



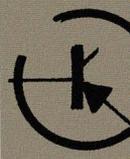
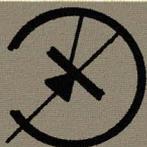
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Howard W. Sams

Transistor Circuit Manual

by Allan Lytel

Schematics and descriptions of
over 200 transistorized circuits de-
signed for industrial, commercial,
and entertainment applications.



Transistor Circuit Manual

by Allan Lytel



HOWARD W. SAMS & CO., INC.
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PREFACE

With the rapid development in the field of transistors and semiconductors, a great need has arisen among engineers, technicians, and experimenters for data on circuit design and operation. The major sources for this data, until now, have been the semiconductor manufacturers themselves. The need for a one-source reference manual thus becomes readily apparent.

Inasmuch as new circuits are being developed almost daily, no single volume could possibly encompass them all. This handbook, therefore, follows the practical approach of including typical designs for general applications in industrial, commercial, and entertainment devices.

In each of the 15 specific circuit categories, schematic diagrams, including notes on parts values and component parameters, are accompanied by text discussions which describe circuit operation, typical applications, and modifications necessary to satisfy specific requirements. In addition, an introductory chapter provides general information on the design and application of semiconductor devices and circuits.

Special acknowledgement must be given to the following manufacturers, who helped make this publication possible by supplying much of the data from which the contents were prepared:

Aladdin Elect., Amperex Elect., Bendix, Bradley, CBS, Clevite, Crystalonics, Fairchild, General Electric, Hoffman, Honeywell, International Rectifier, Magnetics, Motorola, Nucleonic Prod., Radio Corp. of America, Security Controls, Shockley, Solid State Prod., Sprague, Sunair Elect., Texas Inst., and Transitron.

ALLAN LYTEL

November, 1961

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Section 1

BASIC SEMICONDUCTOR DEVICES

Transistor circuits for a wide range of applications are discussed in this book, along with many different diode and transistor types. The most widely used circuit symbols are also shown (see Fig. 1), and each is discussed in detail in later sections of the book. The common names are given in this figure; however, several manufacturers have adopted special names for their own products. For example, the silicon-controlled switch is known as a *Thyristor* by RCA and by Bell Laboratories, while Westinghouse calls it a *Trinistor*.

In addition to the different types of transistors, some thirteen different ways of forming them are shown in Fig. 2. All of these semiconductor devices have one purpose—to produce certain characteristics which can be used to advantage in specific applications. In some cases a transistor is named for the process by which it is made.

TRANSISTOR TYPES

Some basic transistor circuits are shown in Fig. 3. These are the common emitter, common base, and common collector. They are somewhat analogous to the grounded-cathode, -grid, and -plate of vacuum tubes. Transistors, because of their low impedance, are current-operated devices, whereas vacuum tubes are voltage operated because they are high-impedance devices.

A special form of solid-state device, the field-effect transistor, can be considered a stepping stone between a vacuum tube (which is voltage-operated) and a transistor (which is current-operated). Fig. 4A is a schematic of a field-effect transistor. The unit consists of an N-type silicon bar with two ohmic contacts—a cathode at one end and an anode at the other. Two PN junctions are built into the middle, and are connected in parallel to serve as the grid.

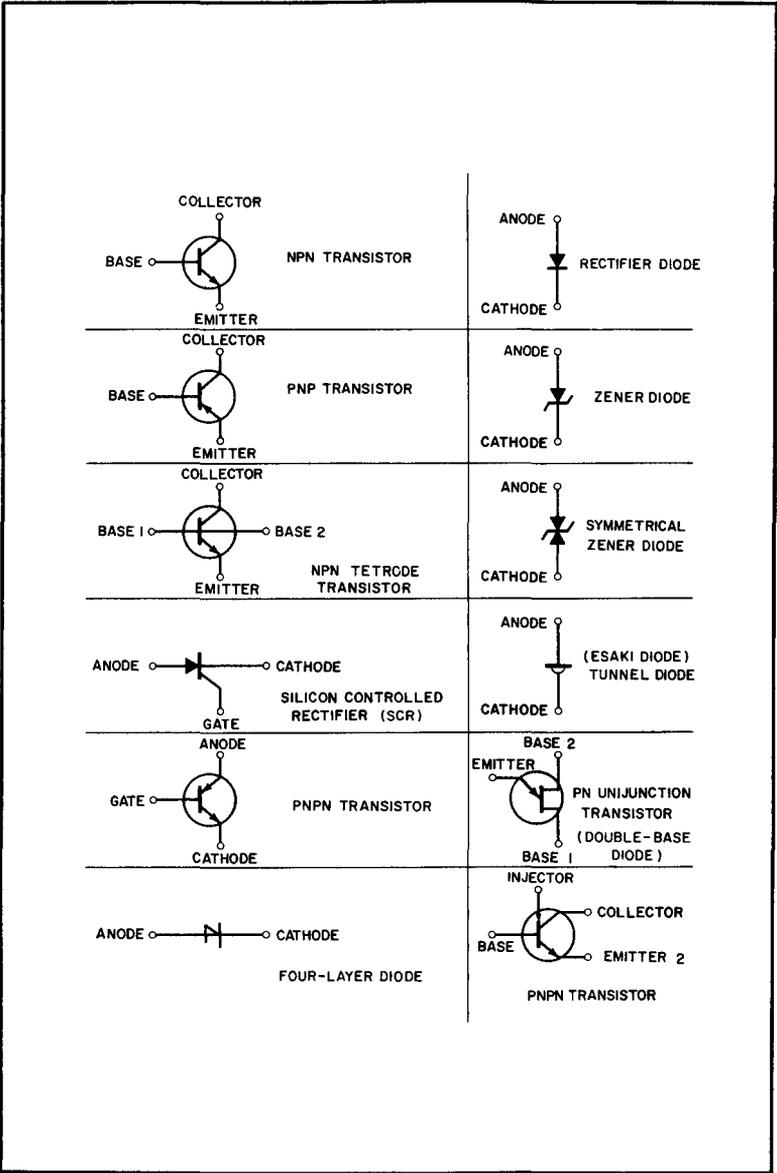
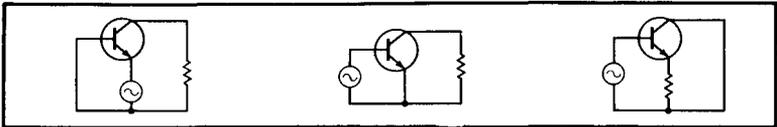


Fig. 1 — Transistor circuit symbols.

PROCESS DESIGNATION	GEOMETRICAL SHAPE B = BAR D = DOUBLE SIDED WAFER S = SINGLE SIDED WAFER	CROSS-SECTIONAL VIEW SHOWING JUNCTIONS (NOT TO SCALE)
RATE GROWN	B	
MELTBACK	B	
MELTBACK-DIFFUSED	B	
GROWN-DIFFUSED	B	
DOUBLE DOPED	B	
ALLOY	D	
DIFFUSED ALLOY (DRIFT)	D	
ALLOY DIFFUSED	S	
DIFFUSED BASE (MESA)	S	
DIFFUSED EMITTER-BASE (MESA)	S	
SURFACE BARRIER	D	
MICRO ALLOY	D	
MICRO ALLOY DIFFUSED	D	

Fig. 2 — Transistor forms.

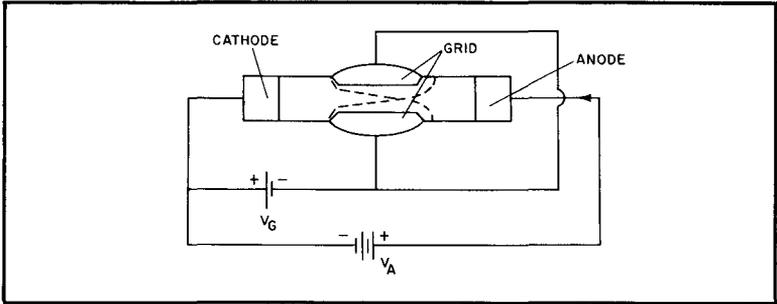


(A) Common base.

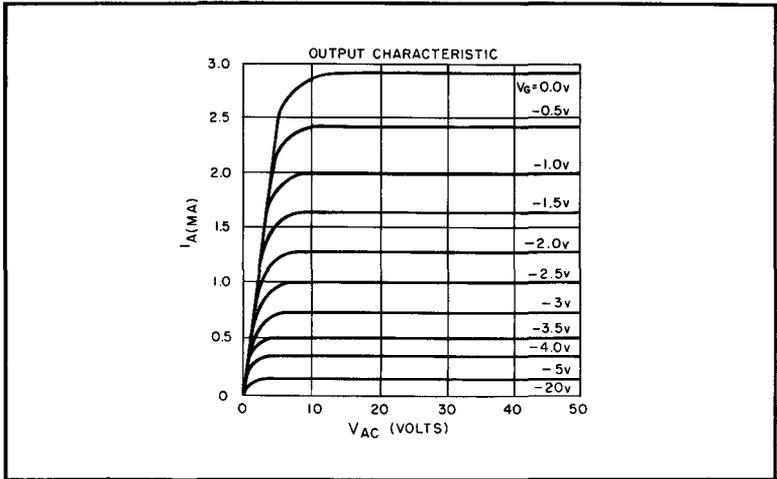
(B) Common emitter.

(C) Common collector.

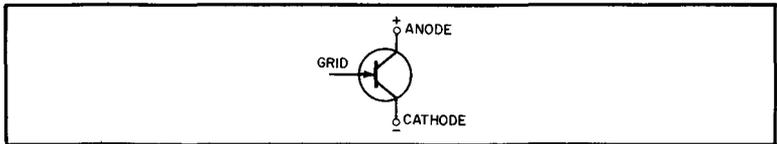
Fig. 3 — Basic circuits.



A) Physical construction of field effect transistor.



(B) Characteristic chart of field effect transistor.



(C) Circuit symbol of the field effect transistor.

Fig. 4 — Transistor types.

A negative bias applied to the grid increases the effective resistance between the anode and cathode, producing a triode-output characteristic. As the anode voltage is increased, a voltage drop develops across the grid junctions, causing them to become reverse-biased. At some point, a further increase in anode voltage will not appreciably increase the anode current. As a result, the output characteristics of the unit closely resemble those of the vacuum-tube pentode.

The anode potential at which anode-current saturation occurs is known as the *pinch-off* voltage. Anode current flowing through the device after the pinch-off voltage has been reached is called the pinch-off current. With zero grid bias, the pinch-off current is the maximum specified anode current. The transistor is in the triode region before pinch-off occurs, and in the pentode region after the pinch-off potential has been reached. This may be seen from the characteristic chart in Fig 4B. Below an anode voltage of about 10 volts, the operational curves resemble those of a triode; to the right they are similar to those of a pentode. Part C shows the circuit symbol of the field-effect transistor. Unlike a tube, the anode and cathode terminals are interchangeable, although a somewhat higher transconductance and lower noise figure is generally obtained by using the unit in the normal way.

The grid normally requires a negative potential. Positive bias on the grid will increase the anode current, but should remain below 0.6 volt. Otherwise, substantial grid currents—capable of destroying the device—will develop.

Except for lower anode voltages, field-effect transistors used as amplifiers have the same circuitry as triodes and pentodes. The polarities of the applied voltages are also the same.

COMPOSITE TRANSISTORS

Packaged amplifiers with gains of up to 30,000 are available in the form of composite transistors. A typical PNP unit, the 2N1161, has a collector voltage of 30 volts with a current of up to 3 amperes. Maximum dissipation is about 50 watts, and the current gain goes as high as 10,000.

Beta (β)—or the current gain when the transistor is used as an amplifier in a common-emitter configuration—usually is less than 300 to 400, although some composite transistors have *betas* of up to 30,000. The drawing in Fig. 5 shows the equivalent circuit. As in a single transistor, there are three external terminals—C, B, and E—corresponding to the collector, base, and emitter. In effect, the composite transistor appears as a low-power amplifier at the input and a high-power unit at the output. The *betas* multiply, and the total *beta* for Fig. 5 would be $B_1 \cdot B_2 \cdot B_3$. However, the diode

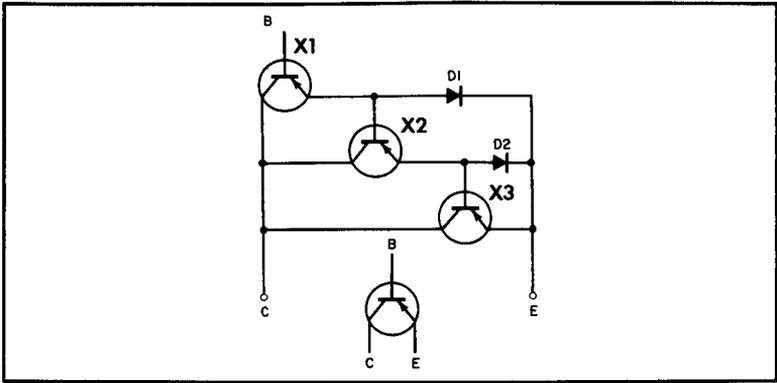


Fig. 5 — Composite transistor equivalent circuit.

shunts absorb some of the base-emitter currents as thermal compensation.

FOUR-ELEMENT DEVICES

Some of these units are *hook* transistors, which are PNN or NPP devices. A PNN unit has three junctions, as shown in Fig. 6. As redrawn, a hook transistor appears as a PNP to the input and an NPN to the output. An NPP unit (Fig. 7) is the reverse of a PNN.

Controlled Switch

The controlled switch or CS (like the silicon-controlled rectifier) is another PNPN device. The CS is related to the controlled rectifier (SCR) in both physical construction and theory of operation, but has a much greater firing sensitivity. It is therefore

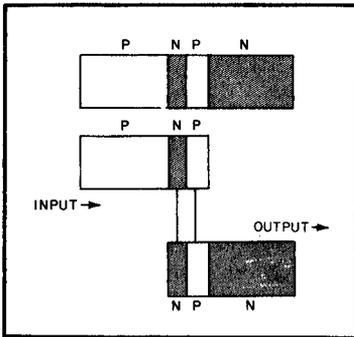


Fig. 6 — Hook transistor (PNN).

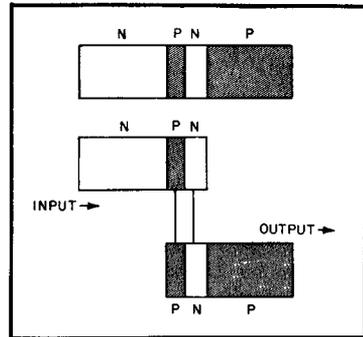


Fig. 7 — Hook transistor (NPP).

useful in many low-level input applications outside the capability of controlled rectifiers.

Consider two transistors connected together as in Fig. 8A, one a PNP and the other an NPN. Electrode A (anode) is attached to the upper P region, C (cathode) connects to the lower N region, and a third electrode (gate) goes to the P region of the NPN triode. Actually, as shown in Fig. 8B, there are only four regions in a single wafer, with three junctions. Electrically, the transistor

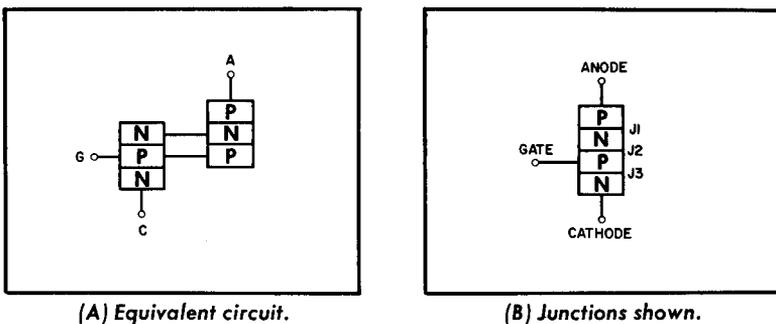


Fig. 8 — Controlled switch.

pair appears as shown in Fig. 9A, while 9B shows the schematic symbol for the CS. In operation the collector of X2 drives the base of X1, and the collector of X1 drives the base of X2. Where β_1 is the current gain of X1, and β_2 the current gain of X2, the gain of this positive-feedback loop is their product, $\beta_1 \times \beta_2 = \beta_3$. Where β_3 is less than 1, the circuit will be stable; otherwise, it will be regenerative. With a small negative current applied to terminal G, the NPN transistor is biased off and loop gain is less than unity (1). The only current that can flow between output terminals A and C is the cutoff collector current of the two transistors, and the impedance between A and C is very high at this time.

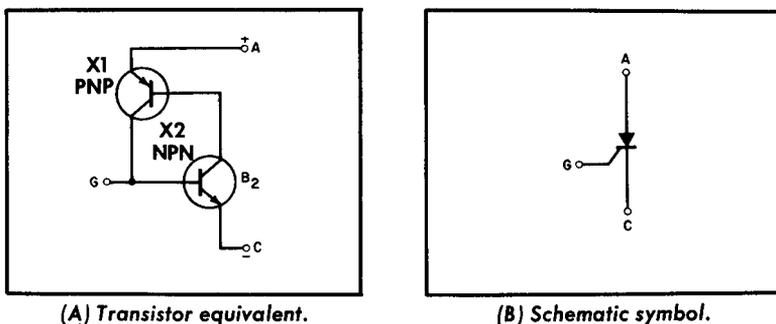


Fig. 9 — Controlled switch.

When a positive current is applied to terminal G, the NPN transistor is biased on, causing its collector current to rise. Since the current gain of the NPN, β_1 , increases with the collector current, a point is reached where loop gain equals unity and the circuit becomes regenerative.

Collector current of the two transistors rapidly increases to a value limited only by the external circuit. Both transistors are driven into saturation, and the impedance between A and C becomes very low. In this state, the positive current which was applied to terminal G to trigger the self-regenerative action is no longer required, since the collector of the PNP supplied more than enough current to drive the base of the NPN.

The CS circuit will remain on until turned off by reducing the collector current below the value necessary to keep β_3 at or above unity.

Trigistor

Another PNPN device of similar construction is the silicon *Trigistor* (Fig. 10). This is a semiconductor component with characteristics which allow it to approximate the circuit function of a flip-flop or bistable multivibrator. It is also known as a *Dynaquad*, a PNPN device with the unique property of trigger control turn-off and turn-on at its base.

The *Trigistor* will turn on whenever a low positive trigger pulse is applied to its base; it will remain on without a sustaining base current. A negative trigger pulse applied to the base will turn it off, and keep it off until triggered on again. The circuit will then remain on until triggered off by a negative current pulse at terminal B, which diverts the collector current of the PNP from the base of the NPN. Since regenerative action is no longer sustained, the two transistors return to their stable cutoff condition.

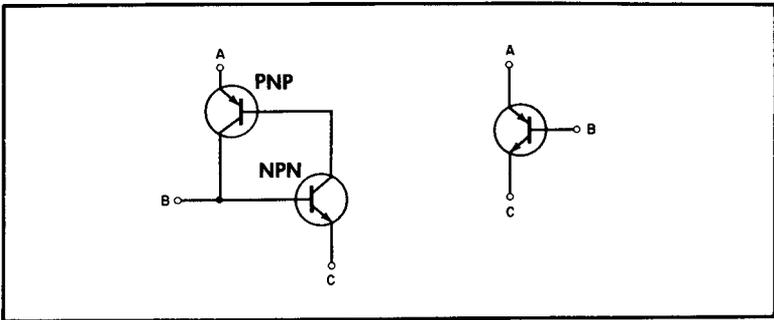
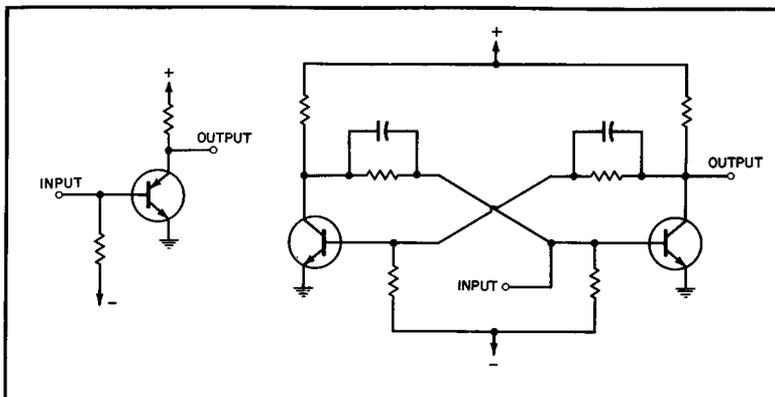


Fig. 10 — PNPN *trigistor* and *dynaquad*.



(A) Bistable circuit.

(B) Conventional transistor circuit.

Fig. 11 — Trigistor and transistor circuits.

Fig. 11A illustrates the inherent simplicity of a *Trigistor* bistable circuit. A conventional transistor flip-flop is shown in Fig. 11B for comparison. *Trigistor* switching circuits require fewer components than do transistors or other switching elements. Normally, one *Trigistor* will perform the same function as two transistors plus several associated capacitors and resistors.

The *Trigistor* is turned off by a gate signal. In the controlled switch (CS) and silicon-controlled rectifier (SCR), the gate turns the device on, and lowering the collector voltage turns it off.

The CS is inherently a highly sensitive device because the input NPN transistor is designed with high gain. It is therefore useful for high-gain switching directly from low-level control signals. Usually no intermediate stages of amplification are needed in the control circuits.

Where high sensitivity is not required or desired, any degree of reduced sensitivity can be achieved by biasing the gate. In fact, some negative gate bias is recommended for all circuits, to insure absolute "no-fire" stability. Since the CS has a very high gain, it should not be operated or tested with the gate open.

For many applications, stabilizing bias is easily achieved by adding a resistor between the gate and cathode. The resistance is determined by the maximum operating temperature for the application. Since biasing reduces the firing sensitivity, the correct resistance is a key part of circuit design.

The Binistor

The *Binistor* is another PNP device. Of the many four-layer devices available, it represents a new mode of operation offering many advantages over more usual techniques. Its negative-resist-

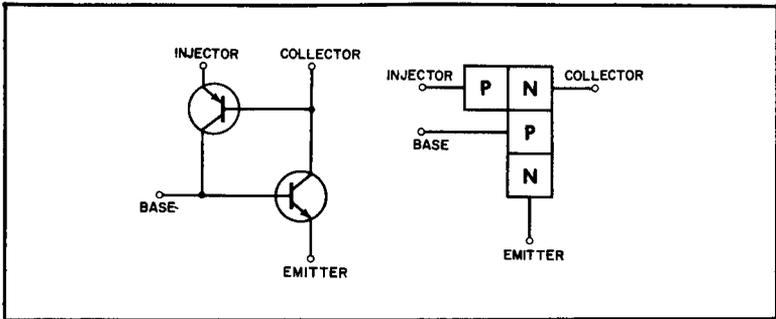


Fig. 12 — *Binistor* equivalent circuit.

ance characteristics, usually determined by internal parameters in conventional four-layer devices, are determined instead by the external circuitry. The result is stable operation over wide temperature limits.

The two-transistor equivalent circuit of the *Binistor* is shown in Fig. 12. Although all electrodes may be used as inputs, the most interesting performance is obtained when the collector is considered an output and the base an input, with the injector providing the "latching" current required for bistability. The injector may also be used to switch the *Binistor* off in certain circuits.

If base current is applied, then normal transistor action will cause the collector voltage to fall. When it drops below the injector clamp voltage, the upper PN junction will become forward-biased and injector current will begin to flow in such a direction that it helps the NPN transistor switch on. Hence, a regenerative action takes place that tends to drive both transistors into the saturated "on" state. No further external base current is required to maintain the *Binistor* in this condition, the base current for the NPN transistor being supplied by the injector circuit.

Switch-off can be achieved either at the injector or, with certain *Binistor* types, at the base. If the injector current is reduced to the point where the base current of the NPN section is insufficient to keep the *Binistor* in saturation, the collector voltage will rise. When it goes above the injector clamp voltage, the upper PN junction will become reverse-biased and regeneration will complete the switch-off. Therefore, the criterion for switch-on is that the collector voltage be taken below the injector clamp voltage. Conversely, for switch-off the collector voltage must be taken above the injector clamp voltage.

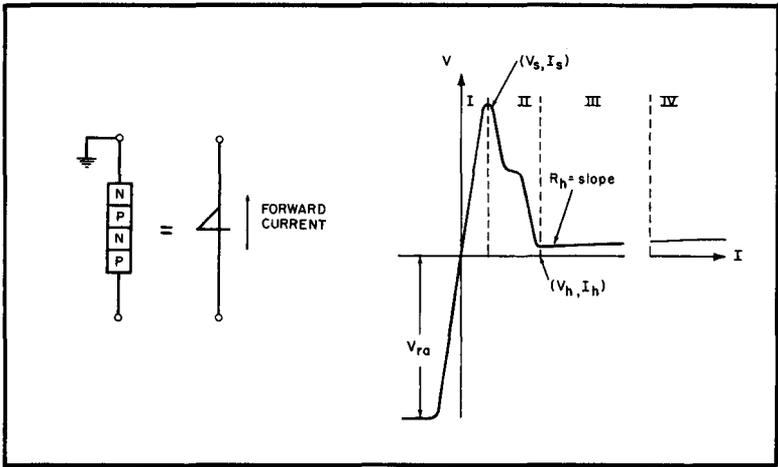
PNPN Diode

The PNPN four-layer diode in Fig. 13A is a two-terminal, self-actuated silicon switch with operating characteristics based on

the principles of transistor action. It has two stable states—an “open”, or high-resistance, state of more than one megohm; and a “closed”, or low-resistance state, of just a few ohms. It is switched from one state to the other by controlling the voltage across it and the current through it.

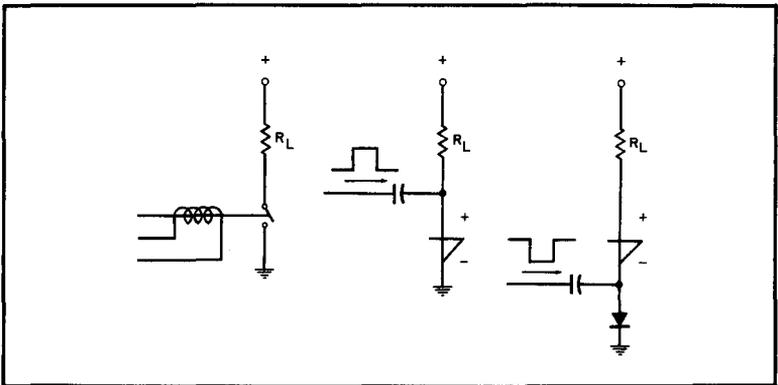
Because of its characteristics, this four-layer diode can serve as a load switch (Fig. 13B). A positive pulse on its anode or a negative pulse on its cathode will start and then sustain conduction.

The voltage-current characteristic for the four-layer transistor diode shows the four essential operating regions (see Fig. 13C).



(A) Four-layer diode.

(C) Voltage-current characteristics.



(B) Load switch.

Fig. 13 — PNP diode.

These are the open, or high-resistance; transition, or negative-resistance; closed, or low-resistance; and high-pulse current states.

When $B+$ is applied, the voltage across the diode rises to the point where it switches the unit to the closed state. (Switching occurs because an internal-feedback mechanism allows the diode to pass a steadily increasing current when the voltage is held at a fixed value.) The current in the closed state is less than $200 \mu\text{a}$; therefore, the transistor diode will pass the required current.

In the closed state, the device has a resistance of only a few ohms. As long as the circuit passes sufficient current, the closed, or "on," condition will be maintained. At the point marked " V_H " on the curve, the circuit is passing just enough current to keep the device in the closed state. If the current drops below this point, the diode will switch back to its high-resistance, or "off," condition.

Prior to switching, the reverse-biased junction of the four-layer transistor diode acts as a capacitor. It is necessary to charge this capacitor as well as to inject current carriers into it during switching. The energy required must be furnished either by a trigger pulse or by circuit elements provided for this purpose. Usually a .002-mfd capacitor or higher is added from the positive terminal to ground.

The switching characteristic of the transistor diode is determined by the "on" and "off" time constants, and the circuit will determine the actual switching time. The higher the trigger voltage applied and the faster it rises, the faster the unit switches. Diodes are available with switching voltages from 20 to 200 volts and holding currents of 1 to 50 ma. Within these limits, a series of standard ranges with specific tolerances makes it possible to select units with characteristics meeting specific needs.

The transistor diode will turn off when the current through it is below the holding current. The speed of this turn-off depends on circuit conditions. In a typical sawtooth oscillator, for example, the device must turn off while holding voltage is applied. This will normally take about one microsecond.

In its "off" condition, the transistor diode may be considered a capacitance and large resistance in parallel. This capacitance is similar to the collector capacitance of a normal transistor, but its value depends on the actual voltage across the device. In its "on" condition, the transistor diode has such a low resistance that capacitive effects may be ignored. In its "off" condition, capacitance current will pass in response to a sharply rising voltage wave. If this voltage wave rises fast enough, switching will occur *below* the DC switching voltage.

Since its resistance decreases as the current increases (to sub-

stantially less than 1 ohm at high pulse currents), the diode can be destroyed unless the load current is limited. To switch the diode on, the series impedance should pass more than the value of holding current.

SPECIAL DIODES

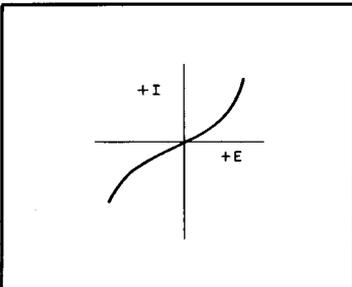
Silicon diodes are used for rectifiers where, with a positive anode or negative cathode, they conduct in the forward direction. A typical operating curve is shown in Fig. 14A. If a small reverse voltage is applied, the current flow will be in microamperes, rather than milliamperes as in the forward direction. The germanium diode, in contrast, does not have as sharp a front-to-back ratio, although it does conduct more heavily in the forward than in the reverse direction (see Fig. 14B).

Zener Diodes

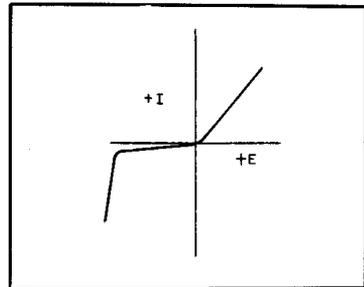
When a reverse voltage is applied to the silicon diode, however, it breaks down at a certain point. This sharply defined potential is the *zener*, or breakdown, voltage. At this point the silicon diode conducts, much like a gas tube. The breakdown does not damage the silicon diode, and it recovers when the reverse voltage is removed.

The important feature is that, at breakdown, the voltage is almost independent of the amount of current flow. Thus, the diode acts as a voltage regulator, maintaining a constant voltage drop over a wide current range.

Silicon diodes designed for this use are called zener types and are designed for specific zener voltages. They are used for voltage regulation and reference. Other silicon diodes used as rectifiers have such high zener voltages that these voltages are rarely reached. Consequently the diode does not break down under normal inverse-voltage conditions.



(A) Silicon diode operating curve.



(B) Germanium diode operating curve.

Fig. 14 — Special diodes.

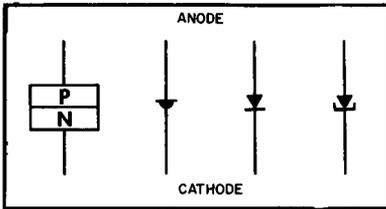


Fig. 15 — Tunnel diode circuit symbols.

Tunnel (Esaki) Diode

The tunnel diode is a fairly new semiconductor device with wide potential as an amplifier, switch, or oscillator. It can be made from either germanium or silicon, and can be identified in a circuit diagram from any of the three symbols in Fig. 15.

Ordinary transistors (and even vacuum tubes) depend on current carriers being influenced by the potential between the emitter and collector electrodes. Carrier speed therefore is limited by the time required for them to travel through these regions. Tunnel diodes, however, operate on a different principle, and their theoretical frequency limit of 10^7 megacycles is much higher than that of any other semiconductor device.

The tunnel diode, so called because of its tunnel effect, operates on the principle of quantum theory whereby a particle can disappear from one side of a potential barrier and instantly reappear on the other side—even though it apparently does not have enough energy to overcome the barrier.

As shown by the characteristic curve in Fig. 16, as voltage is applied to the diode, current rises sharply to a peak. If the applied forward voltage is further increased, the current dips sharply and then rises again to its original peak and even higher. Peak

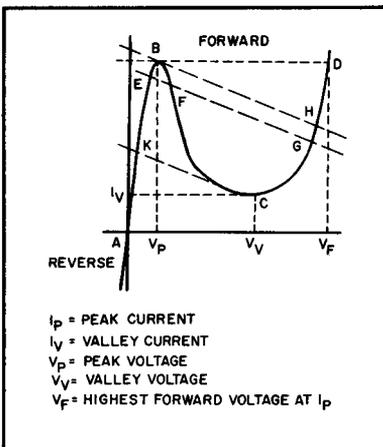


Fig. 16 — Tunnel diode characteristic curve.

currents can be anywhere from only a few microamperes to well into the ampere region.

The negative-resistance region following the first current peak makes the tunnel diode useful as an active circuit device. In addition, a tunnel diode has an extremely low impedance in the reversed-biased state, and a normal diode characteristic at high forward voltages (operating along the second current peak).

The two most common uses for tunnel diodes are as switches (where the unit is switched from a low- to a high-voltage positive-resistance state), and in linear amplifiers and oscillator circuits (where it is biased in the negative-resistance region).

For bistable operation, positive-resistance sections of the characteristic curve are used (current increases with voltage). Referring again to Fig. 16, points A and B (both positive-resistance points) are connected to produce a load line for bistable operation. Point A is a high-voltage, low-current point and B is a low-voltage, high-current point. Each represents a stable state for the tunnel diode. If the diode is biased at A and a trigger pulse is applied to increase the current, the diode will switch to its low-voltage state. Removing the trigger will return the diode to its high-voltage, or second stable, state.

Backward Diodes

In manufacturing, it is possible to eliminate the peak in the forward characteristic of a tunnel diode. With signals smaller than about 400 mv (in a typical germanium diode), the "reverse" quadrant exhibits the low impedance and the "forward" quadrant the high impedance. This, then, is the "backward" diode. A typical characteristic curve is shown in Fig. 17.

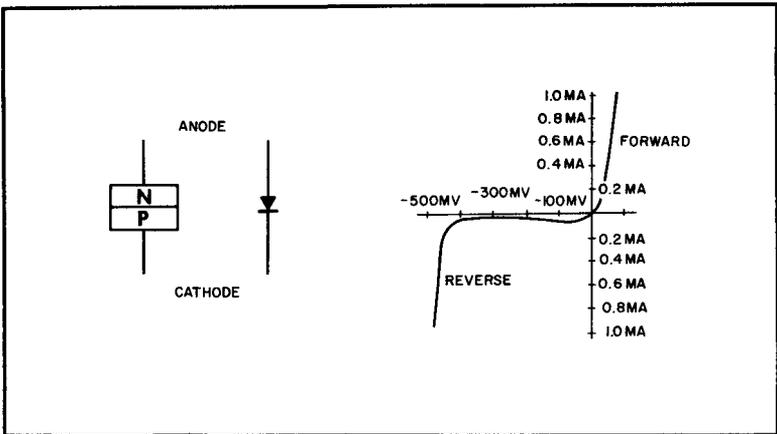


Fig. 17 — Backward diode and characteristics curve.

Typical applications for the backward diode are in tunnel-diode circuits as a unilateralization element, and in detection or low-voltage reference circuits. When the backward diode is biased in the low-impedance direction (reverse-biased), diode action is entirely due to majority current. Recovery time is therefore not limited by any stored-charge phenomena.

Section 2

SWITCHING AND LOGIC CIRCUITS

Because transistors and semiconductor diodes are two-state devices, they are well suited for use in logic circuits. A vacuum tube, on the other hand, requires heater and plate supplies. Thus, it uses a great deal of power even as a simple on-off device. A semiconductor device can perform the same function with as little as one hundredth of the power.

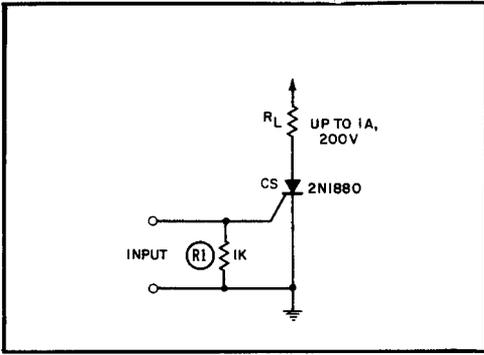
Logic circuits operate on a “go, no-go” basis; that is, they have two recognizable states—on or “one,” and off or “zero.” There are many ways of establishing these two states. The most common are (1) to use pulses or (2) changes in voltage of current level. In the absence of a pulse or a change in the input level, the circuit is in its “zero” state. Application of an input pulse changes the state to indicate a “one.”

Many types of circuits can be used for on-off operation; the problem is that they must be used in large number in order to form arithmetical units capable of counting multidigit numbers (as required of a digital computer, for example). Several circuits may feed into one, or one circuit may feed several others; thus, circuit design is somewhat restricted.

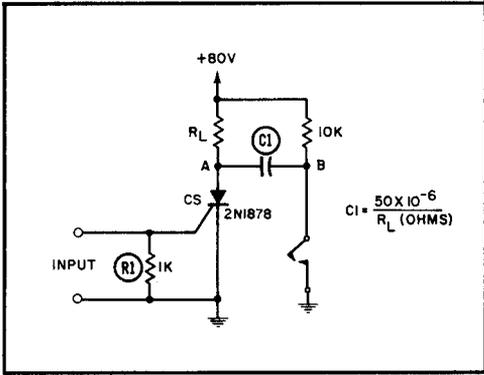
Two basic circuit types are described in this section; one is defined as AND, the other as OR. In an AND circuit, there is an output if (and only if) both elements conduct, just as two switches in series must both be closed before current can flow. On the other hand, OR circuits are like two switches in parallel, where current will flow if either is closed (or if both are).

THE SCR AS A STATIC SWITCH

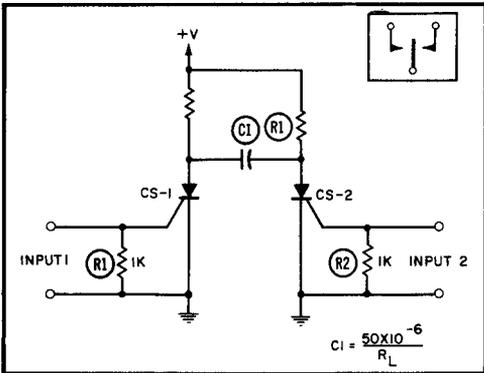
The input characteristics of the CS or SCR, gate-to-cathode, are similar to the base-emitter input of the NPN silicon transistor. Firing occurs at specific values of input current and voltage. Thus, the device can be used as a static switch with either an AC or DC source.



(A) Simple latching switch.



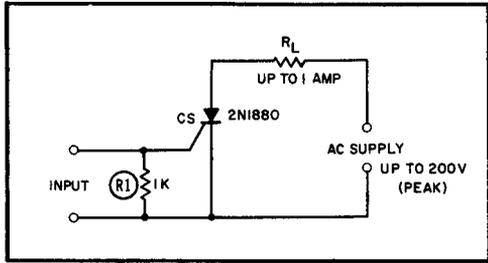
(B) Shunt capacitor turn off.



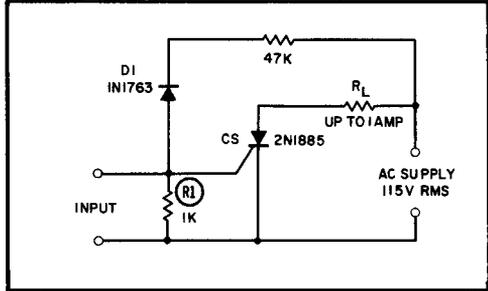
(C) DPDT static switch.

The SCR as

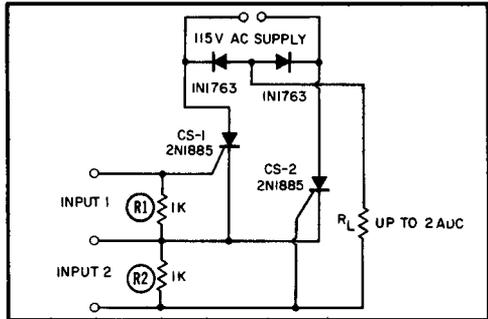
(D) Half wave switch.



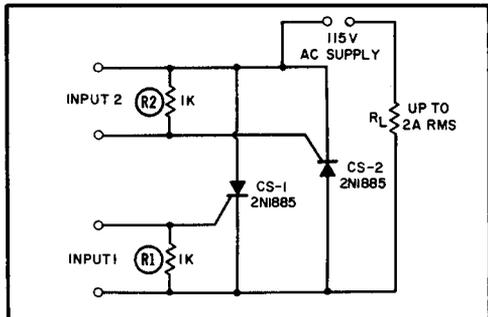
(E) AC static switch.



(F) Full-wave static switching.



(G) Full-wave output.



a static switch.

Circuit A has a DC source, and the CS acts as a latching switch. Once turned on by a control signal, it will remain on. To turn it off, the anode current must be reduced below the dropout level. Resistor R1 provides a negative-gate bias current and insures a stable "off" condition. Less than 20 microwatts of input power (0.6 volt, 20 μ a) for 1 microsecond or longer is required to turn on a load power of up to 200 watts. By proper choice of R1, the sensitivity can be reduced even further.

The CS will latch on at any load current above the dropout level. It will work as well with small loads (10 ma) as it does at higher load currents. The circuit can be used as a single-contact latching switch for direct control of a given load, and is useful for driving relay coils or similar electromagnetic loads. With the CS, an ordinary DC relay can be converted to a high-sensitivity latching relay. For inductive loads a shunt diode may be required, to eliminate a voltage surge when the power is removed.

For the simple latching circuit, turn-off can be accomplished by removing the source voltage. The CS can also be turned off through use of a capacitive shunt, as in circuit B. The CS is off until an input control signal turns it on. When on, the voltage at the anode is about one volt. C1 charges through R2 to about the value of the supply voltage. Closing the switch causes the charge across the capacitor to drive the CS anode negative with respect to ground. Load current is no longer supplied by the CS, but from the discharging capacitor. This method of achieving CS cutoff is known as shunt-capacitor turn-off. The capacitor must be sufficiently large to hold the CS anode negative long enough to insure turn-off.

As shown in circuit C, another CS can be used in place of the switch. Turn-off is accomplished in the same manner, except that a momentary low-level positive pulse is required at input 2. This circuit is actually a power flip-flop. When CS-1 is turned on (by a suitable input signal), CS-2 is turned off by the resultant voltage drop coupled through C1. When CS-2 is turned on, CS-1 is turned off. R1 can be replaced by a second load so that DPST switching between the two loads becomes a simple matter of applying low-level pulses to the appropriate inputs.

With an AC voltage source, the CS performs as a controlled half-wave rectifier, blocking both the positive and the negative half-cycles until a positive control signal is applied to the gate. The CS will then conduct during the positive half-cycles. By proper timing of the applied control signal, the CS can be made to conduct during all or part of the positive half-cycle. Thus, proportioning control of the output is possible, as well as on-off switching.

Circuit D is a simple AC static switch which supplies rectified half-wave DC to the load. The input control signal can be AC, DC, or a pulse. If the load is inductive, shunting it with a diode will supply continuous current through the load during the negative half-cycle. The inductive field built up during the positive half-cycle will return stored energy during the negative alternation. The diode polarity permits this current to flow in the same direction as during the positive alternation.

In AC circuits, the positive control voltage applied to the CS gate must be kept low during the negative half-cycle because of reverse leakage current, which increases along with the positive gate current. If this leakage current becomes large enough, it can cause thermal runaway. The reverse half-cycle leakage current is about half the positive gate current; by use of R2 and D1 (as shown in circuit E), a bucking current can be obtained to cancel the effect of any reverse leakage current during the negative half-cycle.

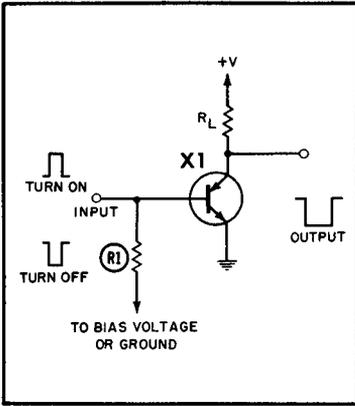
Full-wave static switching is also possible. As shown in circuit F, a full-wave DC circuit can be formed by using two CS stages in a bridge rectifier. Input 1 is applied when CS-1 has a positive anode voltage; during the next alternation, input 2 is positive while the anode of CS-2 is positive. Any output from maximum to zero is possible. For a full-wave AC output, the CS devices are connected in inverse parallel, as shown in circuit G.

PNPN TRIGISTOR PULSE-DURATION SWITCH

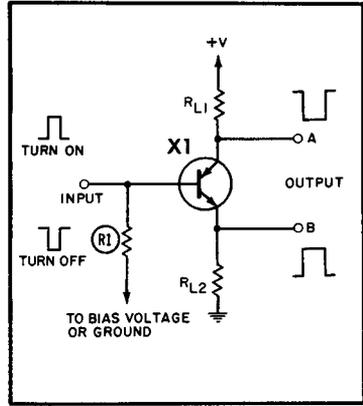
Acting as a signal switch, the PNP *Trigistor* unit has a number of uses. It is particularly suited to memory, counter, gating, timing, logic, and related pulse applications. These functions are usually achieved by combining one or more of the basic bistable circuits shown with appropriate coupling networks.

These basic circuits show some of the possible variations which can be used to obtain a choice in triggering and output points. In all these circuits, the *Trigistor* is turned on by making the base more positive than the emitter. Cutoff is achieved by making the base more negative than the emitter, or by reducing the collector current below the holding value. The *Trigistor* has a preferred off state, which it assumes before any base pulses have been applied.

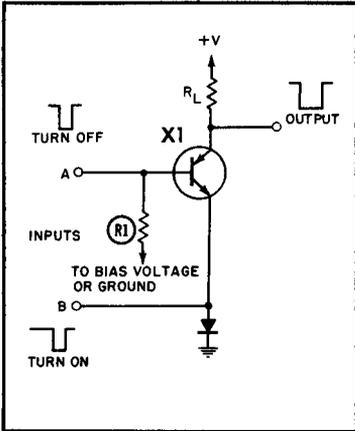
Both turn-on and turn-off are accomplished at the base in circuit A. The output is taken directly across the *Trigistor*. Output-pulse width is determined by the time between input pulses and is independent of input-pulse widths. Thus, this circuit can provide a pulse output of variable delay.



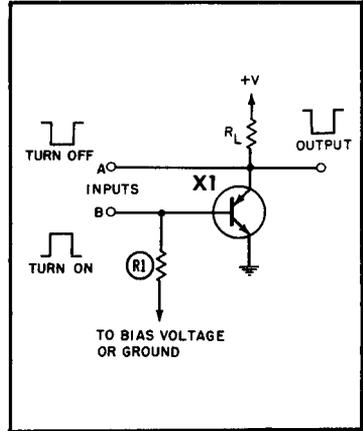
(A) Turn on-off at base;
collector output.



(B) Turn on-off at base;
collector & emitter output.



(C) Turn on at emitter; off at base.



(D) Turn on at base; off at collector

PNPN Trigistor pulse-duration switch.

The circuit shown in B is essentially the same except that outputs are available from both the collector and emitter, thereby providing pulse outputs of both polarities. Input-voltage requirements for both turn-on and turn-off must increase (over that required by the first circuit) by an amount equal to the output voltage at the emitter.

Only negative triggering pulses are used in circuit C. Turn-on is accomplished by applying a negative pulse to the emitter, across a silicon diode in the inverse direction. A diode is used in place of a resistor because its impedance becomes very low when

the *Trigistor* is on. Turn-off is accomplished by applying a negative pulse to the base. The output is the same as for circuit A.

Circuit D is also similar to A except that turn-off is accomplished by driving the *Trigistor* collector negative. Almost all the collector current must be bypassed for turn-off to take place.

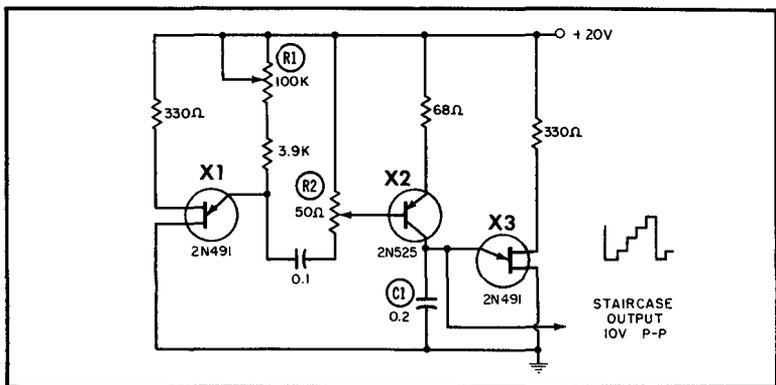
Determining the proper component values for use in basic *Trigistor* circuits is not difficult. The collector resistor and B+ voltage determine the "on" current level. Between 3 and 5 ma will insure best *Trigistor* performance throughout the operating-temperature range. B+ voltages as low as +3 volts can be used. It is desirable, however, to use a B+ value well above this lower limit so the circuits will not be sensitive to small voltage changes.

When the *Trigistor* is off, the collector cutoff current can act as a positive-gate current signal, tending to turn the *Trigistor* on. The base resistor R_b provides bias current to insure a stable "off" condition. For operation up to 125°C., the bias-off current should be a minimum of 150 microamps. Thus, if a bias-voltage source of -1.5 volts is used, the base resistor should be 10K or less.

STAIRCASE-WAVE GENERATOR

Here is a simple staircase-wave generator which has good stability and a wide operating range. Unijunction transistor X1 operates as a free-running oscillator which generates negative pulses across R2. The resultant conduction cycles of X2 charge capacitor C1 in steps. When the voltage across C1 reaches a level which will cause X3 to conduct, this transistor fires and discharges C1.

Resistor R1 determines the frequency of the staircase waveform, and resistor R2 determines the number of steps per cycle.



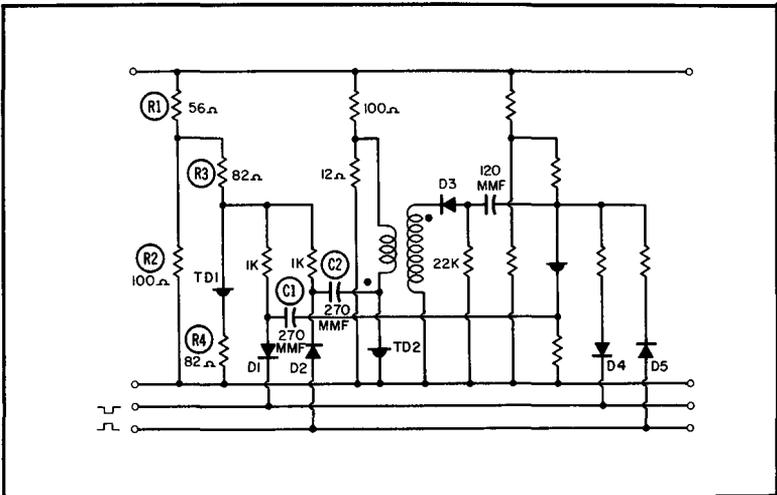
Staircase wave generator.

As shown, the circuit can be adjusted for an output frequency from 100 cps to 2 kc, and the number of steps per cycle can be adjusted from one to several hundred. This circuit can also be adapted for use as a frequency divider by adding stages in cascade, similar to the hook-up between X2 and X3.

TUNNEL-DIODE SHIFT REGISTER

This shift-register circuit uses two monostable tunnel diodes and three backward diodes per stage.

Assuming that stage TD1 is in the high-voltage state, diode D1 becomes forward-biased whenever a negative-going pulse is applied. This pulse is therefore passed, via capacitor C1, to the cathode of TD2, switching it to the high-voltage state.



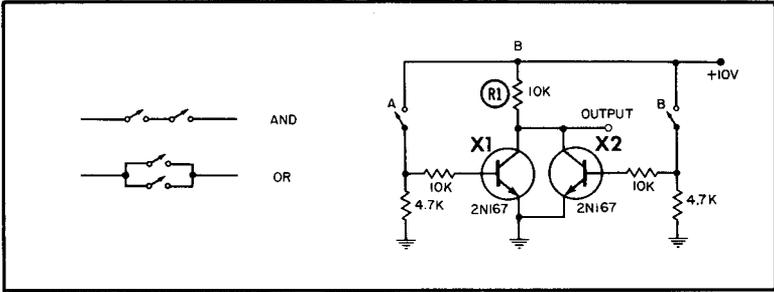
Tunnel-diode shift register.

If the first stage is in the low-voltage state, a positive-going pulse will be applied, via backward diode D2 and capacitor C2, to the anode of TD1. This positive pulse will drive TD1 into the high-voltage state. The resultant positive voltage pulse is stepped up and inverted by the transformer. It is then passed on to the anode of TD2, switching it to its low-voltage state.

For the required triggering voltages to be small, it is desirable to have R3 and R4 as small as possible. With the 1.5-volt supply used, the divider circuit formed by R1 and R2 must be used. By making R2 variable, this becomes a convenient method of adjusting the bias points of the tunnel diodes.

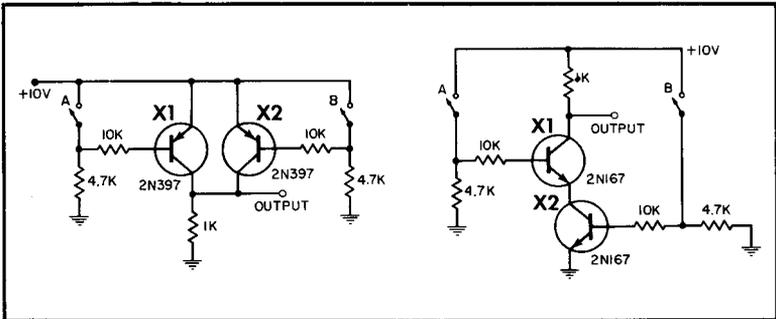
TRANSISTOR LOGIC

As diagrammed in A, two switches in series form the AND circuit; in parallel, they form an OR circuit. In the former, both switches must be closed for current to flow. In the latter, either switch will activate the load.



(A) AND and OR gates.

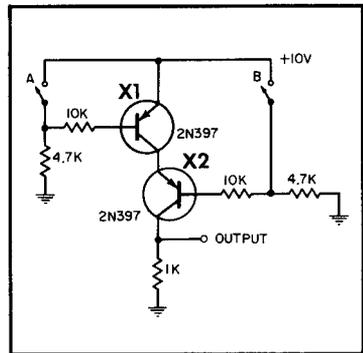
(B) NPN transistor gate.



(C) PNP transistor gate.

(D) NPN transistor gate.

Transistor logic.



(E) PNP transistor gate.

Circuits B and C show logic gates using parallel transistors. The first uses NPN transistors. If closing a switch is an input, the circuit is an OR gate; if opening a switch is an input, it is an AND gate. Circuit C uses PNP transistors. If closing a switch is an input, it is an AND gate; if opening a switch is an input, it is an OR gate.

Circuit C has the same input and output levels as B, but uses PNP rather than NPN transistors. If closing a switch is an input, both switches must be closed before the current through R_L ceases. Therefore, the inputs which make the NPN circuit an OR gate make the PNP circuit an AND gate. Because of this, the phase inversion inherent in transistor gates does not complicate the over-all circuitry.

The logic of circuits D and E are similar except the transistors are in series rather than in parallel. This change converts OR gates into AND gates and vice versa. Circuit D is a gate using NPN transistors. If closing a switch is an input, it is an AND gate; if opening a switch is an input, it is an OR gate. Circuit E shows a gate using PNP transistors. If closing a switch is an input, it is an OR gate; if opening a switch is an input, it is an AND gate.

PNPN TRIGISTOR SHIFT REGISTER

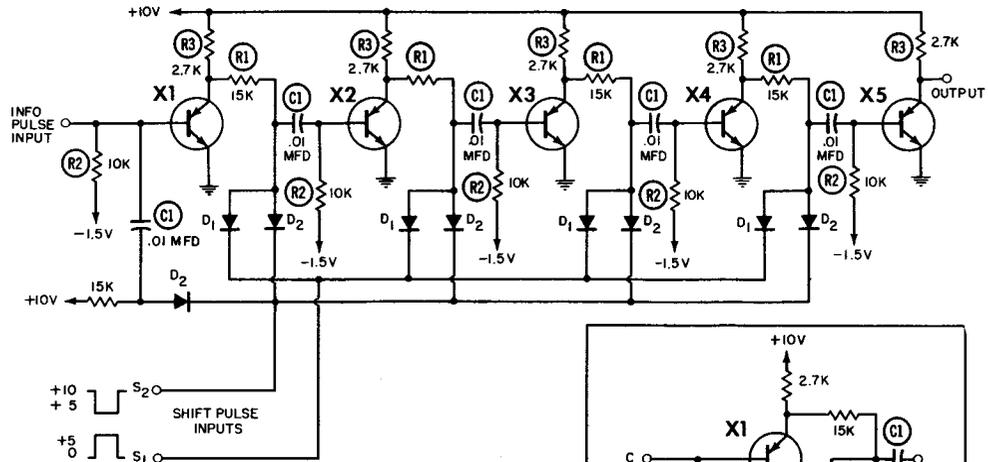
The basic circuit shown in Part A represents a one-bit memory element. It can be connected in cascade with identical circuits to form a complete shift register of as many bits as desired. A five-bit shift register is shown in Part B.

The output pulse of the basic circuit may be either positive or negative, depending on whether the *Trigistor* was previously in an "on" or "off" state. Memory is achieved through the use of coupling diodes D1 and D2 and transition memory capacitor C1. If the *Trigistor* has been off, the capacitor charges to 10 volts (same as the supply). When shift pulse inputs are applied with polarities and references as shown, D2 will conduct and couple the negative pulse to the output. D1 remains reverse-biased and the positive pulse is blocked.

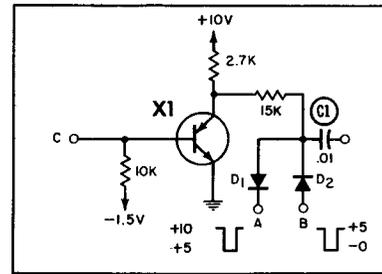
If the *Trigistor* has been on, its memory capacitor is not charged. Thus, when the two shift pulses are applied, D1 conducts and couples the positive pulse to the output. D2 remains reverse-biased and the negative pulse is blocked.

A series of memory circuits, as in B, produces a shift register. When a pulse input is applied to the base of X1, the shift pulses will propagate the signal down the chain.

PNPN Tristor shift register.



(B) 5 bit shift register.



(A) Basic memory unit.

PNPN TRIGISTOR AS A STATIC SWITCH

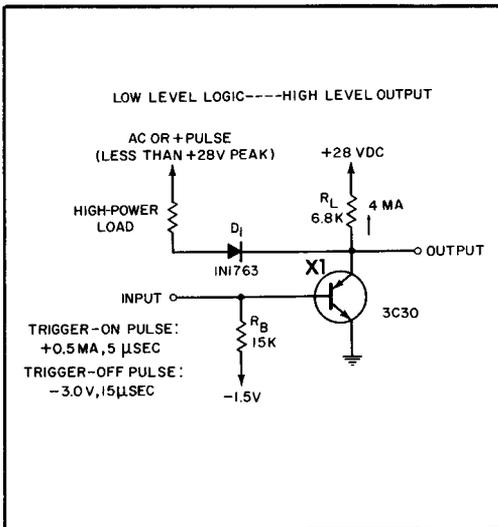
Two circuits using the PNPN *Trigistor* as a static switching device are shown in this diagram. The *Trigistor* acts as both a low-level logic element and a high-level static switch.

Once the *Trigistor* has been turned on, it will carry whatever current the load requires (within its power-dissipation ratings). As an example, loads such as print hammers, solenoids, magnetic clutches, brakes, and relays are usually well within the current-handling capability of the *Trigistor*.

As shown, this circuit has two separate loads. Assuming that diode D1 and the high-power load are disconnected, the rest of the circuit could be used as a portion of a logic circuit, such as a shift register or binary counter stage. When the *Trigistor* is on, the collector current through R_L is 4 ma. Applying a negative pulse to the base turns the *Trigistor* off, at which time the collector voltage rises to the supply-voltage level.

With the diode and high-power load connected as shown, D1 will block the negative swings of AC voltage. The *Trigistor* collector current cannot exceed 4 ma at this time, so the *Trigistor* can be turned on and off as a logic-circuit element.

When the *Trigistor* is off, its collector will be at the positive DC supply level. Thus, when the AC voltage begins to go positive, D1 will continue to block (provided the DC supply voltage is greater than the peak positive AC voltage). But if the *Trigistor* happens to be on as a result of logic operations, collector current will be supplied to the high-power load through D1 during posi-



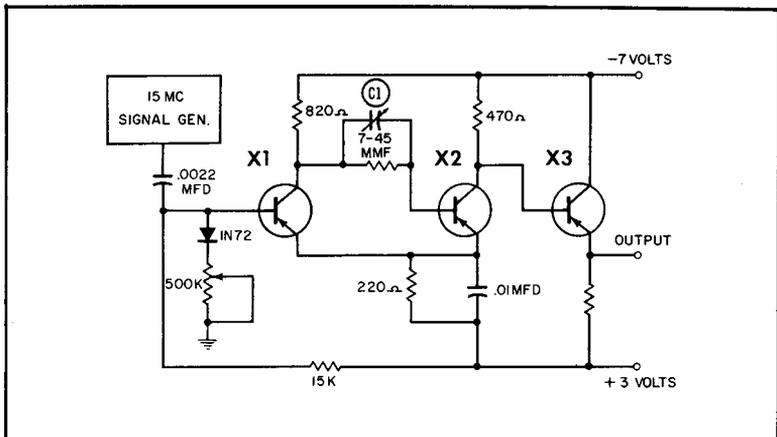
PNPN Trigistor
as a
static switch.

tive AC peaks. During this period of high current flow, the *Tri-gistor* cannot be turned off, so the logic and high-level output functions must be accomplished on a time-sharing basis. During each negative excursion of the AC voltage, one or hundreds of logic operations can be performed.

At the conclusion of a sequence of logic operations, "readout" is obtained by applying a positive voltage pulse to the bus connected to the power loads. Pulse power can be used, instead of AC, to operate high-power loads well up into the ampere region.

15-MC PULSE GENERATOR

This circuit uses 2N501 transistors to form a pulse generator capable of operating from 50 kc to above 15 mc. Capacitor C1 is adjusted for optimum output-pulse shape. Pulse width is determined by the input amplitude and the setting of resistor R1. Variation of the output amplitude can be obtained by returning the collector of X3 to a variable supply voltage.



15-Mc pulse generator.

COMMON LOGIC CIRCUITS

Many transistors readily meet the steady-state requirements necessary for logic circuits. Shown here are six common transistor logic circuits. Part A illustrates a resistor-transistor type in which the logic is performed by resistors. Any positive input produces an inverted output, irrespective of the other inputs. All logical operations can be performed with only this straightforward circuit.

TYPICAL CIRCUIT (Positive signals are defined as 1)	SUITABLE TRANSISTORS	
	GERMANIUM	SILICON
	2N43A* 2N78* 2N167* 2N169A 2N396* 2N525 2N526* 2N635 2N1057	2N335*

(A) Resistor transistor logic (NOR).

	No standard types are characterized specifically for this logic 2N404* 2N525 2N634 2N1115	
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(B) Resistor capacitor transistor logic.

	4JD1A68 (PNP Alloy) Surface barrier types	
--	---	--

(C) Direct coupled transistor logic.

	2N43A* 2N78* 2N123* 2N167* 2N396* 2N525 2N635	2N333* 2N337*
--	---	------------------

(D) Diode logic.

	2N123* 2N396* 2N525 2N526* 2N635 2N1115	2N335* 2N338*
--	--	------------------

(E) Low level logic.

	2N1289 Mesa Types	2N337* 2N338*
--	----------------------	------------------

*Military types.

(F) Current mode logic.

Common logic circuits.

Part B is similar except that capacitors are used to enhance the switching speed. The capacitors provide a more rapid change in base current for faster collector-current turn-on. This type of circuit is faster than the RTL, but at the expense of additional components and stringent stored-charge requirements.

In Part C the logic is performed by transistors only. V_{CE} and V_{BE} , measured with the transistor in saturation, define the two logic levels. To insure stability and circuit flexibility, V_{CE} must be much lower than V_{BE} . Low supply voltages may be used to achieve high-power efficiency and miniaturization.

In Part D the logic is performed by diodes, and the output is not inverted. Amplifiers are required between the gate circuits in series to maintain the correct logic levels. However, several gates may be used between amplifiers, thus attaining high-speed operation. In this circuit, the noninversion feature simplifies circuit design, and the components are relatively inexpensive.

Part E shows a low-level logic circuit using diodes. The circuit output is inverted. Diode D isolates the transistor from the gate, permitting R to turn on the collector current. By proper choice of components, the transistor voltage changes can be made very small. The number of inputs to the diode gate does not affect the transistor base current, thus providing more stable circuit operation. The small voltage changes minimize the effects of stray capacitance and enhance the switching speed.

Part F shows a current-mode logic circuit, where the logic is performed by transistors biased from constant-current sources to keep them far out of saturation. Both inverted and noninverted outputs are available, depending on which input transistor is pulsed. Very high switching speeds are possible because the transistors are operated under optimum operating conditions. Although the voltage excursions are small, the circuitry is relatively unaffected by noise.

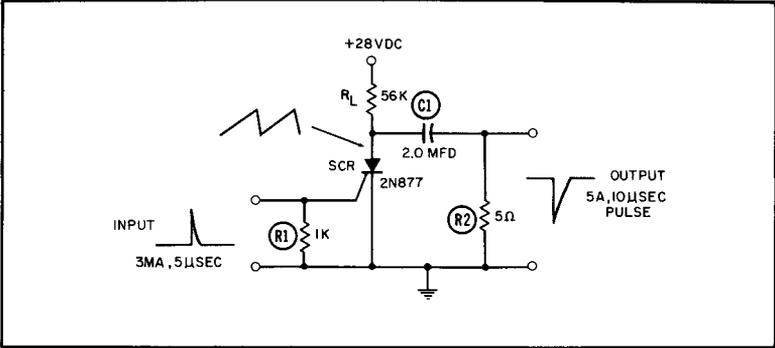
SCR PULSE AND SWEEP CIRCUITS

High-power pulses can easily be obtained from the high-sensitivity SCR. Outputs of 150 volts at up to 20 amperes can be produced from inputs in the 20-microampere and 0.6-volt ranges. A power gain of 10,000,000 can be achieved in some cases.

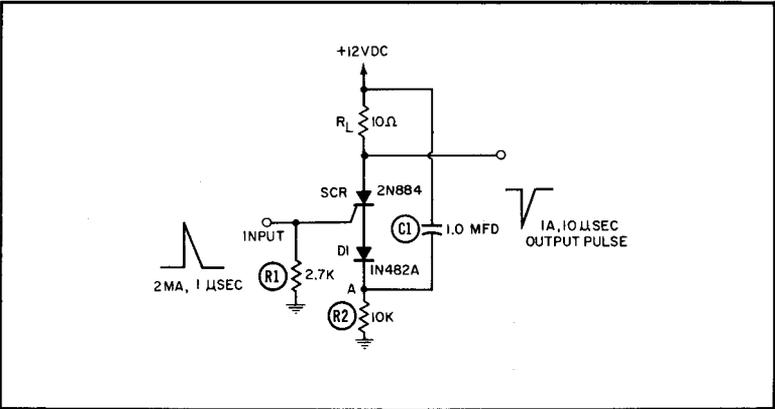
A triggered RC pulse generator is shown in Part A. In its quiescent state, the capacitor is charged to the value of the supply voltage. When a trigger pulse is applied to the input, the CS fires, discharging the capacitor through the output load. This circuit can be triggered at any desired rate, and the output-pulse amplitude will be a function of that rate. The available output

current is limited by the load resistor. A positive pulse output can be obtained by placing this resistor in the cathode leg and connecting the capacitor between anode and ground.

