

- (B) Suppose, on the other hand, that $E_{max} = 1,000$ volts. Find E_{eff} , E_{av} , E_1 at 135 degrees. Show work and polarity of E_1 at 135 degrees.

$$E_{eff} = E_{max} \times .707 = 1000 \times .707 = \underline{\underline{707 \text{ Volts}}}$$

$$E_{av} = E_{max} \times .636 = 1000 \times .636 = \underline{\underline{636 \text{ Volts}}}$$

$$E_{inst \text{ at } 135^\circ} = E_{max} \times \sin(180^\circ - 135^\circ) = E_{max} \times \sin 45^\circ$$

$$= 1000 \times .707 = \underline{\underline{707 \text{ Volts pos}}}$$

ALTERNATING CURRENTS

EXAMINATION, Page 5.

7. (B) (Continued)

(C) Indicate by underlining the factors shown below that are taken into consideration in the equation for calculating average voltage from the design characteristic of a generator:

- (a) Strength of the magnetic field, per pole. ✓
- (b) Watts per second output.
- (c) Number of commutator segments.
- (d) Number of conductors. ✓
- (e) Number of armature slots.
- (f) Frequency of generated EMF. ✓
- (g) Number of poles. ✓
- (h) Revolutions per second. ✓
- (i) Diameter of conductors.

8. (A) The operation of the hot wire meter is based on the (voltage drop, current change, Edison effect, power expended) within the meter. ✓

(B) The expansion of the wire in the hot wire meter varies (directly with, directly as the square of, inversely with, inversely as the square of) the current. ✓

(C) The meter itself ^{is (?)} a thermocouple type meter, such as used in antenna measurements is a (D'Arsonval galvanometer, millivolt meter, milliammeter, milliohm meter). ✓

(D) The thermocouple meter scale is (exactly like, similar to, altogether different from) the hot wire meter. ✓

ALTERNATING CURRENTS

EXAMINATION, Page 6.

8. (Continued)

(E) Check all the advantages of the thermocouple type meter over the hot wire meter:

- (a) It may be overloaded without damage.
- (b) It may be located at a great distance from the observer without loss of accuracy. ✓
- (c) It can be made more sensitive than the hot wire type. ✓
- (d) It measures effective values of both a.c. and d.c.

9. (A) To reduce the current by half when using a current squared meter, reduce the scale reading to (1/3, 1/4, 1/2, ✓
5/8, 1/5, 3/4) of its original value?

(B) The scale of a current squared meter, evenly spaced, when placed in series with the line feeding a television antenna, reads 64. What is the scale reading when the current is reduced to half its original value? 16 ✓

(C) A direct reading r.f. ammeter ordinarily has a scale with (equal spaces, very irregular spaces, spaces decreasing in size from left to right, spaces increasing in size from left to right). ✓

10. A circuit carries both a.c. and d.c. components. The d.c. component is 2 amperes. The RMS value of the a.c. component is 1 ampere. Find I_{max} , I_{min} , and the reading of a d.c. ammeter in the circuit. Show work.

$$I_{max(AC)} = I_{RMS} \times 1.41 = 1 \times 1.41 = 1.41 \text{ amp.}$$

$$I_{max} = I_{DC} + I_{max(AC)} = 2 + 1.41 = \underline{\underline{3.41 \text{ amp}}} \checkmark$$

$$I_{min} = I_{DC} + I_{max(-AC)} = 2 - 1.41 = \underline{\underline{0.59 \text{ amp}}} \checkmark$$

$$\text{DC Ammeter reading} = \underline{\underline{2 \text{ amp}}} \checkmark$$