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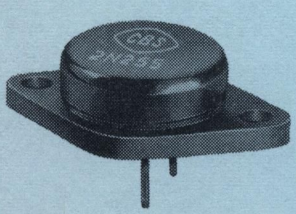
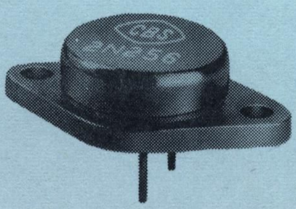
transistor power supplies





by bud tomer

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A DIVISION OF COLUMBIA BROADCASTING SYSTEM, INC.

TRANSISTOR POWER SUPPLIES

By Bud Tomer

Recent developments in the power transistor field have made possible the design of practical, all semiconductor circuits which are efficient and rugged converters of low-voltage D. C. to high-voltage A. C. or D. C. power. These transistorized power supplies, as they are sometimes called, have no vacuum tubes, no moving parts, are very compact, and can be designed with efficiencies which approach 90%. They are instant starting, completely silent in their operation and, in most cases, are easy to filter. They are ideally suited for powering all kinds of battery operated equipment, such as mobile communication systems, aircraft and marine navigational systems, and all other forms of portable apparatus requiring high voltage from a low-voltage D. C. source.

In the past, D.C. conversion has been mainly accomplished by vibrators or dynamotors. These mechanical systems, while still in extensive use in all forms of portable and mobile equipment, have several inherent limitations. Both of these devices have relatively short service life and must be continuously maintained with respect to contacts, brushes, bearings, etc. Both of these systems are susceptible to shock and vibrations, and have problems of ventilation and heat removal. Finally, the make and break nature of the interruption of the D.C. current made by both of these systems gives rise to electrical interference which is sometimes quite difficult to eliminate.

The use of transistors as the switching elements to interrupt the D. C. current eliminates the drawbacks of the previously discussed mechanical systems. This type of converter consists basically of a self-oscillating system which provides both the switching signal as well as the primary power to the load.

Transistors used in this manner replace the usual mechanical elements which enable the system to withstand severe shock or vibrational conditions. Because of the elimination of mechanical friction and metal fatigue, life expectancies are greatly extended and are limited almost entirely to that of the components used. With conservative design and usage, there appears to be no reason why their life should not be indefinitely long.

The fundamental circuit for the transistor converter is shown in Figure 1. Current flows in one collector circuit in excess of that flowing in the other collector circuit, as soon as the battery is connected, due to the inevitable dissimilarity of the two transistors. This asymmetrical flow of current through one-half of the primary winding of T_1 will induce a current in the other half of this winding which is so polarized as to bias the conducting unit into greater conduction when it is applied through a suitable resistor to the base of that transistor. Likewise, by connecting the out-of-phase signal from the conducting transistor to the base of the non-conducting unit, this unit is held in cut-off.

The action is regenerative and continues until the transformer saturates and can no longer provide the drive signal to maintain the rising collector current. At this moment, the currents reverse and the conducting unit is cut off, while the nonconducting unit is driven into conduction. The resulting waveform is essentially square, with a repetition rate which is dependent upon E, the primary inductance of the transformer, and upon the peak collector current drawn by the conducting transistor. Changes in transformer turns, core area, core material and feedback current will all have an effect upon frequency. Experimental units have operated in the range from 60 cycles to 3500 cycles. There are reports which indicate that both higher and lower frequencies of operation are practical.

Due to the large mismatch which exists between the collector winding and the base input impedance, necessitating the use of fairly large dropping resistors in series with the base connections with subsequent large power losses, this elementary circuit is rarely used in practical designs.

Figure 2 shows a more representative form of converter circuit. A third winding has been added, permitting the magnitude of the out-of-phase signal fed back to the individual base terminals to be controlled. All windings are on a single ferrite, or iron core. The primary, or collector winding, will consist of 100 turns or less, of fairly heavy wire, center tapped. The feedback winding is designed to have a step-down ratio from the collector winding, typical ratios being 5 or 10:1.

The output winding, which is connected to the load, steps up the voltage of the primary to that value required by the load. Turns ratio for a given output voltage is calculated on the basis of the voltage across one-half of the primary being equal to almost exactly E. Thus the turns ratio, total primary to total secondary, will be $1/2 \frac{E_o}{E}$, where E_o is the output voltage and E is the primary supply voltage.

In all instances where P-N-P transistors are shown, N-P-N devices can also be used, provided the proper polarity reversals are made. Maximum efficiency and power output can only be obtained when transistors capable of maintaining a high Alpha, even at values of emitter current of several amperes, are used. CBS 2N155, 2N156, 2N255 and 2N256 are such devices.

Maximum power output is defined as that load power which causes the oscillator to stop. Maximum power output of the oscillator depends upon the driving voltage across the feedback winding and on the battery voltage E. This voltage should not exceed 1/2 the maximum D.C. collector voltage rating. Since switching transients are present, which may exceed this rating and damage the transistor, caution should be exercised to see that the peak-to-peak instantaneous voltage across 1/2 of the collector winding never exceeds the transistor's maximum collector to base rating. Since the actual collector-to-base voltage will be the voltage appearing across 1/2 the primary minus the voltage appearing across 1/2 the feedback winding, the use of the above rule will result in conservative designs. Precautions should be taken to see that maximum collector current, maximum base current and maximum junction temperature ratings, as shown in the manufacturers' data for the transistors used, are never exceeded under any condition of load or battery voltage.