Circuit B shows another type of pulse generator, which is useful as a frequency divider as well as a pulse generator. Frequency



(A) Triggered pulse generator.



(B) Frequency divider generator.

SCR pulse and sweep circuits.

division to 1/10 is possible. The charging resistor R2 is in the cathode circuit, and load resistor R_L is in the anode circuit. With no charge on the capacitor, the full supply voltage appears across R₂. This provides a large negative bias between the gate and the cathode. Diode D1 is reverse-biased, preventing the gate-to-cathode voltage rating of the CS from being exceeded. As the capacitor charges, the voltage across R₂ decreases toward zero. The CS will fire when the voltage at point A equals the gate firing voltage of the CS plus the forward drop of D1 (approx-

mately 1 volt total). Suppose the input-pulse amplitude is +2.5 volts between gate and ground, and the input-pulse rate is 20 kc with a supply voltage of 20 volts. If the time for the voltage at A to reach +1.5 volts is 500 microseconds, then one output pulse will occur for each 10 input pulses. The output rate will be 2 kc, giving a frequency division of 10.

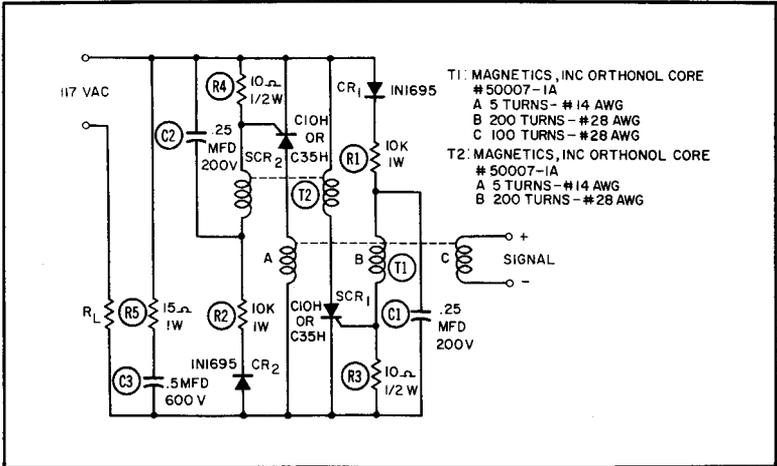
In RC pulse circuits which operate from a DC source and require the CS to turn off after each pulse output, C1 must be large enough to prevent the steady-state current through the CS from exceeding the dropout value. An upper limit also exists for R2; it must supply enough current to permit the CS to fire. The requirement for a minimum value of R2 does not apply to circuits turned off by other methods.

AC STATIC SWITCHING CIRCUIT

This circuit utilizes the characteristics of square-loop core materials and SCR devices. Two small toroidal cores are used, together with two back-to-back stages (Types C-10H or C-35H). This is directly analogous to a single-pole electromechanical contractor with an electrically isolated solenoid. It is also possible, with slight modification, to make an analogy to an electromechanical latching relay.

Both SCR stages will fire when they receive a gate signal, and will thereby supply full-wave AC to the load. They will also act as the closed contacts of a relay or contractor. If no gate signal is supplied, no power will be supplied to the load.

There are two core transformers. T1 has three windings (A, B, and C), while T2 has two windings as shown. During the "open"



AC static switching circuit.

state, both cores T1 and T2 are saturated. Rectified current from the AC supply flows through the B windings and the diode rectifiers during alternate halves of the cycle.

When open, the gate voltage applied to the SCR's is limited to less than 0.25 volt by the voltage division across R1-R3 and R2-R4. The SCR's do not fire and no current flows in any of the reset windings.

A low-voltage signal, applied to input winding C, will fire the SCR, because the core of T1 will reset when the anode of SCR-1 goes negative. At this time CR1 is nonconducting. As the SCR anode begins to go positive, current will flow through winding B of the transformer. C1 will charge through R1. Core T1 will saturate after about 1 or 2 milliseconds, discharging C1 through the gate of SCR-1 and causing it to conduct. Current will then flow from the line, through SCR-1, to the load.

Gate firing for SCR-2 is the same as for SCR-1, but no separate signal winding is used. Core T1 depends on current through winding A to reset the core and allow SCR-2 to fire.

If SCR-1 is fired by the above sequence, its anode current will reset T1. SCR-2 will fire on the following half-cycle, and full-wave current will be delivered to the load.

T1 will in turn be reset by the current through SCR-2. Hence, once SCR-1 begins conducting (initiated by a positive pulse on the signal winding of T1), the switch will remain closed even though a signal is no longer applied to the input.

The switch may be turned off by a negative pulse on the signal winding of T1 and thereby prevent winding A from resetting T1. SCR-1 will then not fire on the following half-cycle, since the interruption of load current stops the reset action on T2. As a result, the circuit will revert to its "open" state.

The circuit acts like a latching relay, which is closed by a current flow and then held closed by a mechanical latch. Once this circuit has been turned on, it will stay on, even though the main voltage is interrupted for long periods of time. In other words, this circuit "remembers" its last state as open or closed, even throughout power interruptions. Reset action requires a minimum load current of one ampere with the circuit closed.

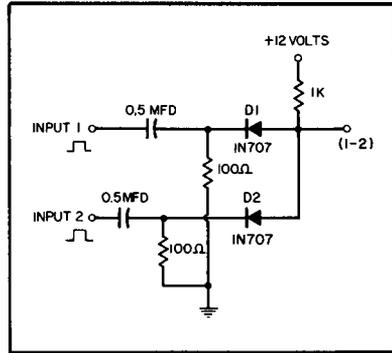
Shorting out winding A on T1 is a modification of the circuit. When this is done, load current will not reset T1, and a continuous positive DC signal must be applied to winding C of T1 to keep the contractor closed. The contractor will open within one cycle after this DC signal has been removed. Sensitivity of the switch to a control signal can be improved by increasing the number of turns on the C winding. C3 and R5 form a filter to prevent line-voltage transients from triggering the switch.

DIODE AND CIRCUIT

In this diode AND circuit, both anodes return to +12 volts through 1,000 ohms. With no input to either diode, both are in the conductive state. The output voltage is nearly zero, since most of the drop is across the 1,000 ohms.

A high positive pulse applied to the input of D1 will turn it off, but D2 will continue to conduct and there will be no output. High inputs to both diodes will turn both of them off, and the output will be high. Hence, an output is obtained from both diodes; neither is capable of producing an output by itself.

Diode AND circuit.

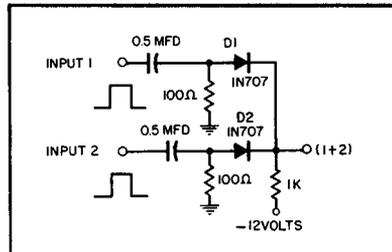


DIODE OR CIRCUIT

All cathodes in this diode OR circuit are returned to -12 volts; thus, the diodes conduct with no input. If a positive input is applied to the anode of one diode, its low forward resistance will place the cathode voltage at about +5 volts. This +5 volts is the output; because it is positive and appears on the other cathode, the other diode will be blocked unless it receives a positive input pulse greater than 5 volts.

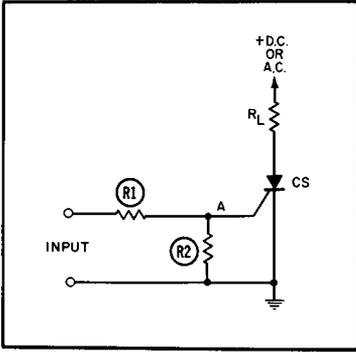
Thus, with a positive input at either diode, an output will be obtained.

Diode OR circuit.

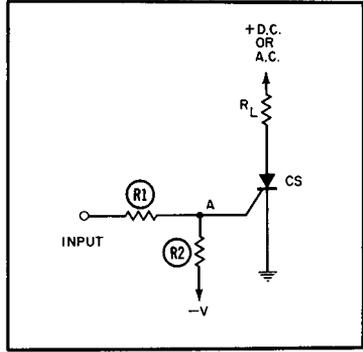


VOLTAGE-LIMITING SCR DETECTORS

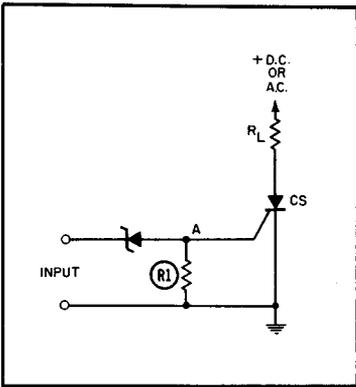
Their properties make the CS and SCR particularly useful as voltage-limiting detectors and other voltage or current threshold circuits. The high-sensitivity series, with a maximum gate firing current of 20 microamps and approximately 0.5-volt-gate firing voltage, has been designed for this type of application. The threshold firing point can be set at any desired value, from 0.6 volt up, by the use of an input voltage divider or zener diodes.



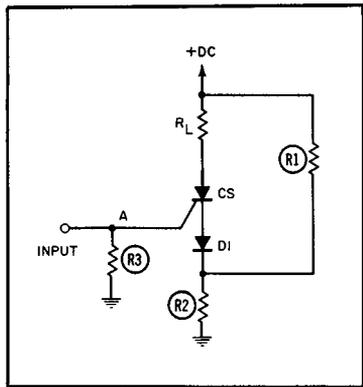
(A) Basic voltage limiting detector.



(B) SCR detector for use above 100°C.



(C) Zener diode SCR detector.



(D) Cathode bias detector.

Voltage-limiting SCR detectors.

Voltage-limiting detectors can use either DC or AC load power. If DC is used, the CS will latch when the input exceeds the threshold voltage. If AC load power is used, the CS will supply power to the load only when the input voltage exceeds the threshold voltage. Voltage-limiting detectors using the CS are

quite simple and useful in a variety of timing, sensing, indicator, warning, and safety applications. Since the CS can handle high load power, it can directly actuate the controlled circuit in many cases. A low power input from pressure, temperature, speed, flow, light, or similar transducers can be made to turn on the CS at a preset level. The CS can then actuate a control circuit, relay, solenoid, buzzer, indicator light, horn, or other output.

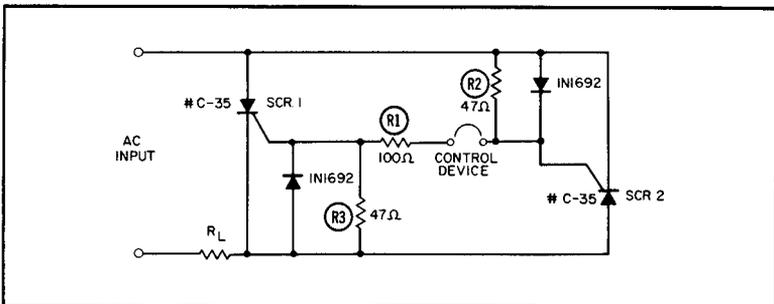
A basic form of voltage-limiting detector is shown in circuit A. Its operation is based on the fact that the CS will not turn on until the minimum gate firing voltage is exceeded. The ratio between R1 and R2 determines the threshold firing voltage at the input. The firing voltage of the CS has a negative temperature coefficient of approximately 3 millivolts per degree C. Compensation will be necessary if a uniform firing voltage is to be used over a wide operating-temperature range.

The value of R2 is determined by the required bias-off current at the upper operating temperature, to insure a stable "off" condition for the CS.

Circuit B is for operation at temperatures above 100°C. With a negative bias supply, R2 can be larger than when returned directly to the cathode. A larger value will also reduce current loading on the input.

A zener diode can be used to set the input threshold as shown in Part C, where a higher input voltage and minimum loading are desired. A zener diode with a positive temperature coefficient can be used to compensate for the negative coefficient of the CS. A further degree of refinement could be achieved by using a negative temperature-coefficient resistance for R2, to compensate for changes in firing current with temperature. *Thermistors* work very well for this purpose. Another arrangement, which uses positive cathode bias, is shown in Part D.

THE SCR AS AN AC STATIC SWITCH



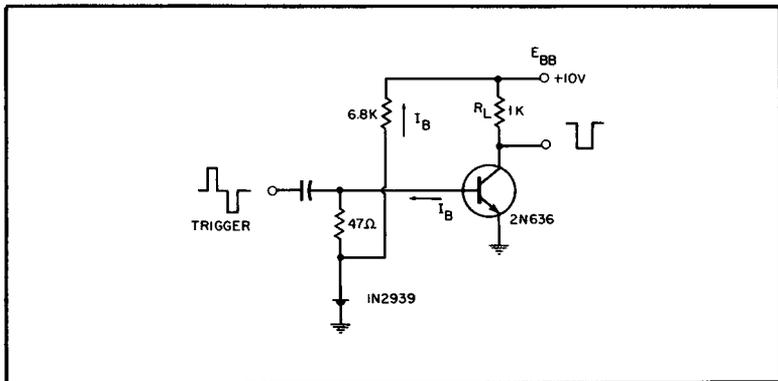
SCR's as AC static switch.

SCR's can be used to control the amount of AC power applied to a load. In this circuit, C-35 rectifiers are connected in inverse parallel and conduct during opposite alternations. The SCR's act only to *control* the AC; they do not act as rectifiers.

The control signal which permits each gate to fire may be from an electronic control amplifier actuated by light, heat, pressure, etc. When the control device closes, the SCR's fire once for each alternation. When the switch is open, neither SCR fires. In this way, AC power to the load is controlled. C-35 SCR's are shown, where R1 is 100 ohms and the input is 117 volts. Other parts values may be used for different input voltages.

TUNNEL-DIODE BISTABLE CIRCUIT

Tunnel diodes are fast and effective switches. A simple bistable circuit or flip-flop is shown here. The tunnel diode is biased to the low-voltage state by a current which is slightly lower than the peak current. Since the transistor is off, the collector is at the supply voltage.



Tunnel-diode Bistable circuit.

If a positive trigger pulse supplied at the input is such that the tunnel-diode current exceeds the peak current, the tunnel diode will switch to its high-voltage state. It will remain in this state, with most of the bias current being diverted into the base, until a negative trigger returns the diode to its original low-voltage state.

Section 3

COUNTERS

Any bistable or two-state device can be used to count. Since a transistor has only two states—cutoff and conducting—it is a count-by-two, or binary, device. In computer circuitry, a series string of these binary devices may be reset in such a manner that one is conducting (on) at the start of each cycle.

When a pulse is applied to the input, the “on” stage is cut off. By the coupling arrangement, this cutoff stage transfers its pulse to the second stage, thus turning it on. The next input pulse turns the second stage off and the third stage on. In this manner, the count progresses stage by stage until the final count is obtained.

Since the fundamental counter is of a binary nature and most counters must count higher than 2, some other arrangement must be made when higher counts are desired. As seen from the explanation of the stage-by-stage counter, any number of counts may be obtained, depending on the number of stages and type of coupling.

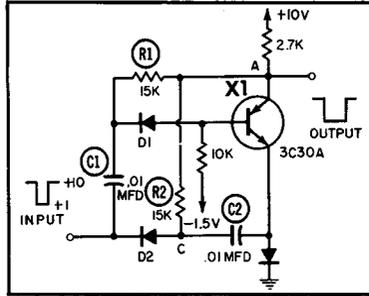
In ring counters, the output from the last stage is fed back into the first stage in order to start the counting cycle over.

A flip-flop counter is one in which a pulse is required to turn a stage on and another to turn it off. As an example, as stage 1 is turned on, it causes its neighboring stage (2) to cut off (flip) and as stage 1 is pulsed off, it causes *its* neighboring stage (2) to turn on (flop). Hence the term, flip-flop.

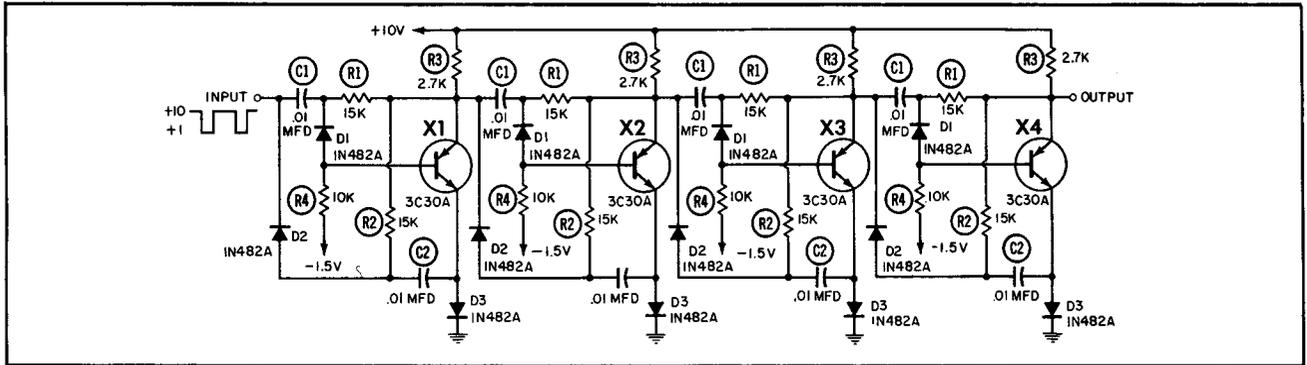
FLIP-FLOP BINARY COUNTER

A binary-counting flip-flop circuit using PNPN *Trigistors* is shown in Part A of the diagram. This circuit is a 2-to-1 binary divider operating on negative trigger pulses. Diodes D1 and D2 act as gates; and R1, R2, C1, and C2 provide gating bias.

While the *Trigistor* is off, point A is at +10 volts and C2 also is charged to +10 volts, while C1 remains uncharged. Whenever



(A) Basic unit.



(B) Four stage counter.

a negative pulse appears at the input, D2 conducts and couples the pulse to the emitter. This causes the *Trigistor* to conduct. Since C1 is uncharged, point B drops from +10 to +1 volt. D1 remains reverse-biased and the trigger pulse is blocked from the base.

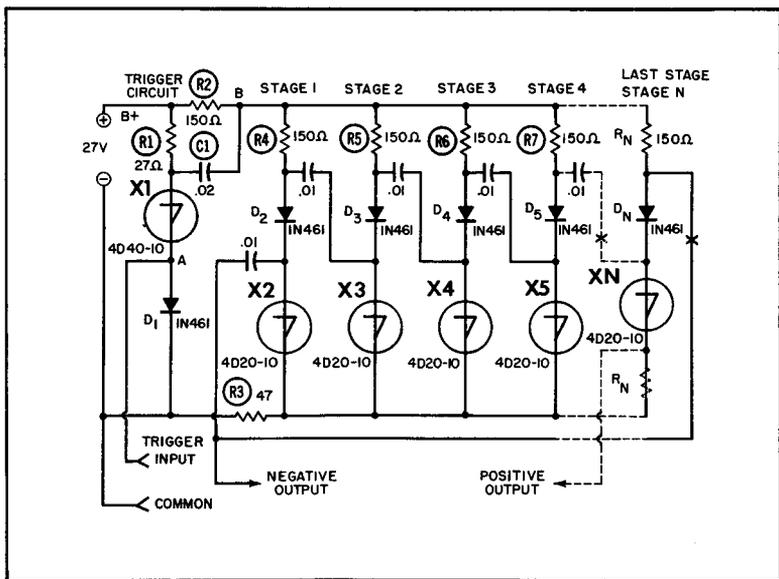
With the *Trigistor* on, points A, B, and C are all at +1 volt. When the next negative input pulse occurs, D1 conducts in the forward direction, coupling the pulse to the base and thus turning off the *Trigistor*. Meanwhile, D2 remains reverse-biased and blocks the pulse from the emitter.

The input of this circuit is driven from the collector of an identical *Trigistor* flip-flop, or from the collector of an NPN silicon transistor.

A four-stage counter is shown in Part B. Since each stage requires two pulses, sixteen are needed to produce an output. Thus, this circuit has a division of 16:1.

FOUR-LAYER DIODE RING COUNTER

Here, a ring counter is shown in which four-layer transistor diodes are used as conducting stages. When DC is applied to the



Four-layer diode ring counter.

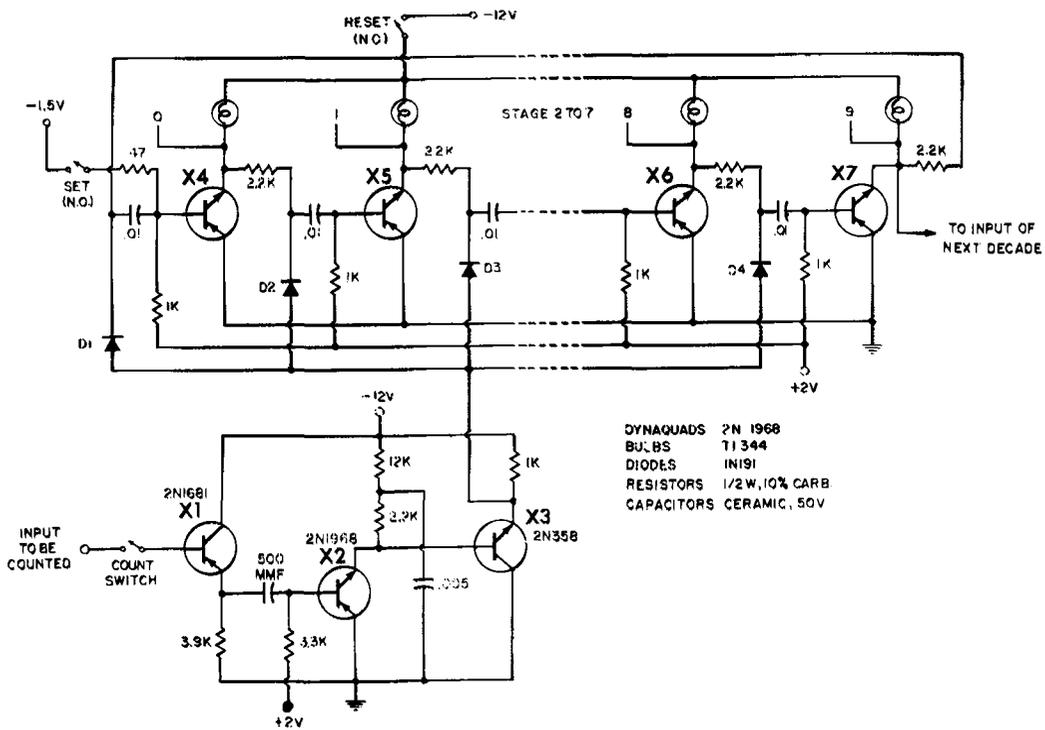
circuit, one of the counter stages will conduct and the other will remain cutoff. The conducting stage is furnished a holding current which makes it continue to conduct. The .01-mfd capacitor between the conducting and the next higher stage (at point A) triggers diode X1, but causes only momentary conduction since R1 does not provide a holding current. When X1 conducts, the voltage at point B drops to zero and remains there until capacitor C1 starts to charge. The loss of voltage at point B causes the counter stage to cease conducting. As C1 charges, the voltage at point B rises toward the B+ value. During this rise, the voltage of the charged coupling capacitor, added to the voltage at point B, triggers the next higher counter stage and it starts to conduct.

Therefore, each time diode X1 is triggered, the counter is advanced one stage.

DYNAQUAD DECADE COUNTER

In this decade counter, the pulses to be counted are fed into an emitter follower. Here, a low-impedance, negative-going pulse is developed across the emitter resistor and capacitively coupled to the 2N1968 *Dynaquad*, which is a three-terminal PNP device operated as a monostable multivibrator. The eight-microsecond pulses generated by the *Dynaquad* are coupled directly to the base of the 2N358 NPN emitter follower. The 2N358 develops eight-microsecond positive-going pulses across its 1K load resistor. These pulses are diode- and capacitively coupled to each of the 10 *Dynaquad* bases. Whenever a positive pulse appears on the base of a *Dynaquad*, that stage is cut off. A negative-going pulse is developed at its collector, which is RC coupled (2.2K, .01 mfd) to the base of the next *Dynaquad*. As a result, the latter *Dynaquad* is turned on. Each count, as it progresses down the line, therefore turns each successive *Dynaquad* on. The tenth count is coupled back to the input, turning on the zero indicator. It is also coupled into the input circuit of the next decade, which will therefore count at one-tenth the rate of the first decade.

The reset switch interrupts the *Dynaquad* collector voltage, cutting off all conduction in the counter. The set switch turns on the zero-indicator *Dynaquad* by applying a negative voltage to its base. In the circuit shown, the resistors and capacitors limit the speed of operation to 20 kc, and lamps (No. 334, 10 volts, 14 ma) are used as indicators.



- DYNAQUADS 2N 1968
- BU, BS 11 344
- DIODES 1N191
- RESISTORS 1/2 W, 10% CARB
- CAPACITORS CERAMIC, .50V

Dynaquad decade counter.

UNIUNCTION RING COUNTER

In this ring counter, transistor X1 conducts when no pulse is being applied to C1. Now, assuming that X2 is conducting, C2 and C5 will both charge to some positive value. As an incoming timed pulse cuts off X1, the conduction path of X2 is opened. The charge on C2 cannot bleed off because it is blocked by the diode in the X3 circuit. Therefore, the emitter of X3 is held at a positive voltage. C5 now discharges; and as its charge appears at C2, X3 is driven into conduction.

When the cutoff pulse to the base of X1 is removed, this transistor again conducts and re-establishes the conducting path for the counter. This time, however, conduction is through X3 instead of X2. In this manner, the count is advanced stage by stage until it reaches the output of X5 and is coupled back to X2 to start the sequence over.

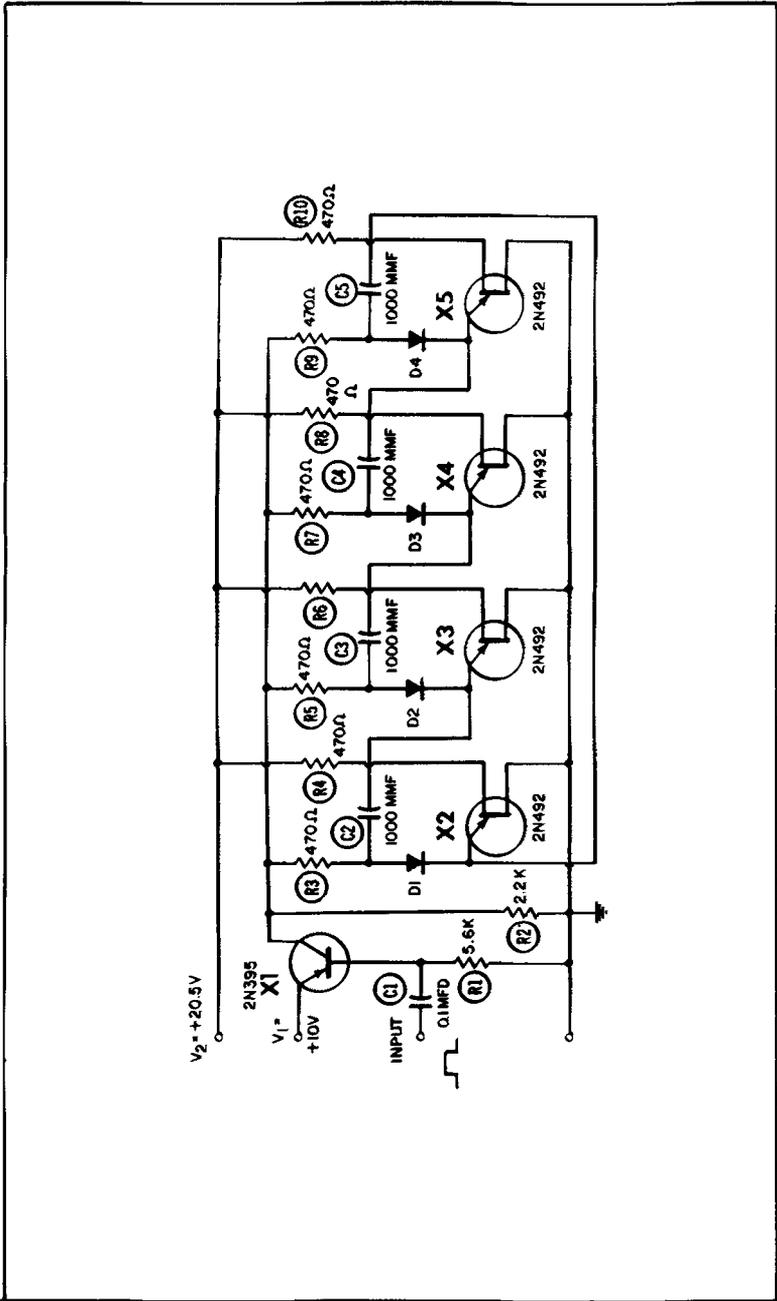
BINISTOR RING COUNTER

The ring counter shown in this diagram operates with a positive input pulse to the base of transistor X1.

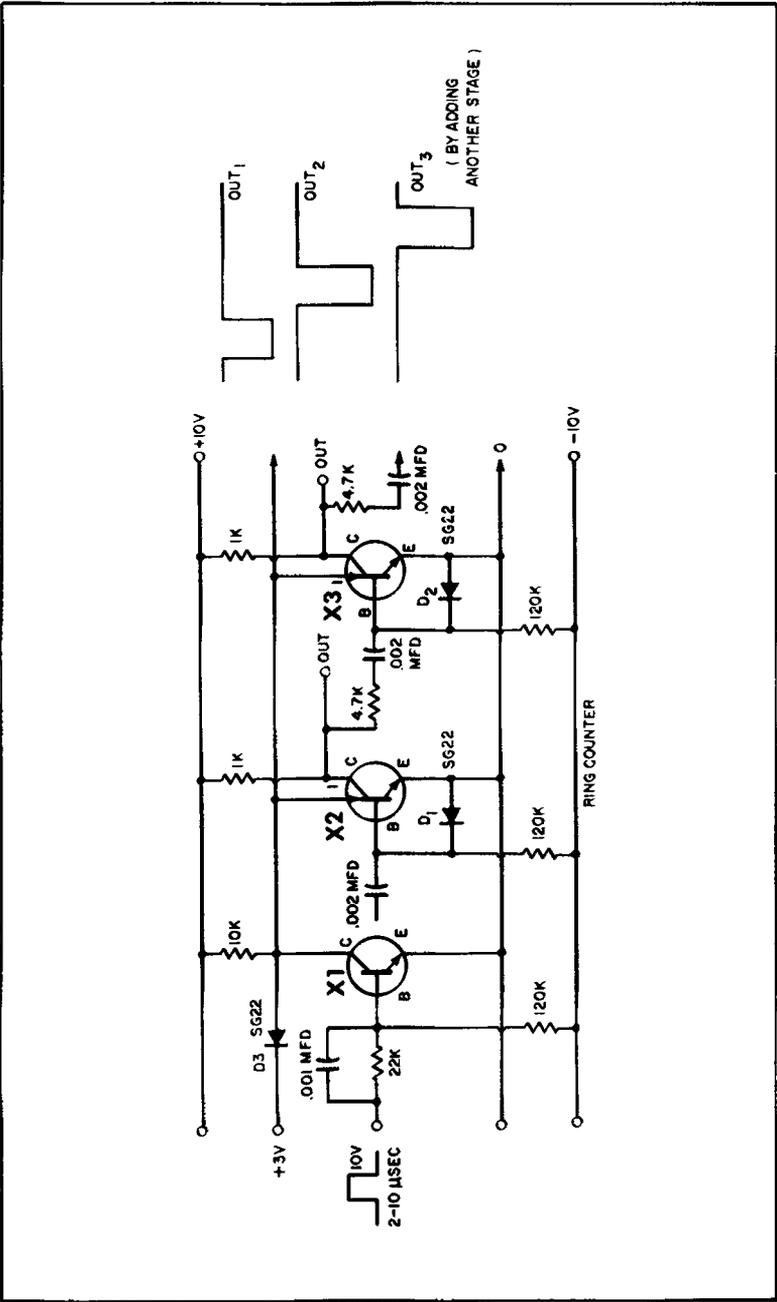
Before the trigger pulse is applied, one stage (for example, X2) is assumed to be on while all others are off. When pulsing transistor X1 is switched on, injector current is diverted from the "on" *Binistor* (X2), thus switching it off. The positive-going transient at the collector of X2 is then coupled to the base of X3. At this time transistor X1 is cut off and the injector voltage again rises to +3 volts. This combination of base pulsing and injector voltage causes X3 to conduct. The "on" state has therefore been passed along from one stage to the next at the triggering frequency. The output from this ring counter is as shown. (See page 52).

TUNNEL-DIODE RING COUNTER

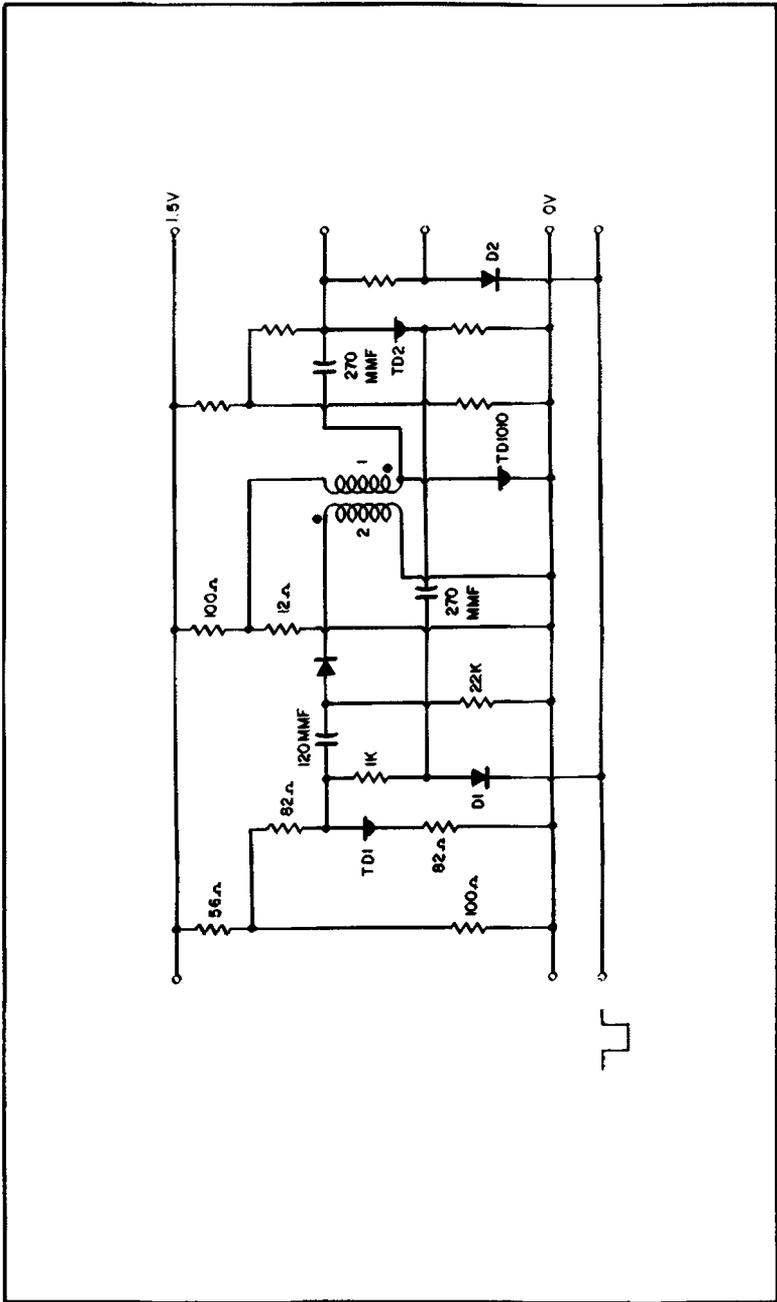
In this ring counter, let us assume the first stage (TD1) is in the high-voltage state (nonconducting). Diode D1 will then become forward-biased whenever a negative pulse is applied to its cathode. This pulse is passed to the cathode of the succeeding tunnel diode TD2, switching it to the high-voltage state. The positive transient which results at the anode is used to trigger the monostable circuit. The positive pulse from the monostable circuit is inverted and applied to the anode of tunnel diode TD1, switching it to the low-voltage state. (See page 53).



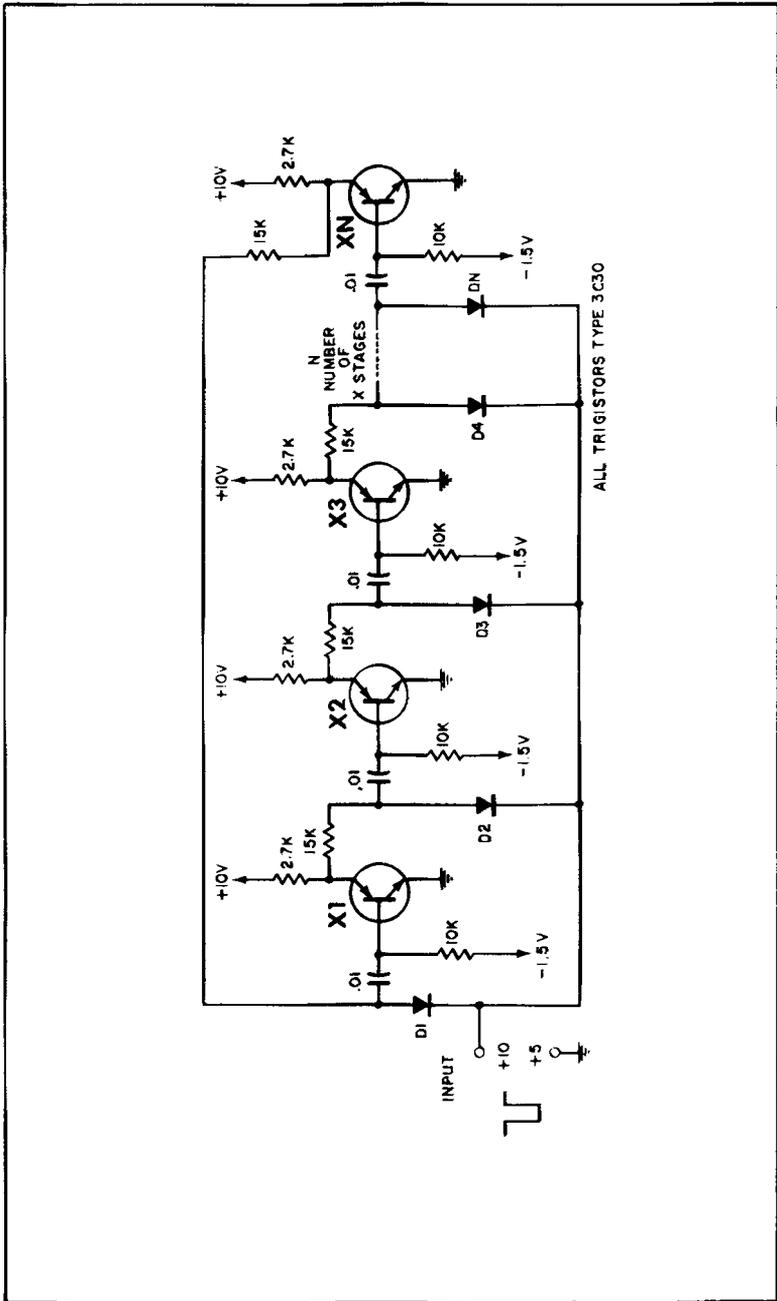
Unijunction ring counter.



Binistor ring counter.



Tunnel-diode ring counter.



Trigistor ring counter.

TRIGISTOR RING COUNTER

This circuit shows a ring counter in which only one stage is on. For example, if X2 is conducting and a negative input pulse is applied to all base circuits through their respective diodes and capacitors, two things happen. First, the incoming pulse will drive X2 into cutoff. Second, a positive-going collector pulse from X2 will then be coupled to the base of X3 and cause that stage to conduct. In this manner, the count is advanced stage by stage until the desired final count is obtained.

Section 4

FLIP-FLOPS

A free-running relaxation oscillator is actually a two-stage R-C amplifier with the output fed back to the input, forming an astable multivibrator. Operation is continuous, with one stage conducting while the other is cut off, and switching time depends on the R-C values.

Output from this type of circuit, obtained from either collector, is essentially a square wave. Synchronization is achieved by the application of positive trigger pulses, triggering a nonconductive stage just before conduction would normally occur.

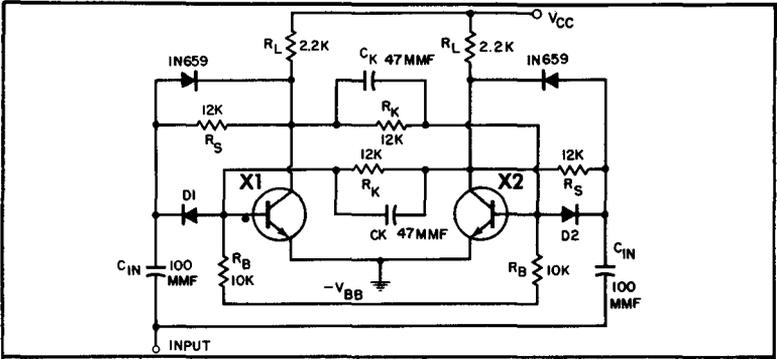
An Eccles-Jordan flip-flop circuit is quite like the cross-coupled multivibrator except it has two stable states (bistable) and can remain at rest in either one. In control circuits and computers, for example, its "one" state is X1 on, X2 off; the "zero" state is X1 off, X2 on. A pulse input is often applied to X1 as the clearing or reset pulse to assure the off, or "zero," state at the start.

A negative pulse switches the state, causing a neon lamp to light; this is the "one" state. After another pulse, the state is again reversed and the lamp goes out. Because this two-stage device requires two trigger pulses to restore its original state, it is known as a count-by-two circuit.

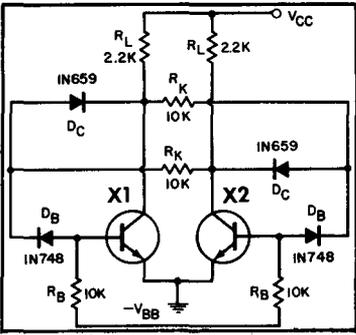
Another circuit variation is the monostable multivibrator, which has only one stable state. When triggered into its other state, it will automatically return to its primary, or stable, state. This type of circuit is also known as a one-shot multivibrator.

NONSATURATED FLIP-FLOP

There are two major types of flip-flops—saturated and non-saturated. When the stages are switched from cutoff to saturation, it is a saturated circuit. Such circuits are slower in operation (lower in frequency) than nonsaturated circuits because of the storage time of minority carriers. On the other hand, a saturated flip-flop can switch more current.

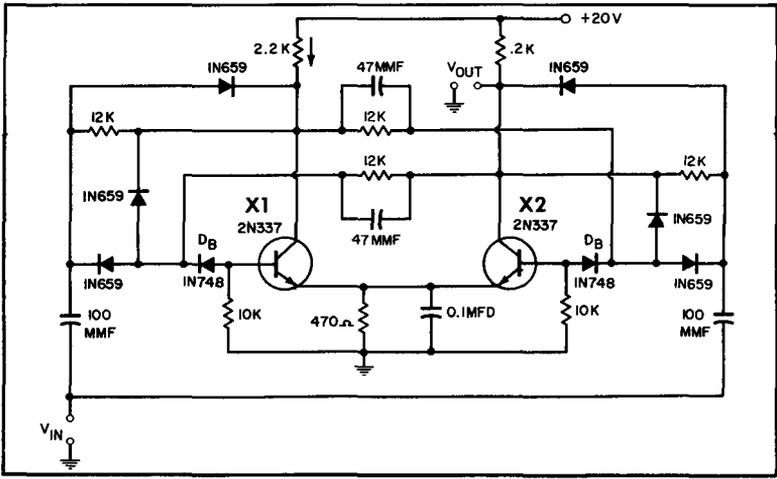


(A) Basic RC coupled flip-flop circuit.



(C) Basic flip-flop circuit.

TEMP °C	P W mμsec	RESO- LUTION mc	V _{IN} (p-p) volts	V _{OUT} (p-p) volts
25	150	2.0	6-9	9-12
125	200	2.0	6-9	9-12



(B) Nonsaturated flip-flop.

Nonsaturated flip-flop.

To permit pulses from a single source to trigger either transistor, steering circuits are used. The 1N659 diodes and resistors R_s form the steering circuits in circuit A.

Capacitors C_k are used to speed up circuit action. The diodes connected across R_s are used so that the circuit will respond at the maximum repetition rate. If a number of flip-flops are cascaded to form a binary counter, only the first stage, and possibly the second, need these diodes.

Negative base triggering is used for all flip-flops; for NPN transistors, negative pulses applied to the base turn an "on" transistor off. A flip-flop usually drives a number of circuits; therefore, its output must be sufficient to handle a fairly heavy load. When flip-flops are cascaded, the output voltage or current must be sufficient to trigger the next stage. The input-pulse width and amplitude are also important and will usually determine the input and cross-coupling capacitor values.

One technique for designing a nonsaturated flip-flop is to hold the transistors out of saturation with reference and clamping diodes. This technique is illustrated in circuit B, where diodes have been added to the basic circuit. During the time a transistor is on, diode D_c clamps the collector voltage above the base voltage by the reference voltage of D_b , thus keeping the transistor out of saturation. D_b passes more than enough current to control the collector current and voltage. When the transistor is off, D_c does not conduct and D_b still maintains a reference voltage but now passes only a very small current.

Test results of circuit B are shown in the chart. PW is the pulse width of the input measured at the 10% amplitude level; resolution is the maximum rate of the input pulses for a full output voltage.

Coupling capacitors, input capacitors, and steering circuits may be added to circuit C. This is essentially what has been done in circuit C; however, the input steering diode connects to the junction of D_c and D_b rather than to the base of the transistor, thus permitting smaller trigger voltages to be used.

MONOSTABLE MULTIVIBRATORS

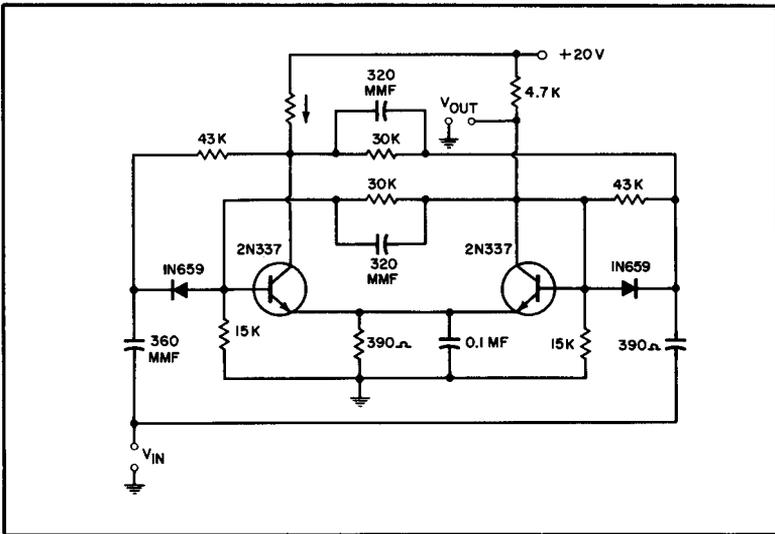
Both circuits shown here have only one stable state. When triggered, each circuit switches to the unstable state. This state is achieved by using cross-coupling between stages. Because of the time constants used, the circuit remains in the unstable state for a predetermined length of time, after which it reverts to its stable state. Because of this action, these circuits are useful as pulse standardizers.

SATURATED FLIP-FLOPS

Circuit A shows the component values and temperature performance data for a saturated flip-flop using 2N337 transistors. Only one 20-volt power supply is needed. Collector current is 3.5 ma.

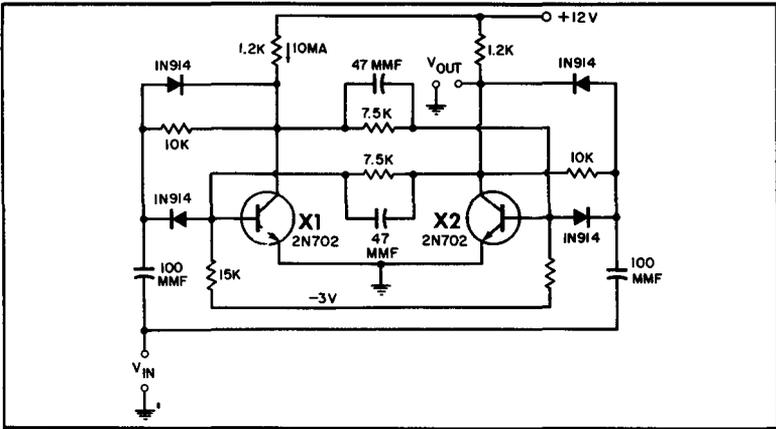
Circuit B shows the 10-ma saturated flip-flop circuit for the 2N702 double-diffused mesa transistor. The cross coupling and input capacitors are chosen for a maximum resolution rate at an output-to-input ratio greater than 1.0. V_{OUT} has a voltage swing of 10 volts, and two power supplies are used.

Circuit C demonstrates the advantages of low-storage-time mesa transistors. Two power supplies are used to operate the 2N706A at a collector current of 10 ma. Reliable operation at 10 mc is obtained over the temperature range of -55°C . to $+125^{\circ}\text{C}$. (V_{IN} less than V_{OUT}), driving another flip-flop through a buffer stage.



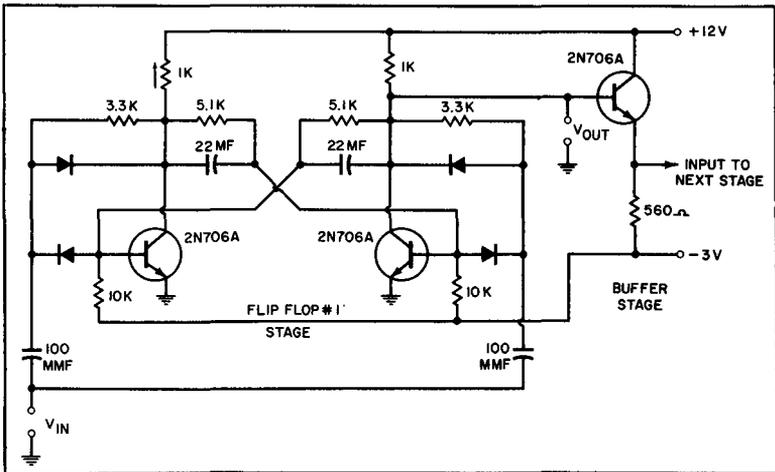
TEMP $^{\circ}\text{C}$	P W $m\mu\text{sec}$	RESOLUTION mc	$V_{IN(p-p)}$ volts	$V_{OUT(p-p)}$ volts
125	1000	0.25	8.0	14.7
25	400	0.25	4.0	15.3
-55	200	0.25	2.0	15.3

(A) Using the 2N337.



TEMP °C	P W mμsec	RESOLUTION mc	V _{IN} (p-p) volts	V _{OUT} (p-p) volts
125	100	4.0	8.5	10
25	100	6.3	6.0	10
-55	100	5.6	5.0	10

(B) Using the 2N702.



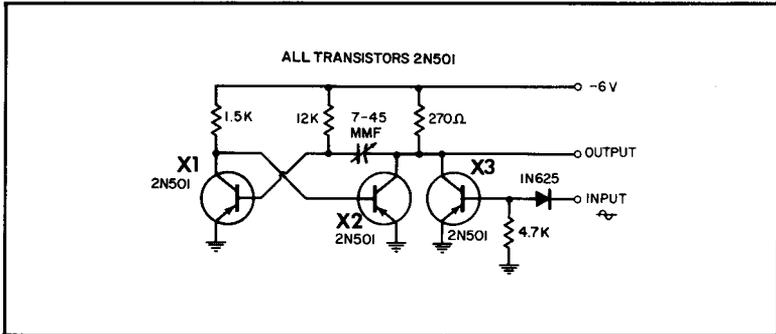
TEMP °C	P W mμsec	RESOLUTION mc	V _{IN} (p-p) volts	V _{OUT} (p-p) volts
125	50	10	4.0	6.1
25	50	10	3.2	6.1
-55	50	10	4.9	5.1

(C) Using the 2N706A.

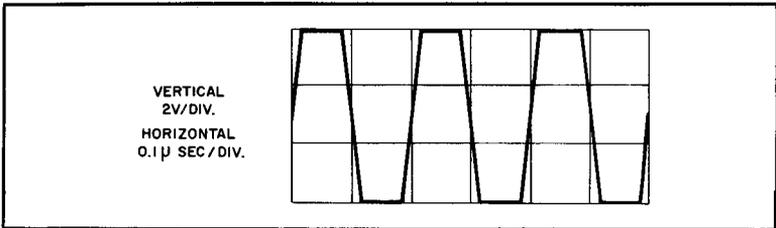
Saturated flip-flop.

DIRECT-COUPLED FLIP-FLOP

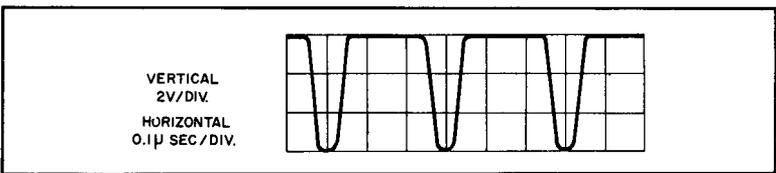
This circuit illustrates a monostable flip-flop multivibrator that can be triggered with a sine-wave input. The rise time of the output pulse is less than 18 microseconds. Output-pulse width is determined by the setting of the variable capacitor.



(A) Monostable multivibrator.



(B) 5-mc waveform.



(C) Output waveshape with 10-mc input.

Direct coupled flip-flop.

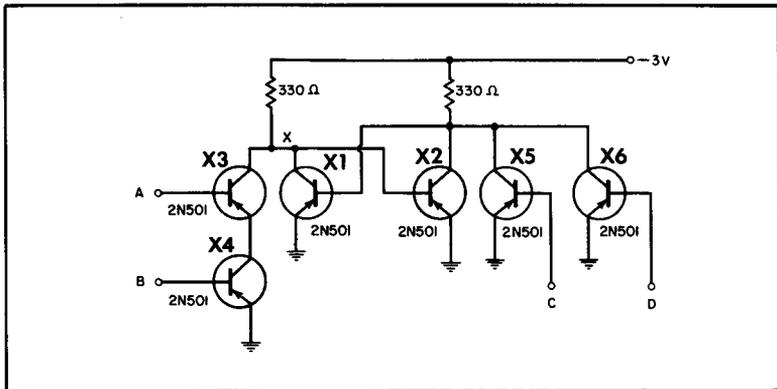
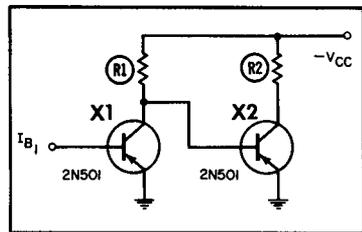
Output-pulse widths of less than 100 microseconds were obtained with a standard input pulse generator (or a sine-wave generator operating above 1 mc). Drawing B illustrates the output waveshape at 5 mc. A stable scale-of-3 counter has been achieved by feeding in a sine wave from 9 to 12 mc and adjusting the capacitor for a value of 30 mmf. The output waveshape in drawing C was obtained with a 10-mc input.

This circuit was found to be insensitive to supply-voltage variations ranging from -2 to -8 volts, and to temperatures up to 65°C . The same circuit, when triggered from a continuous sine wave of 4 to 6 mc, was found to count down by a scale of 2. One of its frequent applications is in computer systems requiring a countdown of pulse-generator repetition rates.

DIRECT-COUPLED TRANSISTOR LOGIC FLIP-FLOP

These figures show direct-coupled transistor logic circuits, which offer simplicity and the full use of transistor characteristics. No interstage coupling networks are needed because of the low saturation voltage of the 2N501. The main requirement of a

(A) Direct coupled switch.



(B) Set AND, reset OR.

Direct coupled transistor logic flip-flop.

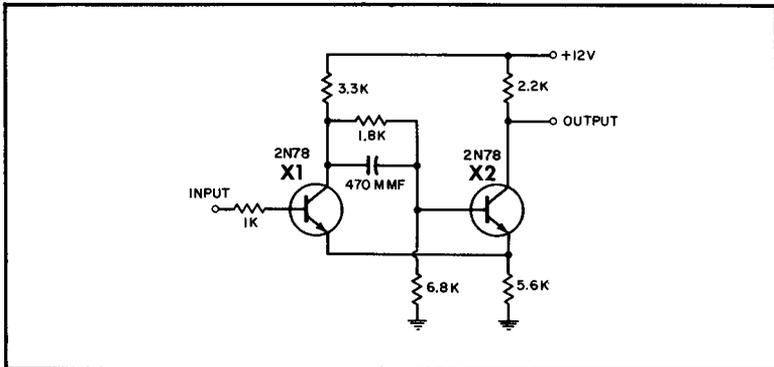
DCTL configuration is that the saturation voltage of the transistor, applied to the base of the second stage, drop to the cutoff level. Circuit A is a two-stage direct-coupled switch. The collector of X1 is coupled directly to the base of X2. In the quiescent state, X2 will be on (conducting) and X1 will be off (nonconducting). Upon application of sufficient base current (I_B), the collector voltage of X1 will reach a saturation level of less than .05 volt. This voltage is low enough to turn off X2.

If the output of X2 is coupled directly to the input of X1, a binary stage is formed. As shown in Part B, the DCTL flip-flop is set by an inverted AND gate (X3-X4) and reset by an inverted OR gate (X5-X6).

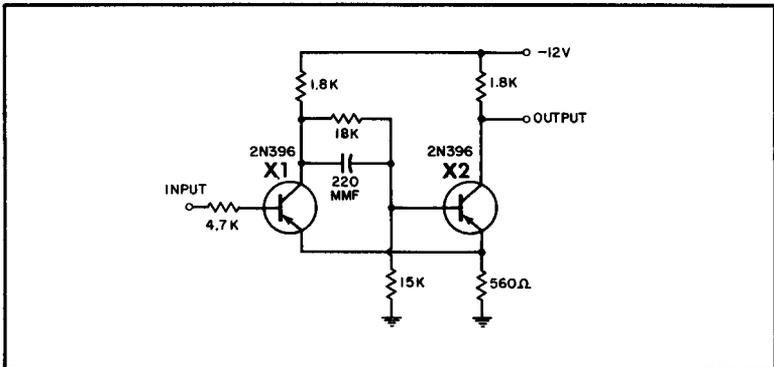
Assume X1 is off at the outset. X2 is then in an "on" state. If signals are present at A and B simultaneously, X3 and X4 will conduct, causing the voltage at point X to fall below .05 volt. This will turn off X2 and supply a base current to X1 which will turn it on, maintaining point X at less than .05 volt. The flip-flop is now said to be set. In order to reset the flip-flop and change the state, an input must be supplied at C or D.

SCHMITT TRIGGERS

The Schmitt trigger is a bistable R-C amplifier. In circuit A, when X1 is not conducting, the voltage at the base of X2 will be about 6.8 volts because of the three-resistor voltage divider



(A) 1-mc trigger.



(B) 500-kc trigger.

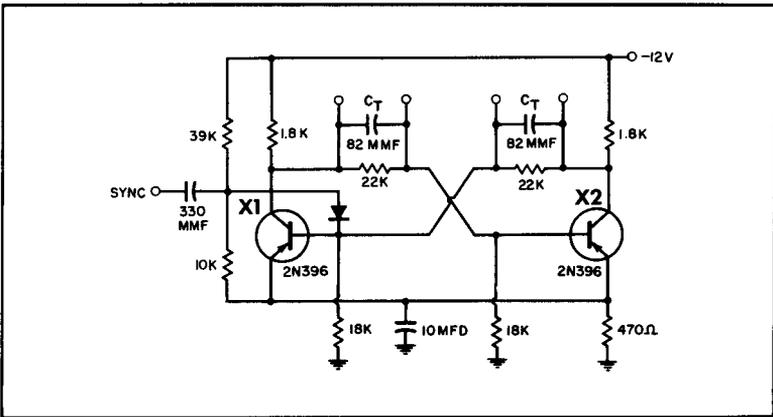
Schmitt triggers.

between the +12-volt source and ground. The emitter voltages of both stages are less than 6.6 volts. Thus, conduction will occur when the base is greater than 6.8 volts; X2 will conduct when the input signal is less than 5.2 volts. When the input voltage rises above this value, X1 starts conducting and X2 is cut off. When the input level drops to less than 5.2 volts, X1 goes into cutoff and X2 again conducts. This circuit operates efficiently at frequencies up to 1 mc, and provides an output of at least 2 volts.

The circuit in B operates up to 500 kc. X1 conducts with an input of -5 volts or greater, and X2 conducts when the input is more positive than -2 volts. The output always has a minimum-level change of 8 volts.

FREE-RUNNING (ASTABLE) MULTIVIBRATOR

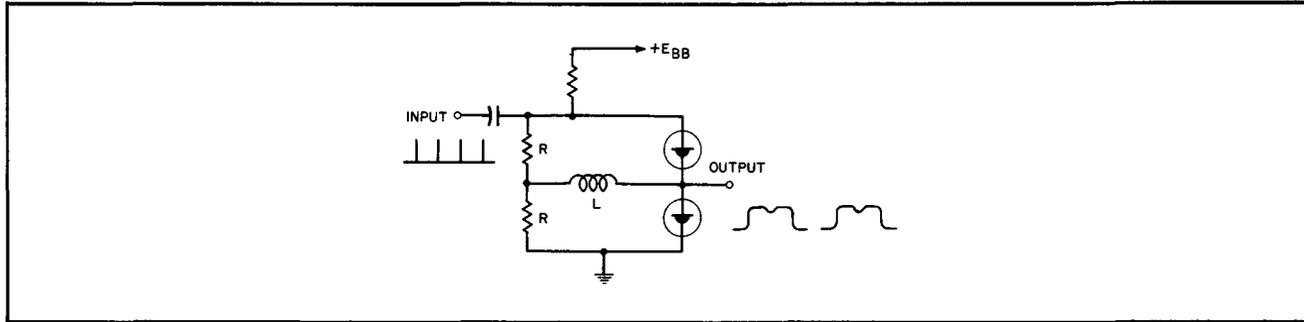
The free-running, or astable, multivibrator shown here has a frequency range from 1 cps to 250 kc, depending on the value of C_T . Synchronization at a specific frequency can be achieved by using sync pulses having an amplitude greater than 1.5 volts. The output has at least an 8-volt swing.



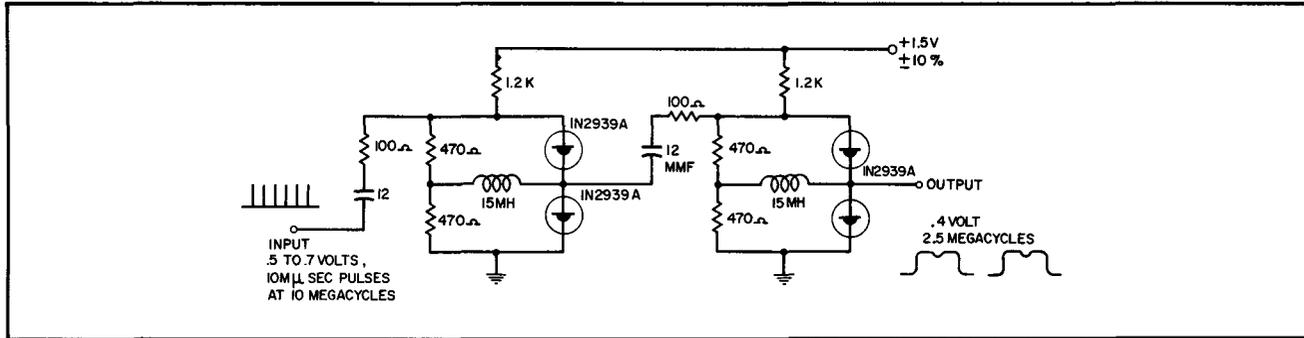
Free-running (astable) multivibrator.

TUNNEL-DIODE FLIP-FLOP

A tunnel-diode flip-flop which requires a trigger pulse of only one polarity is shown here. The supply voltage is of a value that will permit only one tunnel diode to be in the high-voltage state. The difference between the two tunnel-diode currents flows through the inductance.



(A) Basic flip-flop.



(B) Two-stage counter.

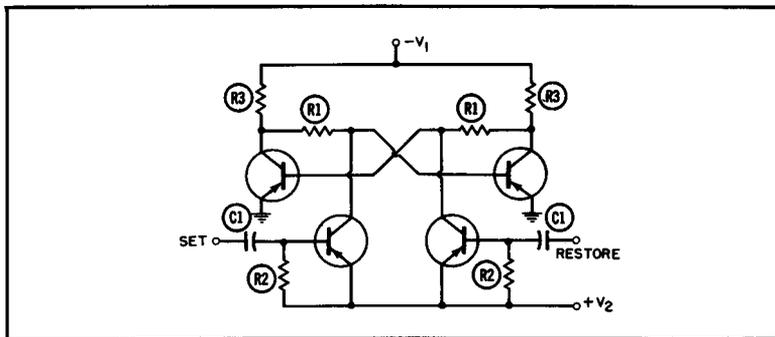
A positive trigger pulse causes the diode in the low-voltage state to switch to a high-voltage state. This action decreases the current through the inductance, resulting in the development of an induced voltage which changes through it. This voltage is of a polarity which changes the other tunnel diode to its low-voltage state. A pair of trigger pulses is required to complete one switching cycle.

The basic flip-flop circuit can be interconnected to form a counter, as in Part B. With the values of components and input pulses indicated, this counter will operate successfully up to 10 mc.

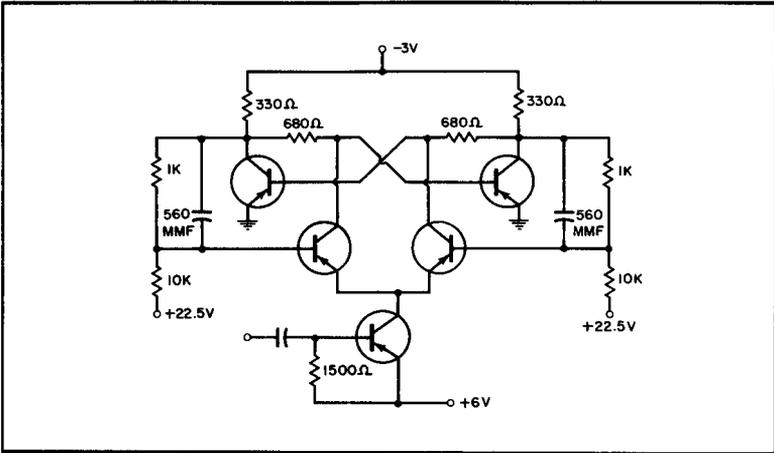
SBT SATURATING FLIP-FLOPS

Here's a circuit which utilizes gating to turn the transistor off instead of on. With the proper value of V_2 , the gate not only turns off the conducting transistor, but also supplies current to the load resistor of the nonconducting transistor in an amount the transistor itself provides when restored to its conductive state. This pseudo-collector current reduces the delay which normally precedes the turn-on transient. Both turn-off and turn-on delay are thus minimized so that an entire flip-flop transition, from the time the trigger pulse is applied to the end of the switching transient, can occur within 20 microseconds when an SB-100 surface-barrier transistor (SBT) is used.

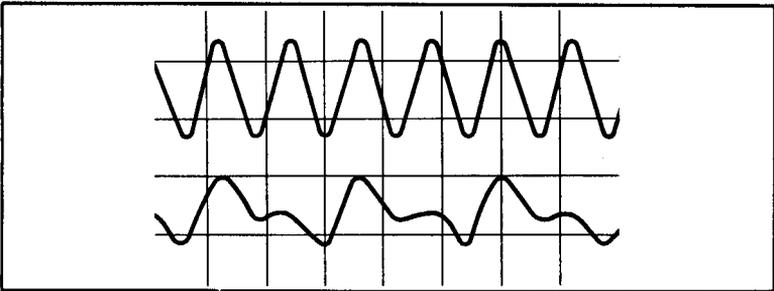
Circuit B shows a modification which can be used for a method of binary counting. The memory voltages for steering trigger pulses to the proper gate are provided by the 1,000-ohm resistors. These resistors, tied back to the 22.5-volt supplies through 10,000-ohm resistors, also prevent forward biasing of the collector diodes of the gates. Using SB-100 transistors, the circuit counts sine-wave inputs up to 55 mc. This circuit has operated satisfactorily



(A) Transistor gated off.



(B) Binary counting.



(C) Input-output waveforms.

SBT saturating flip-flops.

up to 70 mc with 2N501 microalloy diffused-base transistors (MADT).

Waveform response to a 50-mc input for complementing base-gated flip-flops is shown in Part C (vertical scale is 1 volt/division). The input waveform appears above the output waveform.

Section 5

POWER CONTROL

The device used most widely for both AC and DC power control is the PNPN switch known as the silicon-controlled rectifier, or SCR. It has many industrial-electronic applications, such as reversing and speed control for DC motors. In fact, it is rapidly replacing the thyatron tube for this and similar power-control applications.

Silicon-controlled rectifiers can be considered in many ways as the semiconductor equivalent of thyatron tubes. SCR's have a higher efficiency than thyatrons because the voltage drop across an SCR is approximately 1.5 volts or less, as opposed to about 15 volts for a thyatron. Hence, there is a tenfold reduction of power loss for a given load current. Also, flashover and arcing problems are reduced because no electron tubes are used, and there is far less heat dissipation. Moreover, equipment using SCR's needs no time delay in starting, because SCR's have no filaments.

In addition to its anode and cathode, the SCR has a gate. By controlling the phase of the gate signal with respect to the phase of the supply voltage, the firing (delay) angle of the gate can be held to any point in the cycle up to approximately 180° . Through control of the firing angle, the average power delivered to the load can thus be controlled. The magnetic trigger, a special magnetic amplifier with a controllable firing angle, is a useful device for firing the gate circuits of SCR's.

The controlled switch is a PNPN device related to the controlled rectifier. The controlled switch (CS) is similar to the silicon-controlled rectifier (SCR) in physical construction, theory of operation, and circuit applications. The CS, however, has a much greater firing sensitivity and is therefore useful in many low-level input applications not within the capability of the controlled rectifiers.

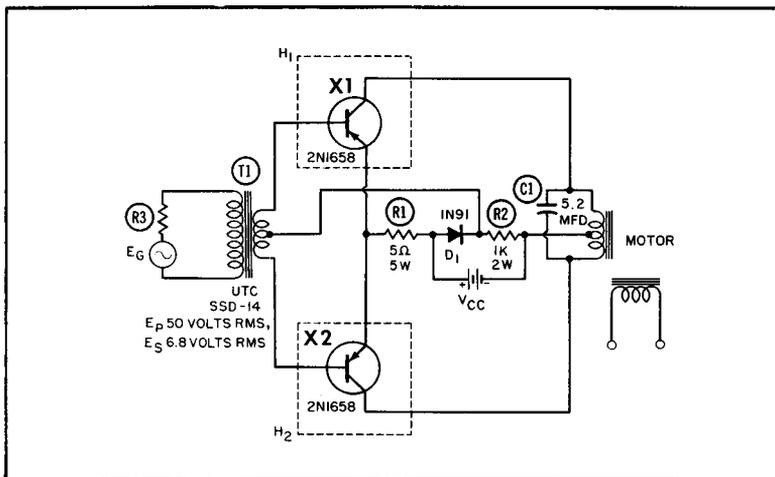
With an AC voltage source, the CS acts as a controlled half-wave rectifier, since it will block both the positive and the nega-

tive half-cycles until a positive control signal is applied to the gate. As long as the control signal is present, the CS will then conduct during the positive half-cycle and block during the negative half-cycle. When the control signal is removed, the CS will block both half-cycles again, since it automatically turns off at the end of each positive half-cycle. By proper timing of the applied control signal, the CS can be made to conduct for all or part of the positive half-cycle. Thus, proportioning control of the output, as well as on-off switching, is possible.

SIX-WATT SERVO AMPLIFIER

This six-watt servo amplifier has a frequency range of 40 to 40,000 cps using 2N1658 transistors, and provides a power gain of about 30 db. Mica insulating washers and heat sinks (aluminum plates 5" x 5" x $\frac{1}{16}$ ") are used. Both sides are in free air. Transformer T1 is a UTC SSO-14 or equivalent with a secondary DC resistance of 22 ohms and a secondary voltage of 6.8 volts rms, end to end. Primary voltage is 50 volts rms end to end, and primary current is 2 ma rms. R1 is 5 ohms $\pm 10\%$, 5 watts; and R2 is 1,000 ohms $\pm 10\%$, 2 watts.

D1 is a 1N91 or equivalent alloy-junction germanium diode. C1 is approximately 5.2 mfd, although this value varies with the motor design. This capacitor is used to correct the power factor of the motor-control field to unity under locked-rotor conditions. The two-phase induction servo motor is a Size 15 rated at 400 cps, 6 watts per phase. Its control field is designed for 35 or 36 volts



Six-watt servo amplifier.

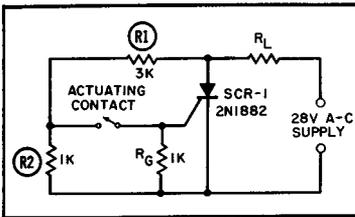
rms, end to end. R_c is the approximately 1,500-ohm output impedance of a 400-cycle generator.

The amplifier operates in a Class-AB mode because of diode D_1 , which also maintains the quiescent current at a constant value over the entire temperature range. With the power factor of the control winding less than unity under locked-rotor conditions, the motor will have a tendency toward single-phase operation, and the power output of the amplifier will be lowered.

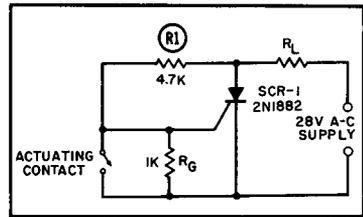
STATIC POWER SWITCHING

Semiconductor-controlled rectifiers are often used where a large amount of power is to be switched, but the contact current and voltage must be kept low for simple and reliable operation. The silicon-controlled switch (CS) or silicon-controlled rectifier (SCR) provide a solution to this common control problem. Both are PNP transistors. The sensitive actuating contacts need supply only the gate firing power, which can be as low as 50 microwatts (1 volt, $50\mu\text{a}$). The CS or SCR will directly provide up to 100 watts or more for the output load.

Three simple arrangements for switching power to loads are shown. The circuit in Part A of the diagram will provide load power when the actuating contact is closed, but not when it is open. The circuit in Part B provides the reverse of this action; power is supplied to the load only when the contact is open. If desired, both circuits can be made to "latch" by operating with DC instead of the AC supply indicated. In Part A, voltage divider

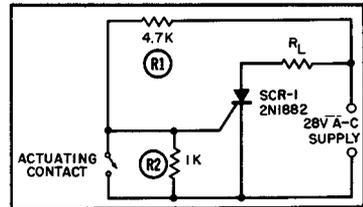


(A) Load current with switch closed.

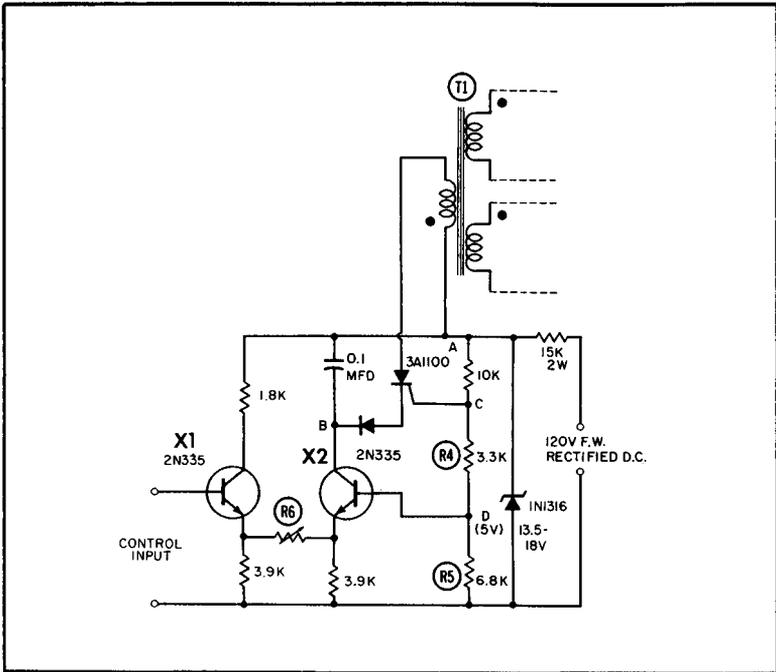


(B) Load current with switch open.

Static power switching—SCR.

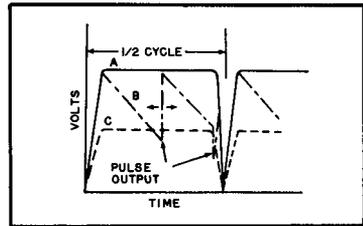


(C) Load current with switch open.



(C) Control circuit with balanced input amplifier.

(B) Output waveforms.



Time-variable SCR control.

formance of the device. When the SCR anode voltage is negative, a positive gate signal substantially increases leakage current and therefore the dissipation. Pulse firing prevents these two undesirable conditions.

A time-variable pulse generator designed for firing high- as well as low-power SCR's is shown in Part A of the diagram. This circuit will deliver 5-volt, 200-ma pulses of 6 μ secs or longer. Pulse-transformer output isolates the two SCR's being triggered. As shown, the circuit is designed for 60-cycle operation. Control is achieved from approximately 10° to 180° of the AC half-cycle.

Since the circuit consumes very little power, a subminiature zener diode can be used. The 15K current-limiting resistor has the highest dissipation, which is approximately 0.7 watt at 120 volts AC. A 2N335 silicon transistor controls the charging current to the 0.1-mfd capacitor, and also provides electronic control of the time delay. Since the transistor is a constant-current device, the charging rate is linear, not exponential. The time delay for firing is inversely proportional to the controlling input current at the base of the 2N335 transistor. A variable resistor can be used in place of the transistor if manual control is desired.

The circuit operation is as follows: AC line voltage is rectified by the D1 through D4 portion of the bridge circuit so that pulsating DC is obtained at point A. The 2N1316 zener diode and the 15K resistor limit the voltage at point A, as shown by the square waveform of Part B. A divider, consisting of two 10K resistors, supplies a bias voltage equal to half the zener voltage to the gate of the 3A16.

At the beginning of each half-cycle, capacitor C is discharged, and the voltage at point B is equal to the zener voltage. Thus, the cathode of the 3A16 is positive with respect to its gate, and the CS is biased off. The 2N482 diode is also reverse-biased to minimize loading effects on the timing capacitor and to prevent exceeding the cathode-gate voltage rating of the 3A16. As the collector current of the transistor charges the capacitor, the voltage at point B drops toward zero. When it falls below the fixed bias on the gate by an amount sufficient to fire the 3A16, the CS will turn on, discharging the capacitor into the pulse-transformer primary.

If, for any reason, the capacitor does not charge sufficiently to fire the CS before the end of the half-cycle, the CS will fire when the voltage at point A drops toward zero at the end of the half-cycle. When the voltage at point A drops to zero, the gate bias voltage for the 3A16 will also be zero. However, with the capacitor partially charged, the voltage at point B goes negative, causing the CS to fire and discharge the capacitor. Timing for the next half-cycle therefore starts with the capacitor discharged.

It is desirable to apply the AC voltage for the control circuit directly across the SCR's being controlled. This removes the supply voltage from the control circuit after the SCR fires, and thereby eliminates unnecessary dissipation in the control circuit.

The impedance reflected into the pulse-transformer primary should be low (20 to 50 ohms) and primarily resistive. Termination of the secondary windings as shown in Part A is desirable. The input impedance of the rectifier being controlled will affect the termination.

For low-power units, R1 and R2 should be 100 ohms. High-power units such as the C35, which require a relatively high firing current, can be driven directly from the secondary windings. Series resistance of the pulse-transformer secondary windings will provide the necessary decoupling, without the need for R1 and R2. The 0.1-mfd capacitor should be replaced by a 0.2-mfd unit to furnish the higher energy requirements of high-power SCR's.

The circuit in Part C is the same as in A except that the single-control transistor is replaced by a pair of 2N335 transistors connected as a balanced input amplifier. R2 in A is replaced by voltage divider R4-R5, which provides a reference of 5 volts to the base of X2. The balanced amplifier is self-compensating for temperature variations of transistor parameters.

The two 3.9K resistors in series with the emitters of X1 and X2 act as constant-current sources, establishing the total emitter current of both transistors at approximately 2 ma. With a control input voltage of 5 volts applied to the base of X1 (the same as the reference voltage applied to X2) the two transistors share equally the total available emitter current of 2 ma. X2 provides a charging current of 1 ma to the 0.1-mfd capacitor. Under this condition, R6 has no effect on the circuit, since the current through it is zero.

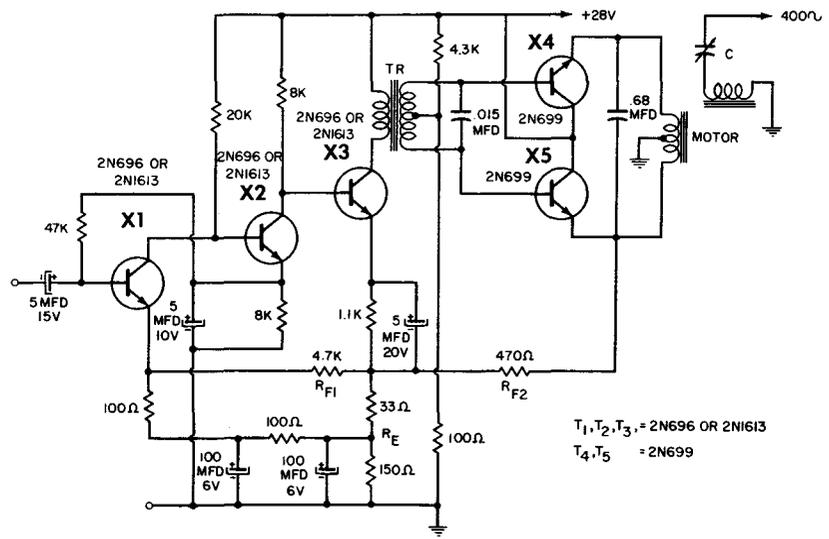
When the control input voltage is raised above 5 volts, X1 requires more current, taking it from X2 through resistor R6. When the control voltage is below 5 volts, the current through X1 is reduced and the charging current through X2 increases. The center of the proportioning-control voltage range is established by the reference voltage applied to the base of X2. A zener diode or any other voltage reference may be used in place of the simple voltage divider if greater reference stability is required.

Resistor R6 controls the gain of the balanced amplifier and can also be used to adjust the proportioning-control voltage range above and below the 5-volt center. When R6 is zero ohms, gain is maximum. Pulse delay is approximately 10° (almost full output) when the control input voltage is 4.9 volts, and 170° (almost no output) with a 5.1-volt input. Thus, a 4% input-voltage change can control the SCR from essentially zero to full power output. Increasing R6 reduces the gain and broadens the proportioning range without altering the range center.

In the control circuit shown in Part C, an increase in control voltage decreases the power output. By applying the reference voltage to the base of X1 and the control input to the base of X2, the control sense can be reversed if desired.

Two-watt servo amplifier.

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TWO-WATT SERVO AMPLIFIER

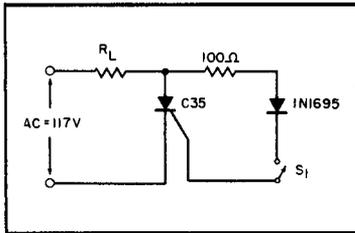
This servo amplifier has a gain of 1,000 and an input impedance of more than 10K ohms. It operates over an ambient temperature range of -55°C. to $+125^{\circ}\text{C.}$ and has a continuous power output of 2 watts.

The first three stages are direct-coupled in order to reduce the number of time constants. This increases the phase margin for use in gain-stabilizing feedback. Direct coupling has the additional advantage of permitting a large bias resistor for X1 in order to increase the input impedance while retaining operating-point stability by DC generation.

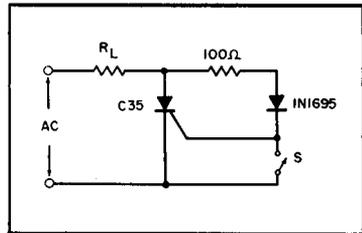
X3 is transformer-coupled into the common-collector output pair consisting of X4 and X5. Center-tapped operation utilizes the positive temperature coefficient of the motor winding to stabilize the quiescent operating point of X4 and X5.

AC SWITCH FOR THE SCR

Two circuits are shown for the C35 controlled rectifier. This C35 SCR is a three-junction semiconductor for use in power-control and power-switching applications requiring blocking voltages

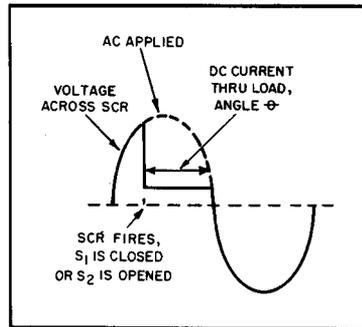


(A) Series switch.



(C) Shunt switch.

AC switch for the SCR.



(B) Circuit waveform.

of up to 400 volts and load currents of up to 16 amperes. Series and parallel circuits may be used for higher power applications.

The CR reverse characteristic is similar to that of a normal silicon rectifier, in that both represent essentially open circuits with a negative anode-to-cathode voltage. The forward characteristic is such that it will block the positive anode-to-cathode voltage below a critical breakover voltage if no signal is applied to the gate terminal. However, by exceeding the forward breakover voltage or applying an appropriate gate signal, the device will rapidly switch to a conducting state and present the characteristically low forward voltage drop of a single-junction silicon rectifier.

Part A shows a simple series switch S, which applies an AC signal to the gate. R limits this gate current to a safe value, and the diode prevents the application of inverse voltage between the gate and cathode during the nonconducting cycle. Load R can be of any value within the limits of the SCR. For the C35 series, the maximum current is 16 amperes average at a forward drop of less than 0.9 volt.

As long as S is open (Fig. A), the SCR will not fire when AC is applied. Closing S allows the positive alternation to cause conduction, since the gate fires the SCR and its anode is positive. As shown in Part B, the SCR fires for 135° and will not fire on the negative alternation. Thus, closing S will control the firing point for each positive alternation, and DC current will flow through the load.

It is possible to use DC on the gate to control the firing point. Or, as in Part C, the circuit can be fired by opening S where the switch is from the gate to the cathode.

In circuit A, the load current can be interrupted by opening S or by the negative anode voltage. In B, the load current can be interrupted by closing S or by the negative anode voltage.

Section 6

TIMERS

Timing circuits have an important place in industrial electronics. Applications range from delay elements which permit large power tubes to heat up before the anode supply is applied, to a sequential-circuit control for use with welders. Sweep circuits like those in oscilloscopes, sweep-signal generators, or light flashers are, in a sense, also timing circuits.

One can divide timers into two circuit elements—active (such as the tunnel diode, transistor, or unijunction), and reactive (usually a capacitor, although it could be an inductor). In an RC circuit, for example, a capacitor charges exponentially through a resistor. At some point along the charging curve, the voltage across the capacitor is sufficient to fire the active element and produce an output. In this way, various time periods may be produced as different values of capacitance are switched into use.

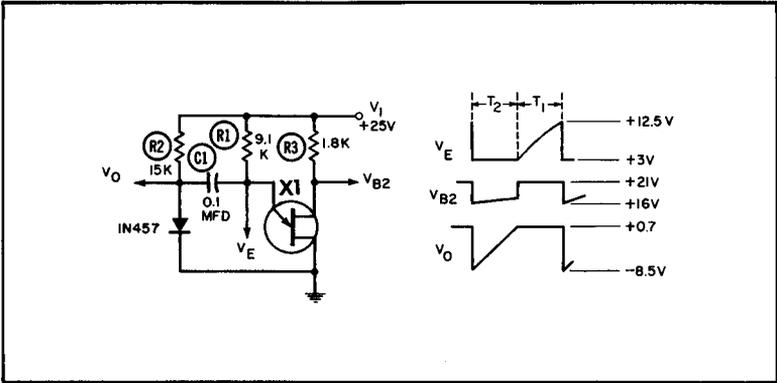
For more precise timing, a stable oscillator can be used as a signal source. By clipping and differentiating, pulses can be produced; if these are counted in a digital fashion, quite accurate timing can be accomplished.

UJT TIMER CIRCUITS

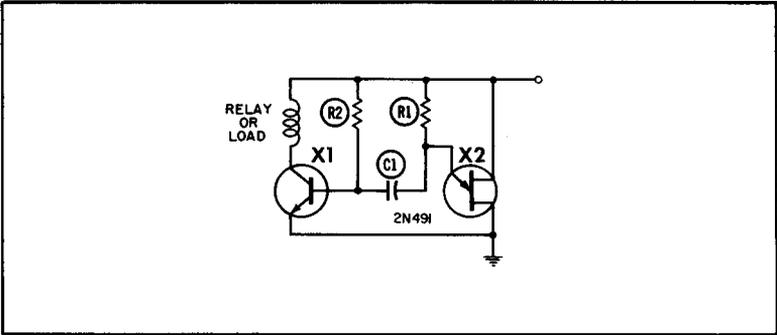
Unijunction transistors (UJT) are useful as timing switches in transistor circuits. Part A shows a unijunction-transistor multivibrator circuit with a frequency of about 1 kc. The length of time the unijunction transistor is off (no emitter current flowing) is determined primarily by the value of R_1 , while the value of R_2 determines the UJT "on" time.

An NPN transistor may be direct-coupled to the multivibrator by replacing the diode, as shown in Part B. The advantage of this circuit is that the load does not affect the timing of the multivibrator.

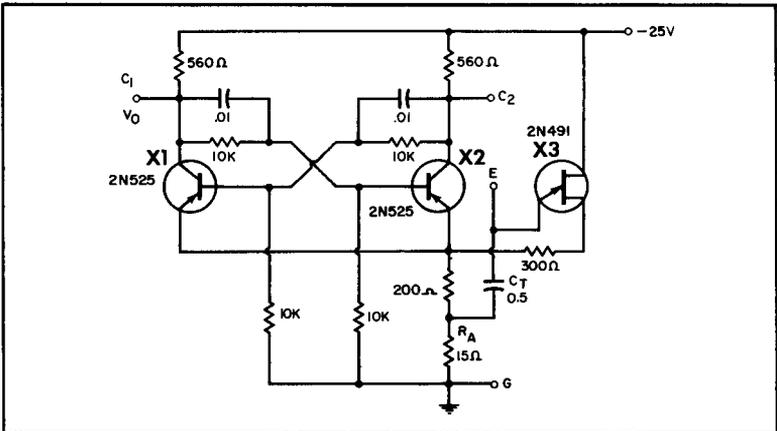
The unijunction transistor can be used in conjunction with conventional PNP or NPN transistors to obtain versatile timing



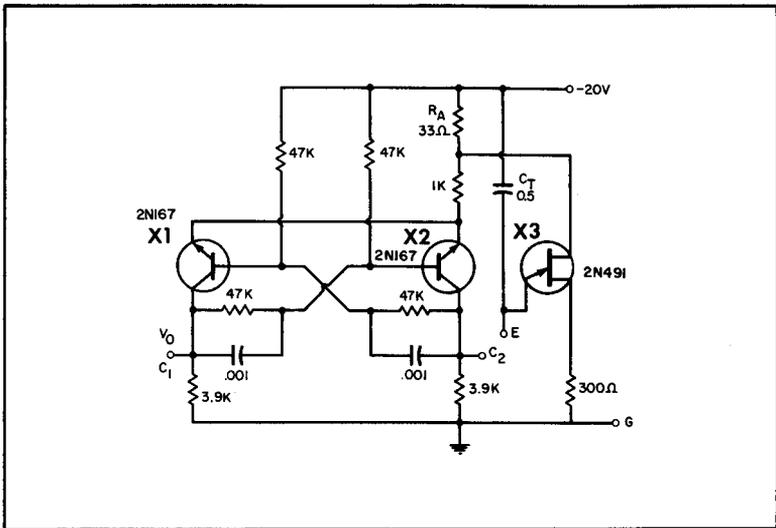
(A) UJT multivibrator with waveforms.



(B) UJT multivibrator driving an NPN transistor.



(C) PNP transistor timing circuit.



(D) NPN transistor timing circuit.

UJT timer circuits.

circuits such as symmetrical and unsymmetrical multivibrators, one-shot multivibrators, variable-frequency oscillators, and time-delay circuits. The advantages of these circuits include: (1) the output at the collector of each transistor is nearly an ideal rectangular waveform, (2) the circuits will tolerate large variations in transistor characteristics, (3) the circuits are not prone to "lock-up" or non-oscillation, (4) the timing stability is excellent, and (5) a single small timing capacitor can be used, avoiding the need for electrolytic capacitors in many applications.

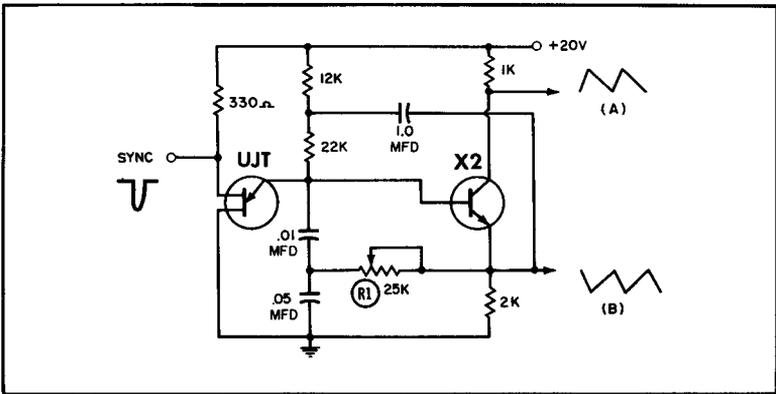
The hybrid timing circuits can use either germanium or silicon transistors. Basic circuits using PNP and NPN transistors are shown in Parts C and D.

In both of these circuits, the junction transistors form a conventional flip-flop, with the unijunction transistor serving the timing and triggering functions. Each time the unijunction transistor fires, the discharge current from capacitor C_T develops a pulse across R_A which triggers the flip-flop from one state to the other. The basic circuits will operate at frequencies from about 1 cps to 500 cps and at temperatures above 75°C . Frequencies from 1 cycle per minute to 100 kc can be obtained by proper choice of C_T and R_A and by suitable flip-flop design. The operating-temperature range may be extended to 150°C . by the use of silicon transistors.

SAWTOOTH-WAVE GENERATOR

In this unijunction generator, NPN transistor X2 is in a state of conduction while the unijunction (UJT) is normally cut off. When a negative-going sync pulse is applied to the base of the UJT, the cutoff bias is overcome and the UJT conducts from +20 volts, through the 12K and 22K resistors, to ground via the UJT.

Because of the UJT conduction, the increased IR drop across the 12K and 22K resistors will cut off transistor X at its base. X's voltage—going positive at the collector and negative at the emitter—is taken off at points A and B, as represented by the waveforms. Outputs A and B are 6 and 10 volts peak-to-peak, respectively, in a frequency range of 350 to 600 cps.



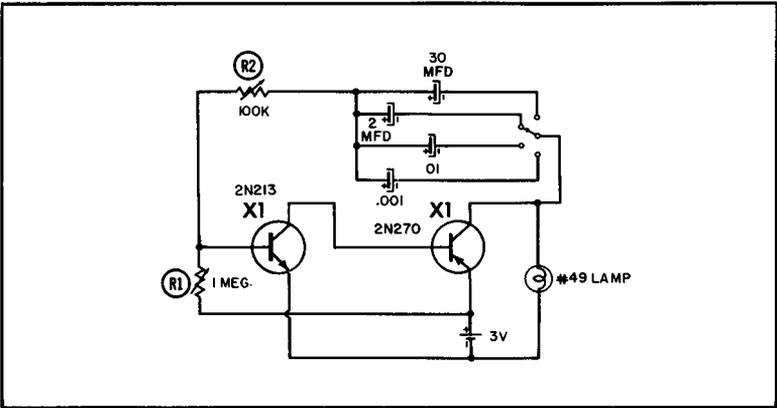
Sawtooth wave generator.

STROBOSCOPES

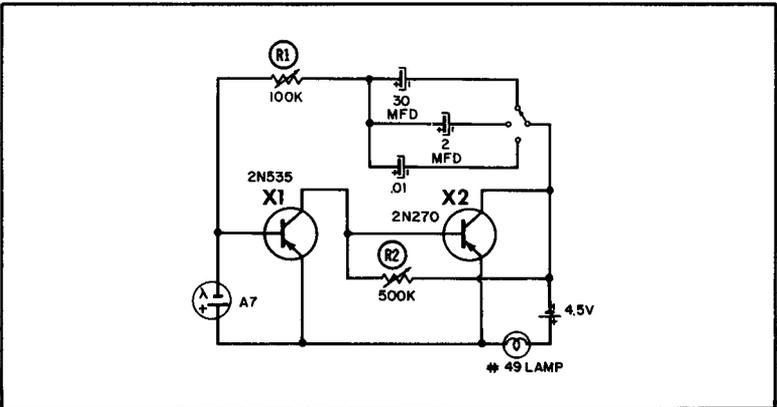
Stroboscopes are light sources which, because they can be turned on and off rapidly, appear to stop motion. Thus, a motor turning at 1,200 rpm will appear to stand still if viewed under a light flashing 1,200 times per minute. A light flashing 1,199 times a minute will make the motor appear to rotate at 1 rpm. At 1,201 times a minute, the light appears to cause a reverse rotation of 1 rpm. Among the many uses for stroboscopes is the measurement of frequency response of photocells.

From 10 through 6,000 sharp sine-wave flashes per second can be obtained on the four-range stroboscope shown in Part A. The 30-mfd selector-switch position is the low range. Increasing R2 increases the flash duration, and increasing R1 increases the period.

Another stroboscope design, shown in Part B, uses a photocell to receive the positive feedback from the output circuit and thereby



(A) A simple stroboscope.



(B) Photocell stroboscope.

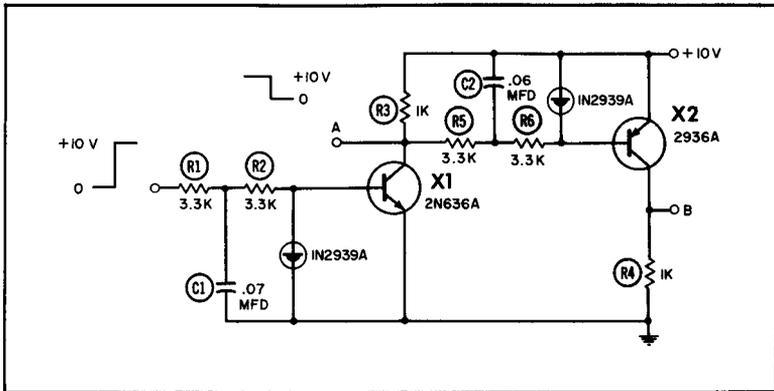
Stroboscopes.

provide the oscillatory flashes. The lamp must be mounted directly on the photocell (or close to it) in order for the circuit to oscillate. Both designs make versatile stroboscopes out of ordinary components.

TUNNEL-DIODE TIME DELAY

In this circuit, a positive-going input signal across C1 and R1 will charge C1. When C1 reaches the avalanche rating of the tunnel diode, TD1 will conduct and apply the necessary bias to X1, which will now conduct. Thus there is a delay of about 120 microseconds between the input and output signals.

When X1 conducts, its collector voltage (normally +10 volts) drops to a very low value. This negative-going voltage overcomes

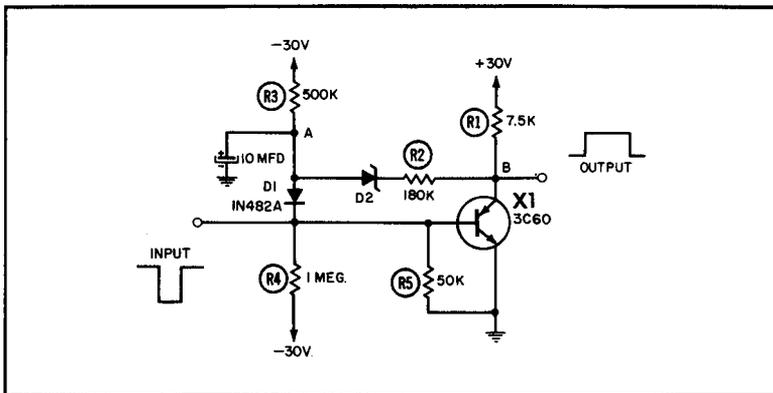


Tunnel-diode time delay.

the bias of the other tunnel diode and causes conduction. Now that its forward bias has been established, transistor X2 can conduct. Thus, by adding an odd number of stages connected in a loop, it is possible to produce a multiphase oscillator.

TRIGISTOR DELAY TIMER

This circuit shows a one-shot multivibrator or delayed-pulse generator using a PNP transistor (*Trigistor*), which can provide accurate timing for delays of up to 10 seconds. The *Trigistor* characteristics have only a small effect on timing, and accuracy is determined essentially by the stability of the 10-mfd timing capacitor and the supply voltage. With the values shown, this circuit will provide a one-second rectangular pulse output.



Trigistor delay timer.

With the circuit in its quiescent condition, the *Trigistor* is on. Point B is at 1 volt, and point A is at -11 volts due to the voltage-divider action of R2-R3 and the 5-volt zener diode. The 1N482A is connected in the reverse direction. R4 and R5 provide bias stabilization.

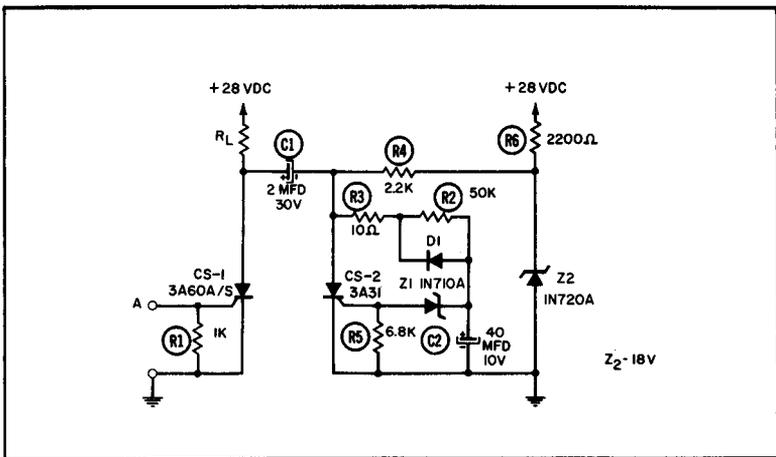
When a negative trigger pulse is applied to the input, the *Trigistor* is turned off. Point B rises to about 30 volts, and the capacitor begins to discharge through R1, R2, and the zener diode. When point A reaches $+1.5$ volts, D1 conducts and the *Trigistor* turns on, bringing point B back to $+1$ volts. The capacitor then charges through R3, back to its quiescent voltage of -11 volts.

INTERVAL TIMER WITH HIGH-LEVEL OUTPUT

Control circuits sometimes require a timer with a high-level output. Semiconductor-controlled rectifier SCR-1 in this circuit provides 1 ampere to the load for one second, using a 28-volt DC supply.

The timing cycle is started by applying an input pulse to point A. (A 5-microsecond or longer pulse with a minimum amplitude of 1 volt is required.) This pulse turns on SCR-1, which in turn supplies power to the load. At the same time, SCR-2 is turned off by the action of commutating capacitor C1, and timing capacitor C2 commences to charge through R2, R3, and R4. Zener diode Z2, which is used to establish a fixed charging-voltage source, minimizes the timing error due to variations in the source voltage.

When the charge on C2 reaches approximately 7.5 volts, Z1 will conduct sufficiently to cause SCR-2 to fire. Using the values



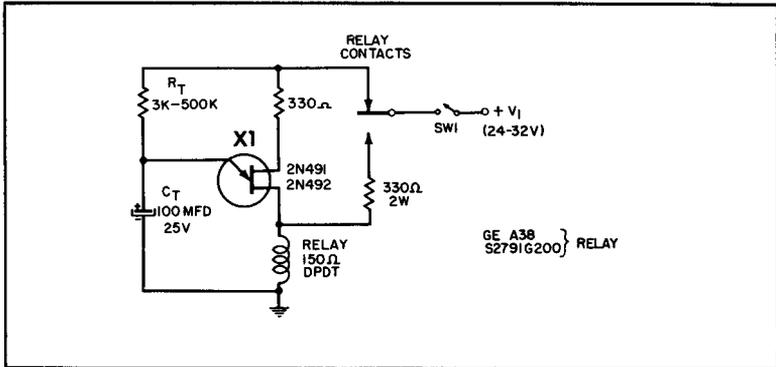
Interval timer with high-level output.

shown, this occurs one second after the initiating pulse, and the action of commutating capacitor C1 turns off SCR-1. Power is thus removed from the load. C2 discharges rapidly through diode D1 and R3, so that total recycle time is less than 1 millisecond.

A short pulse thus turns on the power to the load for a period determined by C2 and its charging-path resistance. This technique takes advantage of the high current-handling capability of the controlled switch. In addition, the circuit can be actuated directly from a low-level pulse; because of the inherently high gain of the SCR, no intermediate amplifiers are needed.

UJT TIME DELAY

This figure shows a unijunction transistor (UJT) used as a time delay. When the switch is closed, the capacitor charges through R_T until the UJT fires. The resultant current through the relay coil closes its contacts. A double-pole relay is often used so that one set of contacts will hold the relay closed while the other set is used for control. A fast-acting relay with low coil resistance is required.



UJT time delay.

The time delay is three seconds with an R_T of 3K, and 500 seconds (over eight minutes) when R_T equals 500K. In other words, a delay of about one second is obtained for each thousand ohms of timing resistance.

Section 7

INDICATORS

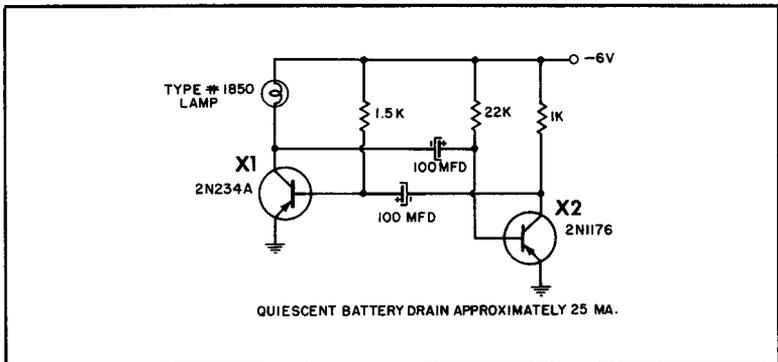
Indicators are neon or incandescent lamps used to show the on or off state of a given circuit (somewhat like a pilot light). They are very important in computer circuits such as counters. In this application, the indicators actually show, by visual means, what number is held in the counter.

In tube circuits, the voltage and current are high enough to light a neon lamp or heat up an indicator-light filament. But in solid-state circuits, the applied voltage is usually too low for a neon lamp, and the current is too low for lamp heaters. Thus special techniques, discussed in this section, are used.

LIGHT FLASHER

Using a 2N234A and a 2N1176 in a free-running oscillator circuit, this transistorized light flasher provides a flash repetition rate of about 60 per minute. The low quiescent current drain of about 25 ma assures long life, and the transistors do not require heat sinks. A single 6-volt source is adequate.

Reducing the value of the capacitors will increase the flash repetition rate, whereas increasing their value will decrease the rate.



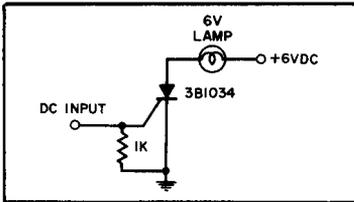
Light flasher.

LAMP DRIVERS

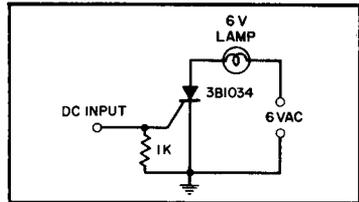
Lamp drivers are used to indicate the condition of a counter, logic circuit, or shift register or to light a lamp in many applications. Three methods of lighting 6-volt lamps are shown here. These are typical approaches to using semiconductor-controlled rectifiers (SCR'S) in lamp-driving circuits. The circuit in Part A takes advantage of the bistable memory characteristic of the SCR when used with a DC voltage supply. The lamp and SCR are in series with the DC supply. The SCR can be triggered on by a positive pulse or a DC voltage level at the input terminal. For the 3B1034, the triggering requirement is 2 volts. Once triggered, the SCR will remain on until reset by momentarily interrupting the anode current, which turns off the lamp. Just as with a thyatron, the SCR gate regains control if an AC anode voltage is used.

In Part B, an AC supply is used and the circuit no longer has a memory. When a DC signal is applied to the input, the SCR will pass current to the lamp during each positive half-cycle of the supply. When the input signal is removed, the SCR turns off on the first negative half-cycle—remaining off until an input signal is again applied.

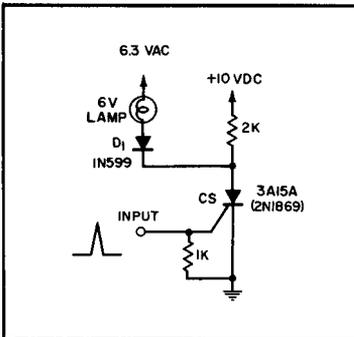
The SCR acts like a high-gain power transistor—with the additional advantage of eliminating a DC power supply for the lamp



(A) DC pulsing—memory.



(B) DC pulsing—no memory.



(C) DC and AC pulsing—memory.

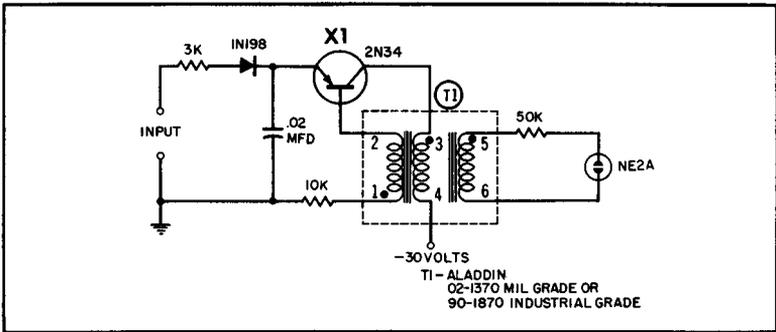
Lamp drivers.

circuit, since the SCR rectifies the lamp current.

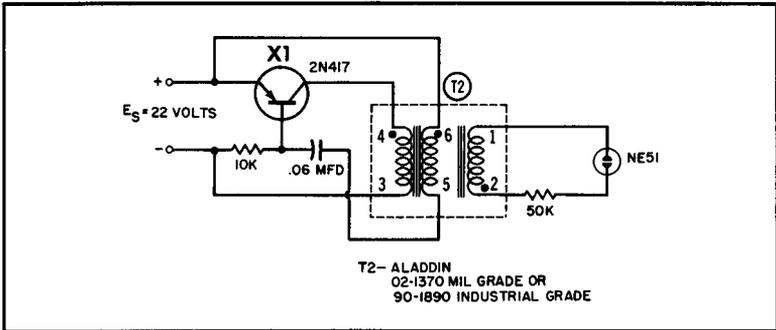
In the circuit in Part C, memory action is achieved by combining DC and AC supplies. Two advantages are thus provided. First, the lamp power is obtained from the AC supply, reducing the DC power requirements. Second, only a small amount (5 to 10 ma) of DC load current is necessary to hold the SCR on when the AC supply is negative. To turn off the SCR, it is necessary only to interrupt the relatively small DC anode current.

NEON LAMP DRIVERS

Neon lamps in computers or data-processing circuits with vacuum tubes have a high enough voltage to fire the neon light. But neon indicator lights in transistorized data-processing systems present a problem, because the 60 to 90 volts needed to fire a neon tube is not easily available. However, if as little as 12 volts DC is present, this problem can be solved by using a transistor oscillator and a tiny step-up transformer for each bulb.



(A) Collector to base feedback.



(B) Collector to emitter feedback.

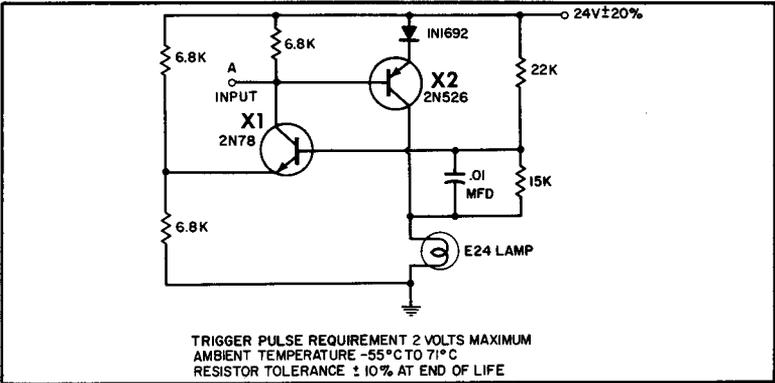
Neon lamp drivers.

Two typical oscillator circuits are shown, using miniature transformers to produce a voltage output large enough to light a neon bulb. Part A shows a transistor oscillator circuit employing collector-to-base feedback. The circuit does not go into oscillation, however, until a signal is applied to the input. Thus, the 30-volt supply may be permanently connected, and oscillation controlled, by the presence or absence of a low-voltage signal or trigger pulse. The circuit will go into oscillation and light the bulb when the input is as low as +3 volts with respect to ground.

The transistor oscillator circuit in Part B employs collector-to-emitter feedback. Operation is similar to that of a free-running blocking oscillator operating at a 50% duty cycle. The waveform is thus more like a square than a sine wave. Lighting of the bulb is controlled entirely by the presence or absence of the 22-volt supply; no trigger voltage is needed.

INDICATOR LAMP DRIVER

In this figure, two transistors are used as a lamp driver for a computer indicator. Use of complementary transistors keeps standby (off) current low. The circuit is bistable, and requires input pulses of 2 volts maximum to light the lamp. Applied at Point A, a negative pulse turns the lamp on. Because of circuit regeneration, the lamp stays on. A positive input pulse turns the circuit off.



Indicator lamp driver.

Section 8

PHOTOELECTRICS

Solid-state devices are replacing some of the older, more familiar phototubes for many applications, including use as controls and sensors for computers. Punched paper tape and punched cards, for example, are often read by a matrix of photovoltaic cells. Here the reliability and smallness of solid-state sensors is important. As the light shines through the holes, different photocells are excited and translate the punched holes into electrical signals. Other industrial devices use photoelectrics to shut off machines when the operator is in danger, and solar cells operate electronic equipment in remote areas and on satellites.

A typical industrial photoelectric use is in paper loop control. Here the drive motors must keep a fixed loop between the paper rolls so the printing equipment will not jam. If the loop falls low enough to break the beam of light, the drive motor will slow down. If the loop is so short that it interrupts the upper beam, the motor will speed up. In the same way, computer tape transports use two photoelectric devices.

Light beams and photoelectric relays are also used in alarm systems. The photoelectric alarm consists of a projector and a receiver. A low-visibility beam, modulated at a specified frequency, is projected across the protected area. An infrared filter makes the beam invisible, even in the presence of smoke. Any interruption of this "black light" immediately triggers an alarm circuit. Attempting to bypass the system with another light beam; tampering with the projector, receiver, or housing; or opening a line will also trip the alarm circuit.

Photoconductive and photovoltaic devices as well as phototransistors are all used in these circuits. Photoconductive devices are thin layers of semiconductor material such as selenium, silicon, cadmium sulfide, lead sulfide, or lead selenide sealed in glass. When light falls on the cell, the resistance of the material decreases and the current flow through the load increases. This current flow can be amplified for control, or it is possible to use a

sensitive relay which closes when the current flow increases and thus controls a large amount of power through the relay contacts.

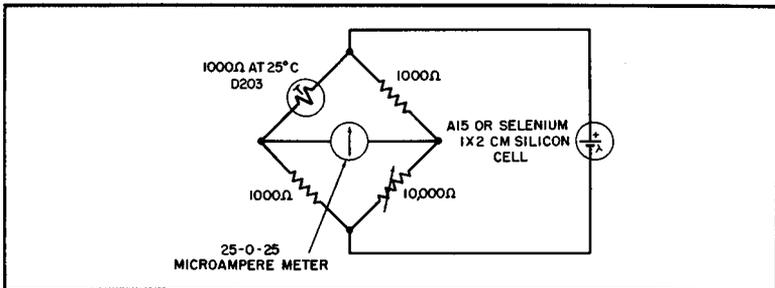
Photoelectric cells are also made from semiconductor materials, but they produce a voltage when light is applied. Because of this, they require no external power; actually, they convert light energy into electrical energy. An example of the use of photovoltaic cells is the installation of a large number of these cells to provide electricity for rural telephones. Several semiconductor compounds may be used for these cells, including silicon and selenium.

A silicon photocell generates energy by use of a PN junction to produce electrical energy from light. Pure silicon is a poor electrical conductor. However, by adding small amounts of impurity material to the silicon crystal, electron conduction will occur.

Classed as a phototransistor is the *Photran*, a bistable switch with many properties similar to those of a gas thyatron. It is essentially a PNP switch triggered by light energy instead of, or in addition to, electrical energy. Before light strikes the *Photran*, it is in a high-impedance "off" state. When a light impulse is applied, it is switched to a low-impedance "on" state. The device will then remain on indefinitely until it is electrically turned off. The light energy used to trigger the device on need only be momentary, since it is not required to sustain the device in the "on" state. In this manner the *Photran* is like a light-activated silicon-controlled rectifier.

PHOTOVOLTAIC THERMOMETER

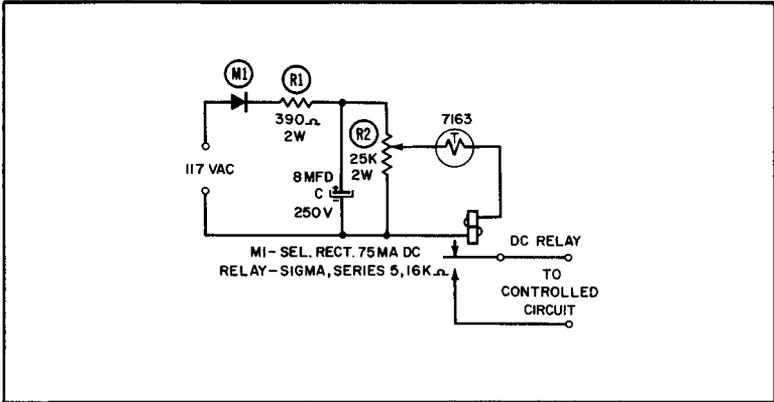
Shown in this diagram is a self-powered *Thermistor* thermometer (a *Thermistor* is a temperature-sensitive resistor). A selenium or silicon photovoltaic cell is used as a voltage source. As the temperature changes, the corresponding change in *Thermistor* resistance creates a bridge unbalance. When the calibrated rheostat (in one of the arms of the bridge) is adjusted for a null meter reading, its position will indicate the temperature.



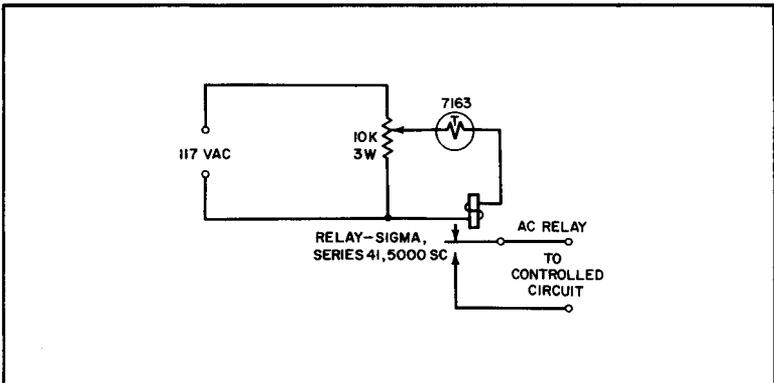
Photovoltaic thermometer.

PHOTOCONDUCTIVE RELAY

The 7163 cadmium-sulfide cell is typical of the photoconductive type for use in control circuits. Part A of the diagram shows a high-sensitivity circuit using a half-wave, 75-mil selenium rectifier and an RC filter. Also used is a 250,000-ohm sensitivity control for the cell. When light falls on the cell, its resistance decreases. This allows more current to flow, and the relay closes. This highly sensitive relay operates at 0.5 mil of current.



(A) High current sensitivity.



(B) On-off circuit.

Photoconductive relay.

For simple brute-force operation, the circuit in Part B uses pure line voltage and an AC relay. It has a lower sensitivity rating than the circuit in Part A, and is typical of the kind used in simple on-off applications.

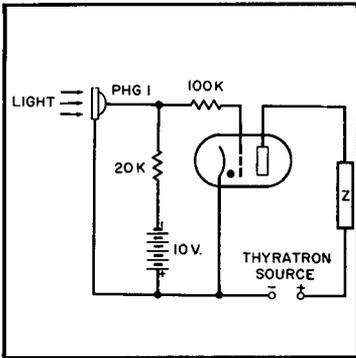
PHOTODIODE CIRCUITS

Three separate circuits using a photodiode are shown in this diagram. Photodiode PHG-1 consists of one germanium junction diode polarized by a suitable voltage. The reverse current of this junction is very low in total darkness (about 10 microamperes), but increases in proportion to the amount of light received by the cell.

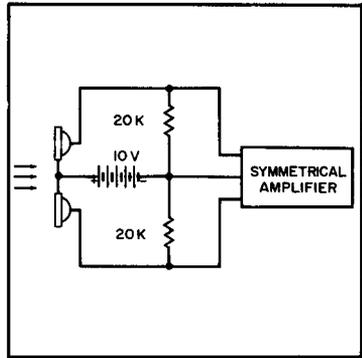
In Part A of the diagram, a circuit for thyatron triggering is shown. Without light on the diode, the tube is nonconducting. When light hits the photodiode, a positive drop across the 20K resistor overcomes the bias and the tube fires.

Part B shows a balanced circuit used for measuring the position of a light spot. The circuit will only be balanced if the light on both diodes is the same; any other condition therefore unbalances the output.

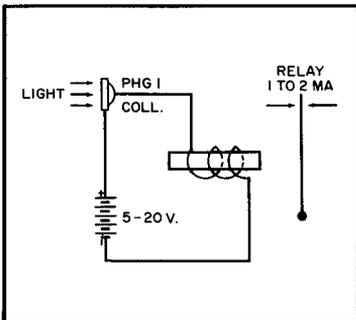
Part C illustrates a directly driven relay for control use. When light strikes the diode, the resultant current flow through the relay will energize it.



(A) Thyatron triggering.



(B) Measurement circuit for a luminous spot or object.

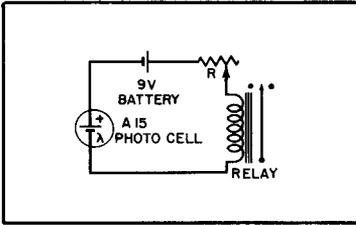


(C) Sensitive relay circuit.

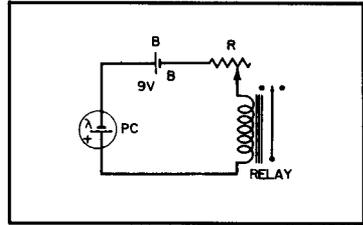
Photodiode circuits.

PHOTOCONDUCTIVE RELAY CIRCUITS

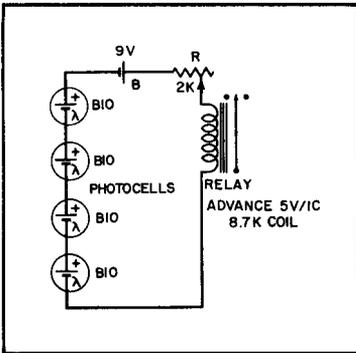
Several basic circuits using the PN photoconductive cell are shown in this diagram. The circuit in Part A uses a Type B15 photocell connected in series with a 6-volt battery and a Sigma Type 5F 16000S relay. With this combination, the relay will be actuated whenever a light intensity of more than 20 foot-candles hits the cells.



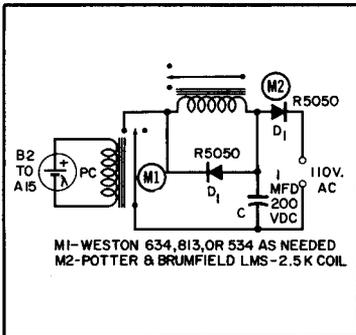
(A) A15 photocell relay circuit.



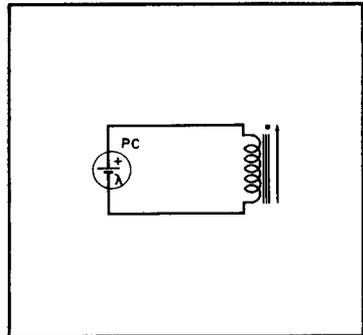
(B) B2M photocell relay circuit.



(C) Series photocell relay circuit.



(D) Cascaded photoelectric relay.



(E) Micropositioner.

Photoconductive relay circuits.

Part B shows a similar photoconductive circuit with a different choice of photocell (a B2M) and relay, for applications where the light intensity is 1,000 or more foot-candles. The relay is an Advance SV/1C with a 5,500-ohm coil.

Part C shows a circuit which has four B10 photocells in series and will function at 50 foot-candles.

This circuit can be used for counting or detecting passing objects, announcing the entrance of guests or customers, providing a protective light curtain around hazardous areas near machinery, etc.

A circuit with cascaded relays, driven by a photocell and incorporating a simple spark suppressor, is shown in Part D. In small-signal applications, relays are frequently cascaded to obtain greater controlling capacity. When this is done, the second relay is an inductive load on the first relay, and a spark-suppressing element is necessary on the second relay. M1 is a highly sensitive Weston meter-movement type of relay with limited contact capacity. It controls M2, a relay with five-ampere contacts. Depending on the size of photocell and the relay used, this circuit will respond to illumination of as low as 10 foot-candles. It is suited for such varied applications as automatic garage-door openers, burglar alarms, and counters (of small objects passing by, for example).

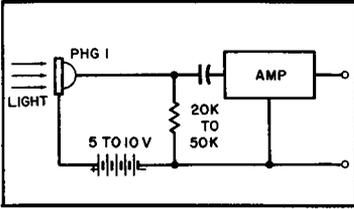
In operation, D1 rectifies the AC line current needed to operate the DC relay, M2. Capacitor C then smooths the rectified pulsating current. When the M1 contacts close, this current passes through power relay M2, closing its contacts. Diode D2 is a simple but effective spark-suppressing element which absorbs the inductive current when the relay M1 contacts break circuit relay M2. D2 thus eliminates arcing at the sensitive relay M1 contacts, which would shortly impair its function. The use of DC for the second relay makes possible this simple method of spark suppression.

Part E shows a photocell driving a *Micropositioner* relay without amplification. This is an A15 photocell and a Type AYLZ4529S relay; with 100 foot-candles, the relay will close.

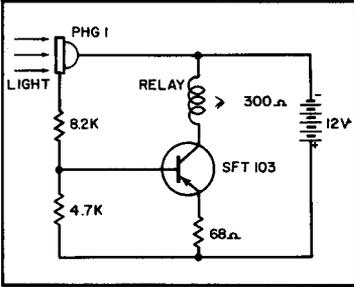
PHOTODIODE RELAY CIRCUITS

In this figure three photodiode circuits are shown. Part A shows a block diagram of a light-detector circuit. The transmitted light is picked up by PHG-1. The resultant IR drop across the resistor then pulses the amplifier, which is used as a receiver in the system.

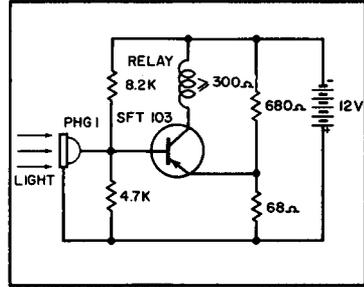
In Part B the relay is energized with no incident light applied to the photodiode, and de-energized with the application of light.



(A) Weak modulated signal detection.



(B) Relay energizes with light.



(C) Relay deenergizes with light.

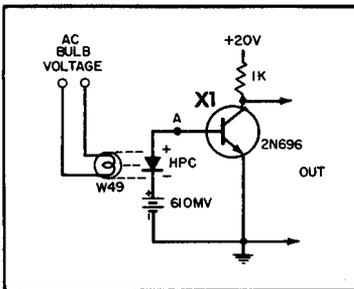
Photodiode relay circuits.

There are two voltage dividers across the 12-volt supply. One leg is the photodiode and the 8.2K and 4.7K resistors. The other leg is the relay impedance and the emitter-to-collector circuit.

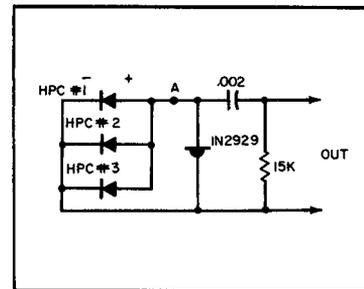
With the circuit rearrangement shown in Part C, the relay remains off until light hits the diode.

PHOTODIODE AMPLIFIERS

A linear amplifier, shown in Part A of the diagram, converts variations in light intensity to variations in output voltage. To illustrate this principle, a sinusoidal voltage has been applied to a W49 lamp. Light variations appearing at Part A as input-signal voltage are doubled in frequency because the bulb filament heats



(A) Linear amplifier.



(B) Multiple input pulse generator.

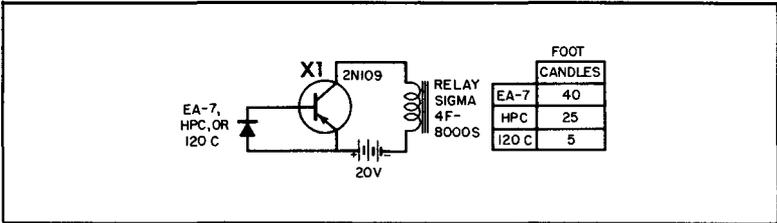
Photodiode amplifiers.

up during both the positive and the negative alternations of input voltage.

Part B illustrates one way that output pulses may be generated from multiple-input HPC readout cells in computer circuits, when the cells are subjected to light impulses passing through coded apertures.

RELAY DRIVEN DIRECTLY BY A PHOTODIODE

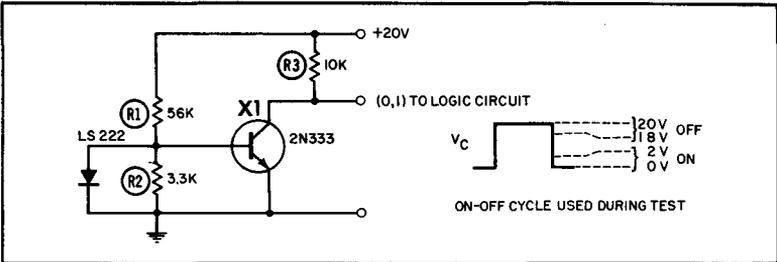
Relays may be operated directly from photovoltaic readout cells. This diagram shows a typical circuit of a photodiode-driven relay. Whenever a beam of light strikes the diode, the transistor conducts, picking up the relay.



Relay driven directly by a photodiode.

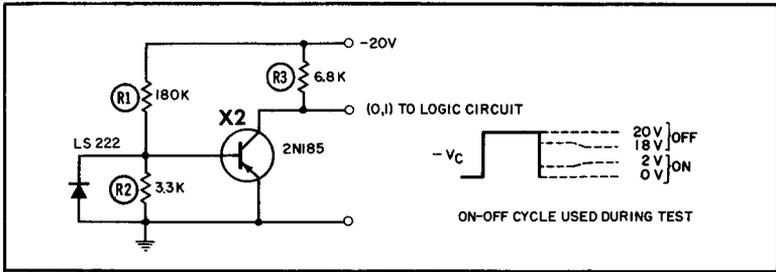
PHOTODIODE LIGHT SENSOR

Part A of the diagram shows the LS-222, a diffused-junction silicon light diode used with a silicon transistor such as the 2N332, 2N333, or 2N338. With +20 volts on the collector, the



TRANSISTOR	R _B	R _L	P _O	V _{BE}	BASE DRIVE	SENSOR CURRENT	LIGHT INTENSITY
TI 2N332	51K	20K	20 mw	0.71 v	175 μa (typ)	100 μa	> 600 ft - c
TI 2N333	56K	10K	40 mw	0.71 v	175 μa (typ)	100 μa	> 600 ft - c
TI 2N338	62K	3.3K	132 mw	0.72 v	175 μa (typ)	100 μa	> 600 ft - c

(A) Silicon transistor on-off circuit.



TRANSISTOR	R _B	R _L	P _O	V _{BE}	BASE DRIVE	SENSOR CURRENT	LIGHT INTENSITY
T1 2N185	180K	6.8K	59 mw	-0.18 v	150 μa (typ)	100 μa	> 600 ft - c

(B) Germanium transistor on-off circuit.

Photodiode light sensor.

transistor is off with incident light and the output is in the 18- to 20-volt range. When light is removed from the diode, the transistor output drops to the 0- to 2-volt range, as shown by the V_c waveform.

Part B shows the same circuit as A, but using a germanium transistor instead of silicon.

Section 9

CONTROLS

In a broad sense, almost all circuits in this book provide some type of control—for example, they control voltage, current, frequency, or some other parameter. However, the circuits in this section are industrial controls, which transfer power from one place to another, adjust the temperature, etc.

One of these circuits switches on emergency power. The regular power from the line is furnished to the load through a switch, which remains off and thereby isolates the emergency power source. If the regular power source should fail, however, the emergency power source will be switched in automatically.

Another type of control is the servo drive, where an amplifier controls the rotation of a servo in one direction. Where a reversing drive is necessary, two amplifiers can be used, one for each direction. A balanced bridge input between the two amplifiers will provide an input signal to the correct amplifier, depending on the polarity of the error signal.

There are several ways of classifying automatic control systems. One way is to define their action in terms of proportional, floating, or two-position. Two-position control provides fully on or off operation of the controlled device; there are no intermediate positions. Many applications such as a simple on-off motor control are best served by two-position arrangements.

In floating controls, the controlled device is moved as required to maintain conditions at the control set point. Floating control permits the system to stop at any position between fully on and fully off. However, its applications are limited because of its tendency to overshoot. Overshooting is likely to set up cycling (also called “hunting”) in the system. Both overshooting and hunting are the result of time lags in the over-all system.

In proportional control, the actuators assume a position proportional to the change in conditions. These conditions can be temperature, pressure, light, or almost any other controlled vari-

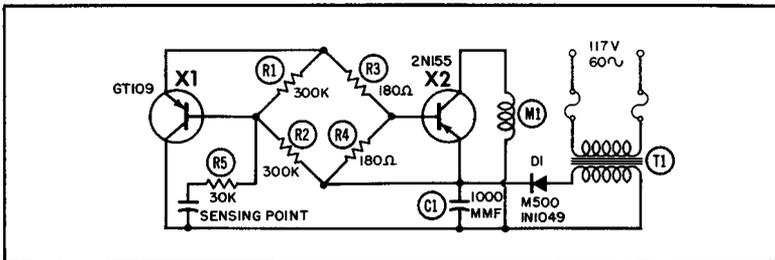
able. For a given increment of change in the variable, the controlled device will move to a position which is proportional to that increment. In this way, the floating control does not cycle, since the actuator always reaches the same position for any given load on the system. In proportional action, feedback links the actuator to the controlled device. As the actuator moves in response to a change in load, a signal is fed back. The effect of this feedback is opposite from the change caused by the variation in load. When these opposite effects balance, the system stops moving, usually before it can reach the extreme open or closed position.

Electronic control systems can measure, detect, count, control, warn, and inspect—but to do any of these things, a sensor is required to produce the electrical signal. A transducer, which is mechanically or electrically coupled into an electronic circuit, can vary capacity, inductance, or resistance. This variation can change the current, voltage, or frequency by means of a wide variety of piezoelectric, photoelectric, or magnetic devices. With this system it is possible to measure pressure, temperature, humidity, or other variables.

TRANSISTOR DETECTION SENSOR

This transistorized control uses currents as low as 50 microamps to prevent arcing at the points of sensing or switching contacts. Two stages of transistor amplification permit operation of a standard 5-amp control relay. The control is designed for operating temperatures from 0° to 50°C. Its dimensions are 10" x 5" x 4", and it weighs six pounds. The control can use one, two, four, six, or eight probes in series, all of which must be contacted to complete the circuit.

A transistorized control utilizes extremely small currents to provide spark-free switching, detecting, locating, and counting. The electronic sensing device operates with currents in the 50-150-microamp range and with voltages between 6 and 7



Transistor detection sensor.

volts DC. Two stages of transistor amplification permit operation of a standard 5-amp control relay.

Small, lightweight metal parts can be detected merely by touching them with a sensitive point or probe. The metal part then acts as a resistor in the bridge arrangement used to bias the transistors. Unbalancing the bridge by addition of this external resistance causes current to flow through the first transistor stage. This current triggers the second transistor. A relay in the collector circuit of the second stage is then energized to control subsequent operations.

The low voltage and current present at the sensing point will allow the sensitive contacts to be only .0001 inch apart without actuating the relay. A maximum of 20K ohms is required for sufficient unbalance to actuate the relay. Yet, an instantaneous signal is given on contact; no pressure or depression is needed.

The unit can detect up to 1,500 actuations or contacts per minute, no matter how light or small. A ¼-inch probe can be placed in a die to check for proper placement of the blank. Precise location of a part or member is possible because of the .0001-inch "no-circuit" feature.

AC from the secondary is rectified and filtered through D1 and C1. X1 and X2 are biased through a bridge made up of R1, R2, R3, and R4. As long as sensing points are open, no current flows through R1. The instant a direct short or external resistance (20K maximum) is felt at the sensing point, the bridge is unbalanced and X1 conducts. Current flow through X1 causes a drop across R3 and R4, and also changes the bias on X2. When X2 conducts, current flows through M1 (which has one pair of normally open or normally closed contacts). Control leads to the sensing probes can be of any length. Thus, the control unit can be placed at a distance from the sensing point.

SCR PROPORTIONAL CONTROL

When used with AC load power, the controlled switch (CS) or silicon-controlled rectifier (SCR) will block and will not conduct during both half-cycles unless a gate signal is supplied. The CS or SCR can be turned on at any point during the positive half-cycle, as long as the anode is more than +3 volts with respect to the cathode. By proper timing of a gate signal, the output of the CS or SCR can be made continuously variable from no output to full output, as shown.

Since the internal dissipation of the CS or SCR is very low, the loss of the proportioning power control is also very low. The low-power requirements for gate firing permit the design of simple proportional-control amplifiers with very high gain.

A proportioning-control amplifier with full-wave rectified DC output is shown here. The DC input voltage, which is variable from 4.9 to 5.1 volts, will provide full output control. This circuit is useful for servomotor driving, temperature control, and related applications. Closed-loop feedback is easily achieved for self-regulating systems.

The power-control circuit becomes a regulated DC power supply when part of the DC output voltage is applied to control input Y. Since the control reference is approximately five volts, a voltage divider across the load will regulate the DC output voltage to 5 volts multiplied by the divider ratio. If the load voltage is unfiltered, a small capacitor may be required across the control input.

Regulated DC power supplies using the SCR eliminate the need for high-dissipation series control elements such as power transistors or tubes. This greatly minimizes heat-sink requirements and permits smaller packaging. In addition, the supplies provide a wide control range. A possible disadvantage is their response time, which can be no faster than one half-cycle of the supply voltage.

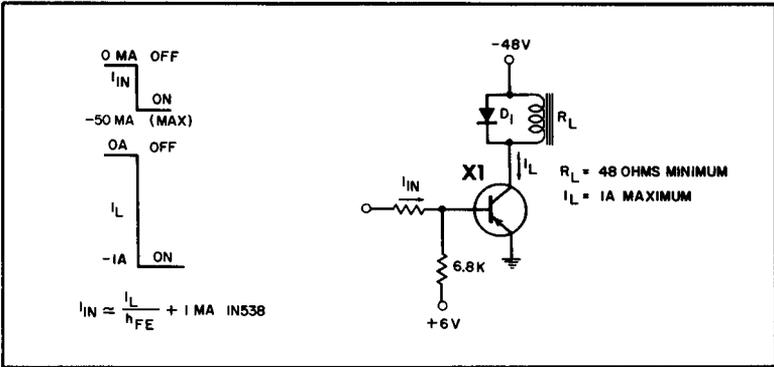
A bridge circuit can be formed by connecting a resistor from X to Y and from Y to Z in the control circuit. Together with the resistor network connected to the base of X2, this bridge forms the basis for many simple and reliable power-control circuits. This it does by using a variable-resistance transducer as one of the two resistance elements at the input. Examples include resistance thermometers for temperature control, and photoconductive cells for light control.

RELAY DRIVER

In many industrial controls, a transistor is needed to drive a relay which, in turn, can control a power circuit. The figure shows a 2N1039 in such an application. A potential of +6 volts is applied to the base, and -48 volts to the collector.

A 50-mil current at the input turns the transistor on and causes a 1-ampere current flow through the relay. The resistance of this coil should be at least 48 ohms. When the input and relay currents stop, the 1N538 diode will clip the reverse-voltage swing.

As the arm of R1 is moved to the left, X1 and its associated SCR's begin to fire. At the extreme left-hand position of R1, the full output voltage appears across the load. As the arm of R1 is moved to the right of center, a similar action occurs except the polarity across the load is reversed.

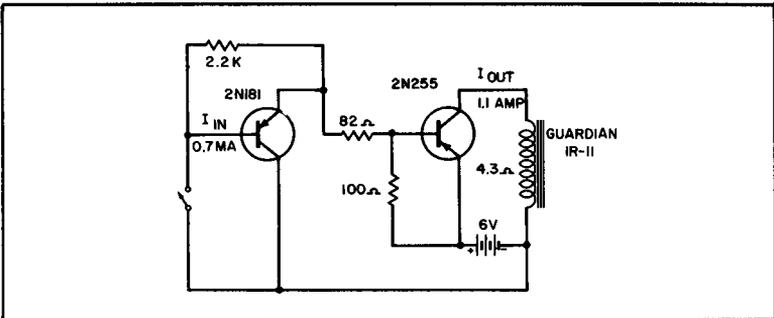


Relay driver.

If the load is a DC motor, a plugging action occurs if R1 is reversed too abruptly. R14 and R15, in series with each end of the transformer, limit the fault current in event a voltage transient fires an odd- or even-numbered SCR pair simultaneously.

RELAY CIRCUIT

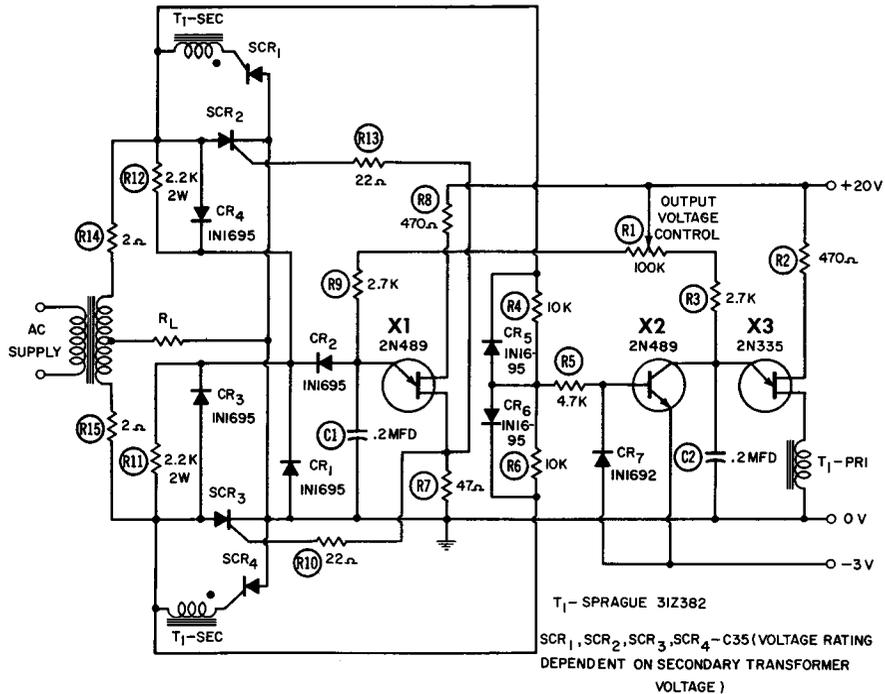
This sensitive relay circuit has a high-temperature stability, and an input current of less than 1.0 ma will control a 1.0-ampere solenoid. It is useful in model boats and airplanes, as well as in other remote-control devices. If the amplifier is not to be subjected to temperature extremes, a 2N107 may be substituted.



Relay circuit.

FULL-WAVE REVERSING DRIVE

This full-wave circuit controls and reverses a servo, as shown in the diagram. Two SCR's (2 and 3) have a common-cathode connection, and the other pair (1 and 4) have a common anode. SCR-2 and SCR-3 are fired by unijunction transistor X1. Since



SCR-1 and SCR-4 have electrically isolated cathodes, the gate signal pulse generated by UJT X3 is coupled to the SCR gates by isolated secondary windings on transformer T1. Transistor clamp X2 synchronizes the firing of X3 to the anode voltages across SCR-1 and SCR-4.

R1 can be made to regulate the polarity as well as magnitude of the output voltage across the load. With R1 at its center position, neither UJT will fire. Hence, no output voltage will appear across the load.

MAGNETIC-AMPLIFIER CIRCUIT FOR AN SCR

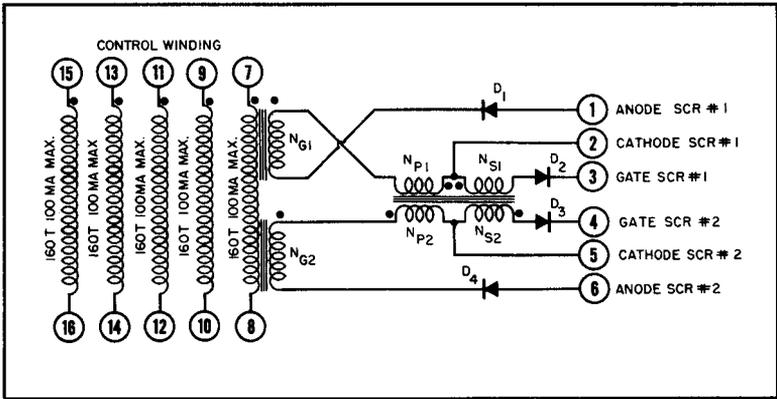
There are several magnetic amplifiers for SCR control, as shown by the schematic in Part A of the diagram. This control amplifier is symmetrical, one half firing a controlled rectifier on one half-cycle of an AC excitation while the other half fires a controlled rectifier on the other half-cycle. Part B shows only one half of this symmetrical circuit working into a controlled rectifier.

The object of the circuit is to be able to gate (turn on) the SCR at any desired firing angle in the forward-conduction half-cycle of the SCR, and thus to control the power to the load. The SCR will be turned on when the required current is put into its gate. A sharp current signal is generated when the magnetic-amplifier winding (N_{G1}) saturates. The time at which it does during the cycle is determined by the ampere-turns of DC control applied to the amplifier.

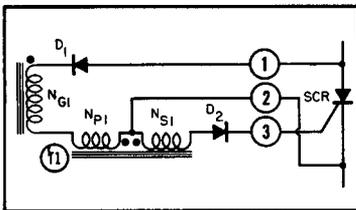
The purpose of T1 is to bypass the current of the magnetic amplifier around the gate. The increase in magnetizing current, when the amplifier is driven with large negative signals, does not fire the controlled rectifier.

Magnetizing current through reactor gate winding N_{G1} is passed directly through winding N_F on the transformer. Since its magnetizing current is more than that of N_{G1} , the transformer cannot change flux. Once the reactor saturates, the high gate impedance no longer restricts the gate current and it rises rapidly. When this increased current equals the magnetizing current of the transformer, the transformer changes flux (saturation-to-saturation). A voltage is induced in secondary N_s as the flux changes, and the resultant current pulse gates the SCR.

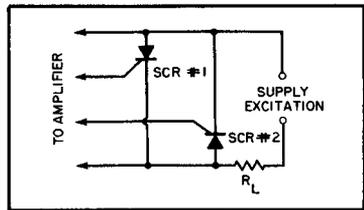
On the next half-cycle, the other half of the symmetrical circuit goes through a similar cycle. Because the transformer is polarized when the reactor of that half of the circuit saturates, the transformer must again change flux level. This means it is at the proper saturation level at the beginning of any half-cycle, and will have to go through a complete flux change if N_G satu-



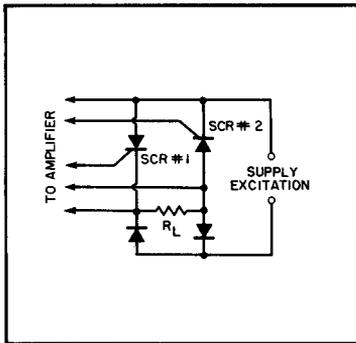
(A) Symmetrical amplifier.



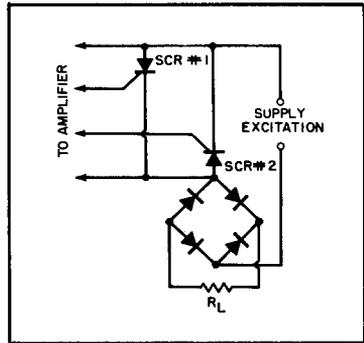
(B) Half-symmetrical amplifier.



(C) Full-wave AC output.



(D) Full-wave rectified DC output.



(E) Full-wave DC output.

Magnetic amplifier for an SCR.

rates at any time during that half-cycle. Diodes X2 and X4, as in Part A, are in series with each of the gates to block reverse currents.

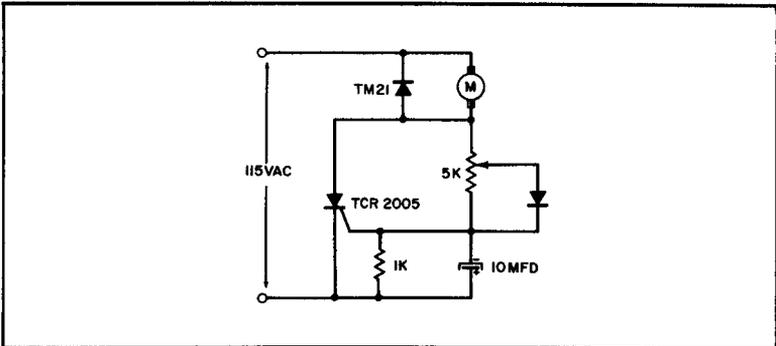
The output of a control amplifier is a narrow pulse, the firing angle of which is varied by the net DC control ampere-turns. The

height and width of this pulse vary with, and are determined by, the gate requirements.

Three typical circuits show the control amplifier and associated controlled rectifiers. These are only representative; many other circuit configurations are possible. The ones in C and E are particularly advantageous, since the two controlled rectifiers are in parallel—the two conduction directions being opposite each other. In the presence of an overvoltage, the controlled rectifier which would conduct because of this polarity voltage will break down. Normally this will occur before the rectifier with a reverse voltage across it breaks down in the reverse direction. In this manner, the controlled rectifiers in these circuits protect each other against inverse voltage breakdown. The surge-current rating of the controlled rectifiers determines the maximum overvoltage that will damage the controlled rectifiers.

SCR MOTOR CONTROL

Controlled rectifiers can provide a simple, accurate speed control for a DC motor. AC is in series with the motor and controlled rectifier TCR-2005. This circuit gives smooth control of motor power over the complete control range. During the negative half-cycle, the 10-mfd capacitor will charge to a negative voltage through the 5K potentiometer. During the positive half-cycle, the capacitor will charge to a positive voltage through diode TK20 and part of the potentiometer. When the voltage at the capacitor becomes positive, diode TK5 will start to conduct and the CR will fire. The greater the resistance shorted out on the potentiometer by diode TK20, the faster the capacitor will recharge, the greater the conduction angle of the CR will be, and the greater the current that will flow through the motor. Therefore, the 5K control is the adjustment for the motor speed.

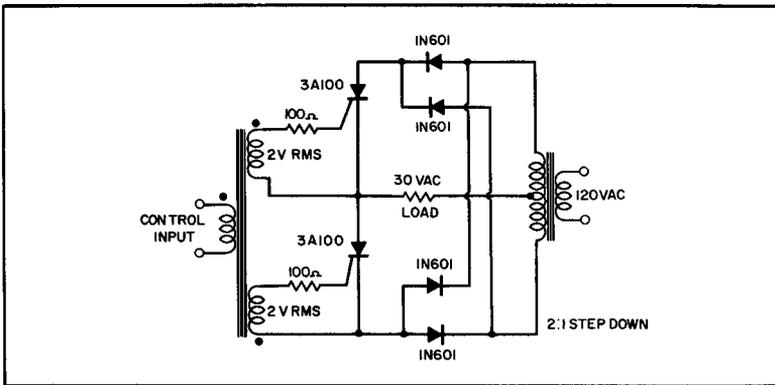


SCR motor control.

SERVO DRIVE

A servo amplifier controls the rotation of a motor. Where a reversing drive is necessary, two amplifiers can be used, one for each direction. A balanced bridge input between the two amplifiers will provide an input signal to the correct amplifier, depending on the polarity of the error signal.

For simple AC systems, the output circuit shown could be used. It provides a constant-amplitude AC sine-wave output with reversible phase. It is therefore a reversing drive for AC motors. The load voltage will either be in phase or 180° out of phase with the supply voltage, depending on whether the control AC input is in phase or 180° out of phase with the supply.



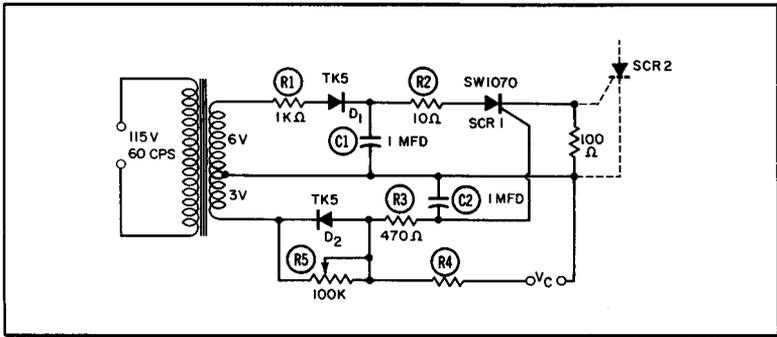
Servo drive.

HALF-WAVE SCR CIRCUIT

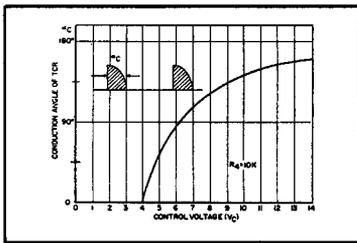
The circuit in Part A shows the half-wave control of the firing of a controlled rectifier. Line voltage is applied through the transformer. During one half-wave, the TCR will not fire. This period is used to charge C1 (via D1) to approximately +8.5 volts, and C2 (via D2) to approximately -4.2 volts.

The control current, caused by control voltage V_c through R4, recharges C2 until the voltage over it reaches the V_{cr} of the controlled switch. This switch is triggered, and the charge stored in C1 can now flow (via a low-impedance path) into the gate of the CR. The control range is from 0° to 160° . The conduction angle of the TCR is determined by the control current and by the voltage to which C2 is charged during the negative half-wave.

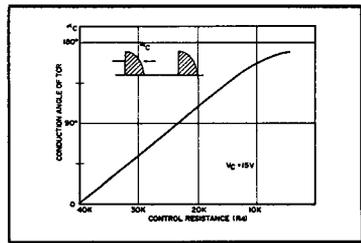
Compensation for line-voltage variations is provided. The conduction angle of the CR has an inverse relationship to the input



(A) Half wave firing.



(B) Control voltage vs conduction angle.



(C) Control resistance vs conduction angle.

Half-wave SCR circuit.

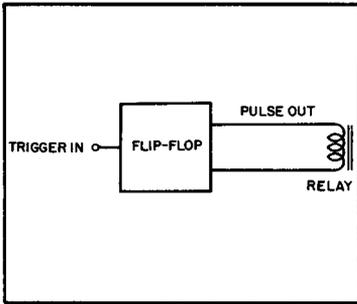
line voltage. The degree of compensation can be controlled by R5.

Part B shows how the control voltage varies between 4 and 14 volts, and its effect on the conduction angle. This angle is always less than 180° . Part C shows how the conduction angle varies with the control resistance, while the control voltage is fixed at 15 volts.

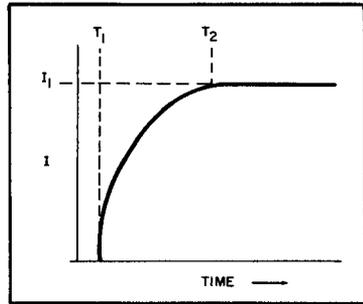
RELAY CONTROL

Relays cannot be driven directly by short trigger pulses. Instead, their pulse-width or current-flow time must be long enough to energize them. Suppose, as in A, that a certain relay requires I_1 amperes before the relay will close and activate the following control circuit. If this current flow starts at time T1, it will not build up to I_1 until time T2, because of the normal lag in current flow in an inductance. One way to use a short-duration, low-level pulse to close a relay is to have this pulse switch a flip-flop, as in B. The flip-flop's output—which is a longer-duration, higher-level pulse than that of the input trigger—then drives the relay. An output current flows from T1 to at least T2.

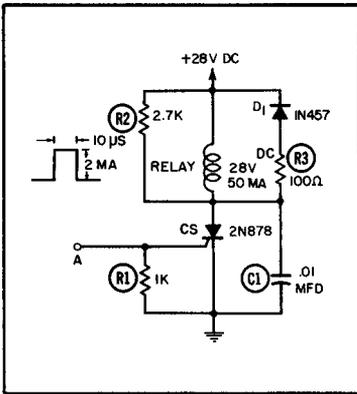
Semiconductor switches can do the same job with fewer components, as shown in C. The relay in C is normally off (not ener-



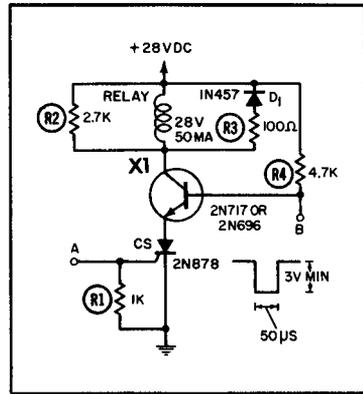
(A) Flip-flop relay driver.



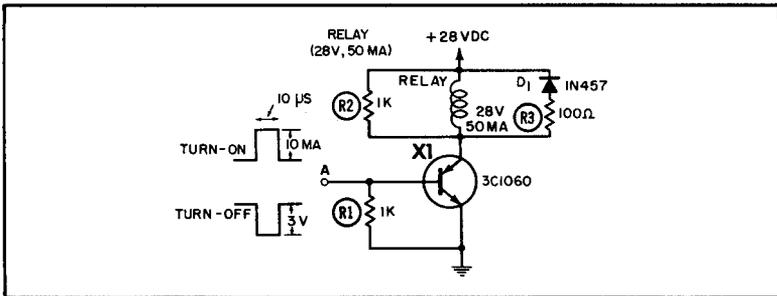
(B) Output waveform.



(C) Relay normally de-energized.



(D) Pulse reset circuit.



(E) Trigistor relay circuit.

Relay control.

gized). When a trigger pulse is applied, the controlled switch is triggered on. Resistor R2 allows the current through the CS to rise above its holding level while the command pulse is present. When the command pulse terminates, the CS remains on and full voltage is across the relay. The time required for the relay to

energize is not important from a circuit viewpoint. This circuit is reset by momentarily interrupting the anode current of the CS. One method of accomplishing pulse reset is shown in D, where an NPN transistor is placed in series with the CS; resistor R4 provides a saturating base drive to the transistor. To reset the circuit, a negative pulse is applied to point B. This pulse momentarily interrupts the anode current of the CS, which turns off. CS will then remain off until a turn-on command pulse again appears at the input.

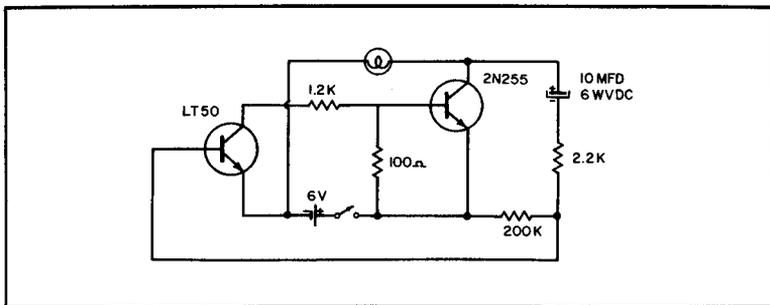
The circuit in E uses a silicon *Trigistor* as the active control element. Since the *Trigistor* can be turned off as well as on at its base terminal, it can perform the same function as the circuit in D but with fewer components. Command pulses for both turn-on and turn-off are applied at the same point, as shown. Turn-off time can be much shorter with the *Trigistor*.

The relays require a coil current of 50 ma. The circuits can be easily adapted to control relays, solenoids, or other loads requiring from 5 to 1,000 ma. In addition, by proper choice of CS or *Trigistor*, pulse widths as narrow as one microsecond can be used as command signals. Many variations are possible, and almost any desired type of pulse control can be achieved.

COMPLEMENTARY MULTIVIBRATOR

A complementary transistor multivibrator using a 2N255 and an LT-50 is shown here. The application is in a battery-operated barricade flasher. The desirable feature of this circuit is that both transistors conduct at the same time, whereas in conventional multivibrators they conduct alternately. The complementary transistor circuit therefore consumes less power.

A 6-volt DC source is used, with 16 mils in the "off" position for both transistors, and 460 mils in the "on" position. The period of operation is 2.4 seconds, as shown, with a duty cycle of 16.6%.

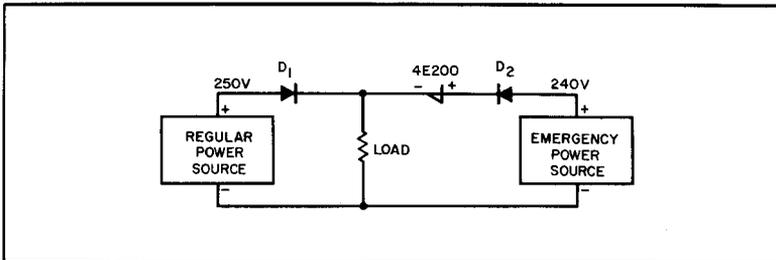


Complementary multivibrator.

POWER TRANSFER

This circuit switches on emergency power in the following manner. As the regular power source is functioning, power is furnished to the load through the four-layer diode 4D1, which remains off and thereby isolates the emergency power source from the load. If the regular power source fails, the full voltage of the emergency power source will be impressed across 4D1 and turn it on. The switching voltage of 4D1 is selected so that normal variations in the voltage of either the regular or emergency power source will not switch 4D1.

D1 is back-biased, isolating the regular power source from the load, and power is fed to the load from the emergency power source through D2 and 4D1. Normal load current keeps 4D1 conducting until the emergency power source is interrupted. As soon as the regular power source is restored, it will take over from the emergency source (provided its voltage is higher than that of the emergency source). D2 prevents reverse breakdown of 4D1 when the emergency power source is not energized. Four-layer diodes have a typical switching time of 0.1 microsecond.

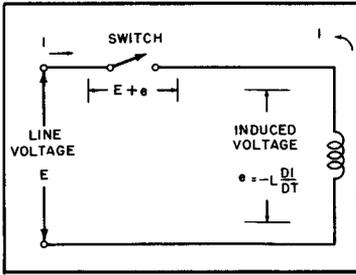


Power transfer.

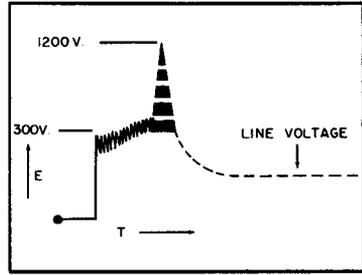
INDUCTIVE ARC SUPPRESSION BY DIODES

Several techniques for arc suppression are shown. Every inductive circuit controlled by switches, relays, or other types of make-or-break devices will, when interrupted, generate high-voltage transients which will cause arcing across the contact points. If the load is inductive, arcing will damage the contacts and ultimately cause them to lock. In addition, the voltage transients are of an RF frequency and therefore a source of interference to any adjacent circuits. They are also of sufficient magnitude to puncture the insulation.

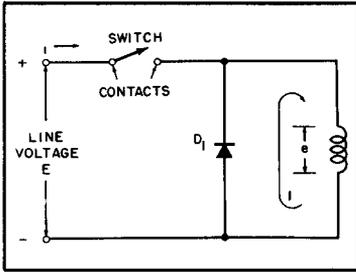
The problem is particularly acute in modern circuits, where certain critical components are operated at their maximum ratings. In such instances, the voltage overload will seriously impair



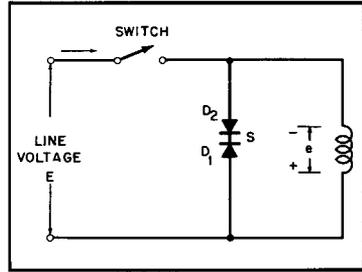
(A) Typical inductive circuit (unprotected).



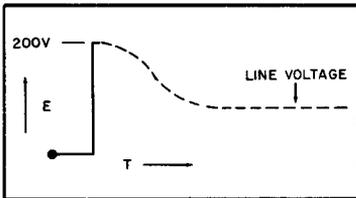
(B) Circuit interruption generating high reverse voltage.



(C) Selenium rectifier shunts coil.



(D) Arc suppressor across coil.



(E) Suppressed circuit waveform.

Inductive arc suppression by diodes.

the efficiency of these components—if not break them down completely.

Part A of the diagram shows how, with a line voltage E , an inductive voltage e is created by a decline of the magnetic field when the switch is opened. Arcing starts here at 300 volts, as shown in Part B.

Part C shows a half-wave rectifier connected across the coil in a DC circuit. The low forward impedance of the rectifier shunts the coil and prevents the reversed voltage (generated by circuit interruption) from attaining arcing potential. Current decay time, however, is prolonged because the low forward impedance of the rectifier allows the current to circulate longer than in an unprotected circuit.

Part D shows an arc suppressor consisting of selenium-rectifier cells connected back to back across the coil. This type of sup-

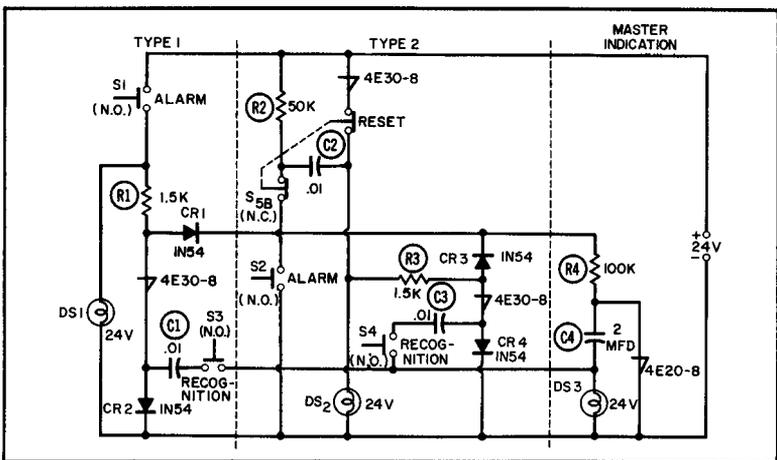
pressor is efficient for DC but essential for AC, since the suppressor must block both voltage polarities. Back-to-back suppression effectively dissipates the induced energy, but does not materially slow down the current decay, as shown in E.

With the switch closed, the A cells act as blocking rectifiers and the circuit performs normally. When the switch is opened, the resistance of the A cells is negligible, while the resistance of the B cells decreases as the voltage increases, preventing the back emf from reaching arcing potentials. The current that is allowed to flow, quickly dissipates the induced energy and causes the induced voltage across the coil to fall, thereby effectively dampening any further current circulation. A and B cells interchange their functions when their polarities are reversed.

ALARM CIRCUIT WITH FLASHING MASTER LIGHT

This circuit provides an alarm system with a flashing master light. It may be used with the two most common types of alarm contacts, high power and signal power, as shown by Types 1 and 2. A system can be composed of all Type 1, all Type 2, or a combination of both.

Type 1 is used when the alarm contact closes positively. It is capable of passing the required current, and must be reasonably close to the alarm panel (unless shielded wire can be used). In Type 1, when an alarm occurs, S1 closes and signal lamp DS1 goes on. In addition, master light DS3 begins to flash. When the fault is recognized, recognition switch S3 is momentarily closed



Alarm circuit with flashing master light.

to turn off the master lamp. As soon as the alarm condition has been removed, S1 will open and signal lamp DS1 will go out.

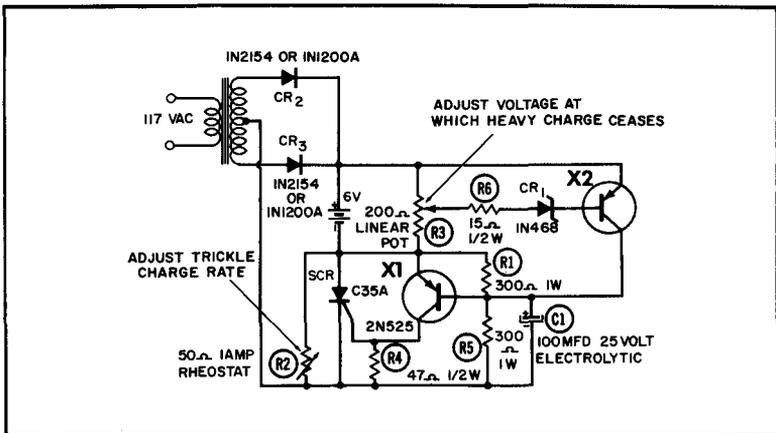
In Type 2 the circuit operation is the same but each alarm point is independent of the others. If an alarm condition exists at S1 and has been recognized but not corrected, DS1 will remain on. If, during this time, an alarm occurs at S2, master lamp DS3 will flash until the second alarm, at S2, is recognized.

BATTERY-CHARGER REGULATOR

This figure, with two 2N525 transistors and an SCR, shows an inexpensive means of utilizing the SCR as a battery-charger regulator. Thus, the problems inherent in electromechanical voltage relays—sticking, contact burning, wide range of pickup and dropout, wear, etc.—are eliminated. As shown, this circuit is capable of charging at a rate of up to 16 amperes. When the battery voltage reaches the full-charge level set by R3, the SCR cuts off and a trickle charge (determined by the value of R2) continues to flow.

A full-wave rectifier, comprising CR2 and CR3, delivers full-wave rectified DC to the SCR in series with the battery. Transistor X2 compares a portion of the battery emf with reference diode CR1. If the battery voltage is low, X2 will be cut off. A positive voltage will be developed across resistor R1 and between the emitter and base of transistor X1 whenever the SCR anode is positive. X1 will conduct heavily into the gate of the SCR, firing it and thus charging the battery.

When the battery voltage rises to the point where X2 starts to conduct, the voltage across R1 will reverse, cutting off X1 and



Battery charger regulator.

thus removing the gate signal from the SCR. In this mode, only resistor R2 will control the charging rate.

This circuit switches from trickle to full charge with less than a 3% drop in battery voltage.

Section 10

TRANSISTOR POWER CONVERTERS

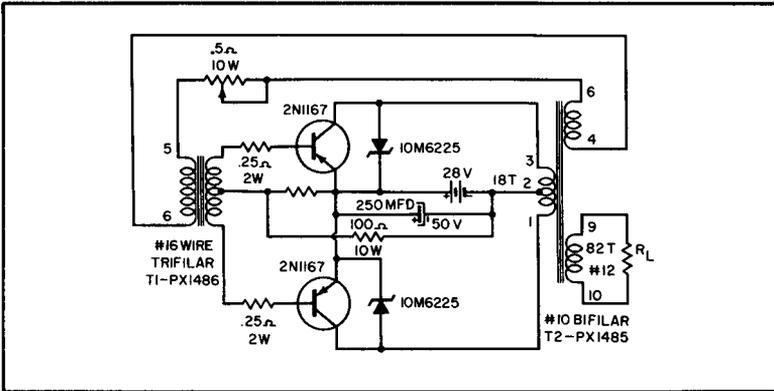
Power transistors make effective switching devices for power conversion from either DC to DC, DC to AC, or AC to DC. Transistors are more reliable than vibrators, and are not as complex or bulky as motor-generators. Also, their efficiency is very high.

High-voltage, low-current DC is used for mobile-radio plate supplies, and low-voltage, high-current AC is applied to servo systems and AC motors. Power conversion from low- to high-voltage DC requires a DC-to-DC converter, while conversion from low-voltage DC to AC requires an inverter. By adding a rectifier filter to an inverter, a DC-to-DC converter can be produced.

700-WATT INVERTER

This circuit shows a two-transistor inverter using 2N1167 power triodes, which have a current gain of 25 at 25 amperes and can thus switch 700 watts (25 amperes at 28 volts). A 10-CFM blower is used to stabilize the case temperature to below 60°C. The transistors are insulated from the heat sink with an anodized aluminum washer, and silicone grease helps lower the thermal resistance from the transistor case to the heat sink.

The two-transformer design allows the feedback transformer to do the saturating while reducing the collector-current spikes. Since the output transformer does not saturate, saturation losses are reduced considerably. The driver transformer is designed to oscillate from 200 to 1,200 cycles with a 2- to 12-volt drive. A multiple tap on the output transformer is wound onto a double 4½-inch *Hypersil C* core, each half having a cross section of about ¾ inch. The driver transformer consists of three identical windings of No. 16 trifilar-wound wire to provide various circuit configurations. The driver core is laminated of mumetal with a core area of about ¾ square inch and about 1" x 1" x ½" outside dimensions. The circuit is operated common-emitter push-



700-watt inverter.

pull. A 0.5-ohm potentiometer is inserted between the feedback winding and driver transformer to allow proper switching and to help control the frequency. Performance is improved by inserting 0.25-ohm resistors in series with the base to equalize the drive and eliminate burnout.

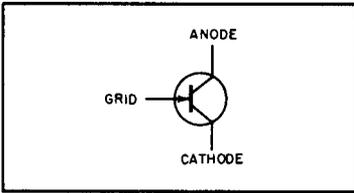
From this circuit a power output of 575 watts is obtained with a power input of 700 watts, for a loss of 125 watts and an efficiency of about 82%. Bias and feedback resistors account for about 25 watts, while another 35 watts is lost in the transistors. The remaining 65 watts apparently is lost in the transformers.

An additional 20 watts is required to operate the blower, which is driven from the output. Currents of up to 34 amperes can be switched and power outputs of more than 700 watts obtained intermittently.

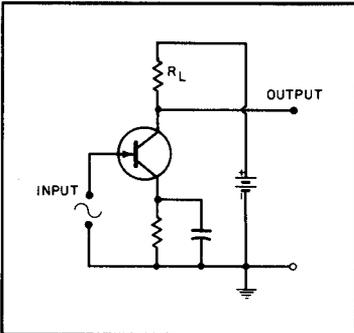
FIELD-EFFECT TRANSISTOR IMPEDANCE CONVERTER

The noise parameters of the field-effect transistor in Part A will be extremely low—even with a very high source impedance—provided the anode voltage is maintained at approximately +3 volts. The device then operates in the triode region and hence is extremely useful as the input stage in very low-noise, high-impedance transistor amplifiers. The output impedance of the device in the triode region is approximately 2.5K, which is the ideal source impedance for conventional low-noise transistors following the input stage.

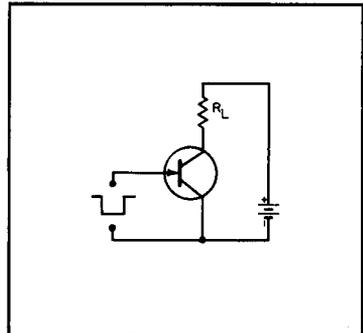
As in the circuit of B, R_L should be at least 10K to avoid undue loss of signal. The stage operates at about unity voltage gain. Impedance converters can also be used as matching devices, where it is desired to use an ordinary transistor amplifier but no signal loading is permissible.



(A) Field effect transistor symbol.



(B) High input impedance amplifier and converter.



(C) Switching circuit.

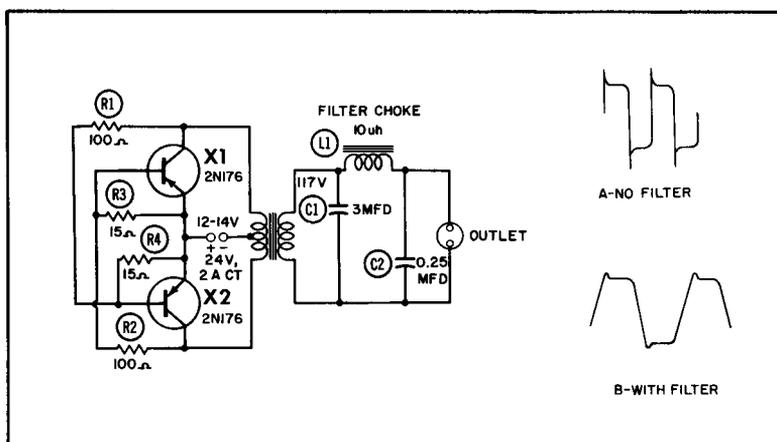
Field effect transistor-impedance converter.

Field-effect transistors can be used as switches in digital applications, as in Part C. Unlike transistors, they require pulses of only one polarity for full on-off operation. The device is on when no voltage appears on the grid, and off when the grid is pulled negative. In the "off" condition, the resistance of the device is around 100 megohms, and the "on" resistance is approximately 2K. Since the input capacitance is approximately 50 mfd, the switching speeds are directly affected by the impedance of the generator driving the switch. For a high switching speed, the driving generator is of low impedance during both build-up and collapse of the driving pulse.

INVERTER (12VDC to 110VAC)

There are several forms of inverters in use. A 50-watt output at 0.5 amperes and 110 volts AC can be obtained from a pair of 2N176 power transistors connected as shown. This is enough power to operate a small phonograph, AC-DC radio, dictating machine, small soldering iron, or a trouble light. Efficiency is about 75% DC-to-AC.

As shown, base bias and collector-to-base coupling are provided through 100-ohm, 2-watt resistors R1 and R2. Bias stability is provided by 15-ohm, 2-watt resistors R3 and R4.



Inverter (12VDC to 110 VAC).

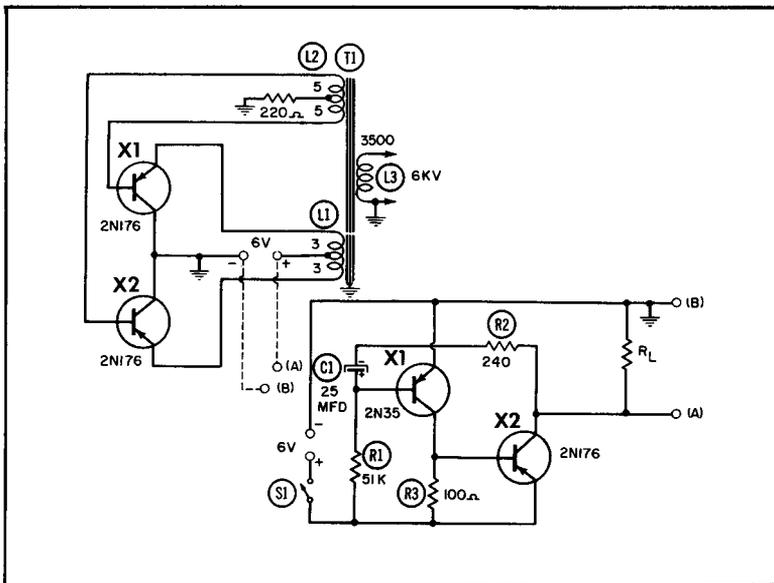
This inverter, designed for use with AC equipment, has a frequency output of approximately 60 cps and a peak-to-peak voltage (between the flat tops) of 250 volts at 50 watts. For many applications this output is satisfactory, even though the waveform is approximately a square wave without the filter. The hash filter (composed of C1, L1, and C2) removes most of the spikes, giving a trapezoidal waveform. With the filter, the frequency is reduced to about 56 cps.

6-KV INVERTER

Inverters can provide power for several applications. An inverter for 6 to 6,000 volts AC is shown here. This 6 kv can be doubled and used for CR tubes. On the left is the inverter, which uses a pair of 2N176's in a common-collector circuit.

The transformer is special; the *Ceramag U* core, AP 11-264(2), is similar to the type often used in TV flyback transformers. L1 and L2 are hand-wound side by side on the cardboard bobbin, with taps brought out on either side. The winding is covered with three thicknesses of bond paper saturated with coil dope. L3 is universal-wound onto this paper layer. The winding is $\frac{3}{4}$ inch wide. After every 250 turns, a layer of doped paper is applied to the winding to strengthen the coil. This builds up the winding to a diameter of approximately $2\frac{3}{4}$ inches. The coil is thoroughly doped, then dried, and covered on the sides and top with masking tape painted with dope. Each coil is wound as follows:

- L1—6 turns, C.T. No. 18 *Nylclad*
- L2—10 turns, C.T. No. 18 *Nylclad*
- L3—3,500 turns, No. 36 *Nylclad*, Silk



6-KV inverter.

The inner lead of L3 is grounded to any convenient point on the frame, and the outer terminal brought out by a well-insulated lead. Windings L1 and L2 must be correctly phased in order for oscillation to be obtained. Correct phasing is best established by trial and error. Reverse the base leads if oscillation is not obtained on the first try.

This unit produces a 6-kv AC output which can be combined with the unit on the right as shown. The right-hand circuit is a time-base generator which can be used as a portable flasher for warning lights (e.g., for construction hazards). They can also be used together.

Consider the time-base generator alone. When a 6-volt supply, a 2N35, and a 2N176 power transistor are used, it is a relaxation oscillator. Network R1-C1 is the time-constant circuit, and R2 controls the pulse duration.

With S1 open there is no output. When switch S1 is closed, capacitor starts to charge, making the base of X1 more positive than the emitter. This charging rate depends on the time constant of R1-C1. At some critical voltage, X1 begins to conduct, followed by X2. When X2 is driven into saturation, the full battery potential is across the load. Conduction of X2 causes capacitor C1 to discharge until, at a low critical value, X1 is cut off, causing X2 to be cut off also. This action is repetitive and establishes the time base.

The frequency of the circuit shown is approximately 90 pulses per minute. Other time rates can be obtained by using different values of R1 and C1. The frequency varies inversely with the value of R1 or C1. As the value of R2 is increased, the pulse duration is also increased. In the circuit shown, the pulse duration is approximately 10 milliseconds. If R2 were increased to 1,000 ohms, the duration would be approximately 50 milliseconds.

The time-base generator can drive a 6-volt incandescent bulb for warning purposes. Connecting A and B, as shown, allows the inverter to drive gas-tube lights.

DC-TO-AC INVERTER

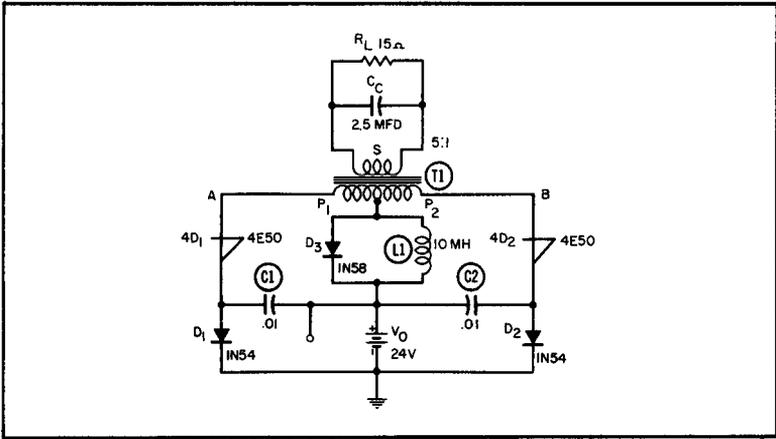
Both circuits shown use four-layer diodes. The first is a high-efficiency circuit with a minimum of components. The second circuit provides a margin against the effects of changes in load, load power factor, or supply voltage. Supply voltages of up to 80 volts may be used with a single four-layer diode in each side of the inverter, and higher supply voltages may be obtained by adding more diodes in series.

Part A of the diagram shows a highly efficient DC-to-AC power converter. The circuit alternately switches a fixed current, supplied through L1, into the two halves of the primary of a center-tapped transformer. The frequency is controlled by input pulses to the trigger point, with two pulses required for each cycle.

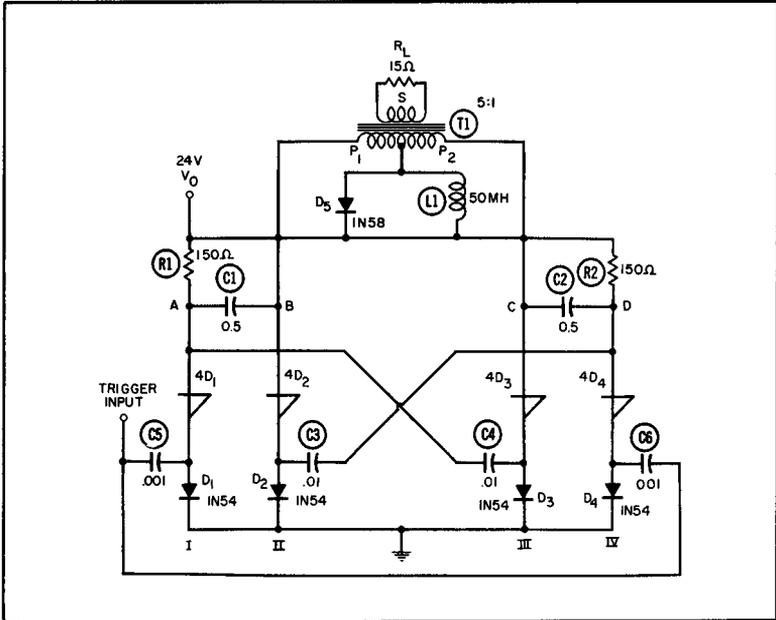
The circuit can operate at any frequency, from a few hundred cycles to more than twenty kilocycles. The DC supply voltage may be from six to several hundred volts. The power output is limited by the maximum current that can be switched into the primary. The circuit efficiency is a function of the DC supply voltage; it is about 95% for higher supply voltages and a minimum of 75% for a 6-volt DC supply.

When 4D1 conducts, current from the DC supply passes through the loop composed of L1, P1, 4D1, and D. This current is limited by the impedance reflected into P1 from the transformer secondary. Point A will be at the holding voltage (1 to 2 volts) of 4D1 and D1 in series. The center tap of the transformer will be at V_0 , and point B will—by transformer coupling between P1 and P2—be twice this voltage, or $2 V_0$.

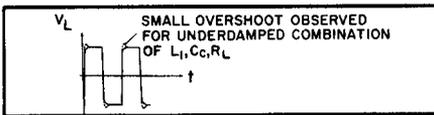
If a negative pulse of sufficient amplitude is applied to the trigger point, 4D2 will begin to conduct. The voltage on commutating capacitor Cc, which is coupled from the transformer secondary into the two primary legs, will drive point A negative. This will switch off 4D1. The DC supply current will be commutated from P1 into P2.



(A) High efficiency converter.



(B) Solid-state inverter.



(C) Waveforms

DC to DC inverter.

The next negative trigger pulse will switch 4D1 on again; and the commutating capacitor will, through transformer action, switch 4D2 off. The cycle is now completed.

The commutating capacitor must be large enough so that its voltage, when reflected into the transformer primary, is capable of turning off the diode. The commutating capacitor can be connected directly across the primary, from point A to point B. (If located in the higher voltage secondary, a much smaller capacitor may be used.)

Conventional diodes D1 and D2 must be capable of passing the high average current flowing in the circuit. For high primary currents, it is possible to replace D1 and D2 with four-layer diodes.

In high-efficiency parallel inverters, there is a tendency for both sides of the inverter to stay on when turned on. This can be prevented by using a normally closed relay in place of LI. The DC supply current passes through both the relay contacts and the actuating coil.

The solid-state inverter circuit shown in Part B protects against variations in load, load power factor, or supply voltage. The circuit is fail-safe because the supply current drops to zero whenever the load is shorted. Normal operation is resumed when the short is removed. The circuit will continue to operate normally despite large changes in supply voltage or poor load power factors.

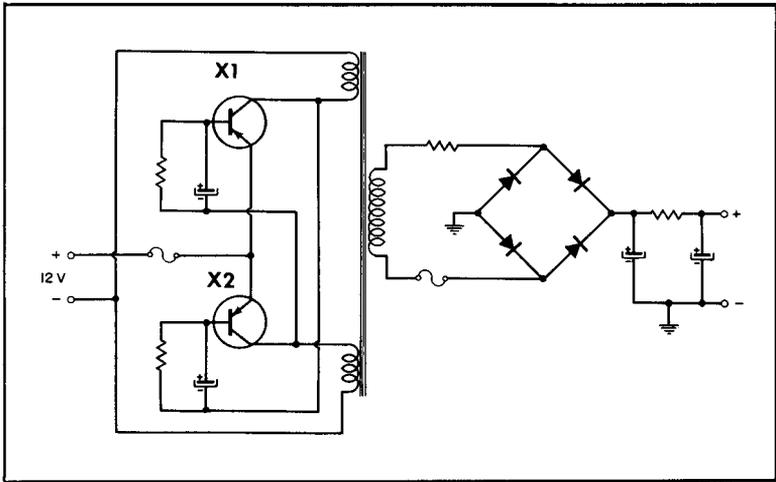
This highly reliable circuit uses outrigger stages, which turn off the adjacent conducting legs of the basic inverter when a trigger pulse is received, independent of the state of the other basic-inverter leg. The onset of conduction in an outrigger stage will also trigger the previously nonconducting inverter leg under normal operating conditions.

Design considerations for the basic inverter are the same as for Part A. Note the absence of the commutating capacitor in the transformer secondary; this function is provided by the outrigger stages.

DC-TO-DC CONVERTER (MOBILE-RADIO SUPPLY)

Transistor DC-to-DC converters are used for plate supplies because they are more efficient and reliable than other types of DC power sources. Power outputs of up to 700 watts are possible.

This figure shows a schematic of a transistor power supply designed to be added to and used with mobile radios. Two triode power transistors operating as a flip-flop oscillator are used. This oscillator is a square-wave generator with a frequency of approximately 100 to 3,500 cps.



DC to DC converter (mobile radio supply).

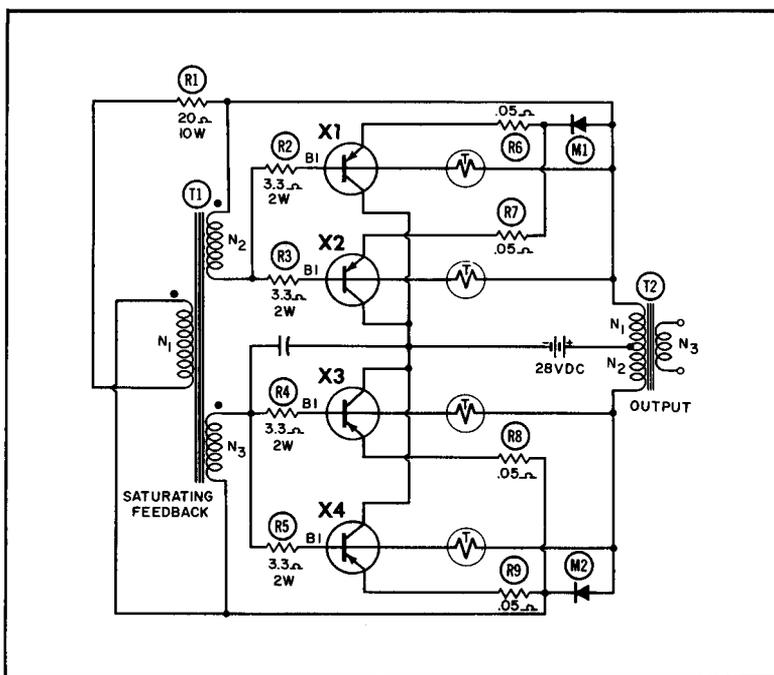
The vibrator-type supply requires an iron-core transformer with materials and construction similar to those for 60-cycle equipment. However, the transformer in a transistorized unit weighs only a few ounces. Therefore, less filtering and shielding are needed because current switching is electronic. Square waves are a source of harmonics into the RF range, but these undesired components are not difficult to suppress.

The stepped-up voltage appearing at the transformer secondary is rectified in a bridge circuit using four silicon diodes. Ripple filtering is accomplished in a conventional RC network following the rectifiers. Power output of the transistor supply shown is usually in the 200-volt, 100-ma range, which is sufficient to power a multistage FM receiver. Over-all efficiency of the supply is 70% to 75%. This is the approximate efficiency of a vibrator supply using a nonsynchronous vibrator and selenium rectifier.

All components except transistors usually are mounted on a small printed-circuit board. The transistors themselves are mounted directly onto the outside of the case, which acts as a heat sink. A protective bracket covers the transistors but still permits air to circulate freely around the heat sink, which maintains the transistors within the recommended operating temperatures.

500-WATT INVERTER

This circuit is a common-emitter, grounded-collector power supply which provides 500 watts of AC output from the 28-volt



500-watt inverter.

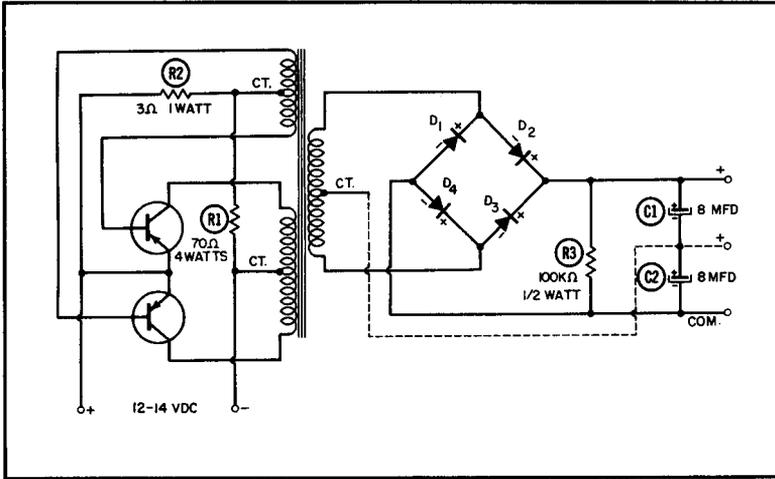
DC supply. Two sets of paralleled 3N46 or 3N50 tetrode transistors are used. R2 through R5 are 3.3-ohm base resistors; R6 through R9 are .05-ohm emitter resistors used to equalize the collector currents.

Voltage drops across diodes D1 and D2, applied to the bases through the *Thermistors*, provide a bias which increases with temperature and thus prevents thermal runaway.

In operation, one pair of transistors (X3 and X4) conducts through the lower secondary of T1 (the DC source) and the lower half of T2. Induced current in the upper secondary of T1 switches X1-X2 on, and AC is supplied through T2 to the output.

85-WATT DC-TO-DC CONVERTER

A DC-to-DC converter using 2N1755 transistors is shown here. When DC-to-DC converters are operated at the higher input voltages, their transformers must be specially designed. Recommended transformer core materials are *Orthonol* or *Deltamax* with .002-inch laminations. Frequency of operation at approximately 2,000 cps offers best compromise between transformer size and converter efficiency, although the frequencies can be



85-watt DC to DC converter.

higher than 2,000 cps if the lower efficiency caused by the reduced squareness of the waveform can be tolerated. Frequency of operation is chosen and the design of the transformer primary winding calculated from the formula shown in the figure. The feedback winding provides approximately two to three volts for each base, and the secondary winding provides the proper voltage to the load. The purpose of R1 is to bleed current into the bases of X1 and X2, to promote starting at low voltage. R2, in conjunction with R1, is adjusted to provide the proper "on" base current. R2 should be from 3 to 10 ohms. The following precautions should be observed:

1. Transformer windings should be balanced and should be bifilar wound to minimize leakage reactances.
2. Switching transients in the collector-voltage waveform should be eliminated by using the "despiking" networks of a small buffer capacitor across the secondary winding.
3. The path of operation (V_{CE} versus I_c) should be observed on an oscilloscope. The most reliable converters are obtained when the V_{CE} versus I_c plot encloses the smallest possible area. Improvements can be made by bypassing R2 with a large capacitor and by assuring that the "on" base current does not exceed the recommended value.
4. Any input transients should be eliminated by placing a capacitor across the input terminals of the supply.
5. Insulating washers between the transistors and heat sink should be coated with silicone grease. The heat sink should have sufficient area to maintain the temperature of the

transistor mounting base below 85°C. at the maximum expected ambient temperatures.

The following maximum input voltages (DC plus peak) are recommended for these transistor types:

Type	Maximum DC Input Voltage (Volts)	Approximate Power Output (Watts)
2N1755	16	35
2N1756	24	60
2N1757	30	75
2N1758	35	85

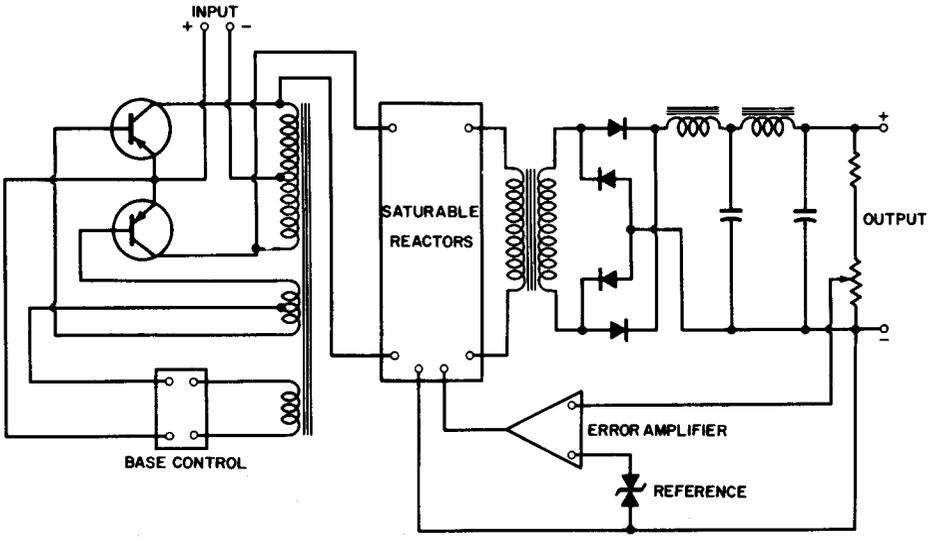
REGULATED DC-TO-DC CONVERTER

This circuit consists of two PNP power transistors in a push-pull switching circuit, which is connected to the DC power source by a control circuit. The two transistors alternately connect the input voltage across each half of the primary of a toroidal transformer. The transistor dissipation is low and the conversion efficiency high. In addition to the primary and secondary, the toroid also has windings for positive feedback from collector to emitter of each transistor.

When one transistor conducts, the supply voltage is placed across half the primary, and the opposite collector is driven negative to twice the supply voltage. At this point the base feedback voltage is reduced. The collector current and voltage across the primary are also reduced, lowering the base drive. This action regeneratively shuts off the conducting transistor and starts the conduction cycle in the opposing transistor. The resultant waveform is a series of square waves across the primary.

The frequency of oscillation is a function of the characteristics of the transformer core, the number of primary turns, and the supply voltage. A base-control circuit is used to prevent excessive transistor dissipation when the oscillator is effectively operating at no-load. The control circuit also provides quick starting and prevents transistor failure if the supply voltage should accidentally be reversed.

The base-control circuit takes advantage of the reversal in polarity between PNP and NPN transistors. This reversal permits the bases of the PNP oscillator transistors to be connected directly to the collector of an NPN control-transistor circuit and then to the positive end of the DC supply. The control transistor has a negative bias voltage obtained from an additional winding on the exciter transformer. The collector current of the control tran-



Regulated DC to DC converter.

sistors (hence, the maximum base current of the oscillator pair) is determined by this bias voltage.

The control transistor has a high effective collector resistance, and the oscillator transistors act as though they were operating with a constant-current bias. Thus, if for any reason the output should become shorted, there will be no bias voltage and the base current will drop very low. This protects the converter from accidental shorted loads, because the other DC power sources are not protected.

Base-circuit regulation may be used; a sample of the rectified and filtered output voltage is compared with the accurate, stable reference voltage of a zener diode. The difference voltage is then amplified by one or two transistors and applied to the base of a regulator transistor in series with the base return circuit of the switching transistors. The control-transistor impedance varies in proportion to the error voltage and thereby changes the output of the switching transistors.

A saturable-reactor regulator may be used between the free-running transistor oscillator and load. Saturable reactors are switched, opening or closing under control of an error voltage obtained by comparing the rectified and filtered DC output voltage with the voltage of a zener diode.

SHORT-CIRCUITPROOF INVERTER

A circuit with protection against shorts is shown here. Inverter circuits that use bistable devices often require protection. The low conducting impedance and high efficiency of the control devices make them attractive for inverter use, but faults will develop if the load shorts or opens or if the gate drive is lost. This circuit has been developed to protect the inverter.

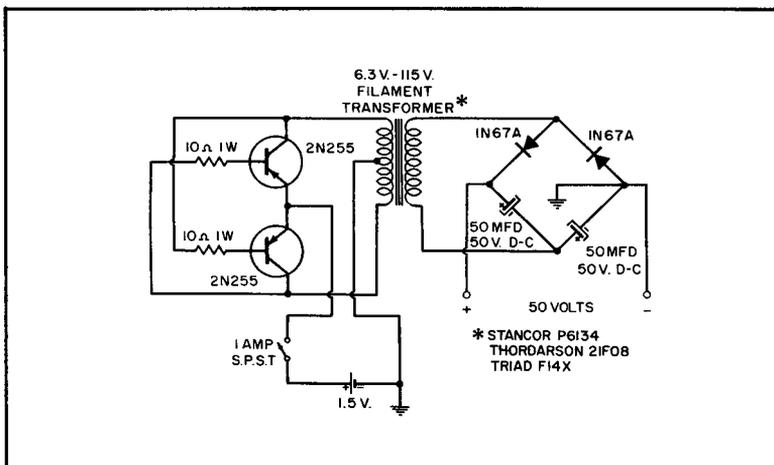
The rectifiers perform the inverter function from a 24-30-volt DC supply to a 110-volt, 300-VA, 400-cycle load. The firing mechanism for the gates is a free-running multivibrator. The additional components in the center of the diagram perform the protective function.

To energize the circuit, switch S1 is closed and lever switch S2 is depressed and released. Considering the basic circuit action only, rectifier 1 fires through the DC power source and half of the transformer primary. When rectifier 2 fires, it takes the identical path but uses the lower half of the primary. The flywheel effect of the commutating capacitor, across the secondary, continues this action. When S2 is depressed, switch sections S2A and S2B provide a fast-charging path for the 1,000-mfd capacitor through the 1.0- and 0.1-ohm resistors. Switch section S2C pro-

controlled rectifiers may be protected against fault currents by a fuse or fast magnetic circuit breaker. To prevent misfiring when the inverter is switched on, the multivibrator must be switched on before the voltage is applied to the controlled rectifiers, or a slight addition made to the multivibrator circuit to assure its proper starting.

DC-TO-DC MULTIPLIER

This DC voltage multiplier converts 1.5 volts DC to 50 volts DC. By providing a high voltage from a low-voltage source, it eliminates the troublesome vibrator or bulky B+ battery. When the transistors oscillate, they provide an AC voltage across the transformer. The output voltage and current are determined by the battery voltage and transformer turns ratio; therefore, they may be varied to suit the application, as long as the transistor and diode ratings are not exceeded.

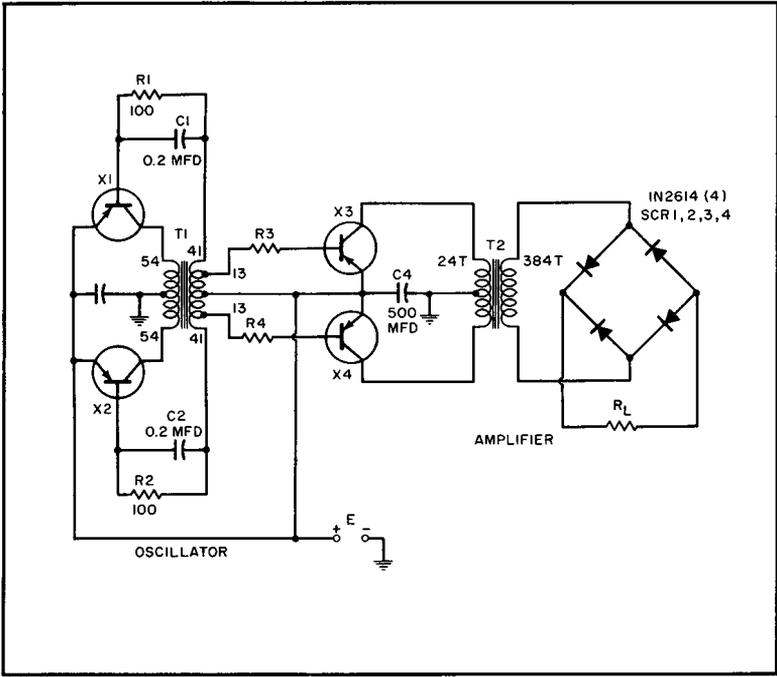


DC to DC multiplier.

OSCILLATOR-AMPLIFIER DC-TO-DC CONVERTER

This oscillator-amplifier circuit can have an input of either 14 or 28 volts. For 14 volts the power output is up to 100 watts; at 28 volts it doubles, to 200 watts.

Transformer T1 is bifilar wound onto an AP 11-424 *Ceramag* core and yoke with No. 22 *Nylclad* copper magnet wire. The primary has 108 turns and is center tapped. The secondary also has 108 turns and a center tap, but has two additional taps 13 turns from each side of the center. Transformer T2 can be wound using Arnold Core Section 4 MIL C Core (AJ-H-12). B_m is equal to 12 kilogauss with an area of 0.5 square inch.



DC Input	DC Output	Repetition Frequency	*X1, X2	X3, X4	R3, R4
14V	200V	400 cps	2N176	2N627	0.5 ohm, 5W
28V	400V	800 cps	2N375	2N629	1.0 ohm, 5W

The following parts are independent of input voltage.
 C1C2—0.2 MFD, 200 VDC, C3C4—500 MFD, 50 VDC, R1R2—100 ohms, 1W, CR1234—1N2614, T2—MTR—916, PX—1301

Oscillator-amplifier DC to DC converter.

When the oscillator is connected, the correct phase relationship between the primary and feedback windings must be maintained. If oscillation is not obtained and the phase terminals are not marked, reverse the collector or base leads.

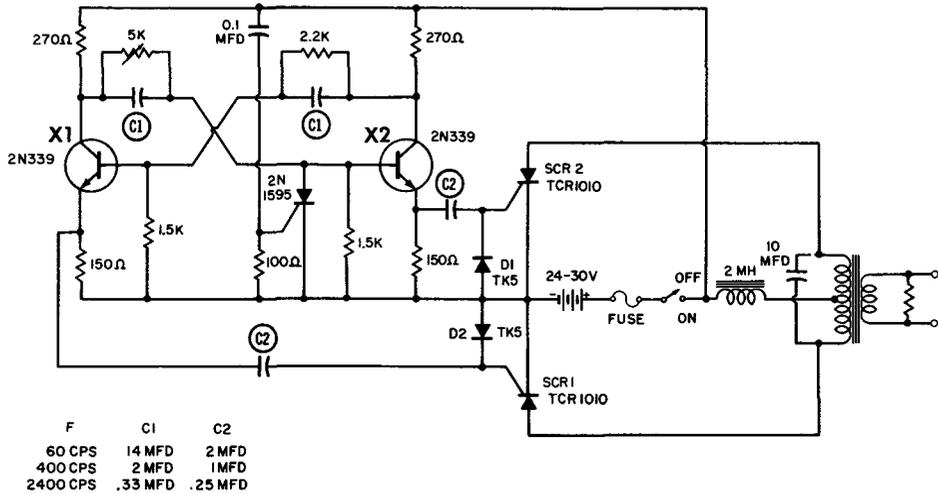
From the curves, greatest efficiency (about 87%) can be obtained at 100 watts for an input of 14 volts, and 200 watts for 28 volts.

MULTIVIBRATOR-DRIVEN INVERTER

This figure shows a multivibrator using 2N339's and firing a pair of controlled rectifiers. To start the circuit, switch S1 is closed to apply the supply voltage to the CR's and trigger circuit.

The sudden rise of the supply voltage at the trigger circuit causes a positive spike at the gate of the small controlled rectifier

Multivibrator driver inverter.



2N1595, which fires. The base of the second 2N339 is then shorted to ground and thus prevented from conducting. The first transistor conducts and turns on CR1. When capacitor C1 is charged, the current through the 2N1595 will drop below the holding current because of the high impedance (approximately 3K) to the flow of current. This controlled rectifier is thus turned off. When the 2N1595 is turned off, normal multivibrator performance of the trigger circuit is obtained, resulting in proper starting and normal inverter performance.

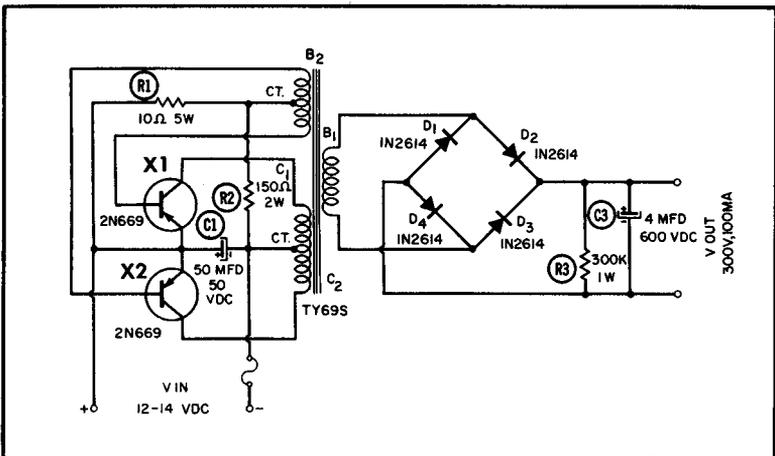
The values of C1 and C2 are given for 60, 400, and 2,400 cps. For better frequency stability, the supply voltage of the trigger circuit may be regulated by using a zener diode.

DC-TO-DC CONVERTER

This converter can be used for a variety of outputs, from 12 to 14 volts DC input at 75% efficiency.

For 250 volts, 65 mils, the transformer is a TY-68S with a pair of 2N669 transistors and 20 square inches of heat sink. Rectifiers are 1N2613's; R1 is 500 ohms, 5 watts; R2, 50 ohms, 5 watts; R3, 300K, 1 watt; C1, 50 mfd, 50 volts; C2 is not used; and C3 is 2 mfd, 400 volts.

Other values—for 300 volts at 100 mils, 325 volts at 200 mils, and 375 volts at 200 mils—are as shown.

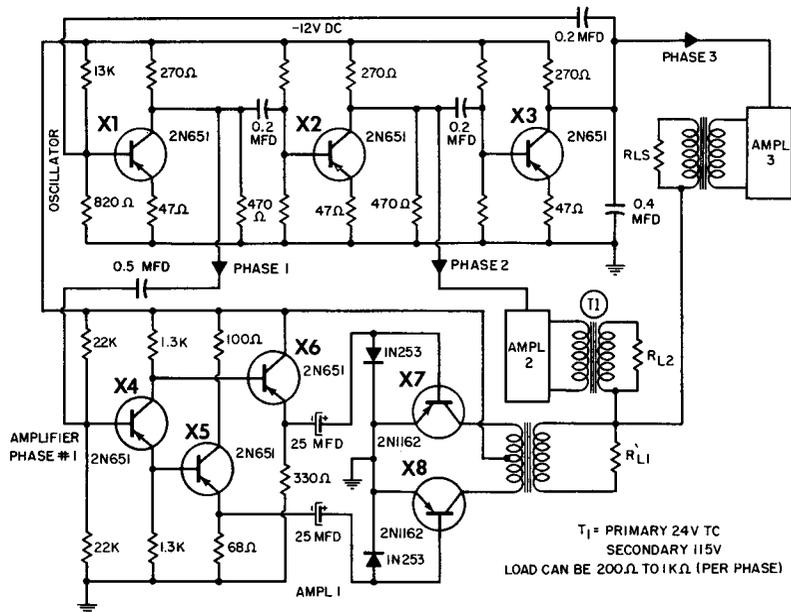


DC to DC converter.

400-CPS 3-PHASE OSCILLATOR AND AMPLIFIER

A circuit for driving a 20-watt, three-phase load at 400 cps is shown here. The three-phase oscillations are supplied by an RC-

400-cps 3-phase oscillator and amplifier.
138

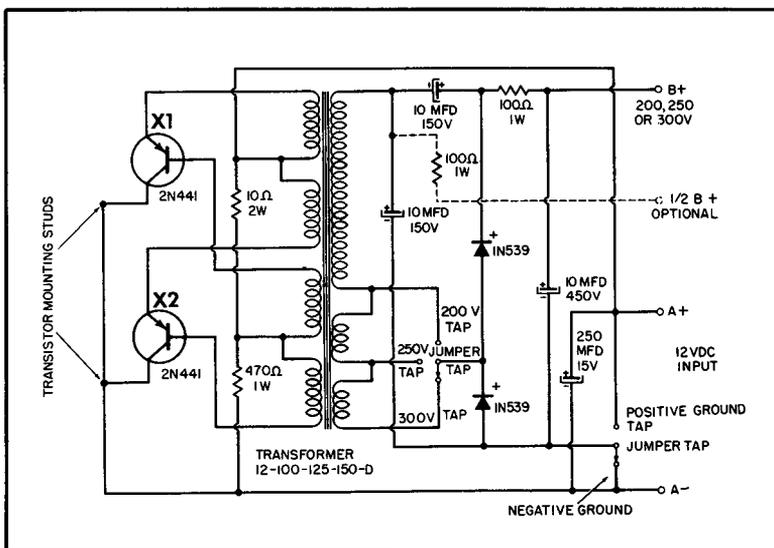


coupled oscillator so that a 120° phase difference exists at the collector of each transistor. An emitter-follower amplifier drives the output-power transistors into saturation. The result is a clipped sine wave on the output-transformer secondary.

This circuit can be used to drive a three-phase aircraft gyro-motor from a 12-volt DC supply.

MULTIPURPOSE DC-TO-DC CONVERTER

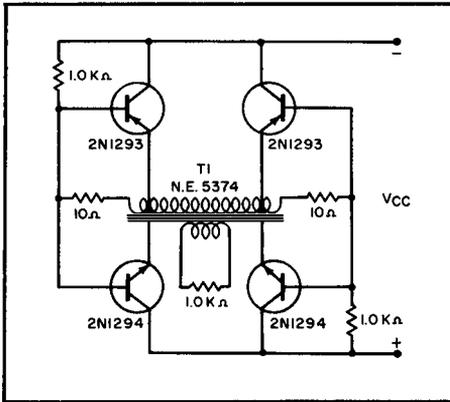
Power converters can be bought as complete "package" units as shown, or special transformers may be purchased separately and a power supply custom-built. A 12-volt transformer can be used in the circuit shown. This unit provides up to 40 watts of output at 200, 250, or 300 volts DC, with current drains of up to 125 ma. Two power transistors are cross-coupled to form an oscillator that operates at about 2 kc. After the voltage has been stepped up, the oscillator is rectified by a voltage doubler and filtered by an RC filter.



Multipurpose DC to DC converter.

COMPLEMENTARY POWER CONVERTER

As power requirements increase, transistor converters become more complex. More transistors are needed; they may be either series- or bridge-connected. Both circuits usually are transistors of the same type. The transformers for converters are complex, requiring six or seven windings.



Complementary power converter.

A complementary transistor converter with a simple circuit is shown. Using complementary transistors results in circuit economy and greater reliability. The transformer uses only two windings. The bases and emitters of the PNP and NPN transistors are in parallel. This prevents the bases from becoming highly back-biased, because if one unit is turned off the other must be turned on. The inherent protection reduces the possibility of self-destruction when the transistors are operated with inductive loads. The converter shown has an efficiency of 87% at an output of 122 watts and with a supply of 45 volts DC.

Section 11

AUDIO AMPLIFIERS

Because of their lack of microphonics and hum, transistors are a natural for audio amplifiers. The low-level stages of an audio amplifier are critical, because noise, hum, or distortion will be carried through the system and amplified (along with the desired signals) at the output. Hum in vacuum tubes comes from the use of AC as the heater source, or sometimes from a power supply with poor filtering. Thus, the fact that transistors use no AC, means that hum-free operation can be achieved.

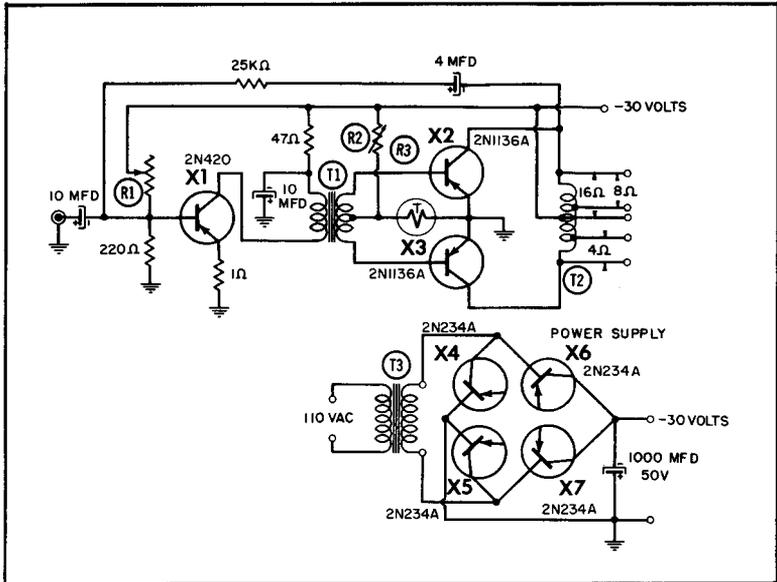
Microphonics is a form of noise caused by vibration of the tube elements. This creates an undesired modulation of the signal; with transistors, however, there is no distortion because semiconductor circuit elements are secure, and hence do not vibrate.

Low-output impedance is another advantage of power transistors in audio amplifiers. Transformers which drive speakers are responsible for many problems in the circuit design of audio amplifiers, because of their inherent frequency limitations plus their size and weight. However, power transistors can drive the voice coil directly, because of the close impedance match; no output transformer is needed.

The low current drain and small size of transistors makes them extremely popular for use in portable equipment. With small components, a lightweight battery source, and four- to six-inch speakers, the entire audio amplifier makes a tiny package. Transistors are also found in preamplifiers, intercoms, and other normally nonportable equipment.

20-WATT HI-FI AMPLIFIER

This is a three-transistor hi-fi amplifier with a response of ± 1 db from 50 cps to 20 kc, and ± 2 db from 20 cps to 20 kc. Harmonic distortion is 0.8% at 1 watt and 2.7% at 20 watts (at 1,000 cps). This power amplifier can be used with a suitable preampli-



T₁ — E-11 (4% Silicon Steel)
 Square Stack — 7/8 in.
 Window Area — 0.574 sq. in.
 Cross Sectional Area — 0.766 sq. in.
 Primary — 450 Turns #28E
 Secondary — 250 Turns #28E ct
 T₂ — Stancor RT204

T₂ — E-12 (4% Silicon Steel)
 Square Stack — 1 in.
 Window Area — 0.75 sq. in.
 Cross Sectional Area — 1 sq. in.
 366 Turns #18E
 183 Turns Tap for 16Ω (also ct)
 92 Turns Tap for 8Ω

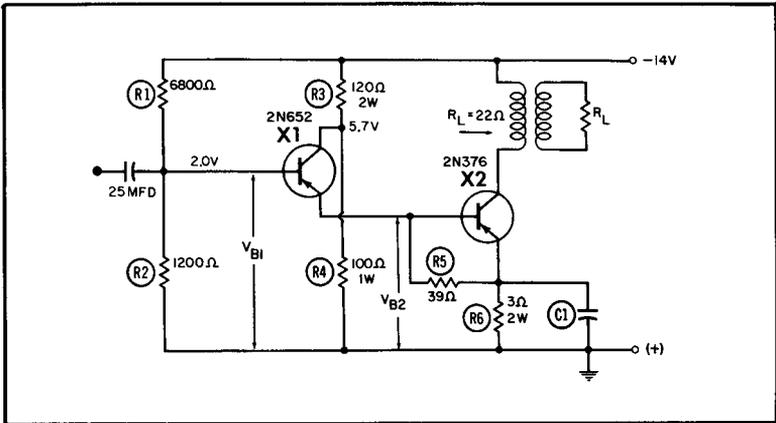
20-watt Hi-Fi amplifier.

fier to obtain 20 watts of output. With the transformer, output impedances of 4, 8, and 16 ohms are provided. A single 30-volt power source, plus a bridge using four low-cost power transistors as diodes, are required. These transistors are efficient in this application because of their low forward voltage drop.

2-WATT HI-FI AMPLIFIER

In this circuit, a 2N652 emitter follower driving a 2N376 power transistor allows maximum amplification with a minimum amount of distortion. A single 14-volt supply is used; and R1 and R2 form the bias network for both stages.

Because the emitter current of X1 is the sum of both the currents of R5 and the X2 base, the emitter current of X1 will be maximum when the lowest-gain transistors are used for X2. R3 and R4 are chosen so that the minimum V_{CE} is about one volt during peak signal conditions. Operating X1 at the lowest possible



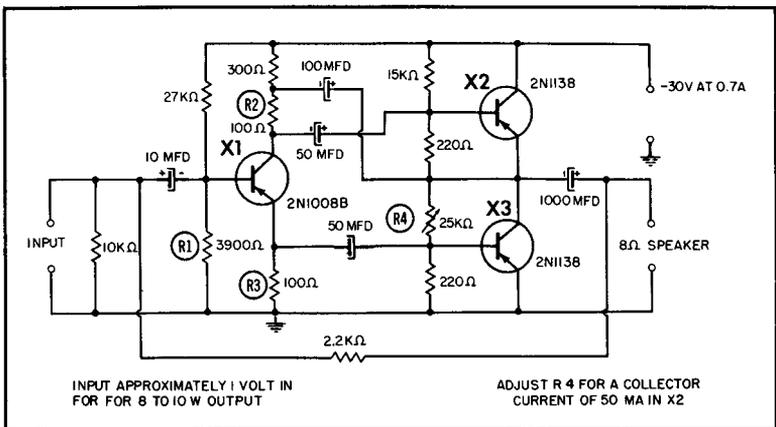
2-watt Hi-Fi amplifier.

voltage will increase the stability, resulting in less power dissipation.

R6 determines the stability of the system and the variation in current gain of X2. The voltage drop across R6 should be larger than the changes in base-to-emitter voltage required to keep the emitter current constant over the expected temperature range for the various transistors.

LOW-COST HI-FI AMPLIFIER

Here is a low-cost hi-fi amplifier using only three transistors and a single 30-volt supply. With a signal input of 1 volt, the out-



INPUT APPROXIMATELY 1 VOLT IN
FOR 8 TO 10W OUTPUT

ADJUST R 4 FOR A COLLECTOR
CURRENT OF 50 MA IN X2

Low-cost Hi-Fi amplifier.

put will be approximately 8 to 10 watts. The power gain of the amplifier is approximately 20 db.

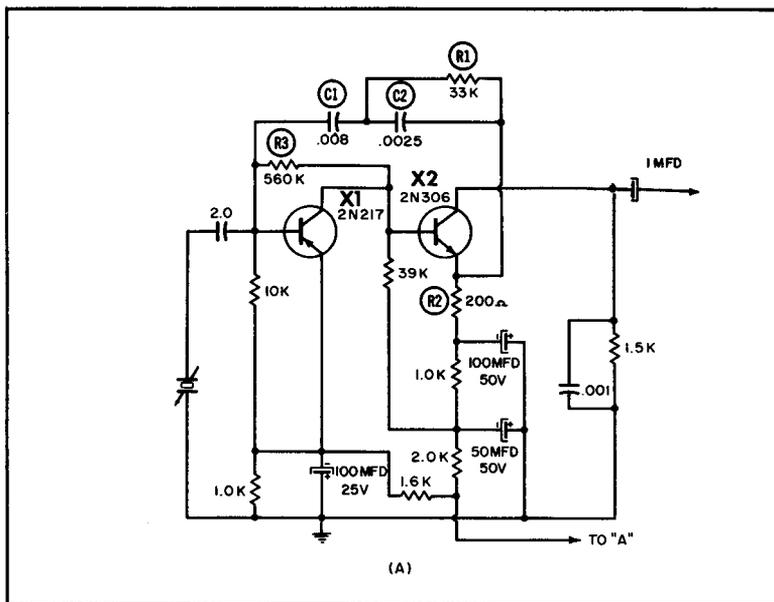
The first amplifier (X1) is used as a phase inverter to feed the bases of X2 and X3, which are operated in push-pull. Stabilizing feedback is obtained through the 2.2K resistor at the speaker tap.

Having no inductive components, the circuit has an almost flat response over a wide audio spectrum.

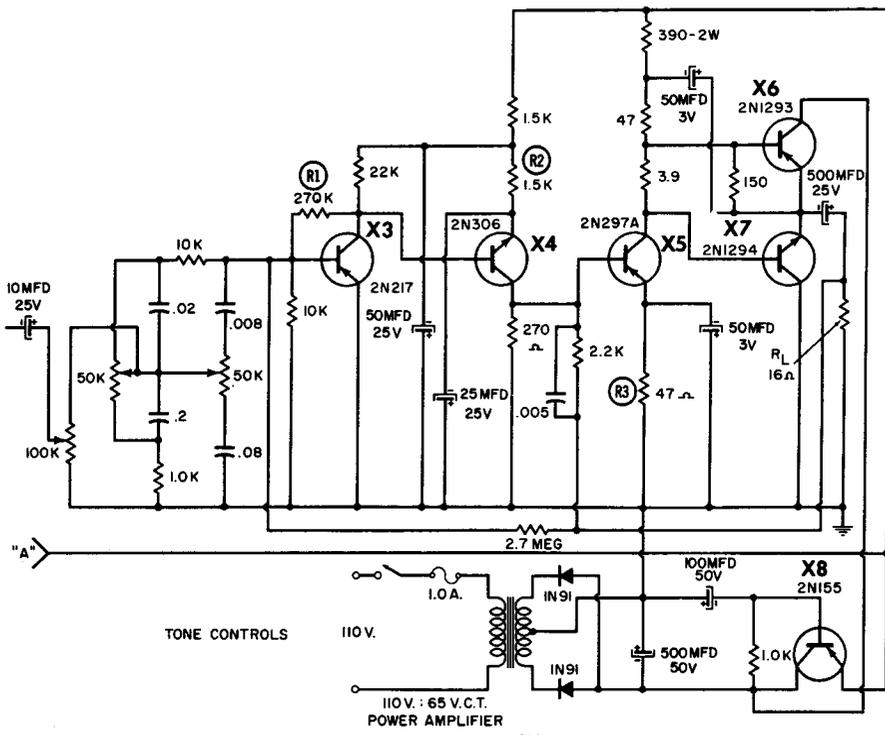
COMPLEMENTARY HI-FI CIRCUITS

Complementary hi-fi circuits are very useful in resistance-coupled applications. Some of the benefits of the cascade complementary amplifier are higher current gain, better temperature stability, and component interchangeability and economy. Part A shows a preamplifier for a ceramic pickup. Frequency stabilization is accomplished by the negative feedback of C1, R1, and C2. DC stabilization is provided by R2 in the emitter of X2, and R3 in the collector of X1.

The main amplifier is shown in Part B. DC stabilization is accomplished by the R1 collector-to-base resistor of X3, the R2 emitter resistor of X4, and the R3 emitter resistor of X5. The output stages are operated Class B, and the driver is operated



(A) Preamplifier.



(B) Power amplifier.

Complementary Hi-Fi circuits.

(B)

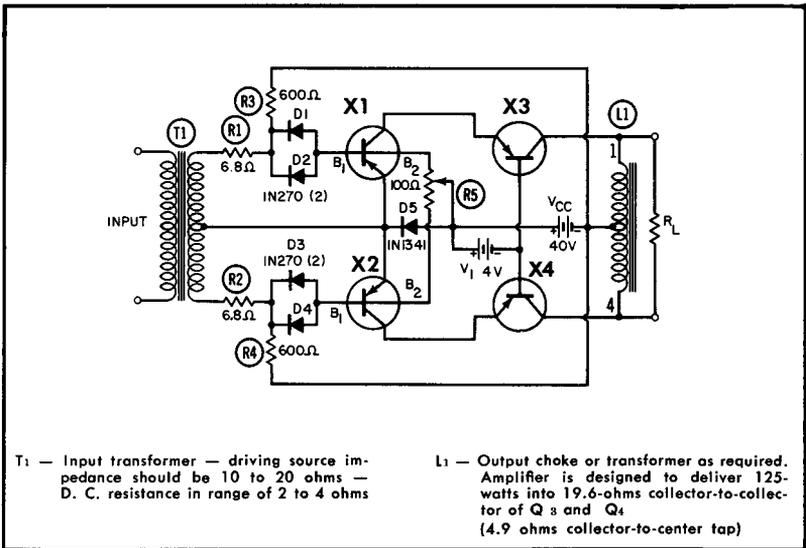
Class A. Feedback reduces distortion and the output impedance. The complete amplifier is rated at 10 watts with noise down 65 db, and the frequency response is 30 cps to 15 kc ± 1.5 db.

125-WATT CLASS-B PUSH-PULL AMPLIFIER

This high-power Class-B audio amplifier uses tetrode 3N47 or 3N51 transistors in a common-emitter push-pull stage for high power gain and frequency response at low voltage. A pair of 2N574A transistors in a common-base arrangement are utilized for the 125-watt output.

A separate 4-volt supply is used for the first stage. The voltage-divider bias network is formed by R3, R1, and the DC resistance of half the secondary of T1. The value of R3 may have to be changed to maintain the collector current if a transistor with a much different gain is used. Diodes D1 and D2, in series with base 1 of transistor X1, block the reverse drive during the off half-cycle. This reduces the high-frequency distortion.

Reverse bias is applied to B2 of X1 through potentiometer R5. This voltage is obtained from the forward voltage drop across silicon power diode D5. By adjusting R5 while observing the total harmonic distortion of the amplifier, it is possible to obtain the desired minimum distortion (balanced output currents from X1 and X2).



125-watt class-B push-pull amplifier.

Drive for X1 and X2 is obtained from the tapped secondary of T1. The collectors of the first stage drive the emitters of the second stage; the 40-volt source is supplied through the output-choke center tap.

The low-voltage source supplies 400 mils peak, and the 40-volt source provides 7.15 amperes peak.

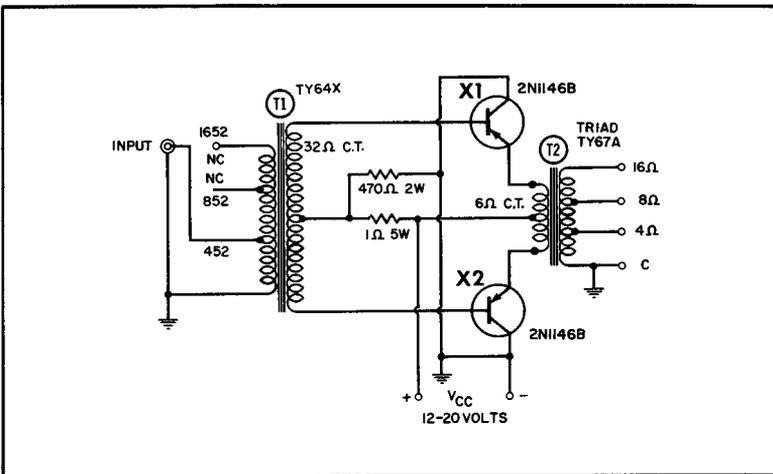
100-WATT AMPLIFIER

This diagram shows a two-transistor (2N1146B) audio amplifier featuring circuit simplicity.

At a 1-watt input, the power source is 12 volts, output power is 30 watts, and the response is flat (within 3 db) from 25 cps to 14 kc.

With 2 watts of input, the power source is 15 volts, output power is 50 watts, and the response is 30 cps to 11 kc.

At 3.8 watts in, the power source is 20 volts, output power is 100 watts, and the response is 50 cps to 17 kc.

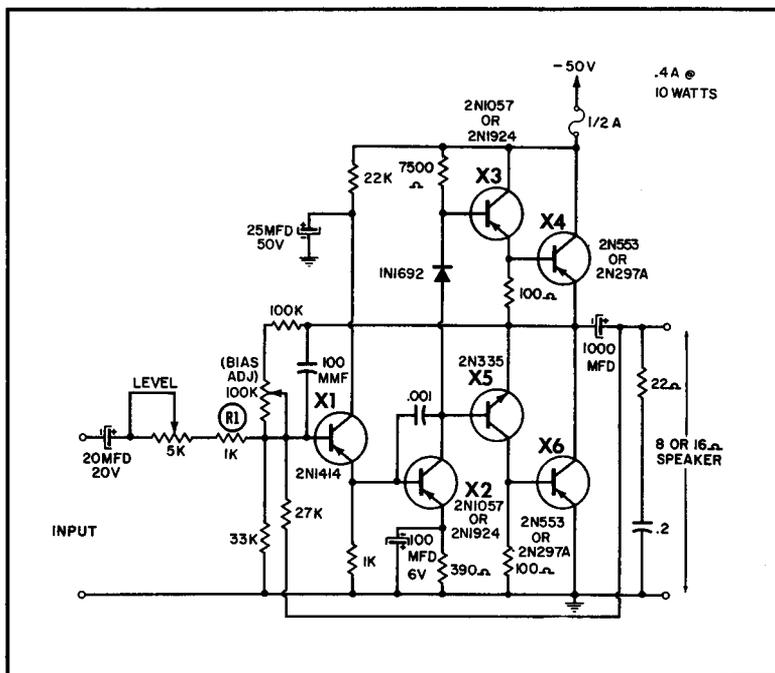


100-watt amplifier.

10-WATT AMPLIFIER

Use of the 2N1042-45 series transistor as an audio amplifier is shown in this figure. The transistors are in push-pull, since the emitter signals are 180° out of phase (as shown on the diagram by the dots at each end of the transformer).

Using the 2N1042, for example, with a —35-volt supply and a 1-ohm emitter resistor, the efficiency is 58% for a 10-ohm load and the distortion is 2.7%.



10-watt amplifier.

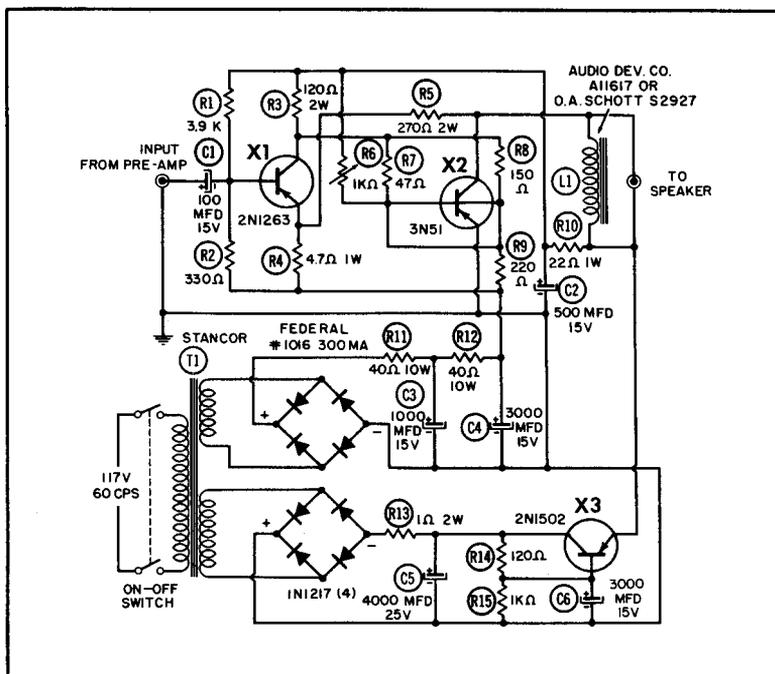
Other transistors with larger supply voltages and lower efficiencies are listed in the table.

5-WATT CLASS-A AMPLIFIER

Using a 2N1263 driving a tetrode 3N51, this audio amplifier produces more than 5 watts of output at a low (1.5%) distortion. The driver is a common emitter with a voltage divider R1-R2 to provide a DC collector current of 100 ma.

The output stage is a common emitter. Base 2 of the tetrode is connected to a reverse-biasing source consisting of a 6-volt supply and a 220-ohm series resistor. Base 1 is forward-biased in the conventional manner with a 1,000-ohm potentiometer R6 connected to a 12-volt collector supply. The combination of these forward- and reverse-biasing networks establishes a quiescent (no-signal) collector current of 1.2 and 1.4 amperes DC. The input signal is divided between the two base connections by means of a fixed 47-ohm and a 150-ohm resistor network.

The coupling between the output stage and load is relatively simple and straightforward. The collector of the output stage is



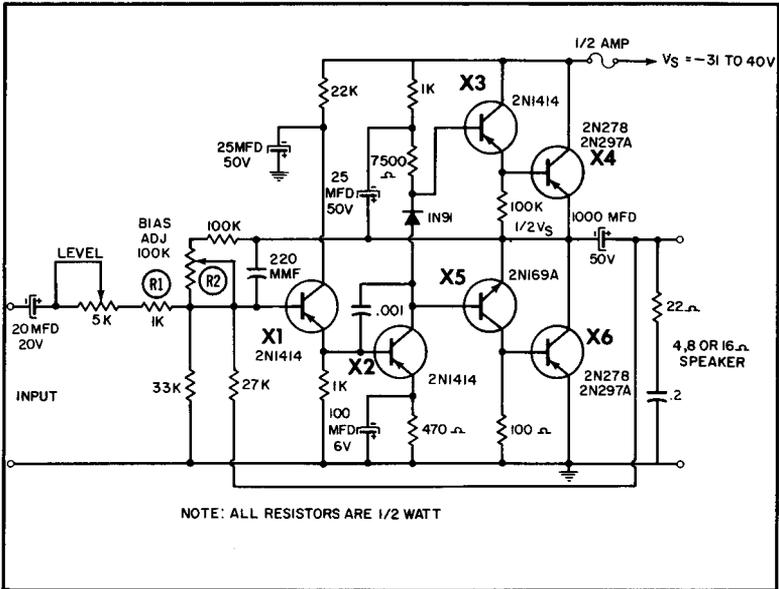
5-watt class-A amplifier.

shunt-fed through a low DC resistance choke. For the collector supply voltage and quiescent current used, maximum power output is obtained with an 8- to 10-ohm load across the collector-to-emitter junction of the output stage. A 50% reduction in power output results when 5- or 20-ohm load resistances are used, but a tapped choke will permit maximum power output into load resistances of 4, 8, or 16 ohms.

7-WATT AMPLIFIER

This figure shows an RC coupled 7-watt audio amplifier in which six transistors are used. The 4-, 8-, or 16-ohm voice coil can be driven directly by the output stage. Hence, no output transformer is needed.

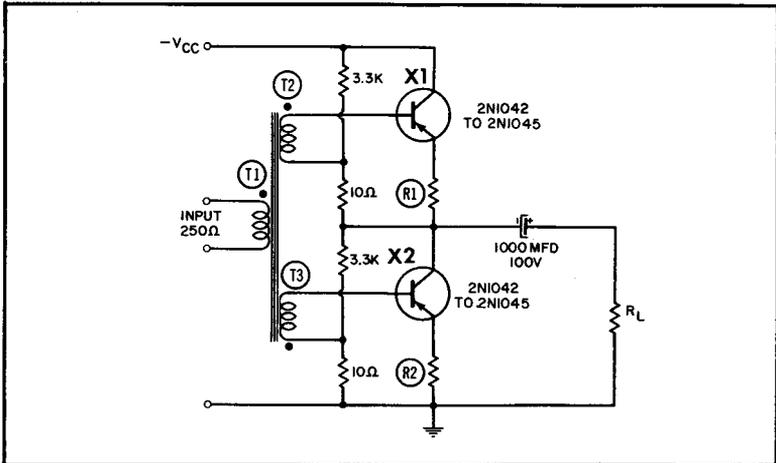
Level control 5K is used to adjust the volume, and bias control R2 helps control the circuit distortion. After amplification in X1 and X2, the signal is split into two paths by X3 and X5. At these stages, the signal is injected into push-pull amplifier X4 and X6, and a full 7 watts is obtained at the output.



7-watt amplifier.

DIRECT COUPLED 10-WATT AMPLIFIER

This is a typical 10-watt audio amplifier featuring a Bias and Volume control. No output transformer is needed. Direct coupling through a 1,000-mfd capacitor is sufficient to drive an 8- or 16-ohm PM speaker.

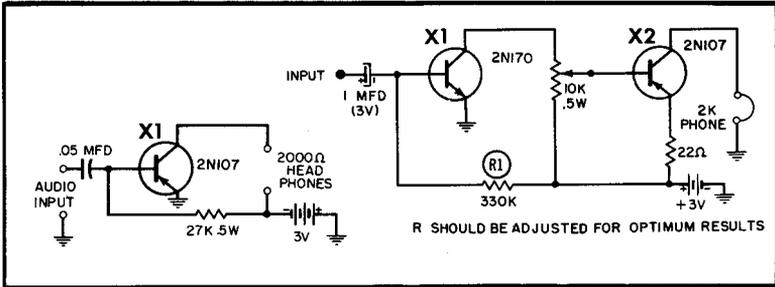


Direct-coupled 10-watt amplifier.

About 6 db of negative loop feedback is used to match the output impedance of the amplifier to the load and further reduce distortion. The feedback path consists of a 270-ohm resistor connected between the collector of the output stage and the emitter of the driver stage. This path includes the emitter current of the driver stage. Because there is practically no phase shift between the emitter and collector currents of this stage in the useful passband of the amplifier, the phase shift around the feedback path is essentially that of the output stage only.

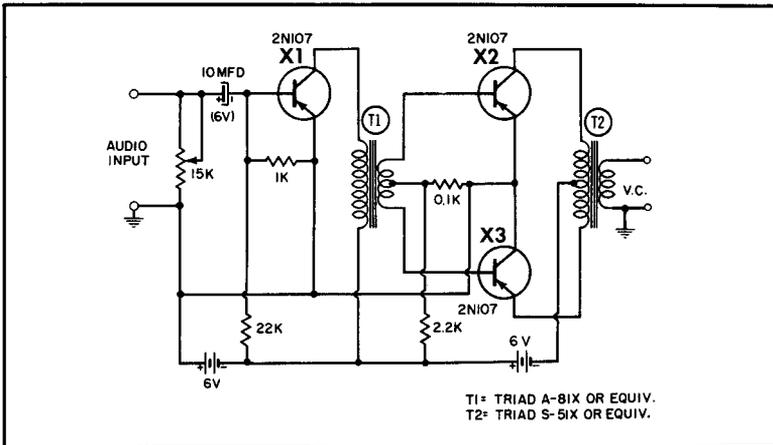
BASIC AUDIO CIRCUITS

Many types of audio amplifiers are possible using a wide variety of transistors. Three basic circuits are shown here. Part A of the diagram is an elementary circuit that can be used with an RF



(A) Simple amplifier.

(B) Direct coupled amplifier.



(C) Amplifier driving speaker.

Basic audio circuits.

detector to provide audio to drive a pair of earphones. Input is to the base of the 2N107, which operates with a grounded emitter. A single 27K, 0.5-watt resistor is used for bias, and the output is taken off through the 2,000-ohm phones.

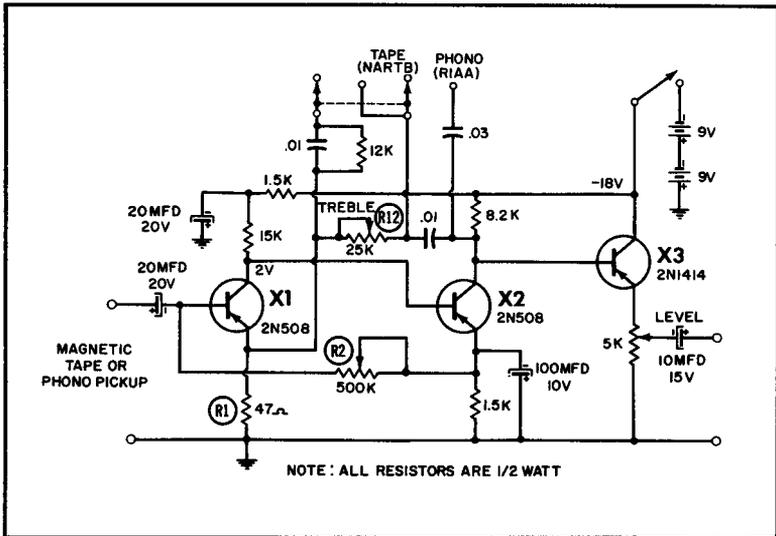
Part B shows a "battery saver," which has a low current drain and uses direct coupling from the 2N170 to the 2N107.

Unlike Parts A and B, which use phones for the output, Part C uses a speaker. Note that two 6-volt sources are employed in the transformer-coupled circuit of Part C.

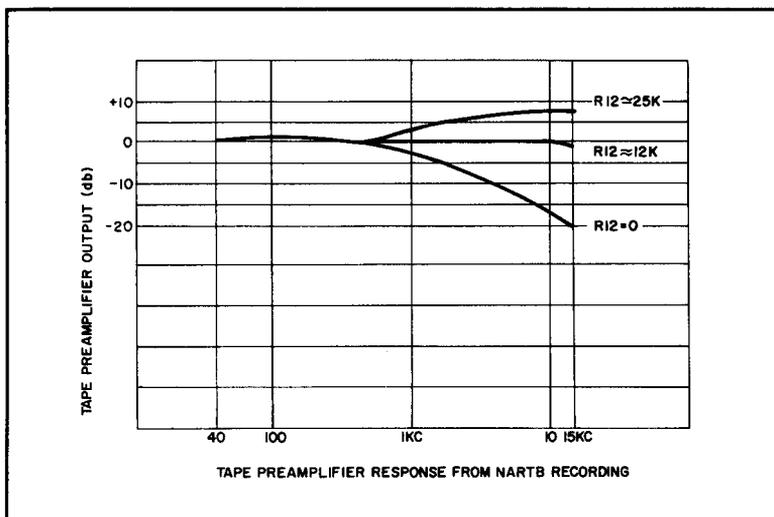
PHONO TAPE PREAMPLIFIER

This three-transistor preamp is designed to produce a signal level of 1 to 2 volts from the low-level signal input and, at the same time, provide compensation for that signal. The total harmonic distortion is less than 2%, and either magnetic tape or magnetic pickups can be used for the input. Feedback resistor R2 is adjusted to provide 2 volts at the collector of X1.

Part B of the diagram shows the output response curve. With treble control R12 in midposition, there is a flat response for standard RIAA recording and NARTB prerecorded tapes. A boost of 8 db is obtained with the full 25K in the circuit, and the treble reduction is 2 db with R12 at zero.



(A) Preamp.



(B) Response curve.

Phono preamp.

STEREO HI-FI PREAMP

This three-stage transistorized preamplifier features four matched input impedances and volume, bass, and treble controls. Stereo reproduction may be obtained with two similar units through the aid of a simple balance control, as shown in the block diagram. The input-selection, volume, and tone controls of the stereo amplifiers are ganged. The balance control is also ganged and connected as shown so that the amplifiers will operate in opposition to each other.

(See page 154)

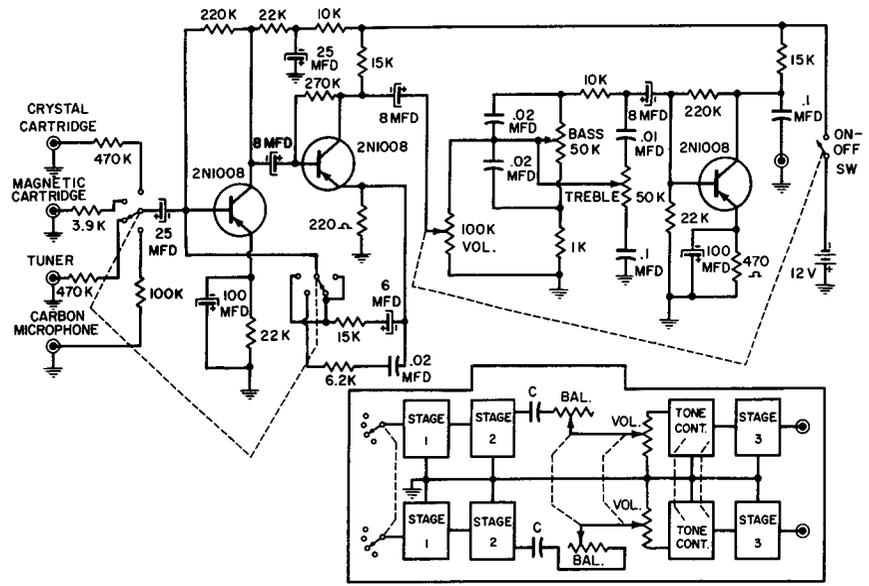
FIVE-TRANSISTOR PHONO AMPLIFIER

In this four-stage, five-transistor amplifier, the maximum output power is 1.0 watt (0.75 watt at 10% distortion). Three RC-coupled stages are used ahead of the push-pull output. All stages are 2N323's except those at the output, which are 2N321's with clip-on heat sinks.

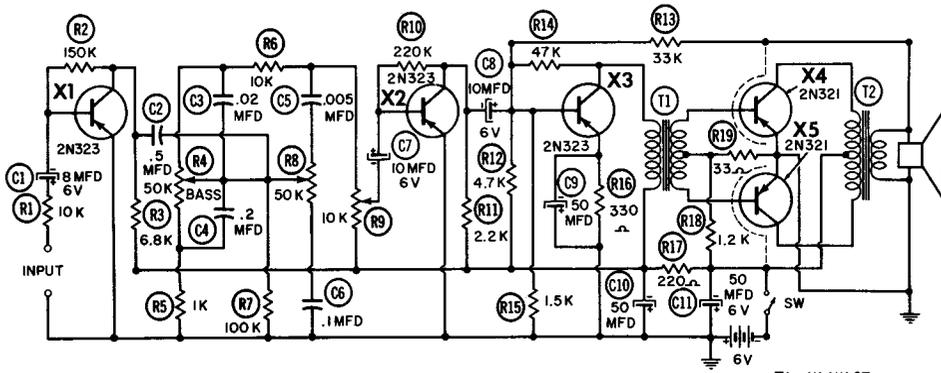
R9, feeding the base of X2, is the 10K volume control. R4 is the 50K bass control, and R8 is the 59K treble control.

(See page 155)

Stereo Hi-Fi preamplifier.
154



Five-transistor phono amplifier.



T1 - 1K/1K CT
 T2 - 100Ω CT/VC

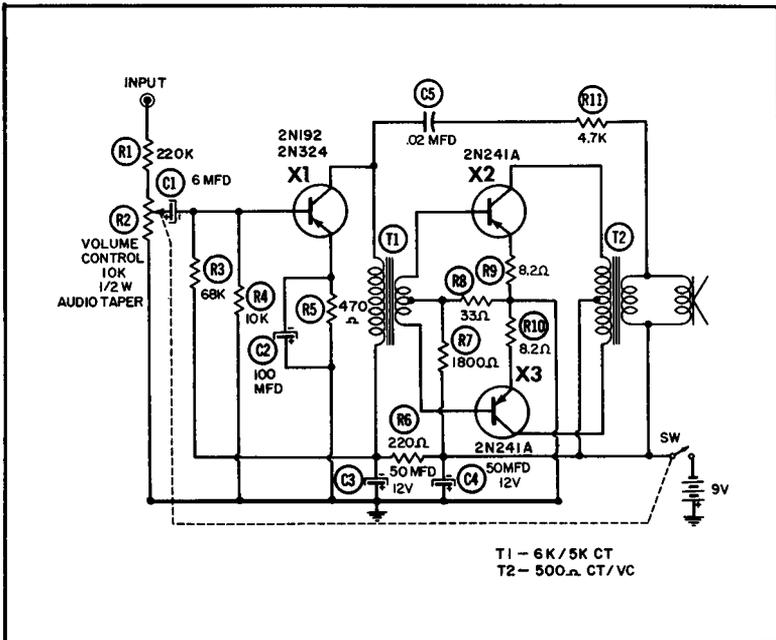
50K

THREE-TRANSISTOR PHONO AMPLIFIER

This is a two-stage, three-transistor amplifier suitable for use with phonographs. The input stage is a 2N192 or a 2N324 feeding a transformer with a center-tapped secondary. The resulting two-phase signal drives a pair of 2N241A's in push-pull.

Maximum output power is 0.35 watt. However, with 10% harmonic distortion, the greatest power output is about 0.25 watt.

A crystal pickup is used in this circuit; and for a magnetic input, R (220,000 ohms) is omitted from the circuit.

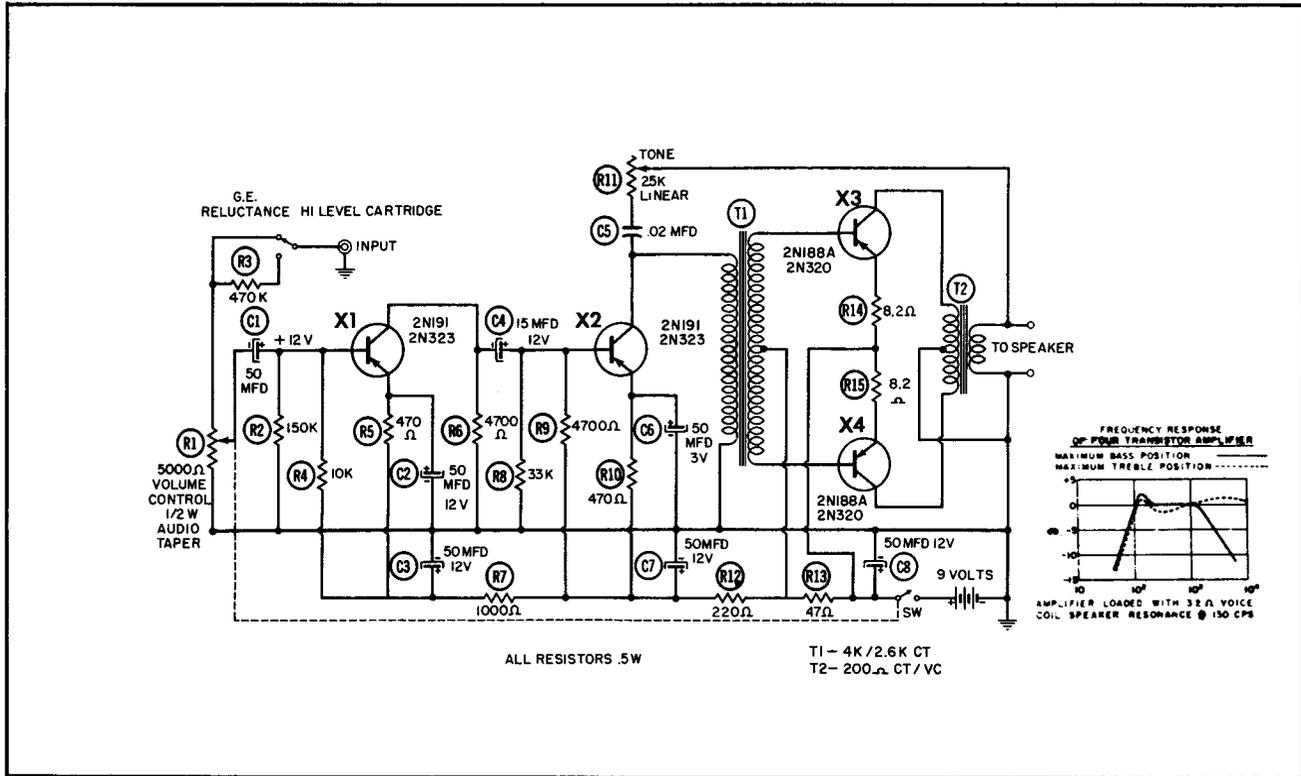


Three-transistor phono amplifier.

FOUR-TRANSISTOR PHONOGRAPH AMPLIFIER

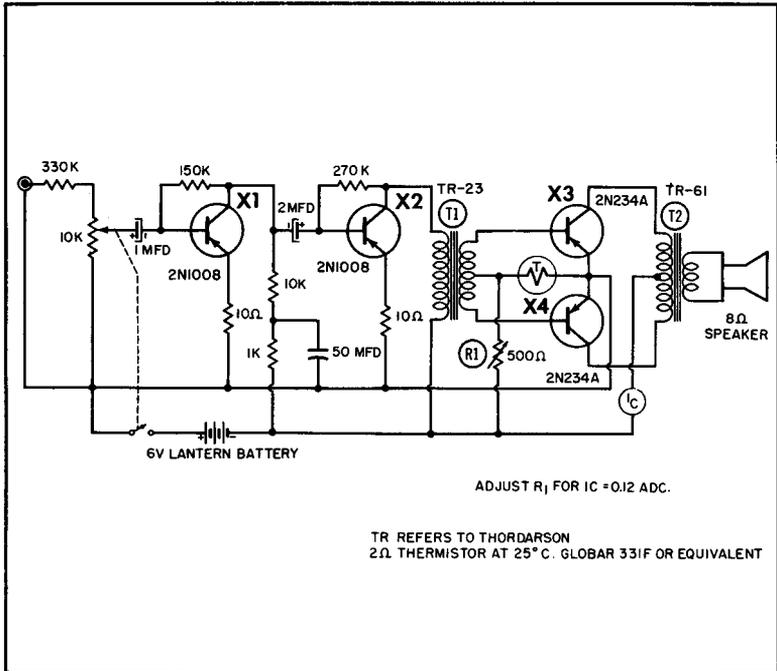
This phonograph amplifier has a maximum power output of 0.75 watt and a distortion of 10% at 0.45 watt. RC coupling is used between the first two stages, while transformer coupling is employed to and from the push-pull output stage.

Provision is made for either a magnetic or crystal pickup. Signal voltage across the 5K control is applied to the base of the first stage to control the volume. The tone control provides the response curves shown.



2-WATT PORTABLE AMPLIFIER

This is a four-transistor, three-stage portable amplifier for phonograph or radio use. The power transistors run at a very low power level and need not be mounted on a heat sink. The circuit is designed to give high output with long battery life, and the gain is more than adequate for most crystal pickups.

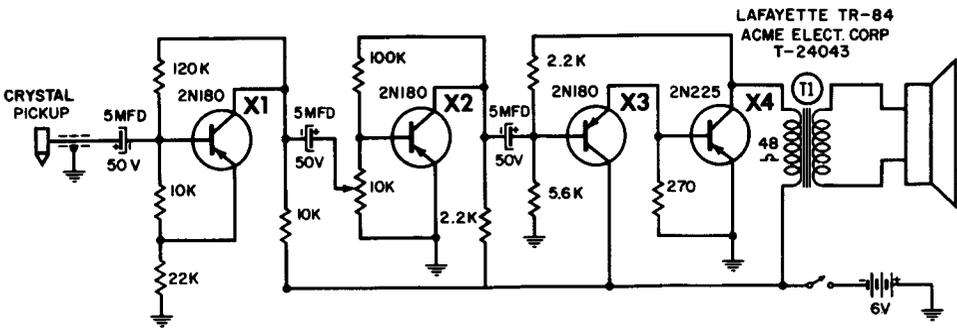


2-watt portable.

PORTABLE PHONOGRAPH AMPLIFIER

A lightweight portable record player having a 0.5-watt output may be constructed using this transistor amplifier. The turntable may be either a battery-powered electric or the older, manual type. A simple electronic power supply may be substituted for the battery. Total current drain is about 514 ma.

Here, four RC-coupled stages are used. The circuit has been designed so that transistors having lower *betas* (such as types 2N107, GT222, and CK722) may be substituted for the 2N180 units.

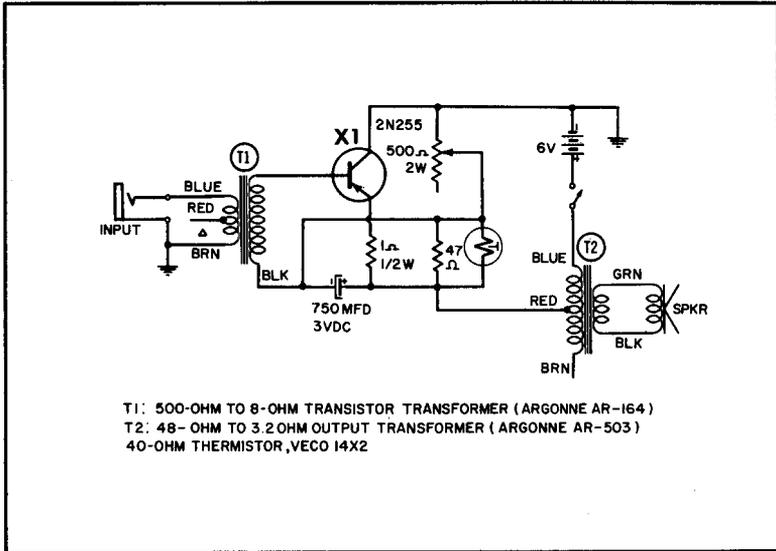


Portable phonograph amplifier.

PORTABLE RADIO POWER AMPLIFIER

This amplifier is plugged into the speaker jack of a small portable transistor radio. The low power output and high impedance of the radio are coupled to the base of the Class-A amplifier (2N255) through impedance-matching transformer T1.

This circuit is capable of developing 1 watt of output power. R1 controls the gain of the circuit by varying the forward bias of the emitter-base junction.

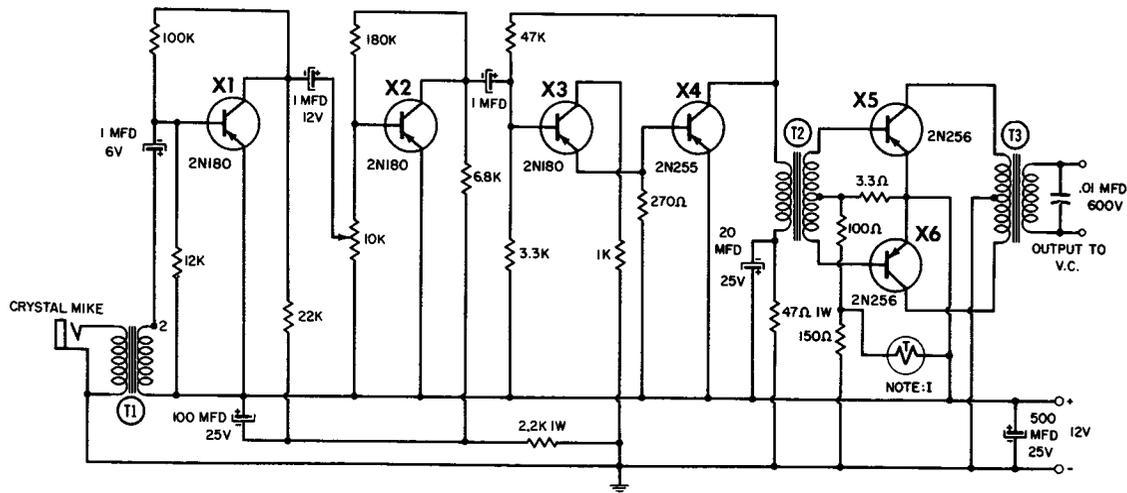


Portable radio power amplifier.

MOBILE PUBLIC-ADDRESS SYSTEM

This high-power amplifier is part of a mobile public-address system. It will operate directly from a 12-volt storage battery without a transformer or vibrator supply. The push-pull, Class B-operated 2N256's will furnish 10 watts of audio power. This design shows a negative ground, for installation in an automobile. Therefore, the circuit ground should be wired to the negative ground and bypassed with a large capacitor. Lower-gain transistors such as the 2N107, GT222, and CK722 may be substituted for the 2N180 units.

This amplifier is shown for use with a crystal microphone. If a dynamic mike is to be used, take out the input transformer and connect the mike to point 2.

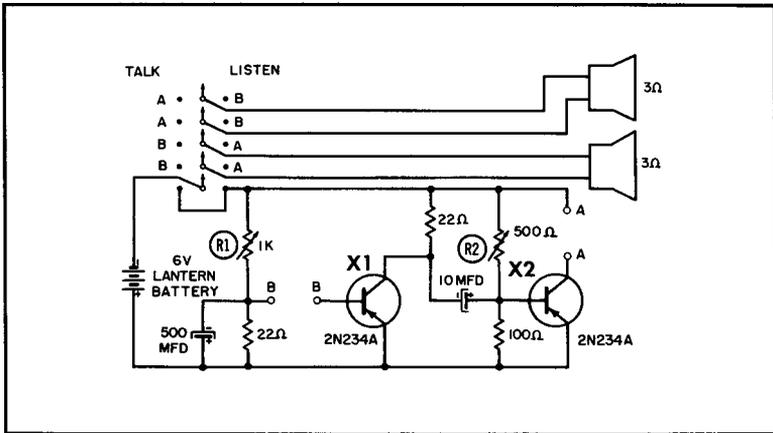


NOTE 1 - THERMISTOR REQUIRED TO PROTECT TRANSISTORS WHEN SUBJECTED TO HIGH TEMPERATURE: VECO 21W1 (100 OHMS, -3.77%/°C)

TRANSFORMERLESS INTERCOM

This is a low-transistor intercom using a single 6-volt source. Because of the low internal resistance of power transistors, the transformerless intercom gives a very high gain and power output even though directly coupled to the speaker.

It is necessary to adjust the bias with resistors R1 and R2 to supply 3 volts of collector-emitter voltage across each power transistor. However, once the bias is set, the resistors can be replaced with the nearest fixed carbon resistor. The Talk-Listen switch should be of the spring-return type to give a long battery life. This intercom circuit is not critical, and a heat sink for the transistors is not necessary. The voice coil is driven directly by the transistors; therefore, no output transformer is needed.

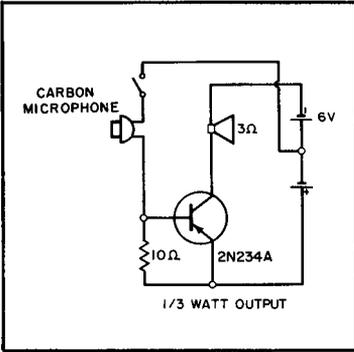


Transformerless intercom.

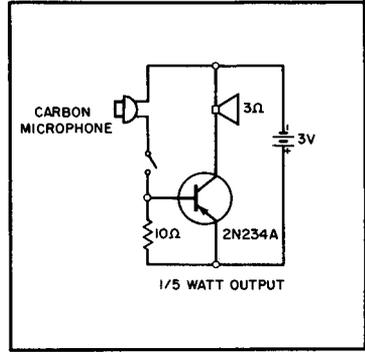
LOW-COST TRANSISTOR MEGAPHONE

Two low-cost transistor megaphones are shown here. Both put out a surprisingly large amount of power, considering the simplicity of their circuitry. It is suggested that the battery and speaker be mounted in a cardboard box, with the microphone on a long wire away from the box to prevent feedback. A spring-return push-to-talk switch should be used to save the battery. Both circuits use the 2N234A transistor.

In Part A, the circuit produces about 0.33 watt. Six volts is supplied, arranged so there are +3 volts and -3 volts, whereas in Part B only one 3-volt supply is required. Both circuits have a 3-ohm voice coil in the collector circuit.



(A) 6 VDC system.



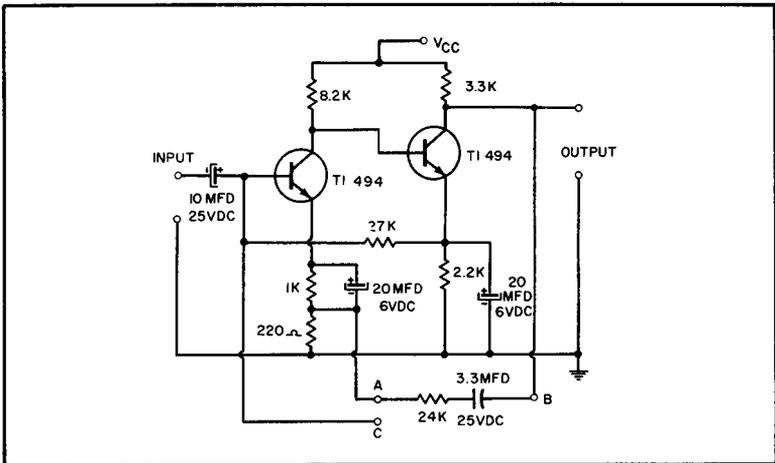
(B) 3 VDC system.

Low-cost transistor megaphone.

TWO-STAGE MULTIPURPOSE AMPLIFIER

A two-stage amplifier using TI-494 transistors is shown. Operating over a temperature range of -20° to $+100^{\circ}\text{C}$., this circuit can provide a voltage gain of 40 db from a power source in the 10- to 25-volt DC range. The circuit is flat within 3 db from 10 cycles to 1 megacycle. This basic amplifier also may be utilized as a sensitive AC voltmeter, tuned amplifier, or tuned oscillator by simply employing different networks between terminals A and B or C and B.

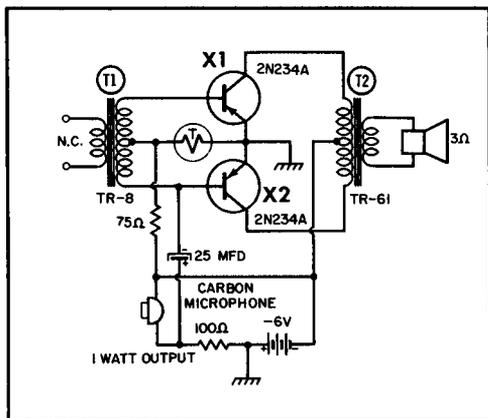
At 1,000 cycles, the input impedance is 20,000 ohms and the output impedance is less than 50 ohms. The maximum input is 80 millivolts rms.



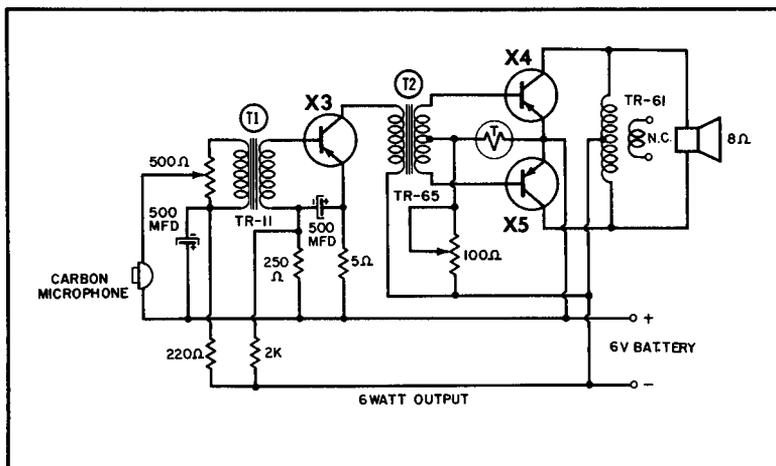
Two-stage multipurpose amplifier.

POWER MEGAPHONE

Here, two power megaphones are shown. In Part A of the diagram a minimum number of parts are used to obtain a 1-watt output. Of the two circuits shown (A and B) the 1-watt output will be adequate for most applications. In Part B the 6-watt megaphone is quite powerful and should be considered a deluxe model. Wiring and parts layout are not critical, and both amplifiers are designed for use with a conventional 6-volt lantern battery. However, the transistors in the 6-watt megaphone should be mounted on a heat sink.



(A) 1-watt output.



(B) 6-watt output.

Power megaphone.

Note in Part A that the output transformer is used with a 3-ohm voice coil, but that in Part B the 8-ohm voice coil is across the primary and no secondary is used.

AUDIO MODULATOR

For modulation, transistors offer much smaller circuits with less power drain than tubes. The transistorized modulator shown here is capable of supplying more than 25 watts of audio power at better than 50% efficiency. Output transformer T1 can be an ordinary 12-300-volt vibrator-type power transformer. It is necessary to mount transistors X1, X2, and X3 on the chassis for efficient heat dissipation. A mounting kit should be used for electrical isolation. The *Thermistor* readjusts the bias to prevent distortion when the chassis becomes warm. The circuit is designed for use with either a crystal, dynamic, or carbon microphone.

For a crystal mike, two stages of amplification are placed before driver X3 as shown. With a carbon microphone, the 14-volt supply is the voltage source through the 220-ohm resistance. The Thordarson 46 then replaces the 45 transformer, and the first two stages (X4 and X5) are not used.

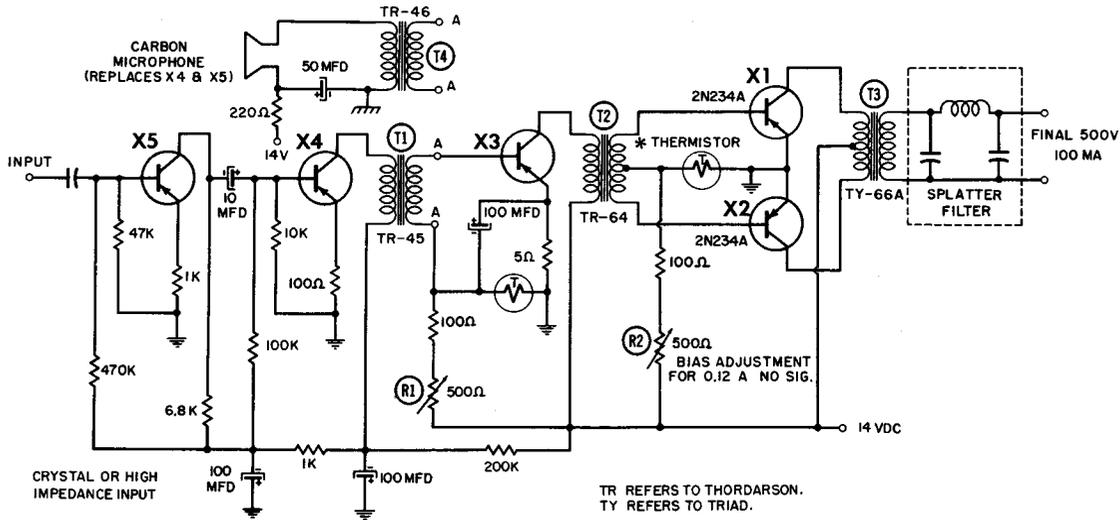
(See page 166)

MOBILE HIGH-LEVEL MODULATOR

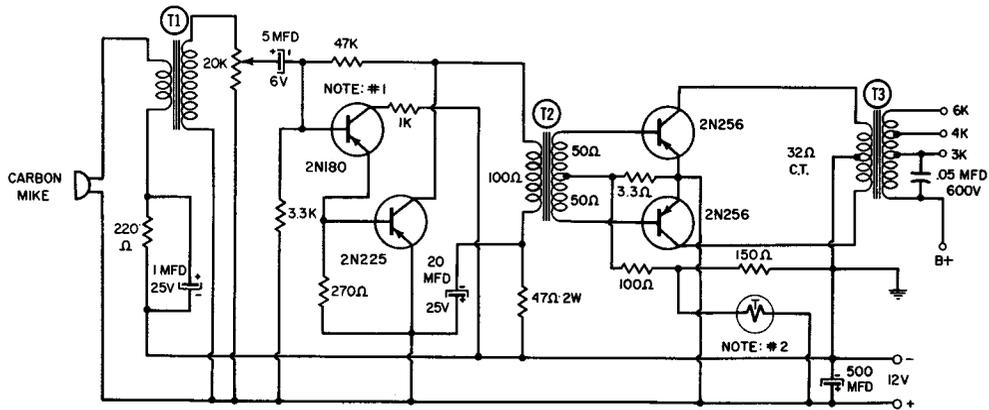
This unit will supply 10 to 12 watts of audio-output power, which is sufficient to 100% modulate a 6V6 or 2E26 final RF amplifier. A carbon-mike input is used, along with a 2N180 amplifier, a 2N255 driver, and a pair of 2N256's in push-pull. This push-pull stage is the output to the RF stage through the modulation transformer. The microphone input transformer is not critical, and the output transformer can be the universal tube-to-speaker type with several impedance taps. One tap is centered; e.g., with 4-, 8-, and 16-ohm taps, the 4-ohm tap is centered between the common and 16-ohm taps. The common tap connects to one collector, the 16-ohm tap to the other collector, and the 4-ohm tap to the power supply. The output impedance of the transistor is twice these values, so that the secondary impedance is double the marked values. Otherwise, the modulation transformer is designed for transistor modulators and connected as marked.

(See page 167)

Audio modulator.



* 2 Ω THERMISTOR AT 25°C. GLOBLER 331F OR EQUIVALENT
R₁ SHOULD BE ADJUSTED SO THAT I_C ON X3 IS 300 MA.



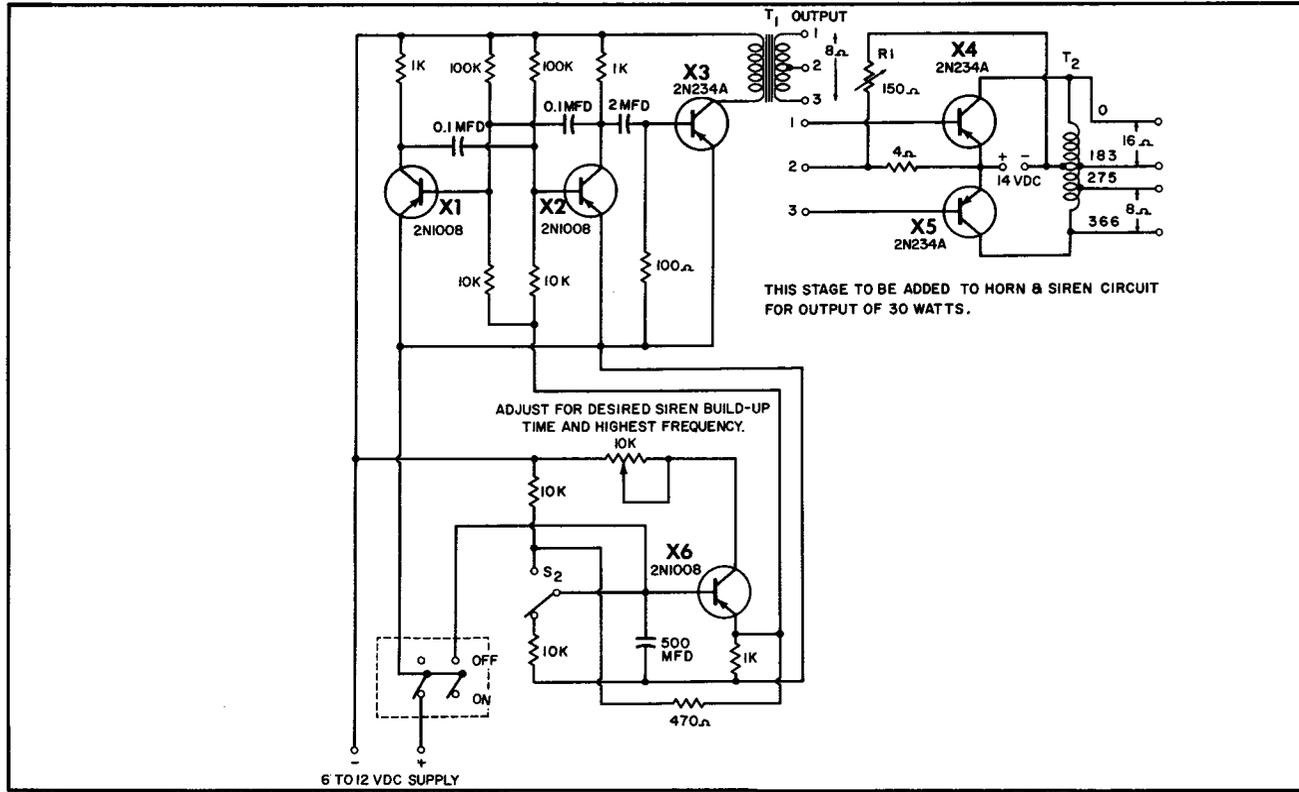
NOTE: #1 LOWER GAIN TRANSISTORS, SUCH AS THE 2N107, 6T222, AND CK722, MAY BE SUBSTITUTED FOR THE 2N180 UNITS.

NOTE: #2 THERMISTOR REQUIRED TO PROTECT TRANSISTORS WHEN SUBJECTED TO HIGH TEMPERATURE: VECO 21W1 (100 OHMS, $-3.7\%/^{\circ}\text{C}$)

T1: TRIAD TY-54 X, TZ-25, OR THORDARSON TR-25.

T2: TRIAD TY-61 X, LAFAYETTE TR-85, ACME T-24042, N.E. 2552, ARGONNE AR504.

T3: TRIAD TY-65Z MODULATION TRANSFORMER, OR TUBE-TO-SPEAKER OUTPUT TRANSFORMER MATCHING 24 TO 32 OHMS INPUT TO 4,000 OHMS



BOAT HORN AND SIREN

This boat horn-and-siren circuit provides an output of 0.75 watt and, using the additional power-output push-pull stage shown, is capable of delivering 30 watts' output.

The Off-On switch is used for the horn. When it is closed, X2 and X3 oscillate at a frequency determined by the 470-ohm resistor tied to the emitter of X1. Output from the oscillator is amplified by X4, which feeds output transformer T1.

As a siren, first the Off-On switch is closed, and then S2. As the large capacitor in the X1 base circuit charges, the siren frequency rises. The 10K pot controls both the build-up and the highest frequency.

Section 12

RF AND IF CIRCUITS

Transistorized RF stages are found in automobile radios because of the low signal input required and the high noise level at which the receiver operates. These considerations apply to both AM and FM broadcast receivers and to mobile receivers used for two-way communications.

Ordinary portable transistor radios seldom need or use RF stages. The first receiver stage is the converter, the output of which is the IF signal.

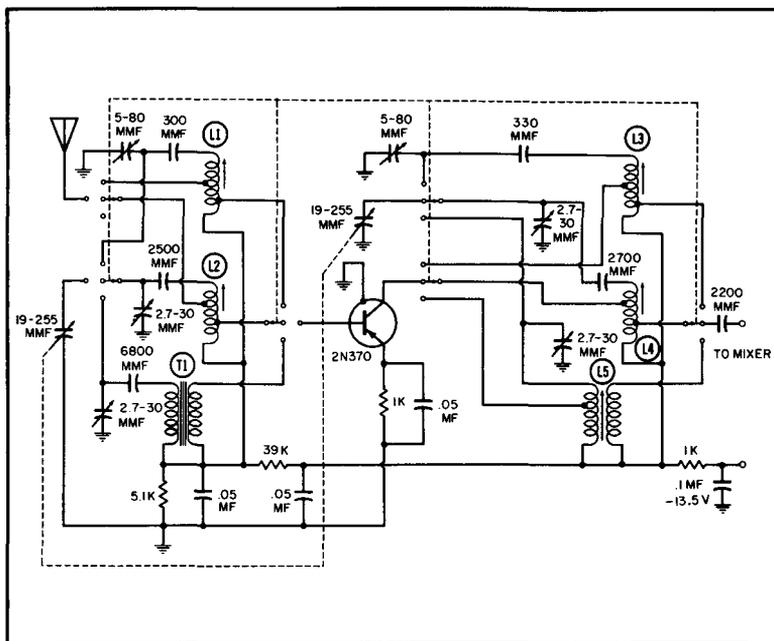
The IF stages are, of course, single-frequency RF stages. Usually tuned transformer circuits are used for coupling. In these transformers, the primary is usually tapped at a low-impedance point to match the impedance of the driving stage. The other four leads are the primary and secondary windings.

Neutralization is sometimes used for stability. Actually, neutralization can be considered as negative feedback. In most broadcast-band RF or IF stages, transistors are chosen because they require no neutralization.

THREE-BAND RF AMPLIFIER

Using a 2N370 transistor, this RF amplifier covers the broadcast, the 4.5-11.5-mc, and the 10.5-23-mc bands. Each band has a separate tuned antenna and tuned output tank circuit. Tapped autotransformer coils are used in all antenna circuits except the broadcast band, where the transformer is wound around a ferrite rod. T1 is the standard broadcast antenna coil; L2 and L1 are the 4.5- to 11.5-mc and 10.5- to 23-mc coils, respectively. Output to the mixer is from an interstage transformer (L5 for the standard broadcast band, L4 for the center band, and L3 for the high band). Gain is reduced by adding feedback resistor R3 to obtain stable operation. The tank circuits are tuned with individual gang capacitors on each band, with provision for individual slug tuning of the coils.

The RF transistor (2N370) is biased with voltage divider R1-C14-R2 in the base-emitter circuit.



COIL	ANTENNA			INTERSTAGE		
	T1 (Standard Broadcast Band)	L2 (4.5 to 11.5 Mc)	L1 (10.5 to 23 Mc)	L5 (Standard Broadcast Band)	L4 (4.5 to 11.5 Mc)	L3 (10.5 to 23 Mc)

Total primary turns	127	21	13	225	21	12
1st primary tap- turns from bottom	—	2	1	13	2	1
2nd primary tap- turns from bottom	—	7	4	—	6	6
Secondary turns	7	—	—	12	—	—
Wire size	10/38 Litz	#22	#24	7/41 Litz	#22	#24
Coil diameter (inside)—inches	.33	$\frac{5}{8}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{5}{8}$	$\frac{3}{8}$
Turns per inch	24	24	24	Universal	24	24

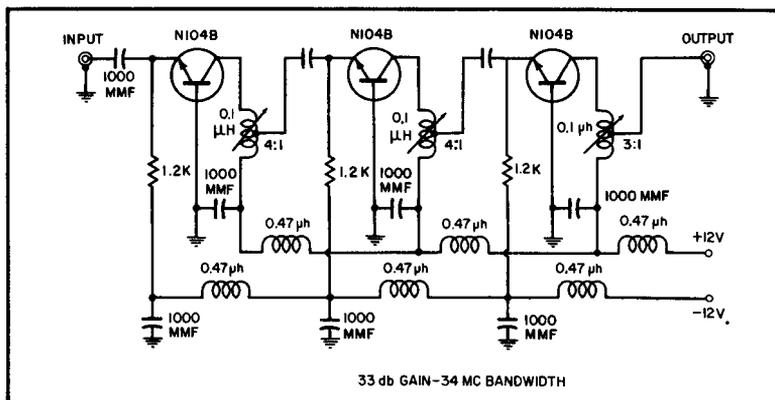
NOTE: Standard Broadcast Band Antenna Coil (T1) should be wound on an 8" x .33" ferrite rod.

Three-band RF amplifier.

WIDE-BAND VHF AMPLIFIER

This circuit shows a VHF (225-mc) amplifier with a bandwidth of 34 mc and a gain of 33 db. Silicon mesa transistors (N104B) are used in a common-base configuration. Although the circuit has less gain than the common-emitter type, its bandwidth is greater and the circuit design is simpler at this frequency.

Short leads and good shielding are required for proper operation of this amplifier.



Wide-band VHF amplifier.

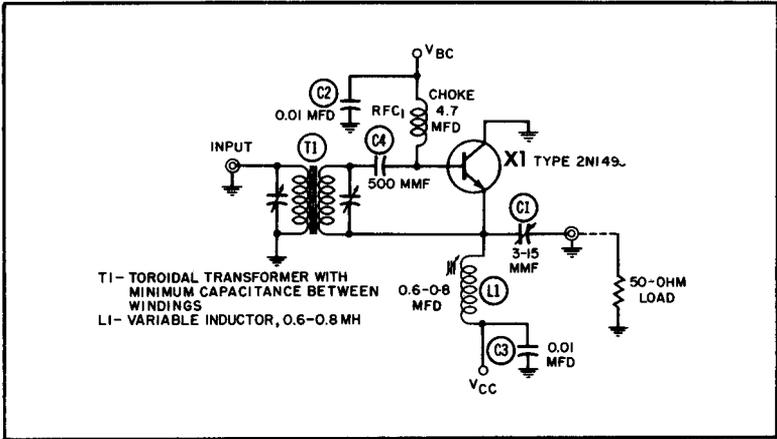
50-MC AMPLIFIER

This figure shows a 2N1493 used as an RF amplifier operating at 50 mc. It has a power output of 600 milliwatts (0.6 watt) and a gain of 10 db, with a collector voltage of 28 volts and a current of 23 mils. With an 8-db gain at 50 volts and 20 mils, an output of 1 watt can be obtained.

As shown, the circuit acts as a common-emitter amplifier—even though the collector is grounded—because the emitter and base are both isolated from ground. The potential of the entire transformer-secondary winding varies with the load voltage, and this potential difference drives the transistor.

The amplifier is biased well into Class C, depending on how much incoming signal is available. Increased drive permits more cutoff bias and thus a higher efficiency.

In operation, the transistor case should be firmly clamped to the chassis. This arrangement provides an adequate built-in heat sink. A 3" x 3" chassis is suitable for most environmental conditions at power levels of up to 1 watt.

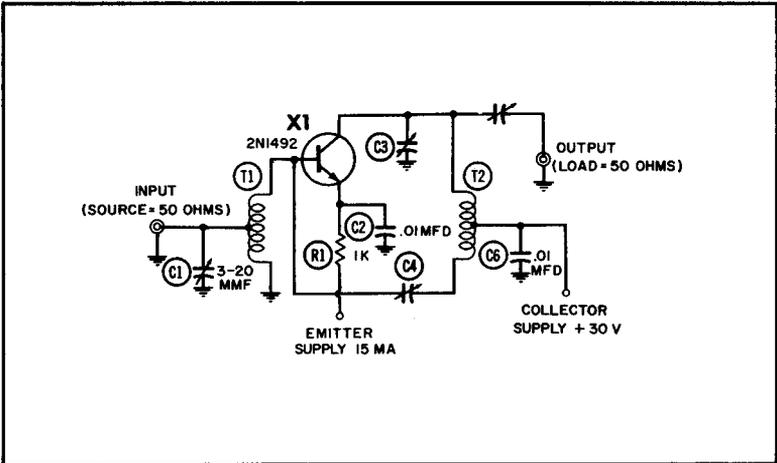


50-mc amplifier.

70-MC POWER AMPLIFIER

By using proper neutralization techniques, it is possible to design high-frequency transistor power amplifiers. This figure shows a 70-mc power amplifier which can be used in intermediate or power-amplifier circuits to boost the output of either a low-level or a crystal oscillator.

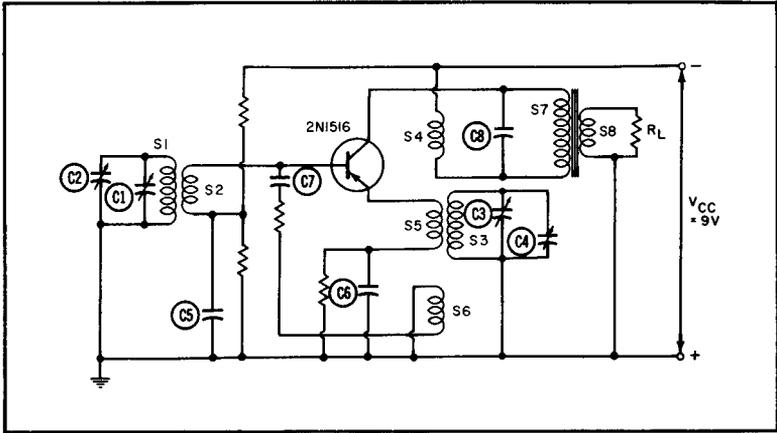
This circuit has a power gain of 15 db at a collector voltage of 30 volts and a collector current of 15 ma. If a 2N1493 is used with the same supply voltages, power gain will be 12 db.



70-mc power amplifier.

SELF-OSCILLATING MIXER (6 TO 26 MC)

This 2N1516 PNP germanium transistor is shown as a self-oscillating mixer. Conversion gain is 25 db at 6.5 mc and 18 db at 26 mc. (Conversion gain is defined as the ratio between the IF power in a 2,500-ohm average load resistor connected across the output terminals of the IF filter, to the available HF power in the antenna circuit.)



Self-oscillating mixer (6 to 26 mc).

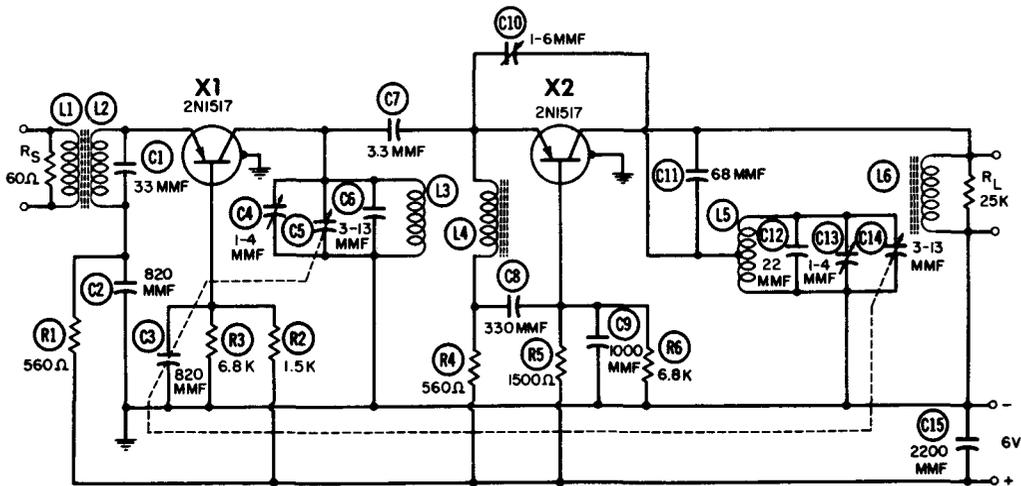
FRONT-END OF AN FM TUNER

This FM tuner consists of an RF amplifier and a self-oscillating mixer stage, each utilizing a 2N1517 transistor. The total available power gain is 26 db average, 22 db minimum. The noise factor is less than 11 db (9 db average), and the image-rejection ratio is 22:1.

The circuit is designed for use with a 6-volt battery. Shift of the oscillator frequency (as a function of the battery voltage) is about 50 kc from 6 to 5 volts and about 100 kc from 5 to 4 volts. At large input signals, the amplification of the RF stage must be reduced (e.g., by reducing the collector current of the stage) to avoid overloading the mixer stage.

The RF transistor operates at a collector current of 1.4 ma, and the mixer has a collector current of 1.5 ma. The tuner is designed for a frequency range of 87 to 101 mc.

For optimum performance, adjustment of the oscillator voltage is recommended. At a battery voltage of 4 volts, the oscillator signal at the emitter should be adjusted to 80 millivolts by means of capacitor C10.

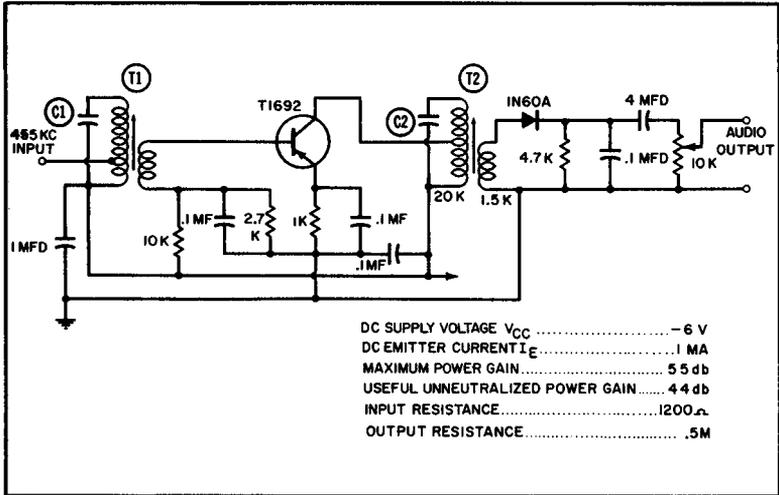


Front end of an FM tuner.

455-KC IF AMPLIFIER AND DETECTOR

This figure shows a single-stage 455-kc IF amplifier using an MADT transistor. A 6-volt DC, one-mil supply is required. The maximum power gain is 55 db, but the maximum useful unneutralized power gain is only 44 db.

A diode detector (1N60A) provides audio across the 10K volume control.



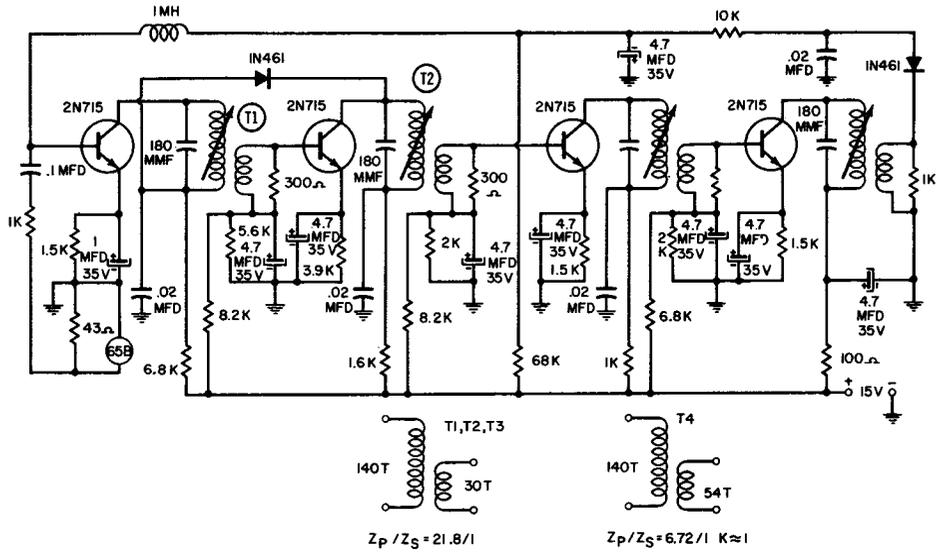
455-kc IF amplifier and detector.

FOUR-STAGE 455-KC IF AMPLIFIER

A four-stage 455-kc IF amplifier using 2N715 silicon transistors is shown in Part A of the diagram. A 300-ohm load across the secondary of the transformers compensates for temperature changes. Gain and bandwidth can be seen from Part B.

AGC is obtained by adding a diode detector and an audio decoupling filter in the output of the IF strip. The detector diode produces a negative-going DC voltage, and an increased signal input tends to bias off the first stage. A diode is also used between the first and second stages to prevent overload.

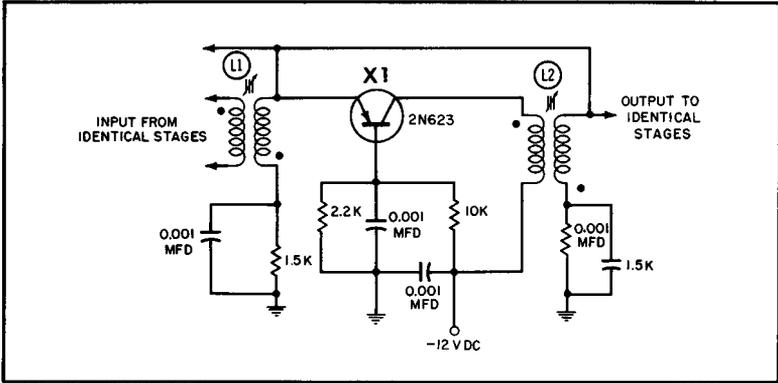
Stage bias is such that a reverse voltage is developed across the diode detector under no-signal and low-signal conditions. As the signal level increases, the first stage draws a low enough current that the diode can conduct. The forward impedance of the diode is now placed from the collector of the second stage to AC ground. Thus, the over-all IF gain is reduced.



Four-stage 455-kc IF amplifier.

43-MC IF AMPLIFIER

This circuit shows a 2N623 used as a 43-mc IF amplifier operating from a -12-volt supply. Power output is 20 milliwatts with an 11-mc bandwidth. Noise figure is 6 db, with a power gain of 15 db.



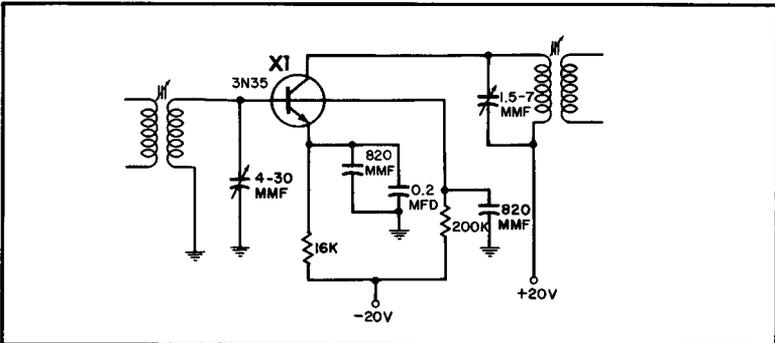
L₁, L₂—Primary: 21T #30
 —Secondary: 2¾T #30*

*Secondary wound over bottom end of primary—¼ dia. form

43-mc IF amplifier.

60-MC IF AMPLIFIER

Here a 60-mc IF amplifier using 3N55 tetrode silicon transistors is shown. This amplifier requires no neutralization and has a bandwidth of 20 mc. The coupling transformers have a primary inductance of 1.365 μ h and a secondary inductance of 0.2475 μ h. The coefficient of coupling is 0.43. Part A of the diagram shows a



(A) Single stage.

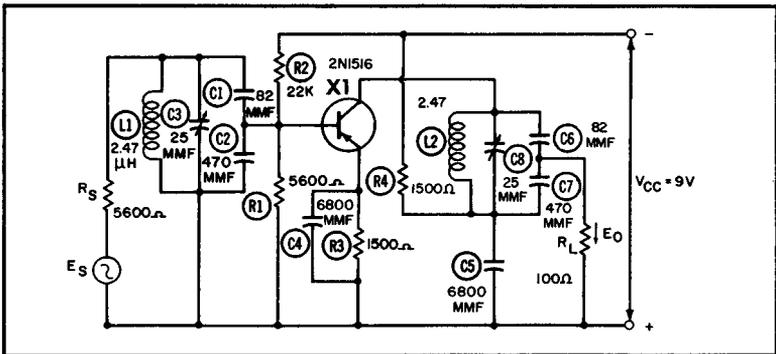
single stage of the eight-stage amplifier. All stages are identical except for the input and output, the transformers of which may be designed for the appropriate driving and load resistances.

In Part B, a two-battery supply is used to obtain a symmetrical circuit arrangement. Each transistor is biased common-base even though the RF circuitry is common-emitter. The large resistors in the emitter and base-2 leads keep currents constant in these elements. These resistors are bypassed for signal frequencies by appropriate capacitors. An additional 0.2-mfd capacitor helps insure that the bias point will remain constant during a pulsed input signal. Decoupling is accomplished by the chokes and bypass capacitors shown in the complete amplifier schematic.

10.7-MC IF AMPLIFIER

The schematic here shows a single 2N1516 stage of a four-stage IF amplifier. The amplifier is operating at 10.7 mc. The load of the stage (input resistance of the following transistor) is 100 ohms, and the source resistance (output resistance of the preceding transistor) is 5,600 ohms.

Instead of the last band filter, a discriminator filter with a selectivity of 1.5 can be used. (The selectivity of the total amplifier at ± 300 kc off-frequency is about 100.) The ratio of power output to power input is 22 db. This figure includes the insertion losses of both tuned circuits (3.8 db each).



10.7-mc IF amplifier.

Section 13

TRANSISTOR AND DIODE OSCILLATORS

Oscillators play two major roles in communications. In the receiver, a low-power oscillator is necessary for superheterodyne operation; and in the transmitter, the oscillator is the basic signal source.

In a receiver a single stage often is a converter. This stage has the RF signal as an input. Since the same stage acts as an oscillator, its own signal is the second input. Usually this signal is higher in frequency than the RF. However, in receivers covering a band of frequencies, it is possible to reduce bandswitching by operating on the low side of the RF for part of the band and on the high side for the remainder of the band.

Either a separate oscillator stage can be used (as with communications receivers and some auto radios), or a single stage can be employed as a converter. The latter is found in most portable transistor radios.

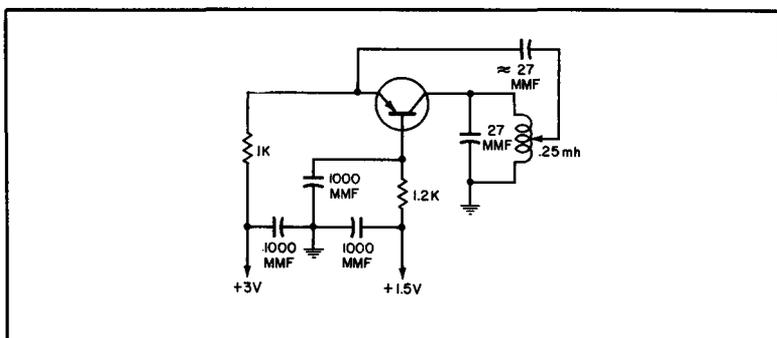
For transmitters, or in some controls which require a stable signal source, crystal-controlled oscillators are needed. With the rapid advance of transistor technology, oscillators are now available from audio frequencies to well into the UHF region.

Hartley, Colpitts, and other familiar oscillators are all used. But since transistors are current-operated devices (unlike tubes, which are voltage-operated), special considerations are necessary. The tube plate, grid, and cathode resemble the transistor collector, base, and emitter in some of their actions. Transistors in oscillator circuits use both NPN and PNP configurations. NPN transistors in a grounded-base arrangement have a negative voltage applied to the emitter and a positive voltage to the collector. In the PNP these voltages (or more accurately, current sources) are of opposite polarity. A grounded-grid tube corresponds to the grounded base, a grounded cathode to a grounded emitter, and a grounded plate to a grounded collector.

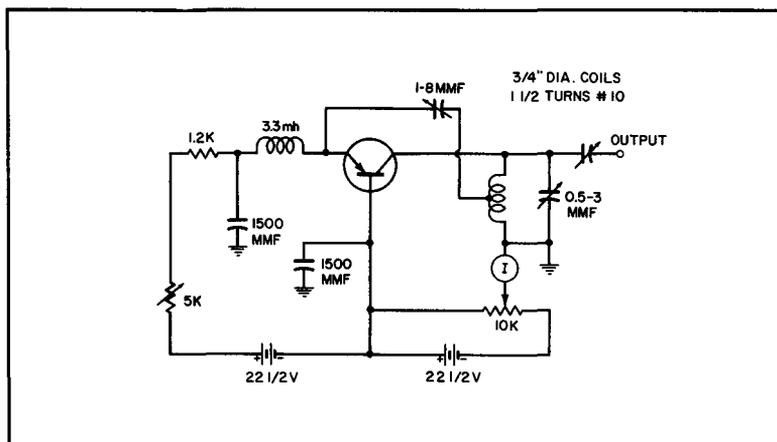
SELF-EXCITED HIGH-FREQUENCY OSCILLATORS

Two high-frequency oscillators are illustrated in this circuit. Part A shows a 50-mc oscillator designed to use a surface-barrier transistor (SBT). Suggested types are a 2N1744, 2N502A, 2N1270, and 2N776. The feedback capacitor from the emitter to the coil tap is about 27 mmf, but its value depends on the transistor used.

Part B illustrates a 200-mc oscillator circuit designed for use with a microalloy diffused-base transistor (MADT). Suggested types are 2N1744 and 2N502A. Here a variable capacitor is used for the feedback. This capacitor, plus the 10K control, are adjusted for maximum output within the ratings of the transistor.



(A) 50-mc oscillator.



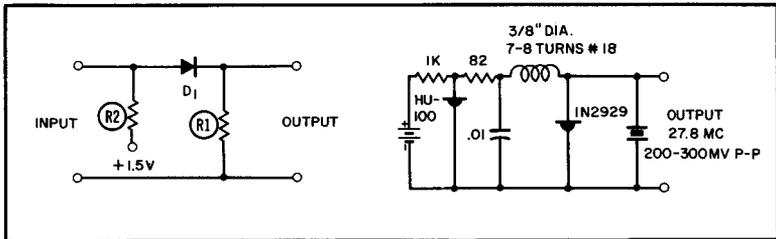
(B) 200-mc oscillator.

Self-excited high-frequency oscillators.

TUNNEL-DIODE CRYSTAL OSCILLATOR

Part A of the diagram shows a tunnel diode used as an amplifier in a typical low-frequency circuit. If the incoming signal is a sine wave, its positive half-cycle will add to and thus aid the battery voltage. Hence, the diode current will drop and so will the IR drop across output resistor R1.

In this way, a positive-going input signal produces an amplified negative-going output signal. This amplified signal can be used with an oscillator. Part B shows a crystal-oscillator circuit at 27.8 mc. A 1N2929 is used as the oscillator, and bias stabilization is provided by backward diode HU-100.



(A) Amplifier.

(B) Tunnel-diode oscillator.

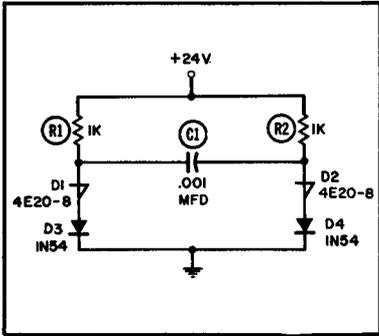
Tunnel-diode crystal oscillator.

FOUR-LAYER DIODE R-C OSCILLATOR

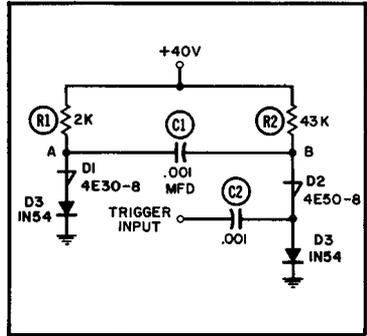
The four-layer diode can also be used for free-running or bi-stable circuits. Part A shows a free-running multivibrator that uses a four-layer diode. If diode 4D1 has just turned on, point A will be at ground potential as long as the current passed by resistor R1 is greater than the holding current of 4D1. As capacitor C1 charges through resistor R2, the voltage at point B will increase to the switching voltage of diode 4D2.

At this time 4D2 will switch on, and point B will suddenly drop to zero. At the instant of switching, there is a negative-to-positive potential across capacitor C, between points A and B. Therefore, as point B drops to zero, point A is driven negative before C1 has a chance to discharge. This reverse bias turns diode 4D1 off, and 4D2 now carries the load current through R2. Capacitor C1 then charges in the opposite direction, through resistor R1, until point A reaches the switching voltage of diode 4D1. As this occurs, diode 4D1 switches on, the voltage across C1 turns 4D2 off, and load current once more flows through R1.

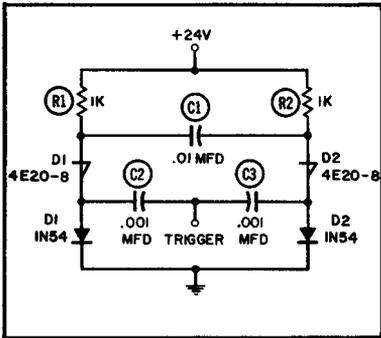
Part B shows the monostable, or one-shot, configuration. Here the circuit is such that when one leg is on, the other is off. This is



(A) Astable circuit.



(B) Monostable circuit.



(C) Bistable circuit.

Four-layer diode RC oscillator.

accomplished by choosing 4D1 to have a lower switching than supply voltage, and 4D2 a higher switching than supply voltage.

A negative-going trigger pulse through capacitor C2 switches 4D2 on. This in turn switches 4D1 off through the coupling action of C1. R2 will pass current to 4D2; if this current is higher than the holding current of 4D2, this diode will remain on until capacitor C1 has charged, through resistor R1, to the switching potential of 4D1. At that time, the circuit will revert to its initial stable condition with 4D1 on.

In this operating mode, the time constant R1-C1, and the ratio between the supply voltage and switching voltage of 4D1, both determine how long leg B will stay on.

Part C shows the bistable multivibrator circuit. This circuit is switched from A to B, and back to A, by successive negative trigger pulses inserted via C2 and C3. The four-layer diodes 4D1 and 4D2 are chosen to have higher switching than supply voltages. R1 and R2 are small enough in value to provide holding currents for diodes 4D1 and 4D2, respectively. Diodes D1 and D2 provide high impedances across which the negative trigger

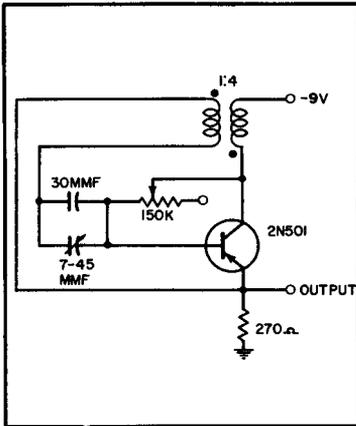
pulses are applied. Their forward-current ratings must be adequate for the load currents determined by R1 and R2. C1 must be large enough to insure positive switching, so that both sides are never on simultaneously.

MADT BLOCKING AND CRYSTAL OSCILLATORS

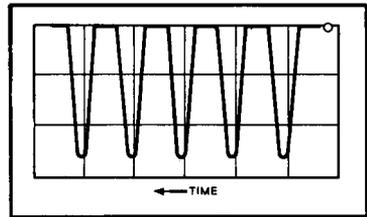
The microalloy diffused-base transistor has characteristics which make it useful as a high-speed blocking oscillator. Part A of the diagram shows a 10-megacycle free-running blocking oscillator. The output pulse has a width of 28 millimicroseconds, as shown in Part B.

In Part C the 4-mc crystal-controlled blocking oscillator does not show any apparent drift in frequency up to 65°C., even though the supply voltage has been varied from -2.5 to -9 volts.

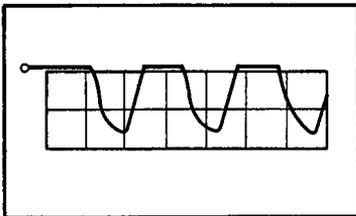
The variable capacitor in either circuit can be adjusted to compensate for slight variations in pulse width, such as will occur when different transistors are used in the circuit. These circuits can be triggered at their bases when the base-to-collector resistor is eliminated.



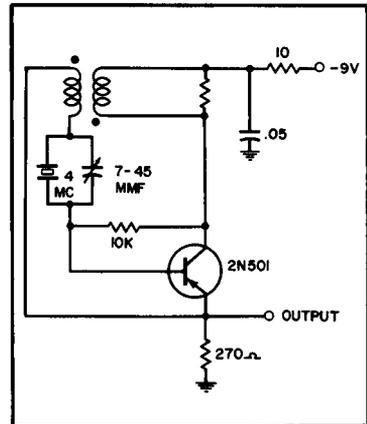
(A) 10-mc oscillator.



(B) 10-mc oscillator waveform.



(C) 4-mc oscillator & waveform.

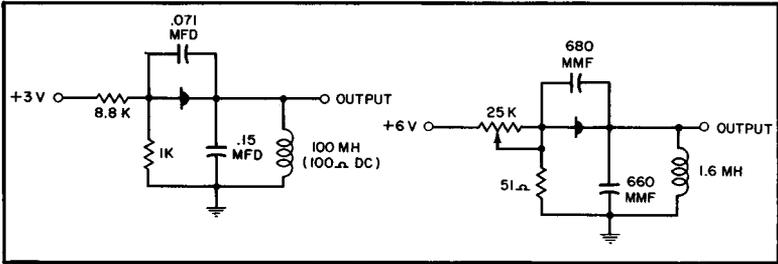


MADT blocking and crystal oscillators.

TUNNEL DIODES AS SINE-WAVE OSCILLATORS

A backward diode can usually be used as a low-current tunnel diode. The ZJ69 is shown here in two circuits. Depicted in Part A is a 1-kc sine-wave oscillator with 1-microwatt output using a +3-volt supply.

Part B shows a circuit similar to the one in A, but for a 100-kc output.



A) 1-kc oscillator.

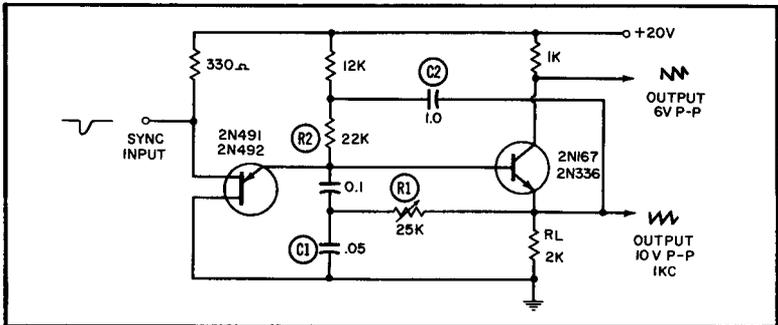
B) 100-kc oscillator.

Tunnel diodes as sine-wave oscillators.

SAWTOOTH-WAVE GENERATOR

In this unijunction generator, NPN transistor X is in a state of conduction while unijunction (UJT) is normally cut off. When a negative-going sync pulse is applied to the base of the UJT, the cutoff bias is overcome and the UJT conducts from +20 volts, through the 12K and 22K resistors, to ground via the UJT.

Because of the UJT conduction, the increased IR drop across the 12K and 22K resistors will cut off transistor X at its base. X's voltage—going positive at the collector and negative at the emitter—is taken off at points A and B, as represented by the waveforms. Outputs A and B are 6 and 10 volts peak-to-peak, respectively, in a frequency range of 350 to 600 cps.

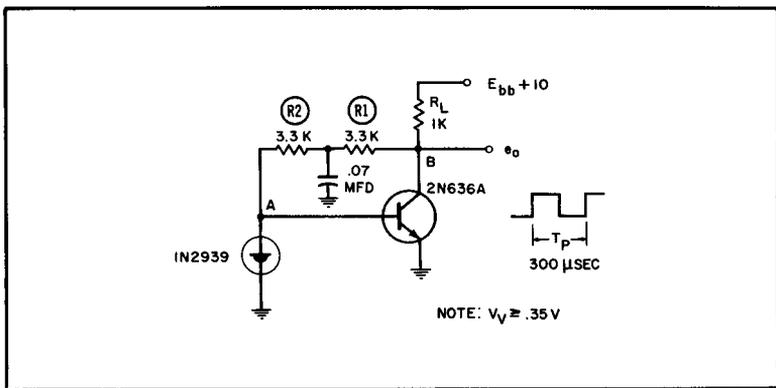


Sawtooth-wave generator.

TUNNEL-DIODE SQUARE-WAVE OSCILLATOR

In this square-wave oscillator, capacitor C charges through R1 and RL until the tunnel diode reaches its peak current and switches. The base current of the transistor then causes the transistor to go into saturation, shorting the collector and point B to ground. The capacitor then discharges through R1 and R2 until the voltage at point A falls below the cutoff of the tunnel diode. The diode will then return to the low-voltage state and turn the transistor off. The cycle is then repeated.

The symmetry of the output can be changed by feeding a small current into or taking it out of point A. The period of oscillation is about 300 microseconds.

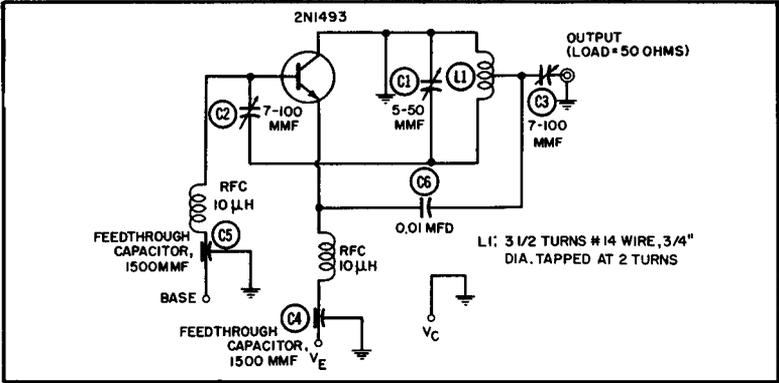


Tunnel-diode square-wave oscillator.

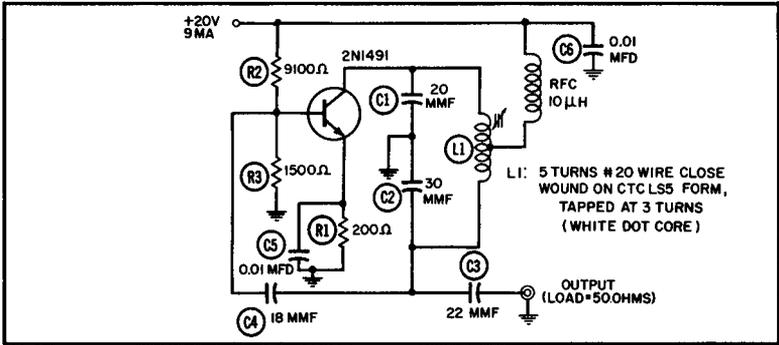
SELF-EXCITED 70-MC OSCILLATORS

Three self-excited oscillators that use NPN silicon transistors (2N1491, 2N1492, and 2N1493) are shown here. At 70 mc the 2N1491 has a maximum collector-to-base rating of 30 volts and can deliver 70 milliwatts, the 2N1492 has a voltage rating of 60 volts and can deliver 100 milliwatts, and the 2N1493 has a 100-volt rating and can deliver 500 milliwatts.

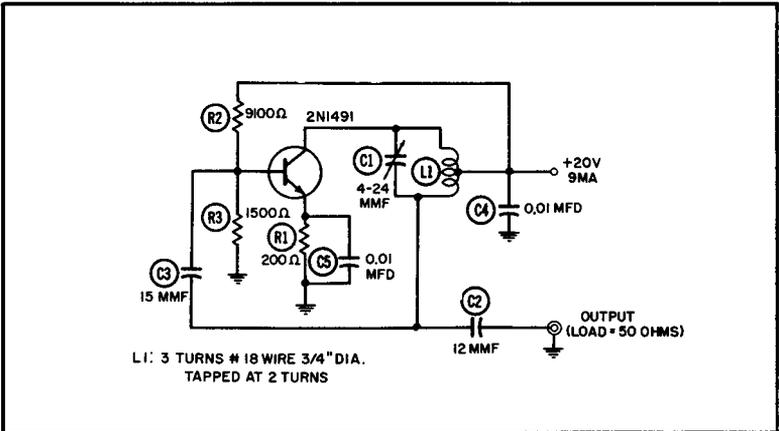
Although the 2N1491 is shown in two circuits, either the 2N1492 or the 2N1493 can be used, with the proper collector voltage, to provide a higher power output. In Part A, an output of 1.25 watts is obtained when a typical 2N1493 is used at a collector voltage of 50 volts and a collector current of 25 milliamperes. The transistor case should be clamped firmly to the copper chassis. This provides a low thermal-resistance path for heat dissipation. No insulating mica spacers are required, since the collector is also connected to chassis ground.



(A) 70-mc Power oscillator.



(B) 70-mc Colpitts oscillator.



(C) 70-mc Hartley oscillator.

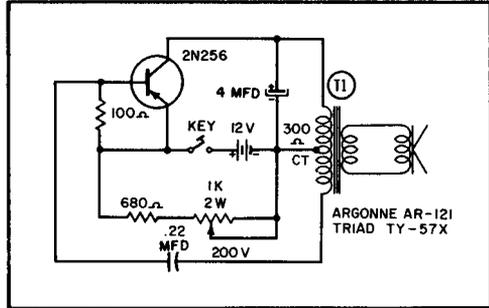
Self-excited 70-mc oscillators.

Low-power VHF oscillators are required in many applications, including local and variable-frequency oscillators in transmitters. An output power of about 25 or 50 milliwatts usually is sufficient. The Colpitts oscillator shown in Part B of the diagram has a maximum output of up to 50 milliwatts and a typical value of 35 milliwatts. The Hartley oscillator in Part C has approximately the same output capabilities. The 2N1492 or 2N1493 may also be used in these circuits if a higher power output is required.

CODE-PRACTICE OSCILLATOR

Shown here is a single-transistor audio oscillator that can be used for code practice. The circuit has sufficient output (300 mw) to drive a small speaker. A control is provided for varying the frequency (tone). If desired, a volume control may be added, in the form of an L-pad in the speaker voice-coil lead.

Code-practice oscillator.

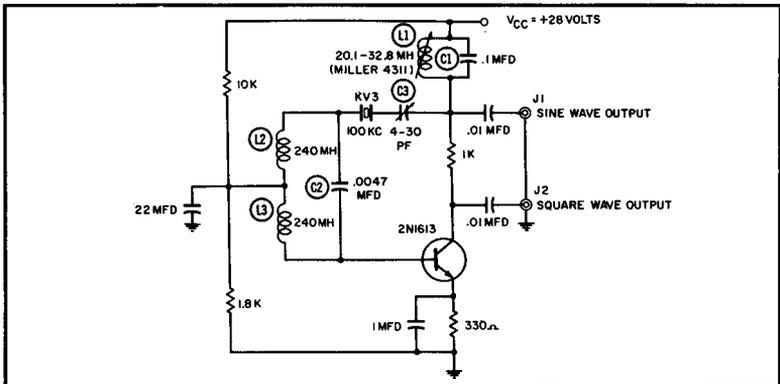


100-KC CRYSTAL OSCILLATOR

This circuit is a 100-kc crystal oscillator using a 2N1613 transistor. The oscillator has both a square- and a sine-wave output. Its frequency stability is excellent (3 ppm over a transistor-case temperature range of -55° to $+125^{\circ}$ C.). In fact, the oscillator is suitable for use as a secondary frequency standard.

The circuit operates like a Hartley oscillator. Positive feedback from collector to base is obtained by using the phase reversal of tapped tank circuit L2, L3, and C2. Oscillator frequency is determined by the resonant frequency of the very high-Q series LC network in the feedback loop. This network is made up of capacitor C3 and a quartz crystal which appears inductive at 100 kc.

Feedback, which drives the collector between cutoff and saturation, is responsible for the square-wave output. L1 and C1 develop the sine-wave output.

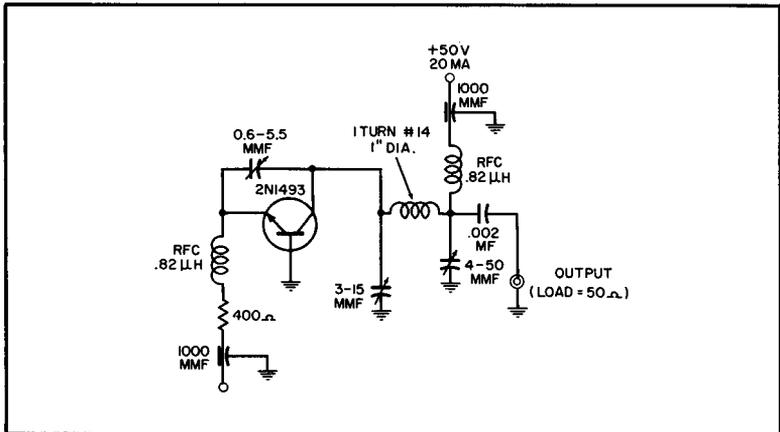


100-kc oscillator.

250-MC OSCILLATOR

The 2N1491-2N1493 transistor series can be used for high-frequency oscillators. This figure shows a 250-mc oscillator circuit using a typical 2N1493. Here an output of 150 milliwatts at 250 mc—with an efficiency of 15% to 20%—is obtained.

The output-matching pi circuit reduces the harmonics in the load. As in all other high-frequency circuits, the leads must be kept short to minimize stray capacitance.



250-mc oscillator.

BLOCKING OSCILLATOR

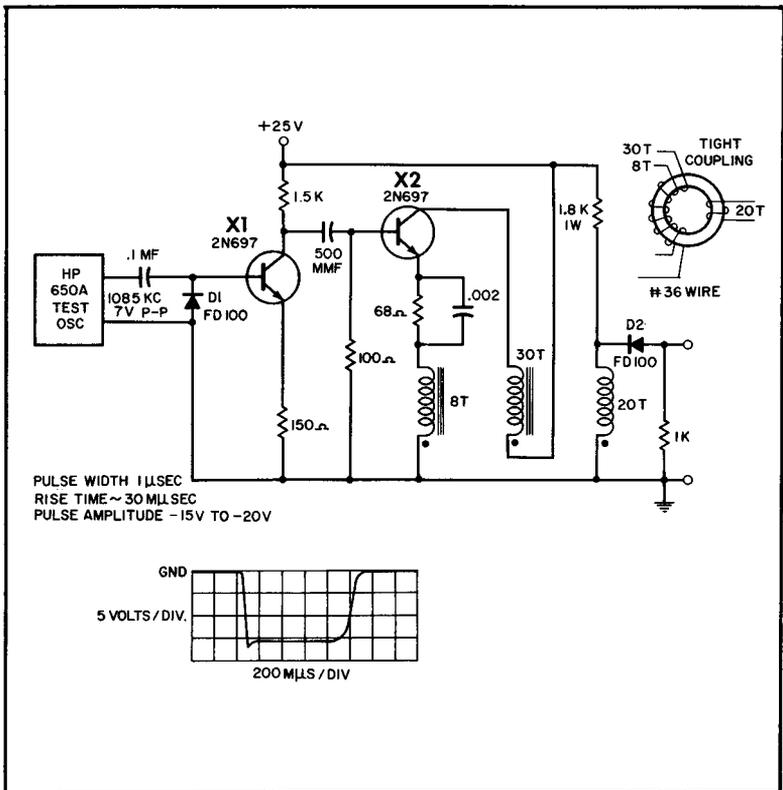
A blocking oscillator using the 2N697 silicon transistor is shown here. This 108.5-kc circuit is triggered by a sine wave at this frequency. The first stage, which is used as a grounded emitter, is

overdriven by the input sine wave to provide a trigger pulse for the following oscillator stage.

The three-winding transformer uses a square-loop core of molybdenum-permalloy. The 20-turn winding has a normal current flow from the 25-volt source in series with 1,800 ohms.

A positive base trigger starts the collector current through the largest (30-turn) winding. This current flow is in a direction which tends to switch the transformer core to the opposite state. As switching begins, the voltage developed across the eight-turn winding drives the emitter negative and keeps the transistor conducting until core saturation occurs.

At saturation, the core voltage drops sharply to zero because of its square-loop characteristic. Without the negative emitter voltage, the transistor turns off and the core is reset. The normal state, to which the transistor returns because of the bias current, is the set state. The emitter capacitor shown speeds the transistor on-and-off action.



Blocking oscillator.

Section 14

POWER SUPPLIES AND REGULATORS

Almost every form of electronic circuit must be operated from a power source such as a battery or an AC supply. Since the advent of semiconductors, power supplies (and their associated regulating circuits) have taken on radical new designs and features. This section presents a wide variety of these newer transistor circuits.

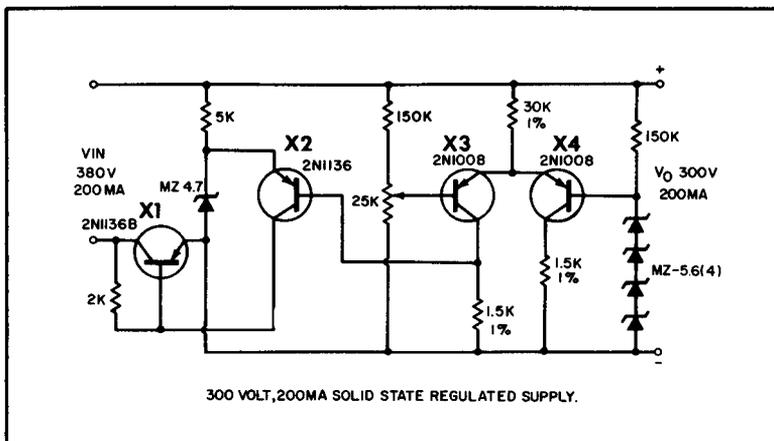
Transistors are well suited for use in power supplies, since they provide varying amounts of power dissipation. This is possible because the transistor (having a low internal IR drop) acts as a variable resistor in the circuit. By effective amplification of the circuit capacitance, the transistor can also be made to act as an excellent ripple filter.

Zener diodes, which in many ways resemble a gas-tube regulator, are often applied to circuits where a voltage reference is required. In most regulated power supplies, a fixed voltage is used as a reference, to establish an operating point for the power-supply circuits.

300-VOLT REGULATED SUPPLY

Zener diodes, along with a transistor having an 80-volt collector-to-emitter bias and 16 watts' dissipation, can be used in the 300-volt range of power supplies. In this diagram, the transistor is in series with the negative lead of the regulated supply, while the series diodes are in parallel across the supply. The difference between the output and input voltage is 80 volts under minimum load conditions. At a maximum power-supply rating of 200 ma, the transistor dissipates approximately 16 watts.

In operation, an increase in load current will cause the parallel combination of X3 and X4 to conduct more heavily. X2 will then be biased more positive and cause the bias of X1 to also rise.



300-volt regulated supply.

As a result, the output voltage will return to its nominal value. A decrease in load current will reverse this action. Therefore, the output voltage of the power supply will be regulated to the particular voltage level required.

LOW-VOLTAGE POWER SUPPLIES

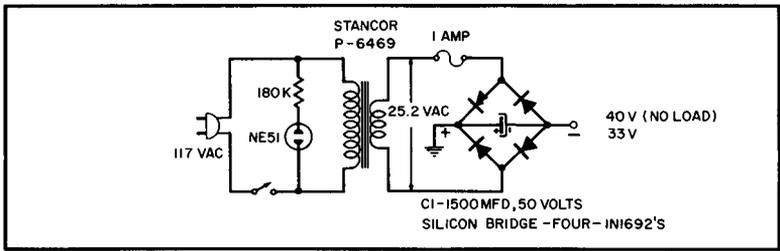
Here are four typical low-voltage power supplies that can be used with either audio amplifiers or test equipment.

Part A of the diagram shows a bridge of four 1N1692 silicon rectifiers with a single 1,500-mfd filter capacitor across them. With a transformer secondary voltage of 25.2 volts AC, the power-supply output at no-load is -40 volts, and the output at 400 mils is -33 volts. This supply can be used to power up to a 7-watt amplifier.

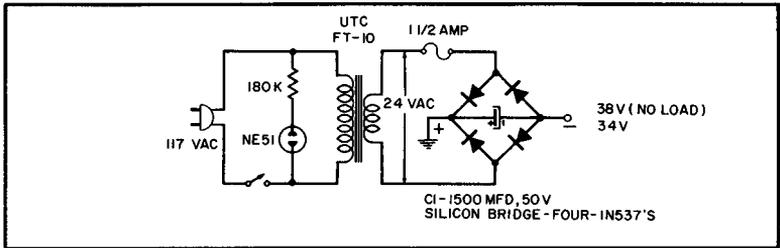
Part B of the diagram shows a supply that can be used to power two 7-watt audio amplifiers. With a secondary voltage of 24 volts AC, the no-load voltage is -38 volts; and with a 400-mil load, the voltage drops to -34 volts.

Part C of the diagram uses the same rectifiers across a 33-volt secondary. Here, the load is split into two parts by bringing the bleeder tap to ground and doubling the filters in capacity. Each output is -50 volts at no-load and -45 volts at 400 mils. This power supply can be used for two separate audio amplifiers of 10 watts each.

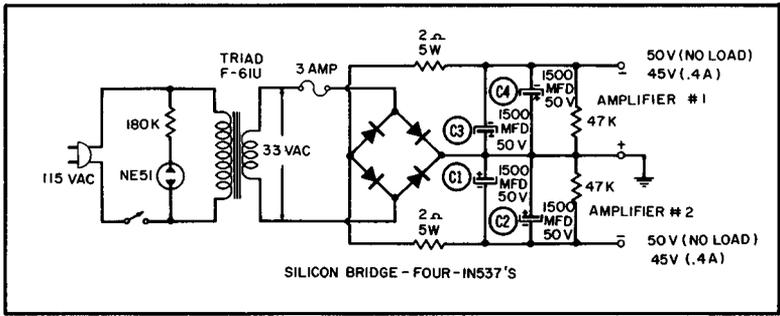
In D of the diagram, a 12-volt, 1-ampere supply is shown. There are two -12 -volt outputs. The one across the 12-volt zener diode is for a low-current load while the other—through the regulated power transistor—is for a high-current load.



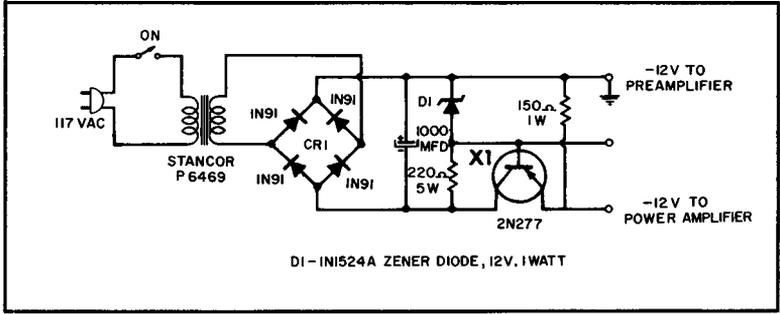
(A) 33 volts, 400 mils.



(B) 34 volts, 400 mils.



(C) Two 45 volts, 400 mils outputs.



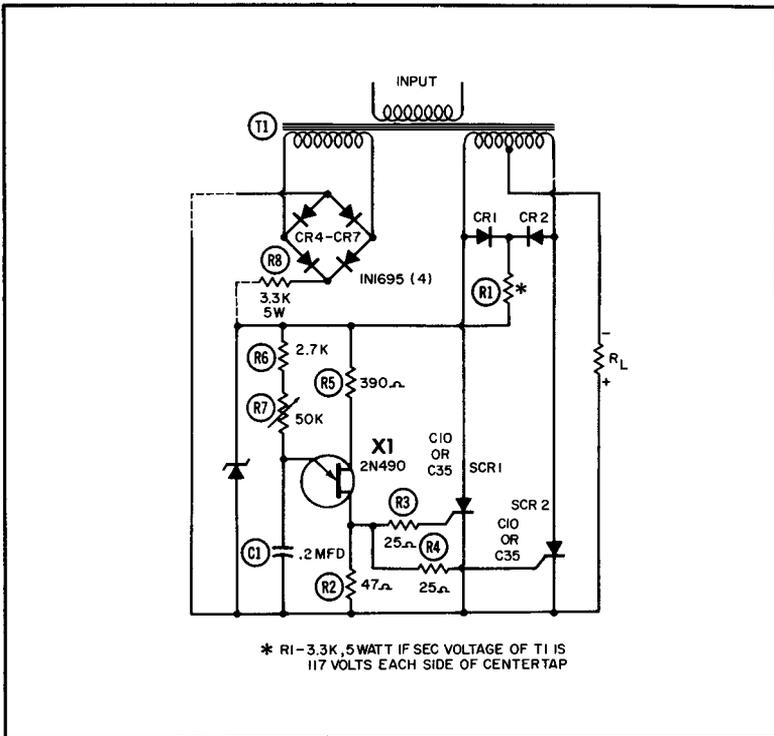
(D) Two -12 volt outputs.

Low voltage supplies.

DC SUPPLY PHASE CONTROL

This figure shows a pair of SCR's in a single-phase power-control circuit in which control R7 permits adjustment of the output voltage from zero to maximum. The single UJT (X1) is used to develop a gate signal to fire both SCR's on alternate half-cycles. Through the rectifying action of CR1 and CR2—and the clipping action of CR3 and R1—a square-wave voltage with an amplitude of 20 volts is applied to UJT X1.

This voltage causes X1 to operate as a relaxation oscillator, and deliver a pulse of gate current to the SCR's at a firing angle determined by the time constant of R6, R7, and C1. The SCR which has a positive anode voltage during the gate pulse is the one that will fire, thus applying voltage to the load for that half-cycle. When X1 reverses its degree of oscillation, the other SCR will fire, thus maintaining the output voltage constant. The firing angle can be adjusted by means of R7. At 60 cps, the firing angle of this circuit can be varied from approximately 10° to 180° (fully off).



DC supply phase control.

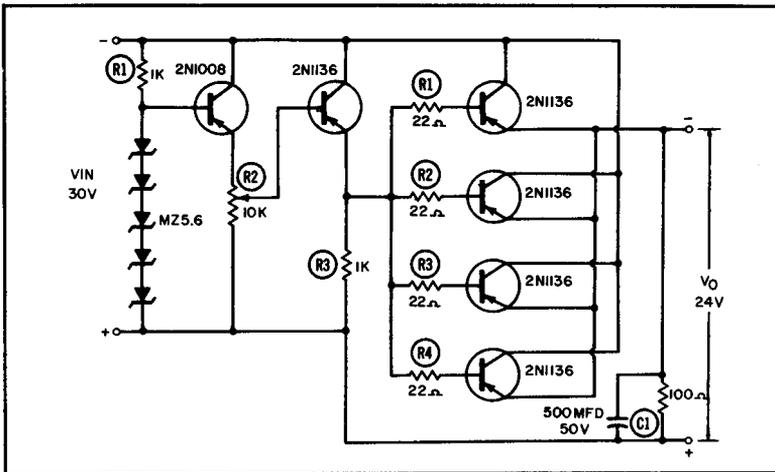
ZENER-CONTROLLED HIGH-CURRENT REGULATOR

A high-current power-supply design depends on the needs of the load. The unregulated source must be able to deliver between three and six volts more than the required output under full-load conditions. Also, the current dissipation of the transistors must be taken into consideration in the design of a power supply.

The circuit in this diagram consists of two cascade current amplifiers controlling four parallel-connected current transistors. Since the output requirement of this power supply is high, the cascaded transistors act as a current amplifier to increase the power rating to 25 watts.

For higher-current applications, several parallel-connected transistors should be used as the current-passing element. As shown here, the four 2N1136 transistors will easily handle 150 watts; and with ideal heat-sink conditions, they can handle up to 240 watts.

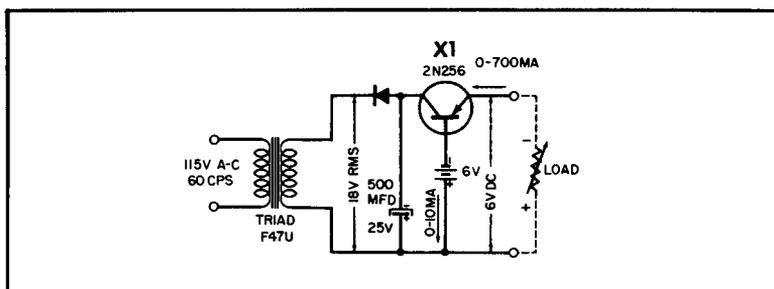
The output voltage is adjusted by potentiometer R2. However, if the input voltage is reduced, the drop across the transistors will increase and the maximum output current will be reduced. This condition can be avoided by incorporating a separate input supply for the zener regulator. In this case, a *Variac* or an adjustable autotransformer would be used at the AC input and would be mechanically ganged to voltage-adjusting potentiometer R2. With this circuit, then, the collector-to-emitter voltages of the current-passing transistors would not exceed 3 to 6 volts. Thus, a great increase in output current would be provided at low voltages.



Zener-controlled high-current regulator.

REGULATED POWER SUPPLY

This is a 115-volt AC regulated power supply in which the output voltage remains constant for wide input variations. The value of secondary AC voltage should never exceed a maximum of 25 volts rms, and the output voltage should be less than one-half volt higher than the reference battery. If desired, the 6-volt battery may be replaced by a zener diode (type A5B or equivalent). Half-wave rectifier D1 is made up of two paralleled 500-ma selenium rectifiers.



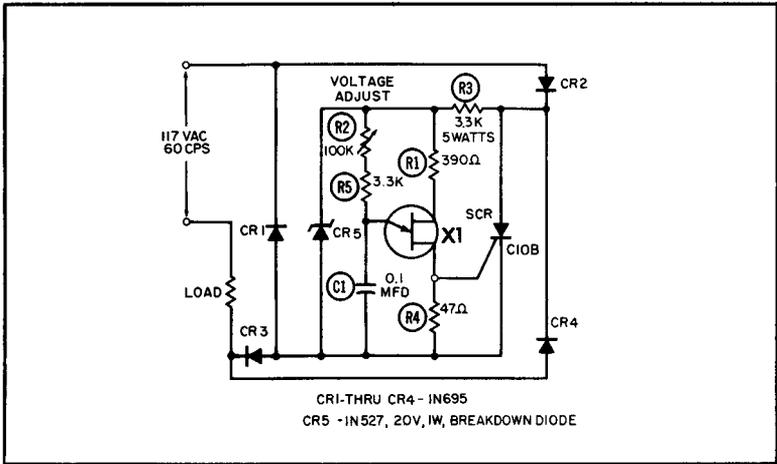
Regulated power supply.

150-WATT VOLTAGE REGULATOR

This is a 150-watt voltage regulator for use (with a variable load) on a 117-volt line. The components used in this circuit are small, low-current devices, thus making it easy to mount the entire assembly in a small wall switch box for use in dimming a lamp load. Efficiency of this circuit is lower than the back-to-back arrangement of controlled rectifiers because of the added voltage drop in the diodes. This type of circuit is limited to systems operating at power frequencies and using standard silicon-controlled rectifiers (SCR's) near their maximum ratings.

In this circuit a full-wave rectified voltage is applied to the SCR through diodes CR1, CR2, CR3, and CR4. On each half-cycle the current will reach almost zero because of the three forward-biased diode drops in series (two diodes and the SCR). Thus, for a 117-volt, 60-cycle system, the current is reduced to microamperes for at least 20 microseconds during each half-cycle.

Because of the slow rise of forward voltage at the power frequency, this time interval is enough for the gate of the controlled rectifier to regain control of its anode. The SCR and its firing circuit (using phase control on each half of the AC cycle) will then apply controlled AC voltage to the series load in the AC line.



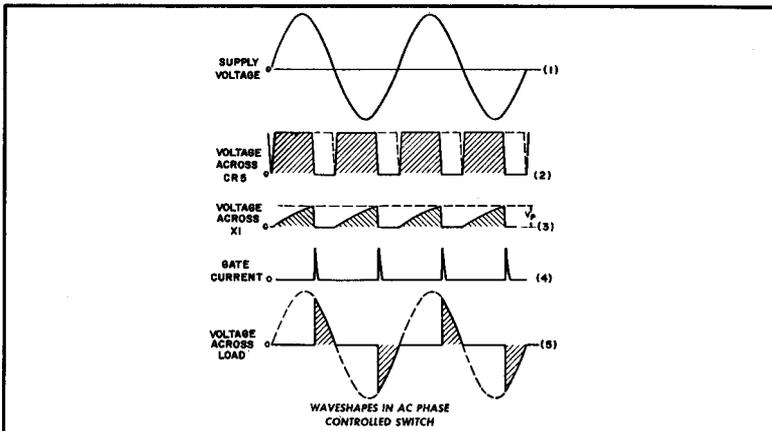
150-watt voltage regulator.

PHASE-CONTROLLED AC SWITCH

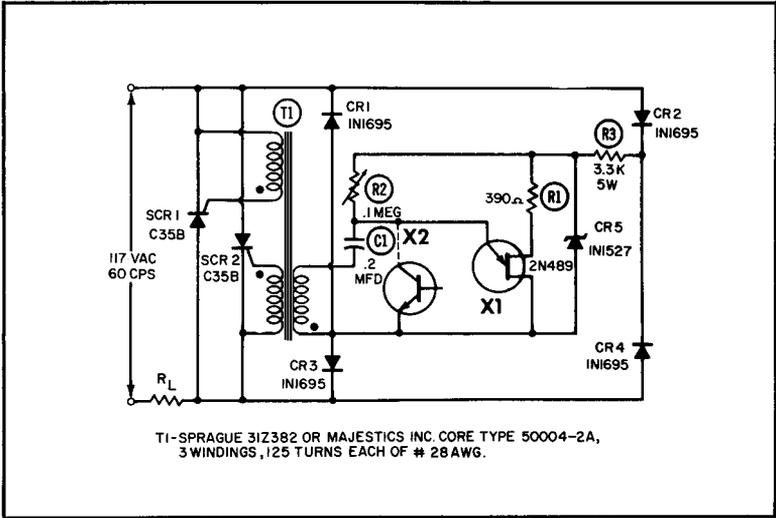
Silicon-controlled rectifiers (SCR's) can be easily controlled by applying AC to their gate electrode, just as a thyatron can be controlled by applying the proper AC to its grid.

In this diagram, the SCR's are connected back-to-back (or cathode-to-anode) across the input. Four diodes (CR1 to CR4) form a bridge across the supply, with the control circuit (X1, X2, and CR5) across the center of the bridge.

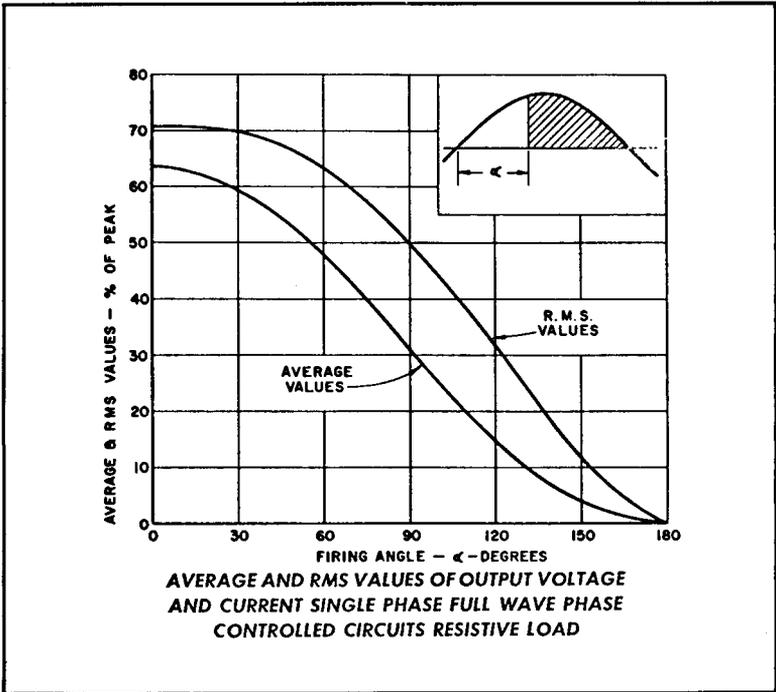
Part A-1 of the diagram shows the AC input, and Part A-2 shows the waveform developed across (1) the bridge rectifiers,



(A) Waveshapes in switch.



(B) Electrical phase control.



(C) Voltage-current waveform.

Phase-controlled AC switch.

(2) the zener diode, and (3) bridge load R3. The positive voltage (Part A-3) that appears across UJT X1 also charges C1 through voltage control R2.

When C1 charges, it causes X1 to conduct, thus discharging C1 through X1. This current flowing through T1 fires either SCR1 or SCR2 (whichever anode is driven positive). The resultant waveforms are shown in Parts A-3 and A-5. When one SCR fires, the voltage across both of them decreases to approximately one volt. This keeps capacitor C1 discharged until the supply voltage is reversed. At this time, a new timing cycle starts for the firing of the alternate SCR.

The firing angle of both SCR's is controlled by potentiometer R2. Minimum output voltage occurs with R2 in its maximum position.

If desired, an NPN transistor (X2) can be used to electrically control the firing angle. The circuit in Part B of the diagram shows how the voltage and current applied to a load can be controlled. This is done by delaying the point in the AC cycle at which an SCR switches from the blocking to the conducting state.

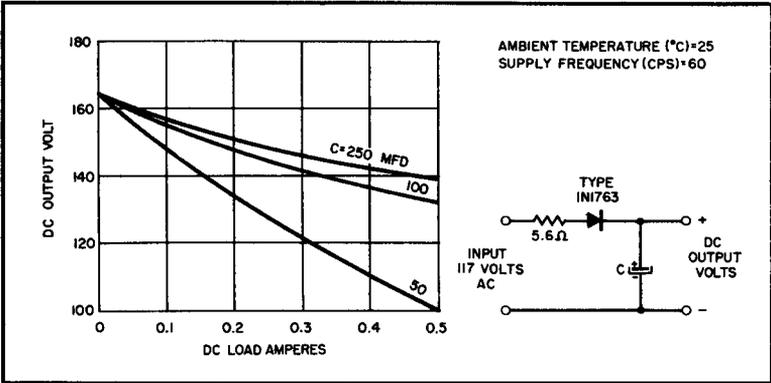
Part C of the diagram illustrates the effect of this delayed firing on the average and rms output voltage and current in single-phase, full-wave AC or DC resistive load circuits. This circuit can be used for lamp dimming, temperature control, and voltage regulation. By using the primary of a transformer for the indicated load, it is possible to control very high voltage or current loads on the secondary.

RECEIVER POWER SUPPLIES

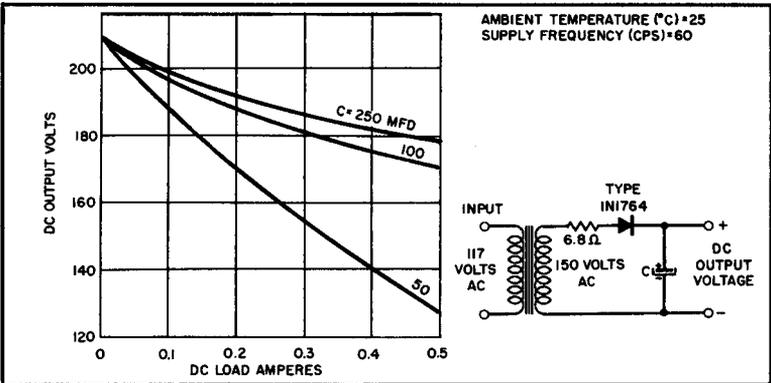
Some TV power supplies use either the 1N1763 or 1N1764 diode in their circuits, as shown in the diagram.

The 1N1763 has a peak inverse rating of 400 volts, and a rated DC forward current of 500 milliamperes. It also has a maximum reverse-current rating of 100 microamperes (at the rated peak inverse voltage and 25°C. ambient temperature). This diode is intended for applications in which peak inverse AC voltages up to 140 volts are found. The 1N1764, however, has a maximum peak inverse voltage of 500 volts; it is intended for rectifier applications subject to inverse peak voltages up to 175 volts.

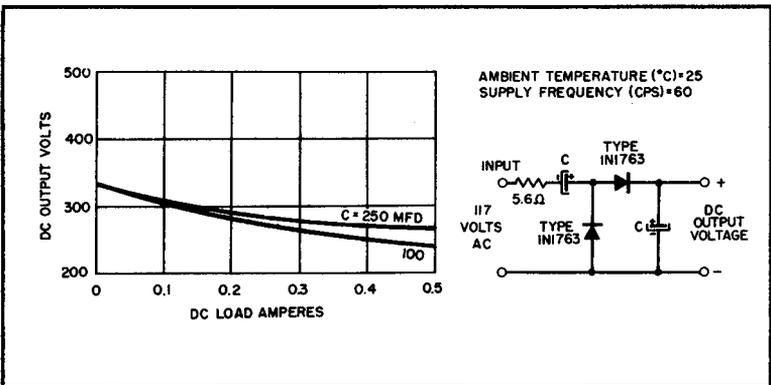
Parts A and B of the diagram show the output and voltage-current curves for half-wave rectifiers, while C and D show the curves for half-wave voltage doublers. Finally, E and F show full-wave voltage-doubler circuits and their characteristic curves.



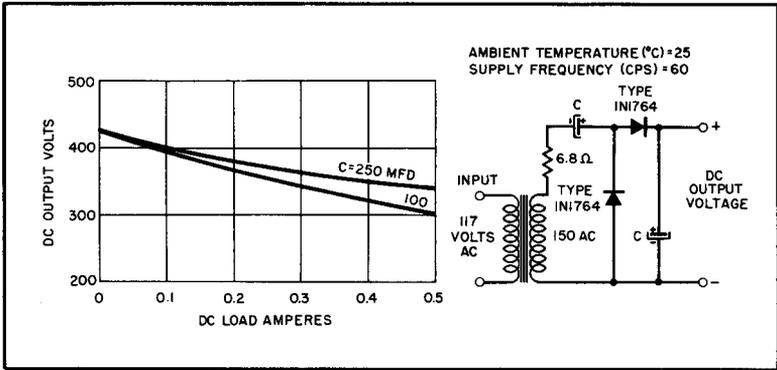
(A) 1N1763 half-wave rectifier.



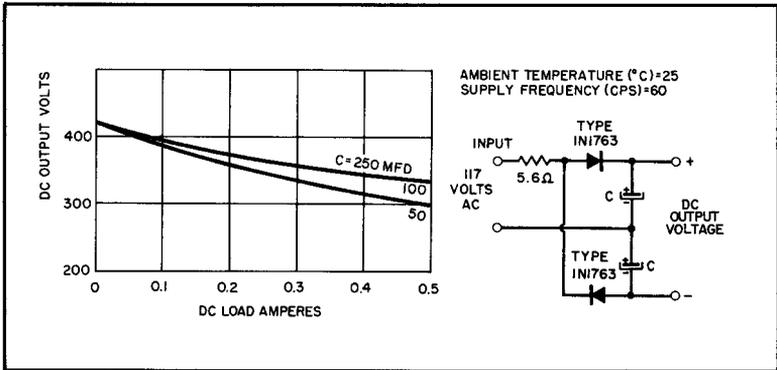
(B) 1N1764 half-wave rectifier.



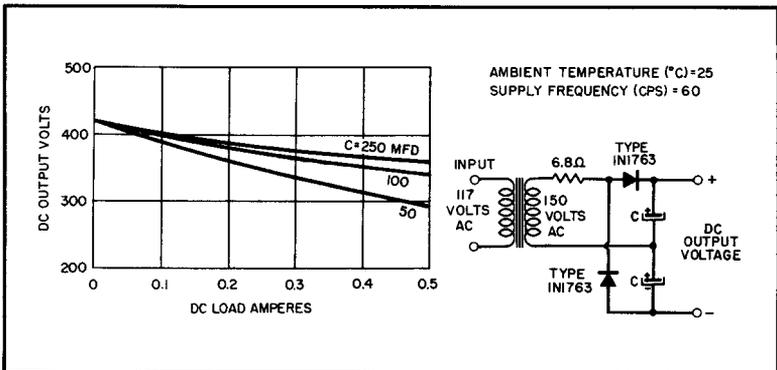
(C) 1N1763 half-wave voltage doubler.



(D) 1N1764 half-wave voltage doubler.



(E) 1N1763 full-wave voltage doubler.



(F) 1N1764 full-wave voltage doubler.

Receiver power supplies.

METER-CALIBRATION SUPPLY

This diagram shows an adjustable regulated power supply for use in transistor testing or meter calibration. Voltages range from 0 to 30 volts, with a regulation of 0.1% for an input of 100 to 130 volts. The supply has a multiratio power transformer for providing an adjustable voltage to the bridge-rectifier system.

On the 10-volt range, a 1N1512 zener diode is connected between the base of X1 and the positive bus, thus causing a regulated voltage to appear across potentiometer R1. A portion of this voltage is fed to the bases of parallel-connected X2 and X3 as bias. Since R1 sets the bias on these current amplifiers, it therefore controls the output voltage of the power supply.

On the 20-volt range, a 1N1516 replaces the 1N1512 and the maximum output voltage increases to 22 volts. On the 30-volt range the two diodes are series-connected, which allows a maximum output voltage of approximately 32 volts. On each voltage range the appropriate tap of the T1 secondary winding is selected to minimize the voltage drop across X2 and X3. This decreased voltage drop reduces both the collector dissipation and the collector-to-emitter voltage of X2 and X3. Thus, the bias across the transistors remains constant for the different input voltages. A fourth section of the range switch changes the multiplier resistor for the voltmeter.

Switch S4 changes the multipliers for the MA meter; and as a precaution against overload, S3 shorts the terminals when the meter is not in use. The resistances for the current or voltage meter depend on the particular meter used.

(See page 204)

300-VOLT, 200-MA DC SUPPLY

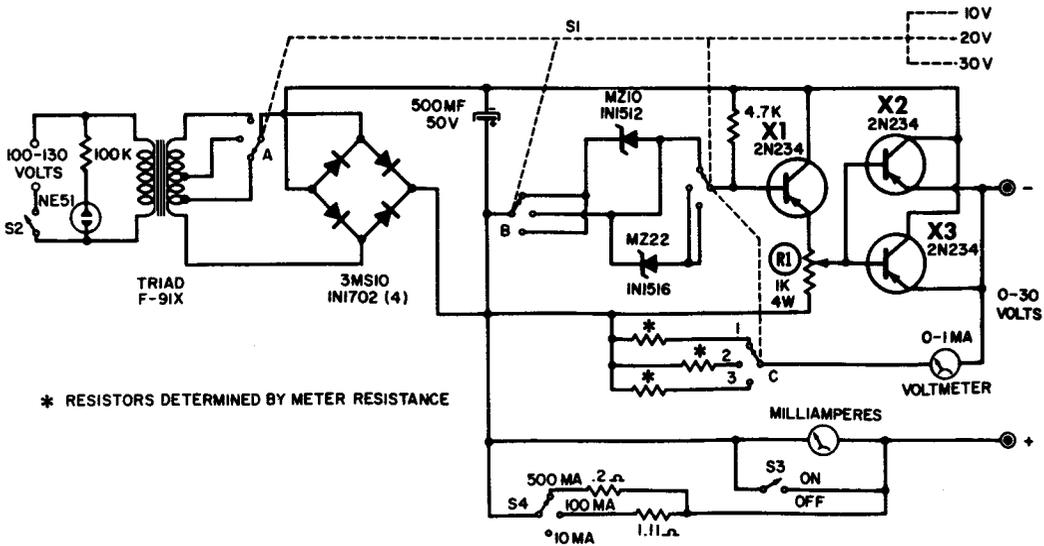
This power supply provides 300 volts DC up to 200 ma. It is a high-voltage supply that can be used where size and regulation are important factors. Each leg of the bridge rectifier contains either one 1N540 or two 1N538's. Following the rectifier is a pi-filter and the transistor regulator section.

The regulation of this supply is $\pm 1\%$ from 0 to 200 ma DC, with an output ripple of less than 3 millivolts peak-to-peak.

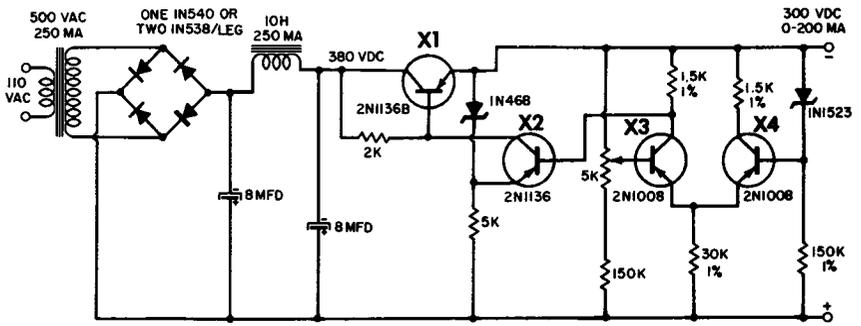
(See page 205)

SHUNT ZENER DIODE-TRANSISTOR VOLTAGE REGULATOR

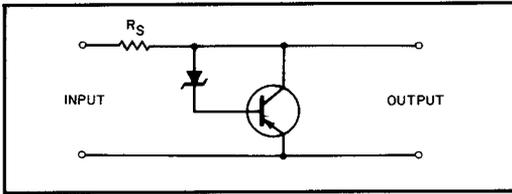
Zener diodes used with transistors make effective shunt voltage regulators. The voltage-regulating factor of such a setup is improved by the current gain of the transistor used; hence, more power can be handled by the regulator.



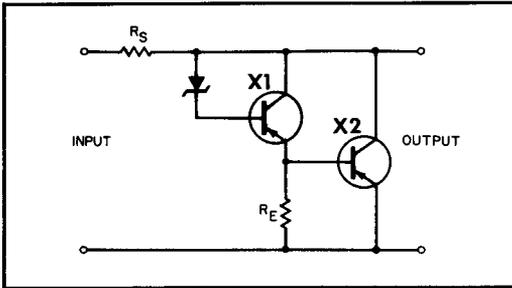
Meter-calibration supply.



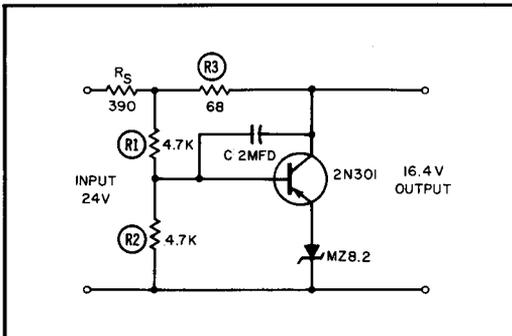
300 VDC 200-ma supply.



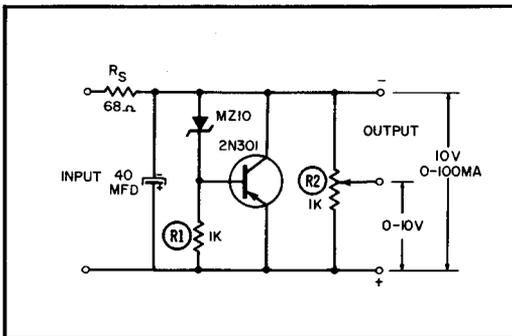
(A) Diode controlling 10-watt load.



(B) Diode controlling base of X_1 .



(C) Circuit for V_o higher than zener voltage.



(D) Circuit for V_o lower than zener voltage.

Shunt zener diode-transistor voltage regulator.

In Part A of the diagram, a 1-watt zener diode can control a load of 10 watts, whereas in Part B the diode controls only the base potential of X1. Here, X1 is used as an emitter follower and current amplifier with its collector-to-base voltage determining the bias on shunt regulator X2. If this regulator were to be used where an extremely large current variation is encountered, several shunt-connected transistors would then have to be employed in place of X2.

Part C of the diagram shows a shunt-regulated supply for outputs greater than the zener voltage (V_z). Here, the output voltage is determined by the formula

$$V_o = \frac{R_1 + R_2}{R_2} (V_z).$$

For example, if R_1 and R_2 are the same value, the output voltage (V_o) will be twice V_z . Resistor R_3 more or less compensates for variations in the supply voltage to the regulator. However, by using a potentiometer in place of R_3 , the exact value of variations can be compensated for. Excessive resistance at R_3 should be avoided because V_o will drop as the input voltage increases. The output-voltage ripple will be less than 10 mv when the regulator is supplied by a full-wave rectifier with a 20-mfd capacity.

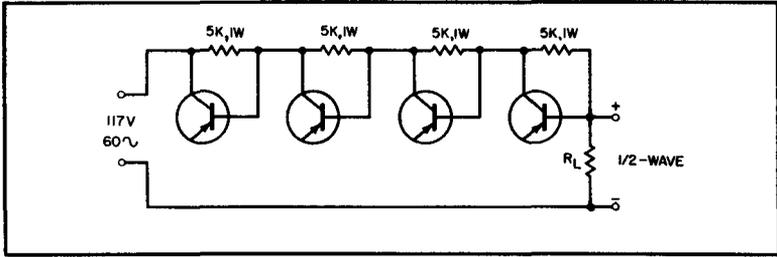
When lower than the zener voltage is required, the circuit in Part D of the diagram may be used. Here, the transistor collector-to-emitter potential is regulated by the diode, and the setting of potentiometer R_2 determines the regulated output voltage. This potentiometer should have as low a resistance as possible, to minimize voltage variations due to load changes.

POWER TRANSISTORS AS DIODE RECTIFIERS

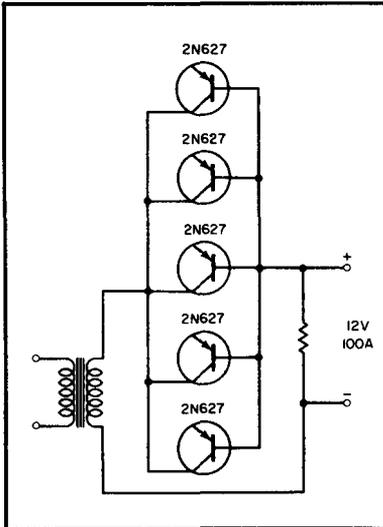
Since transistors connected in series have only a small voltage loss, they can be used for high-voltage applications. Inverse voltage and power dissipation are the two principal ratings to be considered when setting up simple rectifier circuits. Because of these considerations, power transistors (which have low forward-conduction characteristics) are quite useful as rectifiers.

Inverse voltage is that value of peak AC applied across the rectifier(s) in the reverse direction. It may be as high as 2.8 times the average DC output.

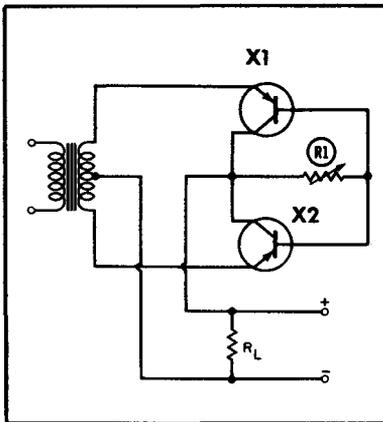
In Part A of the diagram, an example of series-connected transistors operating as a 20-ampere half-wave rectifier is shown. For 117-volt line operation, the peak inverse voltage (PIV) of the four transistors in series will be approximately 400 volts. One-watt, 5,000-ohm resistors are used, as shown, to prevent the entire 400 volts from appearing across any one transistor.



(A) Series rectifier.



(B) Parallel rectifier.



(C) Controlled rectifier.

Power transistors as diode rectifiers.

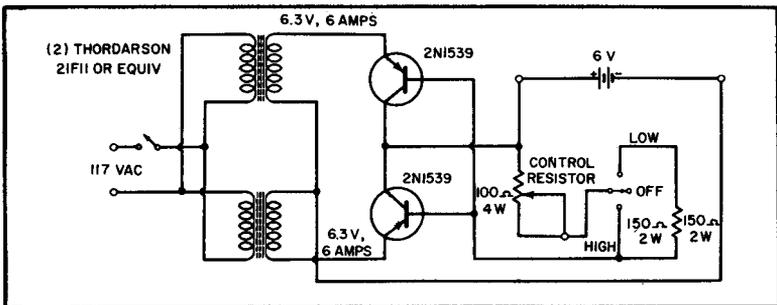
Power transistors used as rectifiers have a small power loss due to their very low forward-voltage drop. A value for rectifier output-power dissipation is approximately 0.5 watt per ampere. For a 2.5-ampere load current, these transistors do not require a heat sink at room temperature. However, for a load requiring 10 amperes, a heat sink capable of dissipating 5 watts must be provided; and at 20 amperes, the heat sink must be capable of dissipating 10 watts. In most equipment these heat-sink requirements are satisfied by anchoring the transistors to the chassis.

The transistors can be made to handle more power by operating them in parallel, as shown in Part B. Five 2N627 transistors may be used as a 12-volt, 100-ampere half-wave power supply. Center-tapped or bridge-type power supplies can also be designed using parallel transistors.

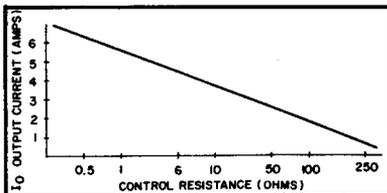
A simple, controlled full-wave rectifier circuit is shown in Part C of the diagram. The current passed on each half-cycle (limited by the load impedance) is controlled by the value of R1. As the resistance of R1 is increased, the base currents of X1 and X2 become more and more limited, thus reducing the current applied to the load. The result is a very smooth and effective control of the output current and voltage.

BATTERY CHARGER

A six-volt battery charger is shown in Part A of the diagram. Two 6.3-volt transformers, each across the AC line, provide 12.6



(A) Charger.



(B) Current waveform.

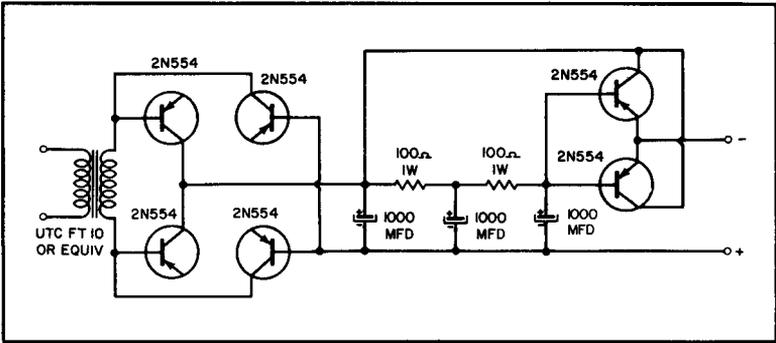
6-volt battery charger.

volts. Two 2N1539's are used as rectifiers, to control the DC current.

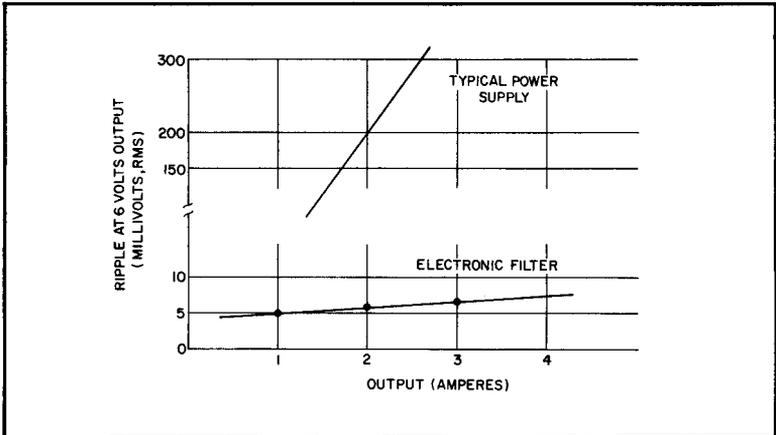
Three positions are available—low, high, and off. With the 150-ohm resistance in the circuit (low position), current flow is as shown in Part B. Current flow on each half-cycle depends on this resistance, and is limited only by the load (battery) impedance.

ELECTRONIC RIPPLE FILTER

An electronic power-transistor filter is very effective in reducing power-supply ripple. The filter capacitance across the load is approximately the value of the base filter multiplied by the current gain of the transistor.



(A) .025-farad filter circuit.



(B) Characteristic curves.

Electronic ripple filter.

This capacitance multiplying factor results in an effective filter capacitance of 25,000 mfd in the circuit of Part A. The curves in Part B show the very low ripple voltages obtained at high load currents. Equally effective filtering by the conventional choke-capacitance method would require the use of a very large and expensive inductor and/or capacitor.

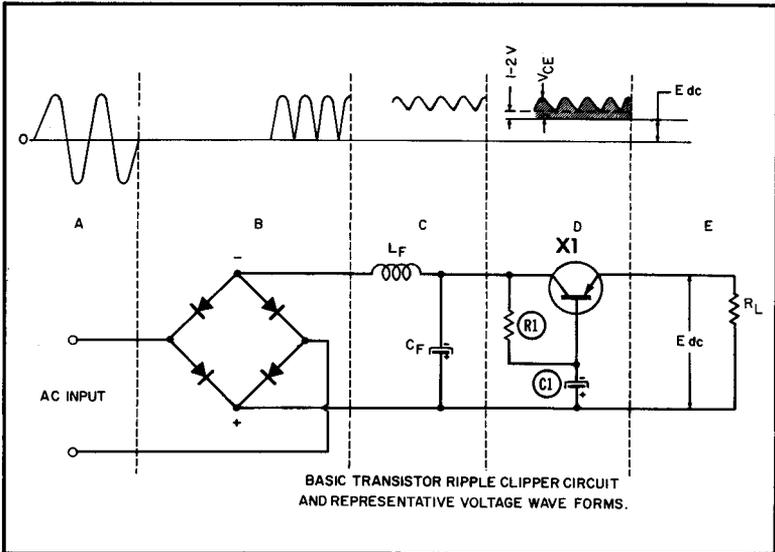
This type of filter may be applied to almost any DC voltage power supply if a low collector-to-emitter voltage is maintained.

RIPPLE FILTERS

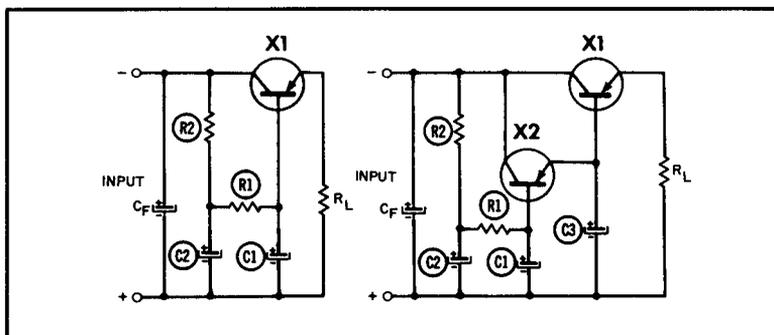
Acting as a variable series resistance, a power transistor makes an effective ripple filter for a DC power supply, where the gain of the transistor is a measure of circuit effectiveness.

Part A shows a basic circuit with (1) the AC input, (2) the rectifier output, (3) the output of the LC filter, (4) the voltage across the transistor, and (5) the circuit output. The shaded portion of (4) represents that part of the voltage dissipated in the transistor. The ripple filtering effect of the transistor is comparable to that in a conventional filter circuit, in which C2 is equal to C1 multiplied by the current gain of the transistor.

The ripple filter will be most efficient when the transistor is operated close to saturation. The minimum voltage drop across the transistor is 1 to 2 volts for the maximum load current ex-



(A) Basic circuit with waveforms.



(B) Higher sensitivity circuit.

Ripple filters.

pected. In Part B the use of decoupling network R2-C2 improves the circuit sensitivity, as does the addition of a second transistor. Typical circuit values for Parts A and B are shown in Part C of the diagram.

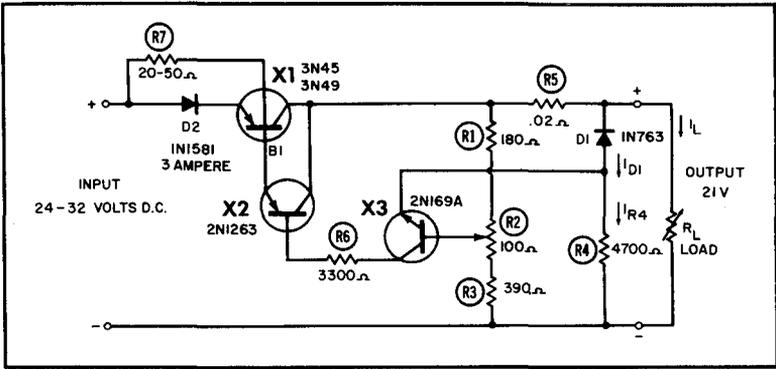
SERIES VOLTAGE REGULATOR

Designed for an output of 21 volts with 1% regulation, this power supply provides an output current up to 3 amperes. Voltage input can vary from 24 to 32 volts DC.

This circuit operates by controlling the regulating impedance in series with the load. Here the variable impedance is a transistor which is controlled by comparing the voltage across R_L with a reference voltage, amplifying any difference in the compared values, and applying this difference to the regulating transistor. The end result is a closed loop in which the load current is proportional to the difference between the measured load voltage and the reference voltage.

Diode D1 determines the reference voltage, and R4 limits the current through D1 to a nearly constant value. The combination of R1, R2, and R3 represents the output-voltage sensing network, a portion of which is compared by X3 with the voltage of D1. The voltage difference between D1 and the portion of the output being compared determines the bias on X3. This difference is amplified by X3 and X2 and applied to X1, where it is again amplified and used as current control. R5 compensates for the difference voltage required to vary the current from no-load to full-load, and R6 limits the current through X3.

The tetrode power transistor (X1) makes possible an improved series-voltage regulator for systems where current requirements vary widely. The second base connection provides good control



Series voltage regulator.

of the total system leakage. This means the output terminals can be opened without loss of control and with very low standby currents. Good gain linearity assures constant regulation over wide current ranges. The degree of regulation can be selected and varied by means of current feedback.

Section 15

RADIO AND TV CIRCUITS

Separate sections of this book cover RF's, IF's, audio sections, power supplies, oscillators, and many other circuits used in radio and television receivers. This section shows and describes an assortment of circuits, including transistorized video amplifiers, video detectors, deflection circuits, and diode detectors and clippers.

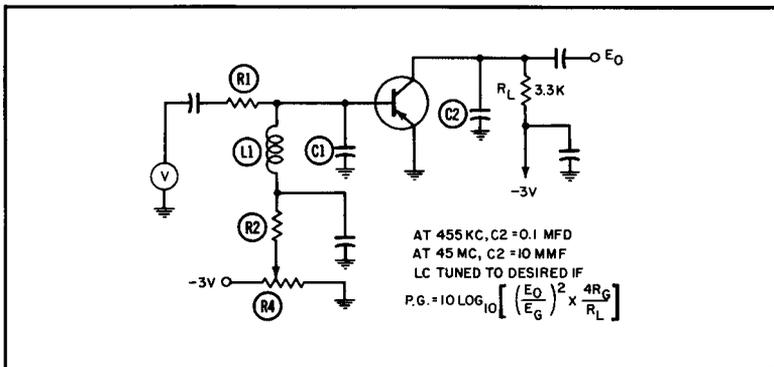
VIDEO DETECTORS

High-frequency transistorized video detectors are made possible by using MADT and SBT transistors. A typical common-emitter circuit is shown here, along with the formula for power gain.

Detection takes place because the transistor amplifies only half the IF input waveform. A filter in the collector circuit separates the IF carrier from the modulation information. Power gain for a detector is figured as shown in the diagram, where E_o is the audio-output voltage for a 30% modulated input signal, and E_c is the magnitude of the unmodulated input signal. Diode detection results in a 14-db signal loss in broadcast IF detectors. However, the use of an SBT results in over 5 db of signal gain, and an MADT will provide a gain of over 15 db.

This circuit can be used as a detector with either a 455-kc or 45-mc input. The only factor to consider is the value of C_2 . As used in this circuit, an SBT will yield about 1 db of gain and an MADT over 5 db, as opposed to the 14-db diode-detector loss.

Desirable characteristics for good transistor detectors are high amplification at the operating frequency and a low output impedance. SBT's and MADT's provide these conditions. In addition to being a good detector, this circuit is a good source of AGC because of the gain it provides.

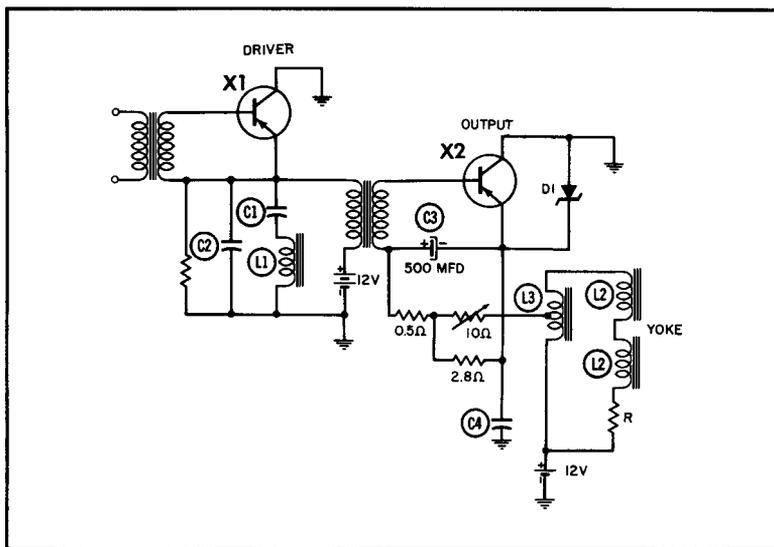


Video detectors.

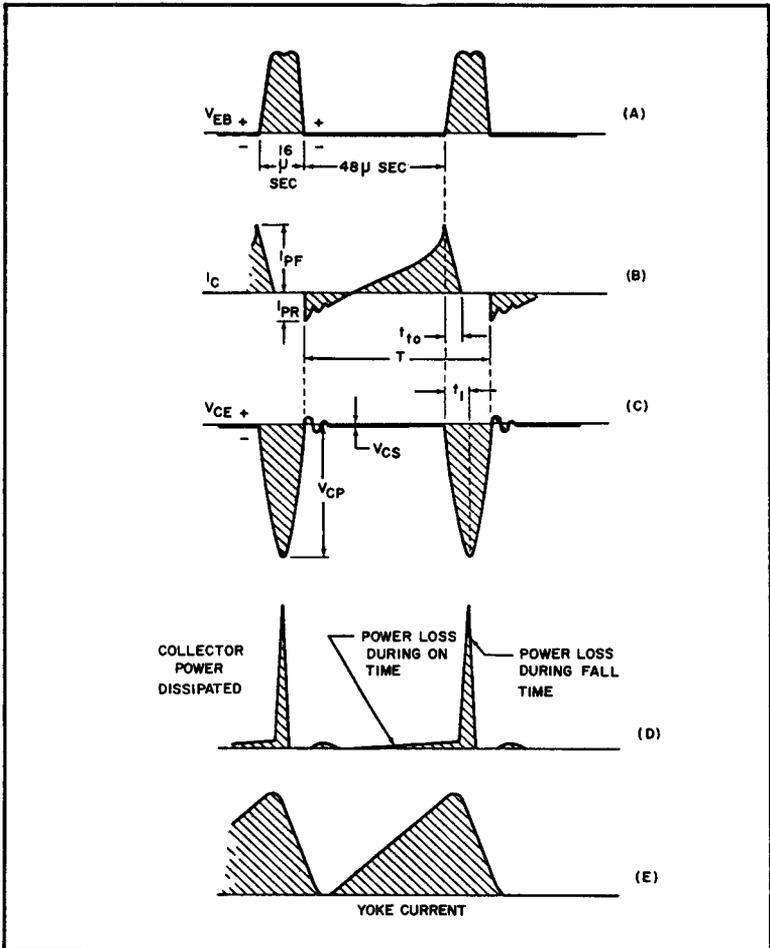
TV HORIZONTAL-DEFLECTION SYSTEM

Switching transistors can be used for horizontal deflection in a TV receiver. Part A of the diagram shows a switching transistor circuit, and Part B the waveform of various parts of the circuit. Three 0.24-ohm wirewound resistors in parallel were used to read the current waveforms shown.

Driver X1 turns X2 on for about 48 μ secs and off for 16 μ secs. Because of the reverse-biased zener diode across the transistor, a current flows in the reverse direction for the first 9 μ secs. After



(A) Horizontal circuit.



(B) Waveform.

TV horizontal-deflection system.

this initial $9 \mu\text{sec}$ current flow, $39 \mu\text{secs}$ is required for the collector current to build up to its peak forward value. At the end of this period, the base of X2 is driven positive, thus reducing the collector current to zero. This collapsing current induces a high voltage across the yoke during retrace. Capacitor C4, in resonance with L3, tunes this circuit to a frequency of $\frac{1}{2}t_r$ (where t_r is the retrace time). As this collapsing voltage passes through 180° and becomes positive, the base is again pulsed and current flows; thus the full 360° cycle is completed. In the driver stage, C1 and L1 form a resonant circuit at the third harmonic of the retrace

frequency, to reduce the peak voltage from collector to emitter of X1. With this circuit, the peak voltage of 90 to 110 volts is reduced to 80 or 90 volts. This reduction affects only the driver, not the output, stage.

The stage gain of X2 can be improved by returning the energy to the battery through bilateral action of the transistor. At the end of the retrace cycle, the collector voltage begins to swing positive. The base and collector currents will be high, being limited only by the transistor saturation and lead resistances. However, these currents will decay rapidly to zero because of the damping effect of the transistor on free oscillations. Thus, part of the energy stored in the yoke during the forward sweep is returned to the battery.

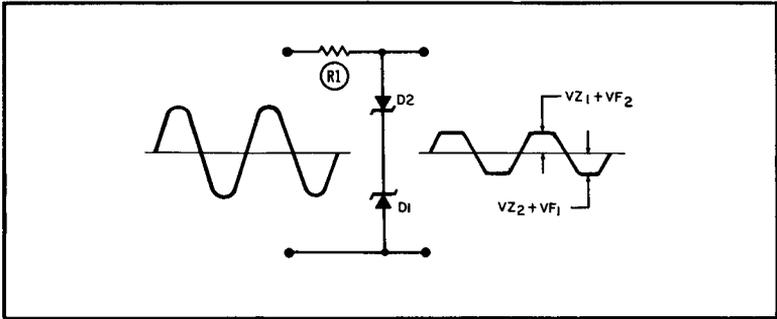
Important requirements of output transistor X2 are high efficiency and the ability to withstand high reverse voltages. The 2N629 and 2N630 series fulfill these requirements. If the yoke is designed to give a higher voltage than the transistor can stand, the collector-to-emitter voltage can be clipped to a safe level by using a 10M91Z zener diode. It is a good idea to use the diode anyway, because it affords excellent transistor protection.

DIODE LIMITERS

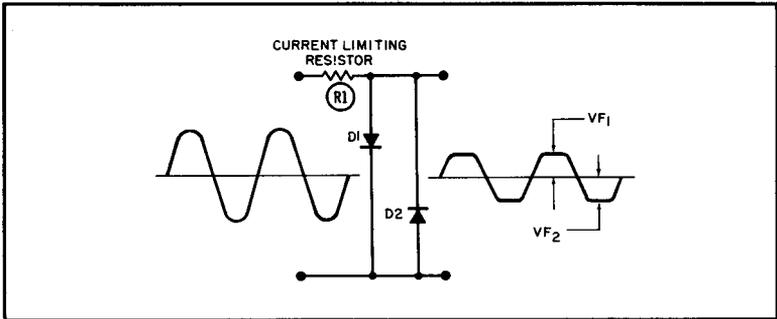
Part A of the diagram shows two diodes connected in series with their polarities reversed in order to utilize their zener-breakdown characteristics for limiting action. Balance of the output voltage may be controlled by selecting proper diodes, each with a particular zener-voltage level. For special applications, two diodes having substantially different zener voltages may be used to deliberately unbalance the output.

The voltage level may be reduced by using a resistive divider. This divider is very effective when the clipped and reduced signal is to be fed to a high-impedance load such as a vacuum-tube grid. When considerable current must be supplied to a load, it might be necessary to select diodes that have suitable zener-voltage levels (IN465 through IN470) and use them without a resistive voltage divider. However, some sharpness of clipping action will be sacrificed in going to lower zener voltages.

As shown in Part B of the diagram, two diodes may be connected in parallel and their polarities reversed in order to utilize their steep forward characteristics for limiting action. The peak-to-peak output voltage will range from approximately 1 to 2 volts, depending on the value to which R1 limits the current. Here two IN138A diodes are recommended where the peak current through R1 is less than 1 ma.



(A) Series connection.

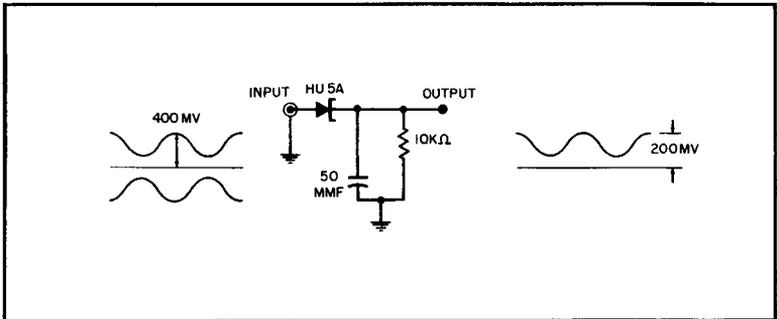


(B) Parallel connection.

Diode limiters.

BACKWARD DIODE DETECTOR

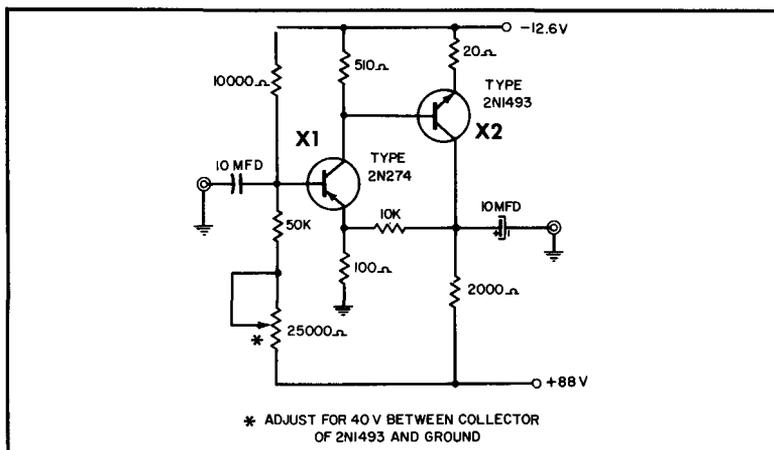
This illustration shows a *Uni-Tunnel* (backward) diode used as a detector. In this circuit the 10-mc input is modulated by a 0.4-volt peak-to-peak, 100-kc signal, while a 0.2-volt detected signal is present across the output circuit.



Backward diode detector.

HIGH INPUT-IMPEDANCE VIDEO AMPLIFIER

This diagram shows a 2N1493 and 2N274 in a typical video-amplifier circuit employing negative feedback. The frequency response is 20 cycles to 7.5 megacycles (15-mmf load), the voltage gain is 75, and the input resistance is 5,000 ohms. This circuit may be used in industrial-television video amplifiers, instrument amplifiers, or pulse amplifiers.

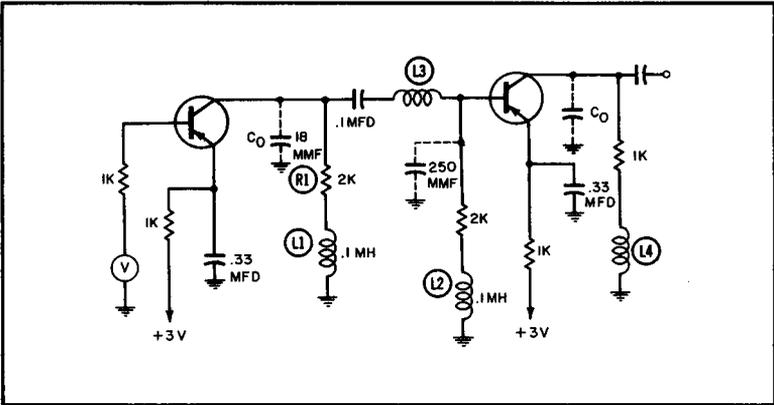


High input impedance video amplifier.

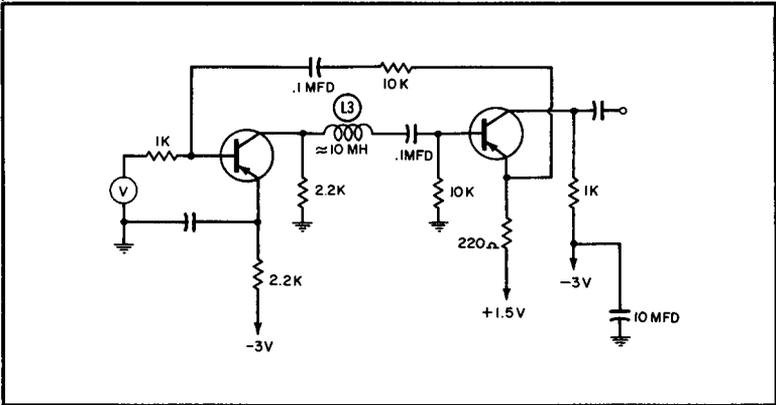
VIDEO AMPLIFIER

Special processing techniques for high-frequency transistors allow design of transistorized video amplifiers. A two-stage video amplifier without feedback is shown in Part A of the diagram. With all coils grounded, the amplifier is an RC-coupled common-emitter circuit. The output impedance of the circuit is essentially the same as the input impedance. A stage gain of 5 and a bandwidth of 5 mc are considered typical. The addition of L3 and L4 improves the bandwidth gain 50%, and L1 and L2 improve it another 30% by decreasing the loading effect of the resistor at the high end of the band. These circuit values were chosen because they aid the gain at 3 mc and above.

Part B shows a video amplifier with feedback. Through the use of series peaking coil L3 and feedback, its bandwidth gain can be made to approach the theoretical limit of the transistor used. With transistors having a cutoff at 45 mc, the bandwidth is variable from 12 to 20 mc, with a corresponding gain variation from 14 to 40 db. Cascading of such feedback amplifiers is possible without interaction, because feedback is independent of the load.



(A) No feedback.



(B) Negative feedback.

Video amplifiers.

VOLTAGE-DOUBLER VIDEO AMPLIFIER-DRIVER

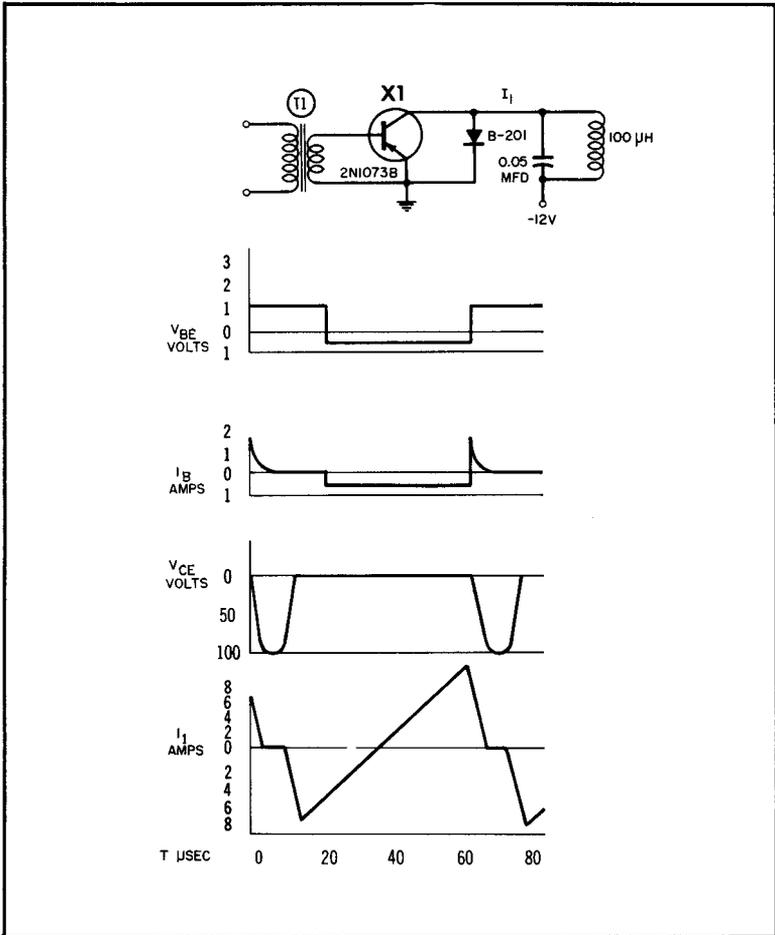
This figure shows an application of three MADT transistors in a video-amplifier voltage-doubling circuit. Bandwidth realized is that normally required for TV receivers.

Following the IN60A diode detector, video input to the first amplifier base is 0.7 volt peak-to-peak, sync positive. Sound and AGC are taken off the collector as shown. From the 250-ohm contrast control in the emitter circuit, the video information is amplified by two direct-coupled stages. The output to the picture-tube grid, after the 4.5-mc trap, is 55 volts peak-to-peak with video sync negative.

TV DEFLECTION

A single-transistor deflection circuit is shown here. Because of its fast switching time and high voltage gain, the 2N1073B is the first transistor found useful for horizontal-deflection circuits. The low saturation resistance of the 2N1073B provides good waveform linearity.

The B-201 rectifier is a high-speed, low forward-drop diode used for the reverse-current swing of the yoke. The drive to the circuit is adjusted for +1.5 volts maximum. The base-to-emitter voltage varies from -0.5 to +1.5 volts, resulting in a peak current of 2 amperes as shown by the waveforms.



TV deflection.

FLEAPOWER SOLAR-CELL CIRCUITS

Some very simple electronic circuits are possible using solar cells. Here, three circuits are shown which represent an extremely low-power application for photovoltaic cells. Two of the circuits shown are oscillators, and each is designed for operation using a single photocell as its power supply.

Either photocell requires much less illumination than direct sunlight. Good room illumination, of at least 100 foot-candles, will furnish the required electrical energy. In Part A of the diagram, the output frequency of the wide-range audio oscillator (multivibrator) may be varied by potentiometer R3. Any frequency between 1 and 1,000 cps may thus be obtained.

This circuit is an asymmetrically coupled multivibrator with its period of oscillation determined by R1, R2, R3, C1, and C2. All these components are nonvariable except R3, which serves as the frequency control.

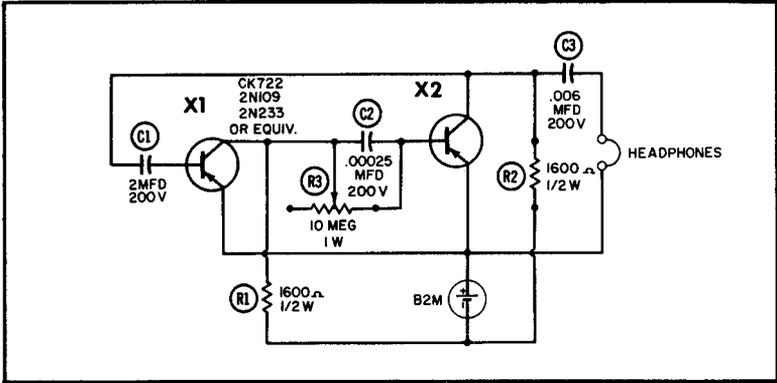
R3 adjusts the frequency by causing a corresponding variation in the coupling between the output of X1 and the input of X2. The output of this circuit is a rectangular wave. For good frequency stability, the illumination on the photocell should remain constant. The output of the oscillator may be increased by using two or more photocells in series.

This handy audio oscillator may be found useful in servicing all kinds of circuits. It can also be used as a code-practice oscillator.

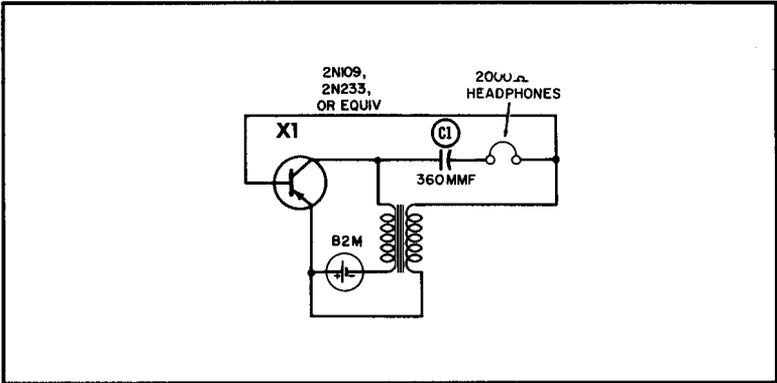
In Part B an audio oscillator with inductive feedback is shown. This oscillator can be used for the same purpose as the one shown in Part A. In this circuit the output frequency is determined by the degree of illumination, with approximately 100 foot-candles required for proper operation. Oscillation occurs as a result of positive feedback obtained from transformer coupling.

One possible use for this device is as an exposure meter in photography, where the output frequency is an indication of the light level measured.

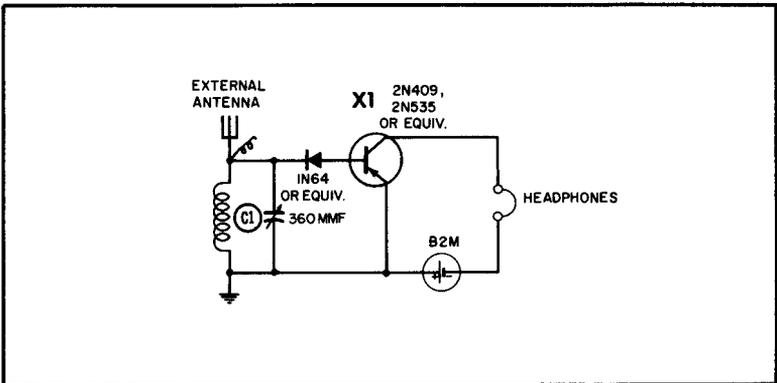
Part C shows a simple sun-powered radio. It is designed to work with a single B2M sun-battery cell requiring very low illumination. The circuit uses a small number of components, and requires only 10 foot-candles of illumination incident on the photocell for proper operation. This will produce good volume in an ordinary pair of 2,000-ohm headphones. However, the sensitivity and selectivity will only allow it to receive strong local stations. Under optimum conditions, the radio will drive a 4-inch PM speaker satisfactorily. In this case the highest impedance primary terminals of a universal output transformer should be connected



(A) Multivibrator.



(B) Transistor oscillator.



(C) Simple radio.

Fleapower solar-cell circuits.

in place of the headphones, and the speaker should be connected across the low-impedance secondary winding.

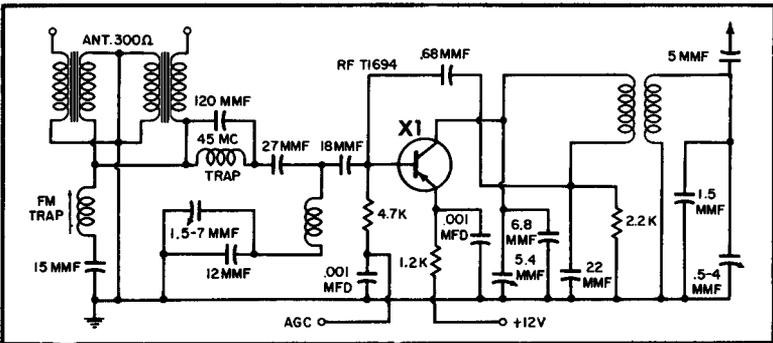
By varying the capacitance of C, any desired frequency in the standard broadcast band can be picked up. A loopstick primary can be used as the antenna, and an extra length added for better performance if desired. A good earth ground will also do much toward improving the performance.

TV/FM TUNED AMPLIFIER

This is a microalloy diffused-base transistor (MADT) RF amplifier used for FM or TV applications. Its performance is given below:

Channel	Center Frequency (Mc)	RF Gain (Db)	3-Db RF Bandwidth (Mc)	RF Noise Figure (Db)
13	213	10	10	9
10	195	11	10	8
6	85	16	8	4
3	63	18	7	3

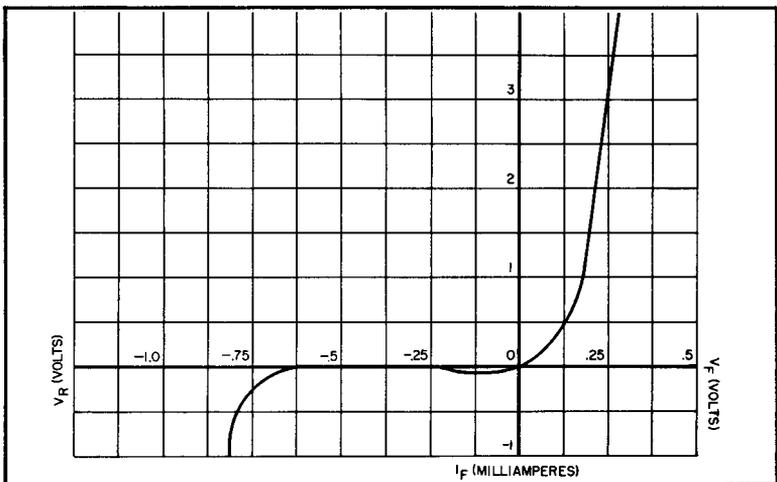
The 45-mc trap in the base circuit of the amplifier is designed to prevent any signal lower than that of Channel 2 from entering the circuit. This improves the rejection of the amplifier.



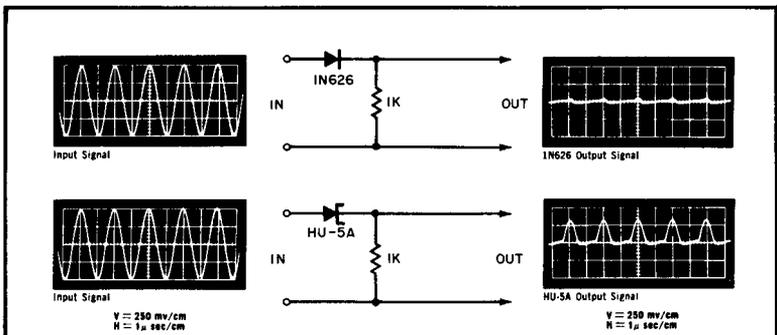
TV/FM tuned RF amplifier.

DIODE CLIPPERS

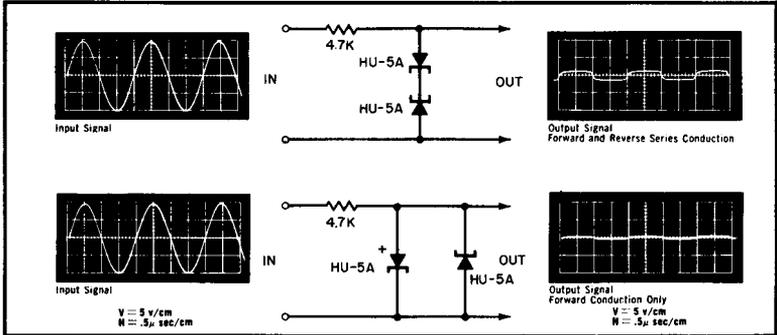
Either the backward or reverse tunnel diode can be used in a clipper and rectifier circuit. Part A of the diagram shows the characteristics of a typical backward diode, and Part B compares the HU-5A *Uni-Tunnel* diode with a 1N626 fast-recovery silicon-junction diode. This comparison is made with a 500-millivolt AC input signal.



(A) Backward-diode characteristics.



(B) HU-5A and 1N626 clippers.



(C) 10-volt peak input clippers.

Diode clippers.

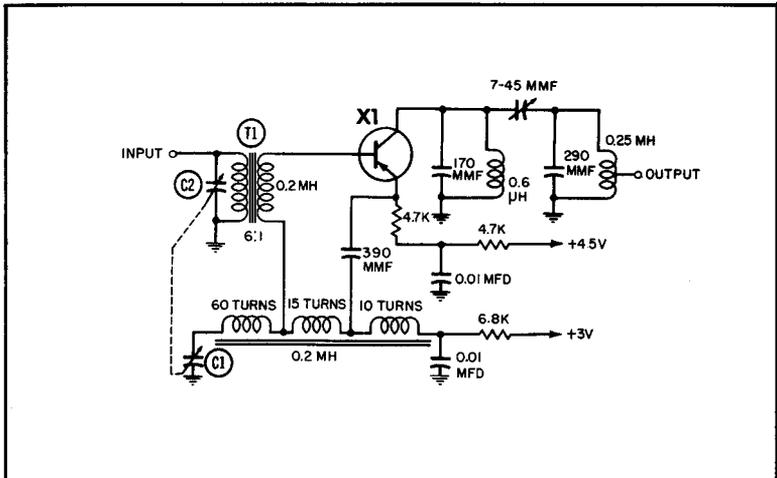
As shown by the output waveforms, the peak rectified voltage across the *Uni-Tunnel* (backward diode) exceeds 250 millivolts, and is far greater than the voltage across the silicon-junction diode. By using a 0.2-mfd capacitor across the 1,000-ohm output load in each circuit, the lower diode will have a DC output of 200 millivolts, whereas the ordinary diode will have an output of only 10.5 millivolts.

A 10-volt peak-input clipping circuit that can be used either to form a square wave or as a limiter is shown in Part C. The output waveforms in the diagram show the circuit action for both the upper and lower circuits.

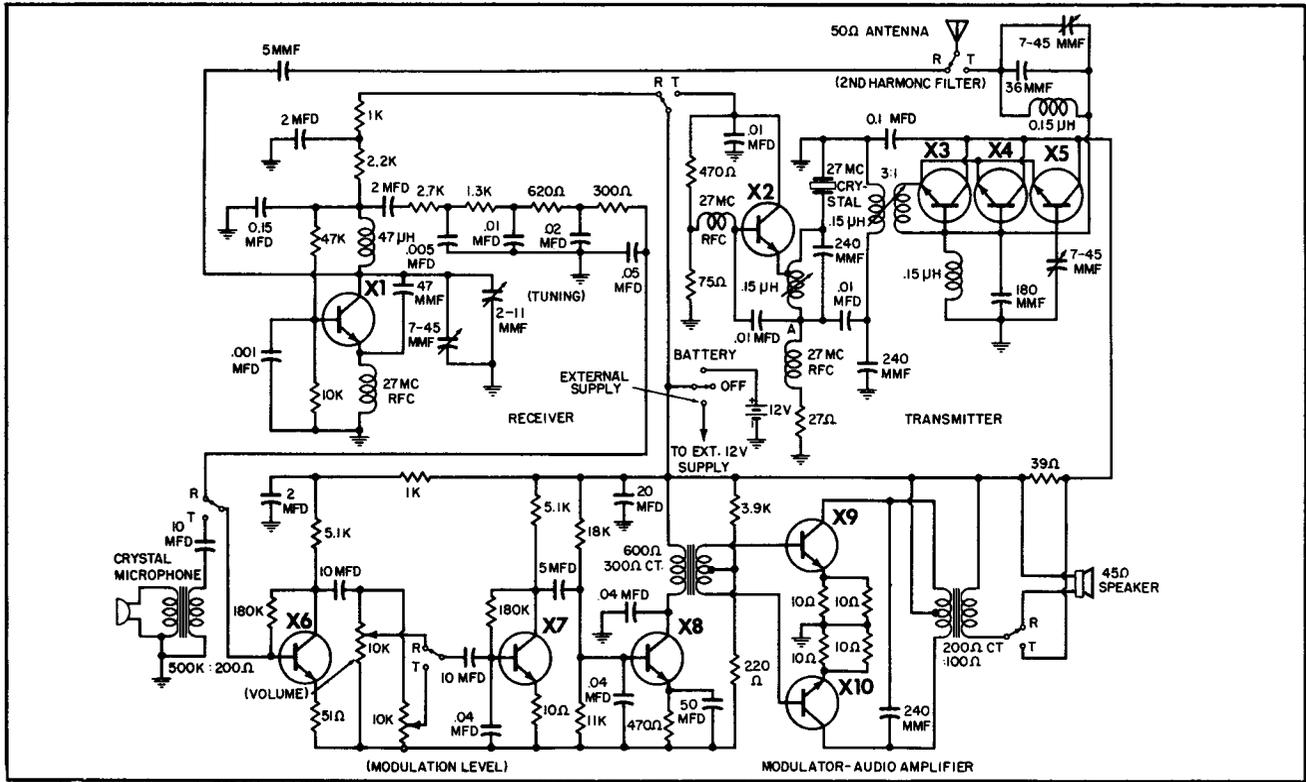
455-KC CONVERTER

This figure shows a broadcast-band IF-converter circuit. The input and local-oscillator signals are mixed at the base-emitter junction, and the collector circuit is tuned to the difference frequency. The collector is thus grounded at the local-oscillator and signal frequencies, and the emitter and base are essentially grounded at the difference frequency. Therefore a gain occurs from emitter to collector. The typical conversion gain of such a stage is 20 db, with a noise figure of 4 db.

Although the circuit performs well at broadcast frequencies, its range of usefulness as a converter extends much further. By employing a microalloy diffused-base transistor (MADT), the complete range of VHF television frequencies can be covered satisfactorily.



455-kc converter.



CITIZENS-BAND TRANSCEIVER

This diagram shows an experimental all-transistor Citizens-band transceiver. This transceiver is *not* intended for use with FCC Part 15 rules (which limit the power output to 100 milliwatts), but rather with regular Class-D CRS rules.

In the receiver arrangement, a superregenerative detector (X1) that provides a sensitivity of approximately two microvolts is used. This detector quenches (goes in and out of self-oscillation) at a 40-kc rate. The low-pass four-section filter in the output circuit removes both the 27-mc and 40-kc components of the output signal, thus allowing only audio to pass. A three-stage audio amplifier feeds a push-pull output. This output uses S-3001 (version of the 2N698) transistors, although many other types of NPN audio transistors will work equally well.

In the transmitting arrangement, the crystal mike is used for modulation, with the level being set by a 10K-ohm pot at the output of the first amplifier. An S-3001 crystal-controlled oscillator, in common-base operation, provides an RF drive of 100 milliwatts to the final. The three final transistors in parallel provide 500 milliwatts of output to the antenna. These finals are operated as common-base amplifiers with collector (high-level) modulation taken from the audio-output transformer.

Either a 12-volt battery or an appropriate external power supply can be used. The transceiver range is about one-half to two miles. Power consumption is about 1.8 watts for the transmit and 350 milliwatts for the receive mode.

(*Note:* This is an experimental unit. It is not licensed and, under current FCC rules, cannot be used without certification.)

Section 16

AM RADIO RECEIVERS

The popularity of pocket-size radios shows how well the transistor has been accepted for entertainment use. Because of their small size, transistors allow designers to make use of many space-saving techniques. The result is a compact circuit with all the features of its counterpart, the tube-type radio.

One such transistor circuit shown here is the autodyne converter—a combination local oscillator, mixer, and first IF stage.

AUTODYNE

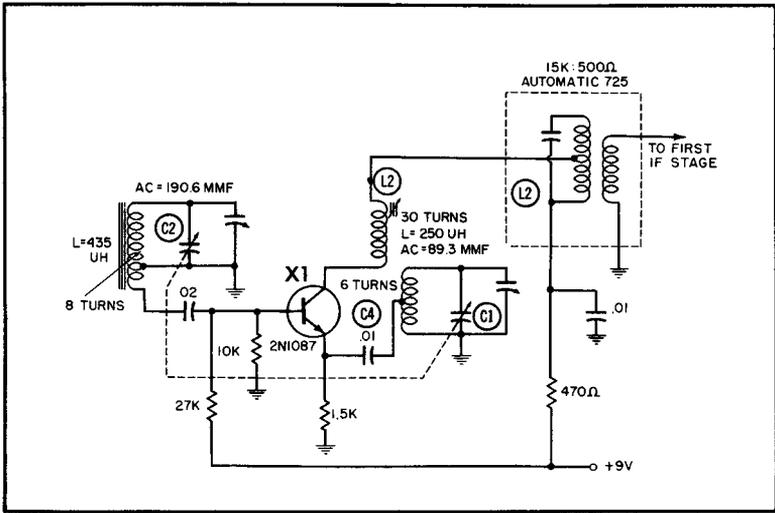
In the oscillator section of Circuit A, random noise produces a slight base-current variation which is subsequently amplified to produce a larger variation in collector current. This alternating current appears in the primary of autotransformer L2 and induces an AC current in the secondary (L2 is tuned to the desired oscillator frequency by C_B). C4 then couples the resonant-frequency signal back to the emitter circuit. If the tickler winding of L2 is properly phased, its feedback will be positive (regenerative) and of the proper magnitude to cause sustained oscillations.

The secondary of L2 provides a proper impedance match between the high-impedance tank circuit of L2 and the relatively low impedance of the emitter circuit.

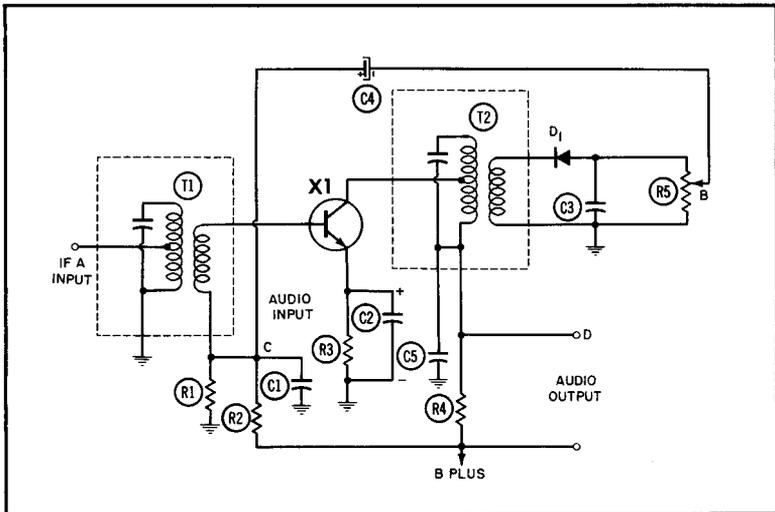
In the mixer action, the ferrite rod antenna is tuned by C2 and the incoming RF is coupled to the base of the 2N1087 transistor. Because of its low bias, this transistor is operating along a non-linear portion of its curve. As a result, the stage mixes the RF and local-oscillator signals, providing an output which consists of both the original frequencies plus both the sum and difference frequencies. The autotransformer in the collector circuit is tuned by its capacitor to only the difference frequency, which is usually the 455-kc IF.

REFLEX

A reflex circuit is one in which two frequencies are amplified by the same stage. For example, it may amplify an IF signal and



(A) Autodyne.



(B) Reflex.

Radio Circuits.

then, after its detection, also amplify the audio modulation. Circuit B shows such an amplifier. The IF is amplified in the usual manner, after which it is detected by the diode. Audio across the volume control is fed to point C through C4.

The secondary of T2 consists of only a few turns of wire. (In essence, it is a short circuit at audio frequencies.) C1 bypasses

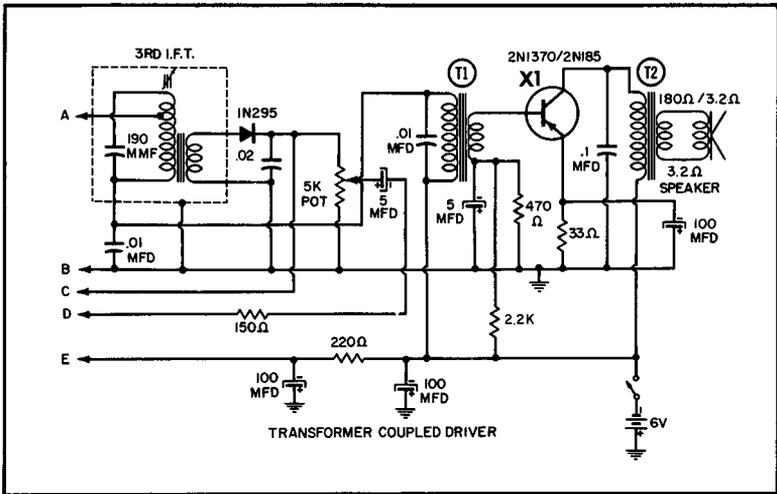
the IF signal otherwise appearing across the parallel combination of R1 and R2. Emitter resistor R3 is bypassed for both audio and IF by electrolytic capacitor C2. After amplification, the audio signal appears across R4. From there it is fed to the audio-output stage. C5 bypasses R4 for IF frequencies.

The advantage of a reflex circuit is that only one stage is needed to produce the necessary gain, instead of two. The savings in cost, space, and battery drain make such a circuit worthwhile. Its disadvantages are that the design is considerably more difficult to produce, and the playthrough (i.e., signal output with volume control at zero setting) is somewhat higher. Also, there is a minimum volume effect, which occurs at slightly higher than zero volume-control setting). At this point, the signal is distorted because the fundamentals from the normal signal balance the out-of-phase playthrough component.

SUPERHETERODYNE

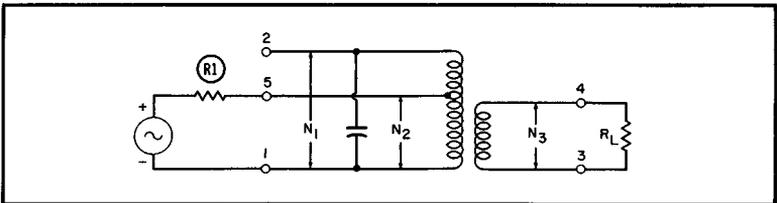
In the superheterodyne receiver, the incoming RF signal is mixed with a high-frequency oscillator signal. The difference (IF) between these two signals is then amplified before being rectified to recover the audio modulation.

Of these three types of receivers (autodyne, reflex, and superheterodyne), the superheterodyne provides the highest selectivity, sensitivity, fidelity, gain, and control. For these reasons it is the most popular design in today's radios.



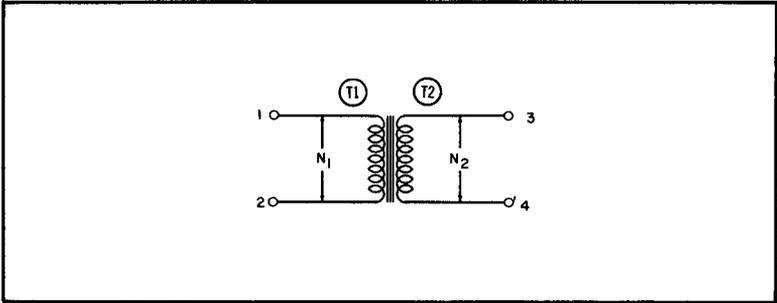
TRANSFORMER COUPLED DRIVER

CHARACTERISTICS	TRANSFORMER COUPLED DRIVER	RESISTANCE COUPLED DRIVER
Rated Power Output at 10% Distortion	35 mw	35 mw
Sensitivity for 5.0-mw Power Output	160 $\mu\text{v}/\text{m}$	380 $\mu\text{v}/\text{m}$
Sensitivity for 35-mw Power Output	280 $\mu\text{v}/\text{m}$	1500 $\mu\text{v}/\text{m}$
Sensitivity for 10-db (S+N)/N	150 $\mu\text{v}/\text{m}$	150 $\mu\text{v}/\text{m}$
RF Overload at 30% 400-cps AM	400 $\text{k}\mu\text{v}/\text{m}$	400 $\text{k}\mu\text{v}/\text{m}$
Modulation Overload at 80% 400-cps AM	200 $\text{k}\mu\text{v}/\text{m}$	200 $\text{k}\mu\text{v}/\text{m}$
AGC Figure of Merit	43 db	43 db
Image Rejection at 600 kc	52 db	52 db
6-db Bandwidth (with 600-kc center frequency)	6.2	6.2 kc
6-db Bandwidth (with 1500-kc center frequency)	9.5	9.5 kc
Current Drain at No Signal	28.0	28.0 ma
Current Drain at 50-mw Power Output	28.0	28.0 ma
Current Drain at Maximum Power Output of 50 mw	27.2	27.2 ma



IF TRANSFORMER DATA

Trans.	Type	Center Tuning Freq.	Turns Ratio $N_1/N_2/N_3$	Pri. Induct.	Tuning Cap.	Q Unloaded	Q Loaded	3-db Band Width	Total Insert. Loss	R_1	R_L
1st IFT	Single	455 Kc	13/3.8/1	0.67 mh	190 μf	63	45.5	10 Kc	12 db	100 K Ω	2.5 K Ω
2nd IFT	Single	455	20/6.1/1	0.67	190	58	45.5	10	14	130 K	1.4 K
3rd IFT	Single	455	4.7/2.0/1	0.67	190	63	10	45.5	11	150 K	1.5 K



AUDIO TRANSFORMER DATA

Transformer	Turns Ratio N_1/N_2	Impedance Ratio	Rated Power Level	Maximum D-C Winding Resistance		Primary Inductance Measured at 150 CPS and Rated Power Level		
				N_1	N_2	Winding	1 dc	L
T 1	1.265/1	$Z_1/Z_2 = 2K\Omega/1.25K\Omega$	1.0 mw	200 Ω	125	N_1	2.0 ma	3.0 hy
T 2	7.5/1	$Z_1/Z_2 = 180/3.2$	35	18	.32	N_1	20	0.2

ANTENNA BAR DATA

I. Ferrite Bar Size

Length 3.68 inches
 Width 0.725 inch
 Thickness 0.125 inch

II. Winding Data

A. Primary

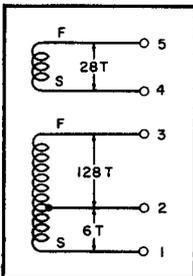
1. Wire size #32 AWG heavy Formvar
2. Length of winding $2\frac{1}{16}$ inches
3. Number of turns 119

B. Secondary

1. Wire size #35 AWG, Gripeze-2
2. Length of winding $\frac{1}{32}$ inch
3. Number of turns 17
4. Method of winding Bifilar with start of primary

III. Electrical Characteristics

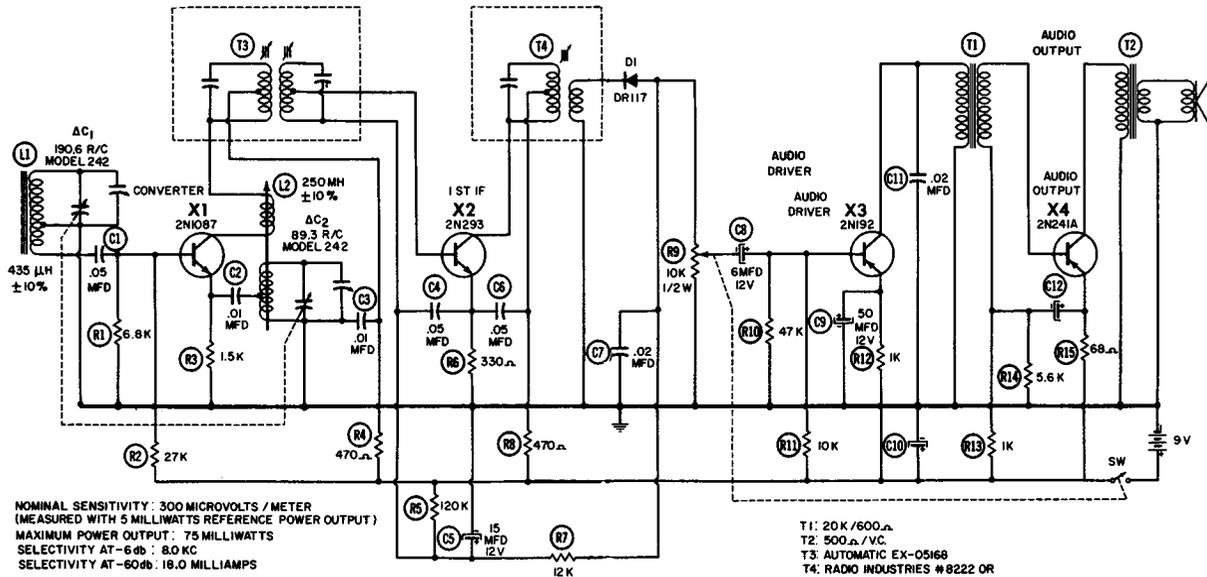
$L_p = 660\mu\text{h}$
 Q unloaded (at 550 kc) = 295
 Q unloaded (at 1000 kc) = 290
 Q loaded (at 1 mc with 5000-ohm load across secondary) ≈ 73
 Coefficient of Coupling, $k \approx 0.60$
 Distributed Capacity, $C_{d1st} \approx 2.0 \mu\text{mf}$
 Output voltage (with $\xi = 0.1\text{v/m}$ and secondary load = 5000 ohms) = 5mv

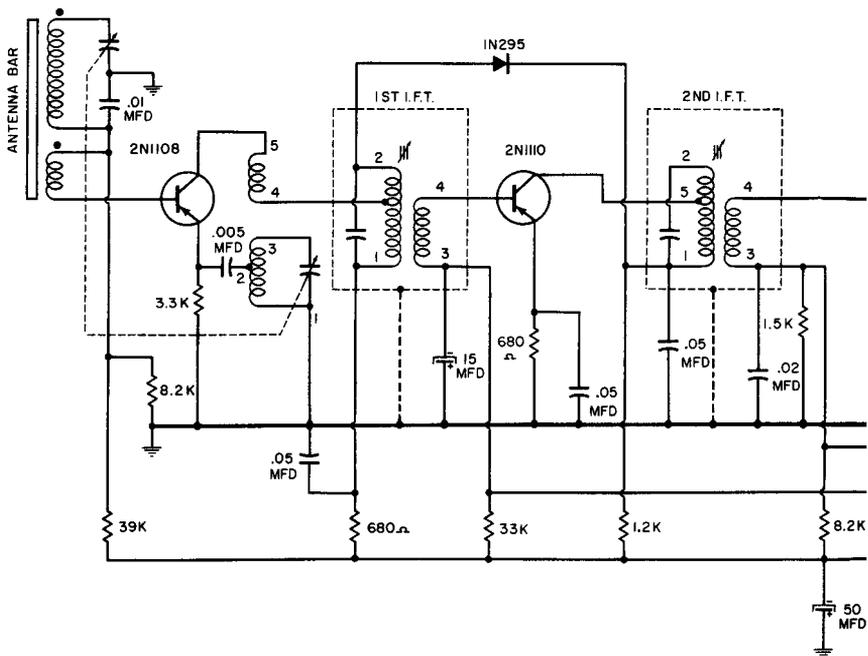


OSCILLATOR COIL DATA

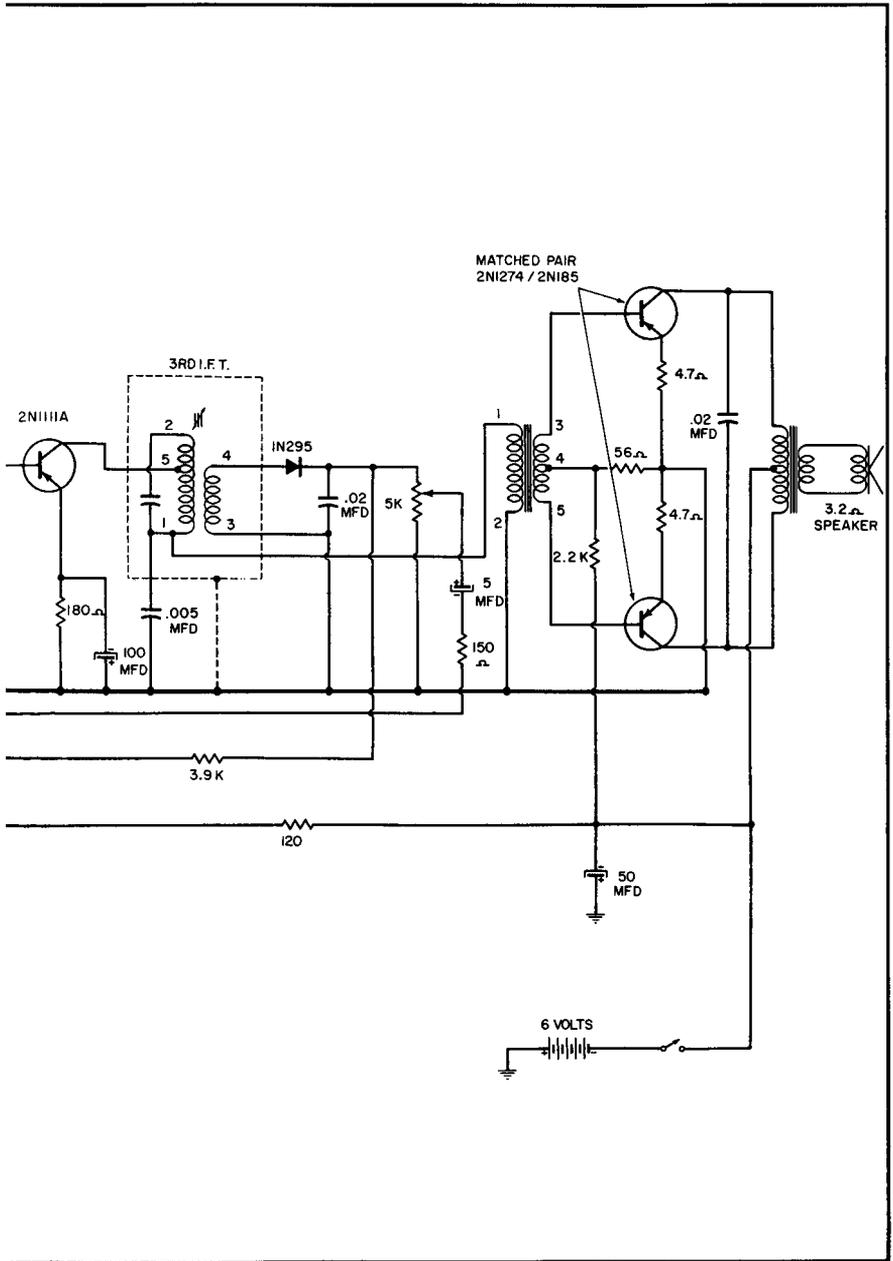
Coil Form EL-RAD #30B801
 Core EL-RAD, Ferrite 21B100
 Base 6 Pin #2B100-1
 Wire #40 AWG, Gripeze-2
 Type Winding 2 Pi
 Spacing between Primary and Secondary 0.1 inch
 Cam Size 0.093 inch
 Gear Ratio 39:41
 Idler Ratio 1:1

Four transistor superheterodyne.



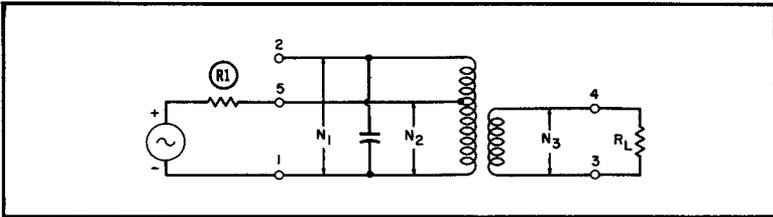


5 Transistor-reflex 6-V Radio



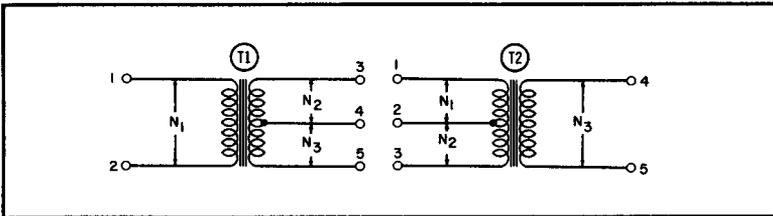
TYPICAL PERFORMANCE CHARACTERISTICS

CHARACTERISTICS	PERFORMANCE
Rated Power Output at 10% Distortion	160 mw
Sensitivity for 50-mw Power Output	150 $\mu\text{V}/\text{m}$
Sensitivity for 150-mw Power Output	380 $\mu\text{V}/\text{m}$
Sensitivity for 10 db (S+N)/N	115 $\mu\text{V}/\text{m}$
RF Overload at 30% 400-cps AM	370 K $\mu\text{V}/\text{m}$
Modulation Overload at 80% 400-cps AM	130 K $\mu\text{V}/\text{m}$
AGC Figure of Merit	54 db
Image Rejection at 600 kc	49 db
6-db Bandwidth (with 600-kc center frequency)	5 kc
6-db Bandwidth (with 1500-kc center frequency)	7.3 kc
Current Drain at No Signal	10 ma
Current Drain at 50-mw Power Output	35 ma
Current Drain at Maximum Power Output of 250 mw	70 ma



IF TRANSFORMER DATA

Trans.	Type	Center Freq.	Turns Ratio $N_1/N_2/N_3$	Prim. Induct.	Tuning Cap.	Q		3-db Band Width	Total Insert. Loss	R_1	R_L
						Unloaded	Loaded				
1st IFT	Single	455 Kc	13/3.4/1	0.64 mh	190 $\mu\text{m}\mu\text{f}$	63	45.5	10 Kc	12 db	100 K Ω	2.5 K Ω
2nd IFT	Single	455	20/3.3/1	0.64	190	58	45.5	10	14	130 K	1.4 K
3rd IFT	Single	455	4.7/2.4/1	0.64	190	63	10	45.5	11	150 K	1.5 K

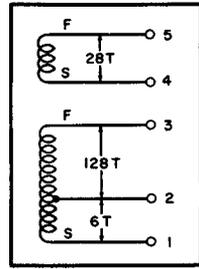


AUDIO TRANSFORMER DATA

Transformer	Turns Ratio $N_1/N_2/N_3$	Impedance Ratio	Rated Power Level	Maximum D-C Winding Resistance			Primary Inductance Measured at 150 CPS and Rated Power Level		
				N_1	N_2	N_3	Winding	I dc	L
T 1	1.92/1/1	$Z_1/Z_2 = 2\text{K}\Omega/543\Omega$	0.6 mw	200 Ω	54 Ω	54 Ω	N_1	2.8 ma	2.5 hy
T 2	4.56/4.56/1	$Z_1/Z_3 = 62.5/3$	150	7	7	0.2	N_1	0	0.06

OSCILLATOR COIL DATA

Coil Form EL-RAD #308801
 Core EL-RAD, Ferrite 21B100
 Base 6 Pin #2B100
 Wire #40 AWG, Gripeze-2
 Type Winding 2 Pi
 Spacing between Primary and Secondary 0.1 inch
 Cam Size 0.093 inch
 Gear Ratio 39:41
 Idler Ratio 1:1



ANTENNA BAR DATA

I. Ferrite Bar Size

Length 3.68 inches
 Width 0.725 inch
 Thickness 0.125 inch

II. Winding Data

A. Primary

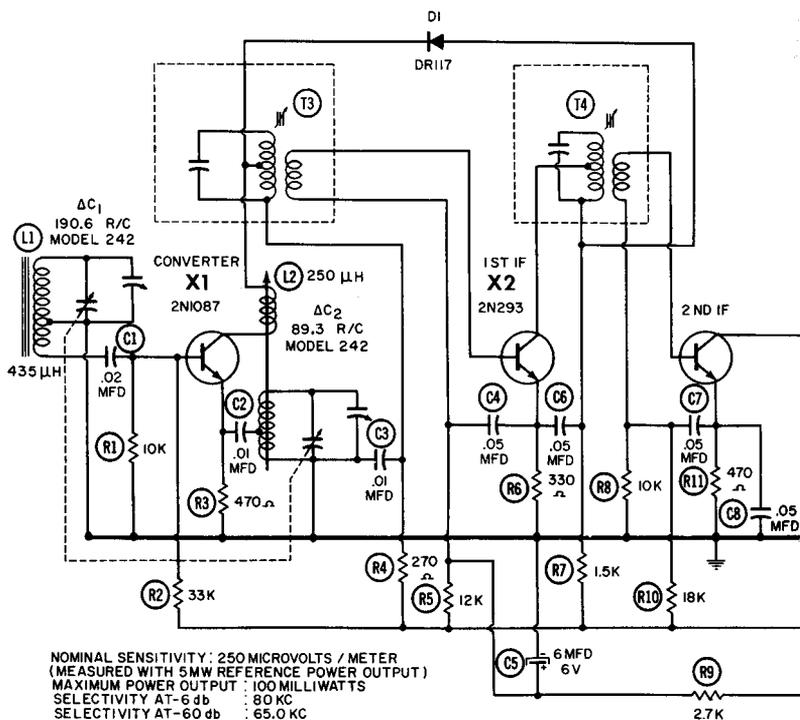
1. Wire size #32 AWG heavy Formvar
 2. Length of winding $2\frac{1}{4}$ inches
 3. Number of turns 119

B. Secondary

1. Wire size #32 AWG, heavy Formvar
 2. Length of winding $\frac{1}{2}$ inch
 3. Number of turns 17
 4. Method of winding Bilflar with start of primary

III. Electrical Characteristics

$L_p = 680 \mu h$
 Q unloaded (at 550 kc) = 295
 Q unloaded (at 1300 kc) = 280
 Q loaded (at 1 mc with 5000-ohm load across secondary) ≈ 73
 Coefficient of Coupling, $k \approx 0.60$
 Distributed Capacity, $C_{dist} \approx 2.0 \mu\mu f$
 Output voltage (with $\xi = 0.1v/m$ and secondary load = 5000 ohms) = 5mv

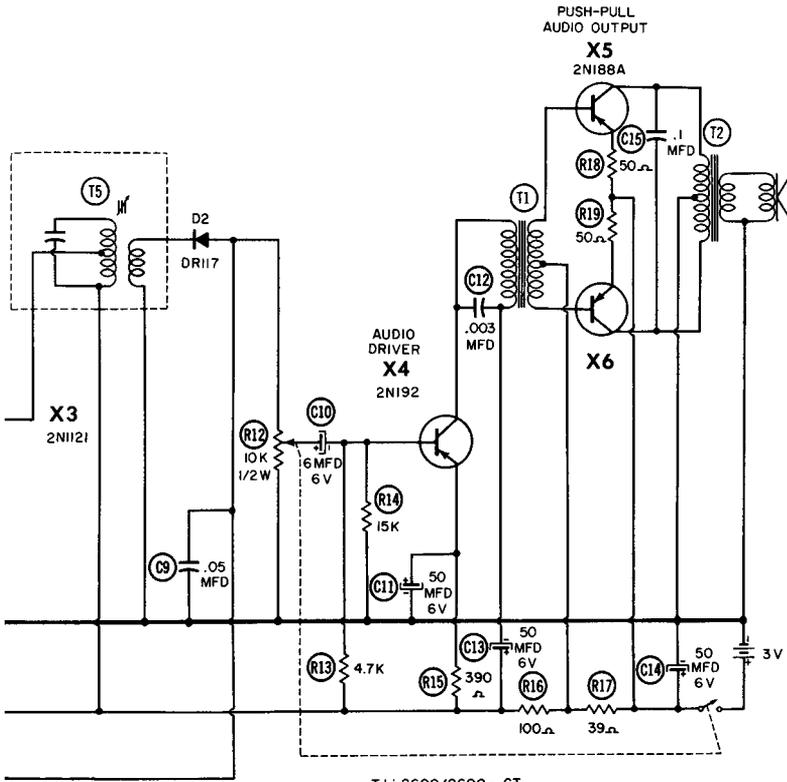


NOMINAL SENSITIVITY: 250 MICROVOLTS / METER
 (MEASURED WITH 5MW REFERENCE POWER OUTPUT)
 MAXIMUM POWER OUTPUT: 100 MILLIWATTS
 SELECTIVITY AT -6 db: 80 KC
 SELECTIVITY AT -60 db: 65.0 KC
 ZERO SIGNAL BATTERY DRAIN: 7.0 MILLIAMPS

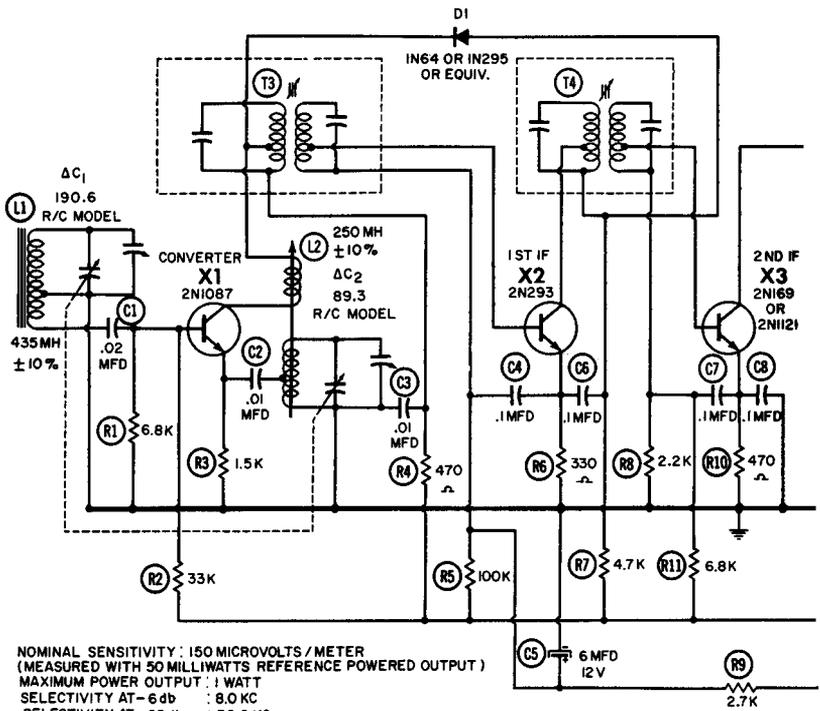
WHERE REQUIRED

AUDIO TRANSFORMERS - 1 5/8 BY 1 3/8 BY 1/2 INCH STACK
 OSCILLATOR COIL - ED STANWYCK 1265
 VARIABLE CAPACITOR - RADIO CONDENSER 242

Six transistor, 3-volt superheterodyne.

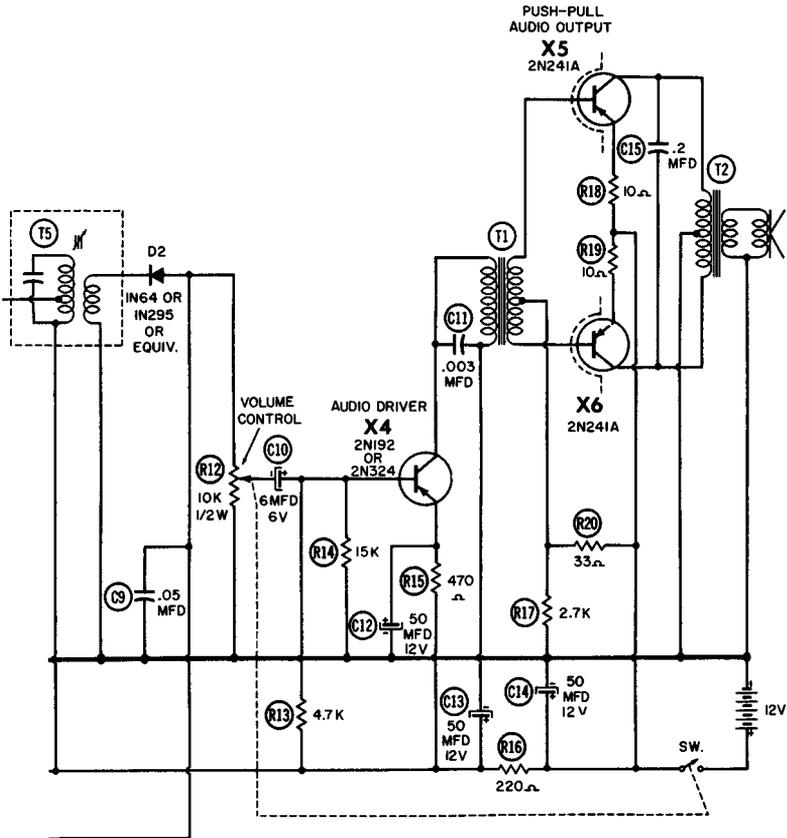


- T1: 2600/2600Ω CT
 T2: 300Ω CT/V.C.
 T3: RADIO INDUSTRIES # 8222 OR AUTOMATIC BS725G
 T4: RADIO INDUSTRIES # 8222 OR AUTOMATIC BS725G
 T5: RADIO INDUSTRIES # 8223 OR AUTOMATIC BS614G



NOMINAL SENSITIVITY: 150 MICROVOLTS / METER
 (MEASURED WITH 50 MILLIWATTS REFERENCE POWERED OUTPUT)
 MAXIMUM POWER OUTPUT: 1 WATT
 SELECTIVITY AT -6db : 8.0 KC
 SELECTIVITY AT -60db : 38.0 KC
 ZERO SIGNAL BATTERY DRAIN: 10 MILLIAMPS

Six transistor, 12-volt superheterodyne.



- T1 : 2000 / 2600 CT.
- T2 : 200Ω CT / VC
- T3 : AUTOMATIC EXO-5460
- T4 : AUTOMATIC EXO-5460
- T5 : RADIO INDUSTRIES # 8223 OR
AUTOMATIC EXO-3015 OR BS614G

WHERE REQUIRED
 AUDIO TRANSFORMERS - 1 5/8 BY 1 3/8 BY 1/3. 2 INCH STACK
 OSCILLATOR COIL - ED STANWYCK 1265
 VARIABLE CAPACITOR - RADIO CONDENSER 242

Section 17

SPECIAL CIRCUITS

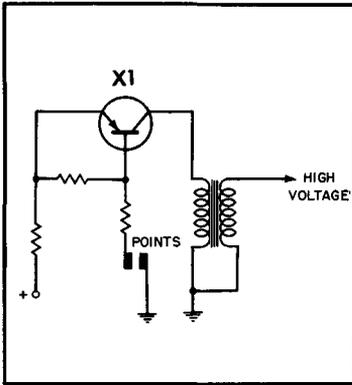
Some circuits which do not fall into the earlier groups are included here. These are general but not related applications of transistors and diodes.

Ignition systems are an example; transistorized ignition systems for cars and trucks are surely just a matter of time. They offer longer life for the points in the internal-combustion engine; points have been and continue to be a weak link in today's high-performance automobiles. Transistor ignition will increase the reliability and efficiency of tomorrow's cars.

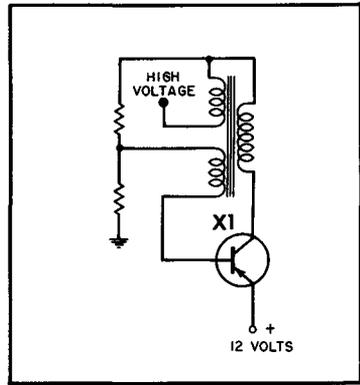
TRANSISTOR IGNITION SYSTEMS

From the first automobile ignition system designed, pitting and poor voltage output at high speeds have been a problem. The heavy current across the points causes wear and surface erosion, both of which mean the points require periodic replacement. Also, the voltage output drops sharply at high speeds when the points are worn, causing incomplete combustion and consequent waste of fuel.

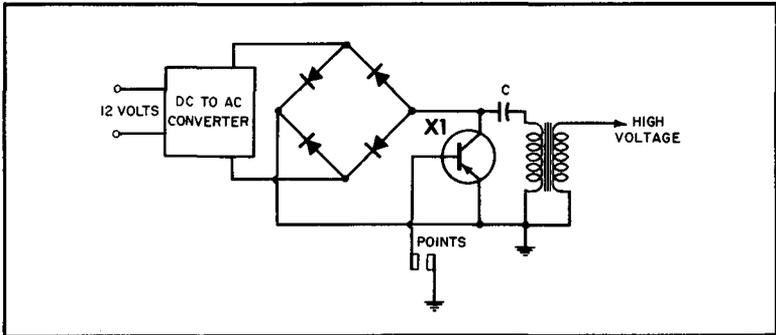
Although electronic ignition systems using tubes have been a possibility for a long time, only the transistor has made possible a rugged, efficient system with no filament warm-up necessary. Three techniques are possible for using transistors and diodes in automotive ignition systems. (1) As shown in Part A of the diagram, primary-current switching can be used in a conventional system, where the transistor switch handles much larger currents than the breaker points. (2) Capacitor energy storage is another good ignition system. It comprises a transistor switch in series with the points, to discharge the capacitor in order to fire the spark plugs. (3) A transistor oscillator is used here to produce continuous or keyed pulses for the spark. All three circuits give a better performance than conventional systems.



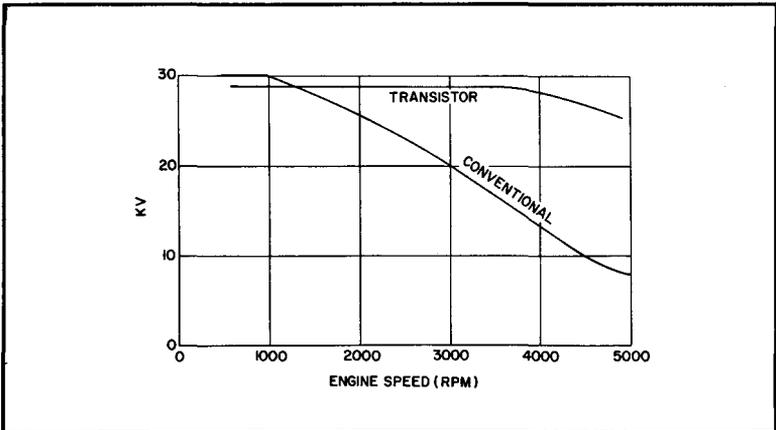
(A) Conventional system.



(C) Using capacitive energy.



(B) Transistor switching.



(D) Blocking oscillator.

Transistor ignition systems.

An auto ignition system requires a properly timed spark of 15 to 35 kilovolts, with a peak spark power of about 900 watts. All three of these transistorized systems can meet these requirements, despite even a wide variation in battery voltage.

Transistor Switching

In the ordinary automotive ignition system the crankshaft, through gears, drives a cam which opens and closes the breaker points. When the points close, the primary current builds up to maximum. When the points open, the collapse of this magnetic field appears across the ignition-coil secondary as a high voltage. A capacitor across the points reduces the arcing and provides a low-impedance path for the current flow. But with the transistor in the circuit, the breaker points carry only 5% of the current, since the points are in the base circuit. The lower current flow across the breaker points will increase their life and reduce maintenance considerably.

After the breaker points open, a large reverse voltage appears across the primary coil and across the transistor. With a conventional 12-volt coil having a turns ratio of 1:100, 300 volts could be developed across the transistor at maximum output. This is the same high voltage that causes arcing and pitting of contacts in conventional systems, and the transistor can be damaged unless some protection is provided. One method is to install a zener diode across the transistor terminals. A higher turns ratio (perhaps 1,000-to-1) can then be used for the transformer. Thus, the voltage across the transistor will be reduced while still providing the required high-voltage output.

One marked advantage of transistor ignition systems can be seen from the graph in Part B. The available output-voltage-versus-engine-speed curve is quite flat for a transistor system. By contrast, in the conventional system the output voltage drops off at higher speeds, since the current build-up is slower. Hence, when the points close, the current flow is not maximum. The result is poorer circuit efficiency.

Capacitive Energy

Although the usual ignition system uses inductive energy, it is possible to design systems in which the energy is stored in a capacitor. This type of system, although complex, is very effective.

As shown in Part C, the 12-volt supply is amplified by a DC-to-AC converter. A bridge circuit of four diodes produces a DC output of about 300 volts used for charging the capacitor. When the transistor base circuit is completed through the points, the transistor acts as a switch so that the storage capacitor will discharge

through the coil and produce the required high voltage. Protection for this transistor from high-voltage transients (and the bridge high voltage) can be provided by zener diodes or several transistors in series (or both). In this type of circuit there are two choices—either the points can do the triggering, or a rotating magnet can be used to induce pulses in a coil and these pulses then amplified for switching purposes.

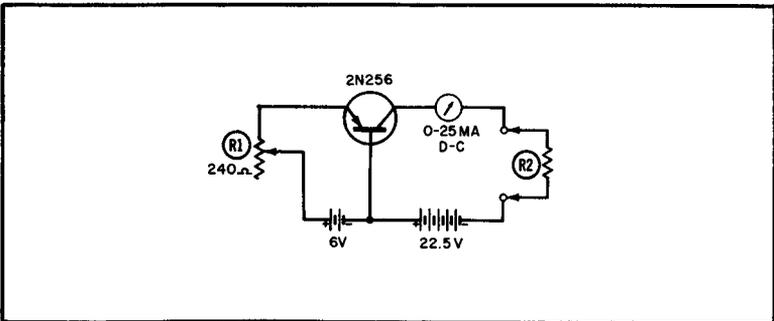
Transistor Oscillators

In the third system, a blocking oscillator can be used as shown in Part D. Here there are two possibilities—a continuous output can be obtained and used for spark, or the circuit can be made to oscillate only as required. With ferrite cores used in the transformer, frequencies beyond 20 kc are possible. Much lower frequencies can be obtained by using other core materials. This transistor also requires protection from high voltages.

METER PROTECTION CIRCUIT

When a DC milliammeter or an ammeter is connected into a circuit to measure an unknown current, the meter movement must be protected from damage. A 2N256 power transistor is ideal for this purpose, as shown in the circuit.

R2 is the unknown impedance through which the current is to be measured and across which the voltage is to be held to 22.5 volts. The current is indicated by meter M. The emitter is supplied from the 6-volt battery and adjusted by resistor R1 to the highest current the meter can withstand (in this case, 25 milliamperes). Meters for higher currents may be used, up to the 3-ampere maximum rating of the transistor, provided the power-dissipation rating of the transistor is not exceeded.



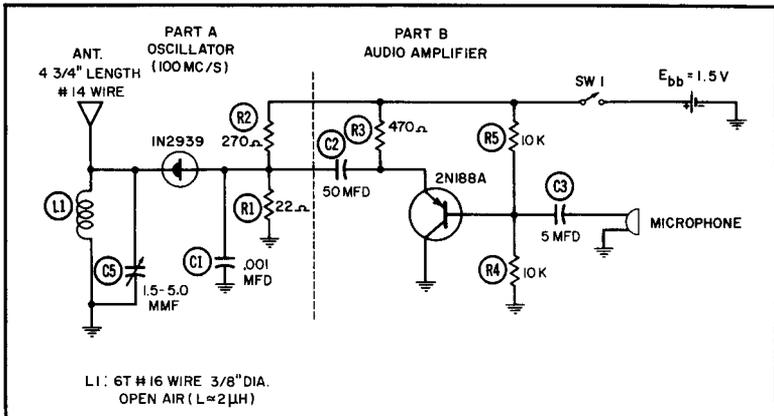
Meter protection circuit.

TUNNEL-DIODE FM TRANSMITTER

Its negative-resistance characteristic makes the tunnel diode ideal for use as an oscillator in the FM transmitter. Part A of the diagram shows a basic tunnel-diode oscillator. Its frequency is determined primarily by the LC components in the cathode circuit. Voltage divider R1-R2 provides a stable low-impedance voltage of about 150 mv for the anode, and capacitor C1 is used as the anode RF bypass.

Part B shows a transistor emitter-follower stage used to amplify the audio input from the microphone. Amplified audio is fed, through capacitor C2, to the tunnel-diode anode. Modulated FM is obtained in the antenna circuit as the audio signal instantaneously alternates the anode bias. For a tunnel diode, the characteristic curve is not perfectly linear in the negative-resistance region. This causes the negative conductance to change slightly with the bias. FM deviations of ± 75 kc are possible from this circuit.

This FM transmitter can be used as a wireless portable microphone. With an average FM receiver having a sensitivity of 10 μ v, an operating range in excess of 100 feet can be obtained.

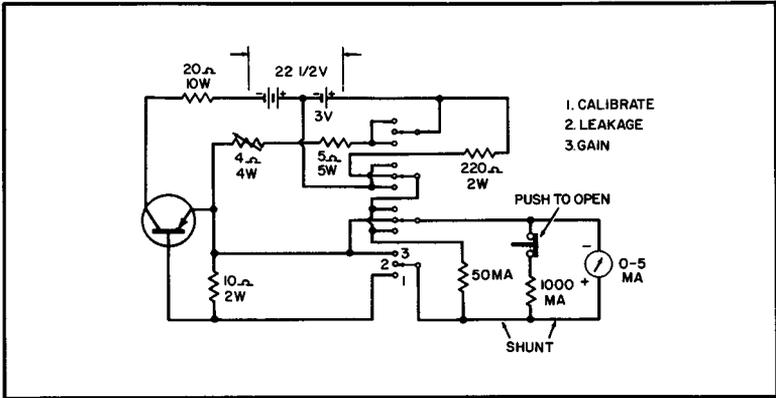


Tunnel-diode transmitter.

TRANSISTOR TESTERS

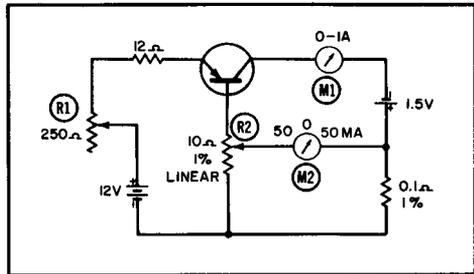
This diagram shows two circuits used for transistor testing. Part A depicts a circuit for testing power transistors. It will reveal all combinations of opens, shorts, leakage, and voltage breakdown, plus power gain as simulated by a DC test.

There are three switch positions: Leakage, Power Gain, and Calibrate. A spring return normally keeps the switch in the Leakage position. In the Calibrate position, the Calibrate knob is



(A) Power transistor tester.

Transistor testers.



(B) Beta tester for power transistor.

adjusted until the meter reads 2 (400 ma). If this is impossible, replace the battery. (Do not push the button.) In the Leakage position, a reading greater than 0.1 (20 ma) indicates a C-B, C-E, or C-B-E short. If the reading is less than 0.1, push the button. A new reading greater than 2 (2 ma) means excessive leakage. Creeping upscale is definitely leakage.

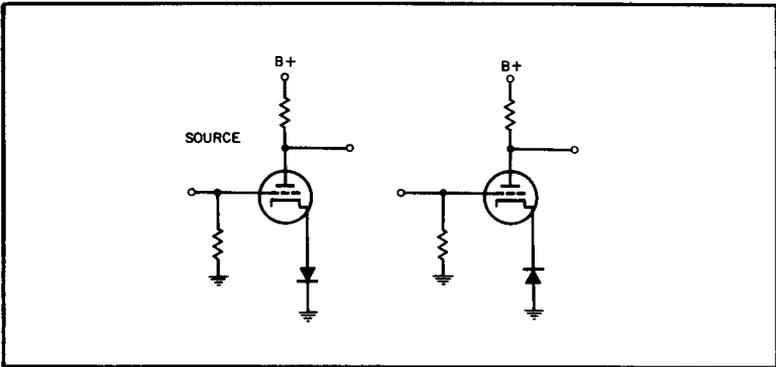
In the Gain position, a reading greater than 0.5 (100 ma) is a B-E short or any open. If the reading is below 0.5 (10 ma), there is a C-B, C-E, or C-B-E short. A reading of 2.2 (44 ma) indicates an available power gain of 30 db. Higher readings indicate lower power gains.

Part B shows a *beta* tester for power transistors. A PNP power transistor such as the 2N255 or 2N256 is plugged into the test socket. R1 is adjusted for the desired collector current (such as 0.5 ampere) as read on meter M1. Then R2 is adjusted for zero current on meter M2. R2 has a dial scale of 0-100 divisions on which *beta* is read directly.

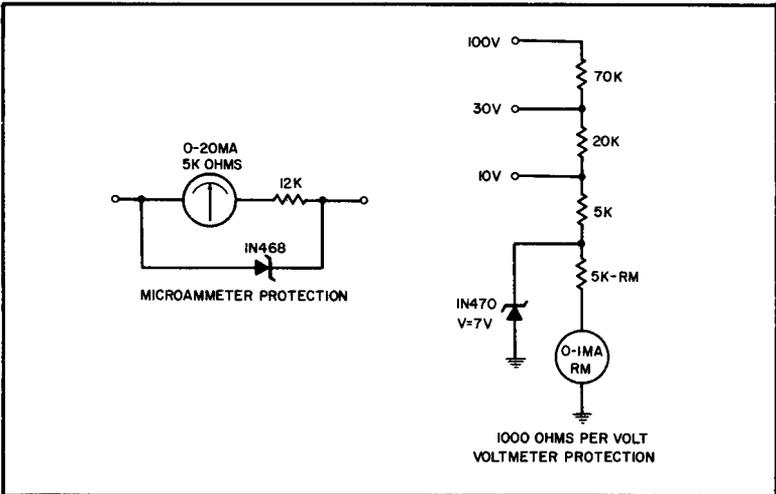
NPN power transistor may be tested by reversing the battery polarities and the connections to meter M1.

DIODE PROTECTIVE CIRCUITS

A low feedback bias can be obtained in vacuum-tube circuitry by using a silicon-junction diode such as the 1N465-1N470 in series with the cathode to provide a self-bias cathode voltage. The loss in small-signal gain of the vacuum-tube stage will be slight when a diode is used for cathode bias, because the circuit dynamic impedance is now much less than the static resistance. In amplifiers (which must have a flat response down to very low frequencies), the use of silicon junction diodes as bias elements will eliminate the need for large bypass capacitors.



(A) Series diode circuit.



(B) Zener diode circuit.

Diode protective circuits.

One or more diodes may be used in series in the forward direction, as shown in Part A of the diagram. However, at higher bias levels it may be more desirable to use a single diode in the zener region, as shown in Part B.

Meter protection is another use for the diode. Both the forward and the reverse characteristics of low-voltage silicon junction diodes can be used to protect electrical instruments from accidental overloads. In order to protect microammeters, it is usually necessary to add external series resistance until the voltage drop across the meter and resistor is approximately 0.4 volt when full-scale current is flowing. At 25°C., a silicon junction diode like the 1N468 will pass only one microampere or so at a forward voltage of 0.4 volt. This means that if the diode is connected in parallel with the meter plus an external resistor, negligible meter error will result at full scale or less. Yet the meter movement will be overloaded by only a factor of two or three, even by current overloads as high as 200 to 300 milliamperes.

Voltmeters with a range of 0.5 to 1.0 volt can be protected by using the forward characteristic of a diode. For higher-voltage instruments, however, very sharp protection can be realized by using a sharp breaking zener characteristic, such as can be found in a 1N470 and 1N200.

LAMP DIMMER

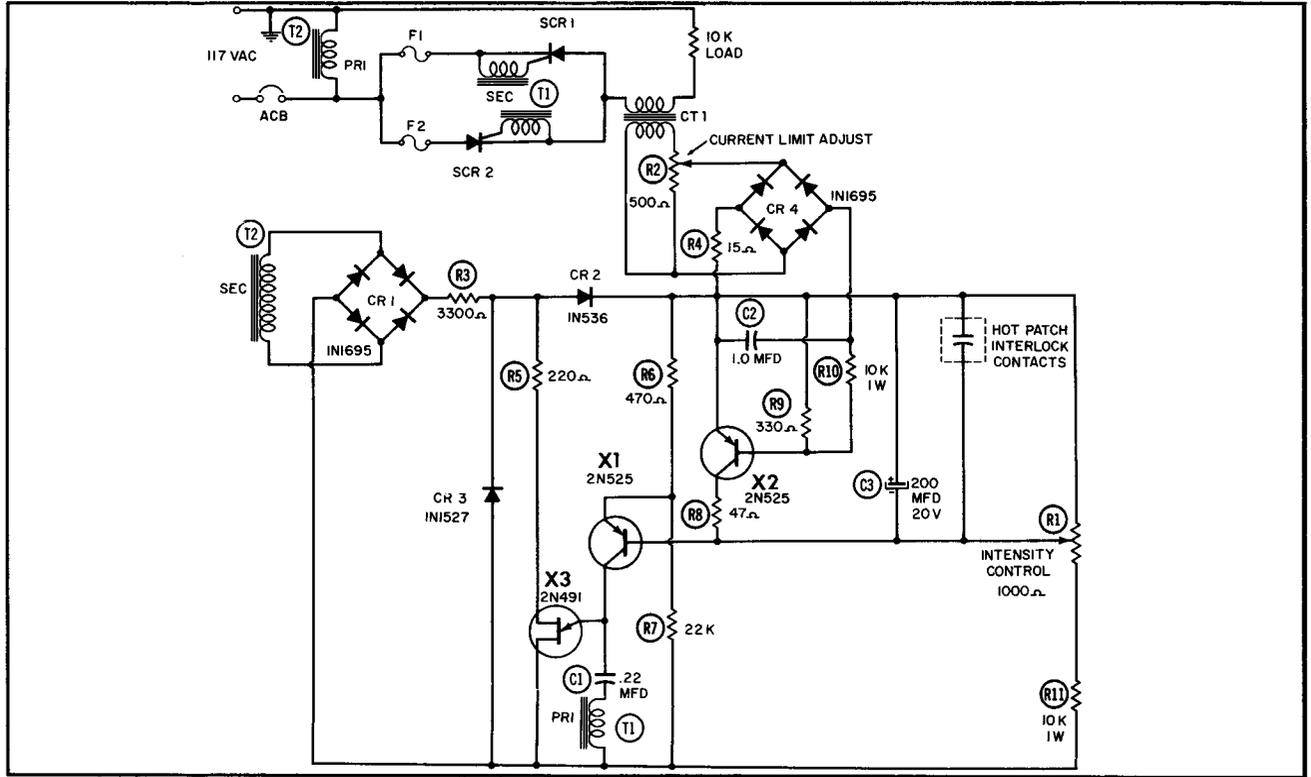
This circuit uses a pair of C-60B silicon-controlled rectifiers (SCR's) to control a 10-kw load of incandescent lighting. Protection against large surge currents is required because of the low resistance and high current of the lamp load. Here, X1 is used to control unijunction X3.

The two back-to-back SCR's control the current through the load, and the rest of the circuit is used to control the SCR's themselves. Intensity control R1 determines the base drive for transistor X1. In the current-limiting circuit, X2 provides overriding control and is driven, through CT1, by the current in the load.

R2 sets a limit beyond which X2 will conduct and reduce the base potential of X1. This bias reduces the collector current of X1 and (through the SCR) the voltage applied to the load. The time constants of the control circuit give a response of one half-cycle of line frequency.

Assume the circuit is energized with full output (R1 setting minimum). Delay capacitor C3 will cause the firing angle of both SCR's to advance from maximum phase retard to full output. This will occur over several cycles of line frequency. When the load exceeds the peak-current limit of one cycle during this starting

10-kw lamp dimmer.
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sequence, transistor X2 will take over and keep the SCR firing angle retarded until the load resistance approaches its steady-state value.

Control R2 is set for the maximum allowable peak current rating of the SCR's. This permits the SCR's to be safely used at their maximum rated junction temperature in order to bring the load quickly to full output.

A mechanical patch interlock is provided in case an additional load is plugged in while the circuit is energized. When momentarily closed, this interlock discharges C3 and reinitiates the starting sequence. With the interlock mounted as an integral part of the plugging arrangement, the delay circuit will be reset every time a load is added. This will allow maximum long-term reliability by holding recurring peak currents through the SCR's to the rated values.