With a given feedback winding design, the power output will vary roughly as the square of any change in E. If provision is made to reduce or increase the feedback winding in proportion to the change in E, then the power output can be made to be roughly proportional to E. Thus, an oscillator capable of delivering 50 watts at E = 24 volts can be made to deliver 25 watts at E = 12 volts by a 2/1 reduction in the feedback winding. However, if the turns ratio is left unchanged, the maximum power output will be slightly more than 6 watts.

The power consumed by the transistors will be practically independent of the load. When the oscillator is loaded, an increase in input power takes place which is sufficient to supply the load plus the added losses in the transformer windings. For this reason, the efficiency of these devices increases with load and is greatest at maximum load, being of the order of 75%, and least at minimum load, where it may be as low as 40%. An increase in load, therefore, produces very little extra heating of the transistors. Because of this fact transistor converters have an additional safety feature in that a shorted load will not burn out the transistors or the transformer.

Transistor converters in their simplest form have one impractical aspect. They may fail to start under load. To overcome this limitation, various circuits have been devised and described elsewhere. The simplest of these is that shown in Figure 2, and consists of two resistors, R_1 and R_2. R_2 is usually of the order of 1 to 10 ohms, while R_1 is adjusted so that E/R_2 is of the order of 100 ma.

The current drawn from the battery by this resistor arrangement flows through R_1 and then divides between R_2 and the input resistances of the two transistors. The current flowing in the emitter base circuit of each transistor depends upon its input resistance. The induced voltage across the feedback winding of the transformer is a square wave of such polarity that it forward biases the emitter-base diode of the transistor which is starting to conduct and reverse biases the other transistor. The forward biased transistor will have a very low input resistance while the input resistance of the reverse biased transistor will be quite high. Thus, most of the starting current drained from the battery will flow through R_2 and the base emitter circuit of the forward biased transistor. It is evident that R_2 must not be low in comparison to the input resistance of the conducting transistor, or it will shunt too much current from the transistors.

These resistors provide additional current to the transistor which starts to conduct first and this insures that the oscillator will start, even under full load. When the transformer saturates and the polarities reverse, this additional current switches also and flows in the emitter-base circuit of the other transistor.

The use of these resistors also provides a convenient method for adjusting power output of certain low alpha transistors in a production design without the necessity of changing the feedback winding turns ratio. This makes allowance for unavoidable variations which will occur between transistors of various manufacturers, or from large production runs.

The use of this resistor network has little effect on the full load efficiency of the power supply. They will raise the low load circuit efficiency as much as 10 to 20%, however. This results from the fact that each transistor is supplied driving power, both from the voltage across the feedback winding as well as from the current through R_1. During the conducting cycle, the transistor emitter-base impedance is changing, being at first very low and becoming quite high. The use of the biasing resistors results in a more uniform base current which, in turn, results in a distribution of collector current in such a manner that the transistor dissipation is reduced.

All of the circuits shown can be adapted to grounded collector usage by suitably connecting the collectors to the ground point, reversing the battery so that its negative terminal is grounded and connecting the emitters to the primary winding. The feedback winding remains connected to the individual base connections and the same values of biasing resistor are applicable. Transformer turns ratios have to be altered so that the feedback winding has a 1/1 or a slight step-up ratio with respect to the primary, or what in this application is the emitter winding.

A specific variation on the basic circuit is that shown in Figure 3. T_1 is similar to those transformers already described except that there are only two windings. Feedback is provided by a second transformer T_2 which is connected across the secondary of T_1, and is so polarized as to provide the proper phase relationships to sustain oscillations. Because of the low impedance into which T_2 is working, it need have only a relatively small core and few turns. This arrangement, while somewhat less economical of space and weight, does provide considerable flexibility in the choice of feedback ratios. In experimental set-ups, this circuit permits the use of stock transformers without the need for altering windings. For instance, a 6.3 volt center-tapped filament transformer can be used for T_1 on a 6-volt system, while a multitap output transformer or low-power modulation transformer having a variety of turns ratio combinations to choose from can be used for T_2. The output voltage of such a system will be approximately 225 volts with the transformers suggested, or may be any other value provided transformers having the right turns ratios are available. The use of biasing resistors as previously described will insure starting under load.

A modification of the circuit shown in Figure 3 is shown in Figure 4. This arrangement permits more uniform operating efficiency by providing current feedback from the load which is proportional to the load and, therefore, capable of driving the transistor base circuits in proportion to the load requirements. T_1 and T_2 are essentially the same as those shown in Figure 3. Due to the increased feedback current, which results from the load current passing through T_2, R_1 can be increased in size considerably so as to draw less current. One disadvantage of this circuit is that it is not short-circuit safe since a dead short across the load will not stop the oscillator.

A final variation on the basic circuits, and one which provides almost flat regulation of the output, is that shown in Figure 5. The use of an additional transistor which draws its reference current from the load to regulate the drive for the oscillating transistors, permits very close control over the operating efficiency under all load conditions from full load to no load. R_3 is in series with the load and should be small compared with the load resistance. R_4 regulates the bias current to the third transistor and thus determines the sensitivity of the D.C. feedback circuit. Since the additional transistor is used in place of R_2 in the biasing network, R_4 should be adjusted until the same base current flows in the oscillator circuit at full load as in the circuit shown in Figure 2. At no load the bias current will be automatically reduced by the action of the third transistor which becomes virtually cutoff as the drop across R_3 is reduced to zero.

The .1 mfd capacitor shown in all circuits is there to suppress transients that otherwise may become excessively high and cause puncturing of the transistors. Since the magnitude of this transient will depend very much upon individual transformer designs and upon their relative leakage reactance, some experimenting with this value may be desirable.

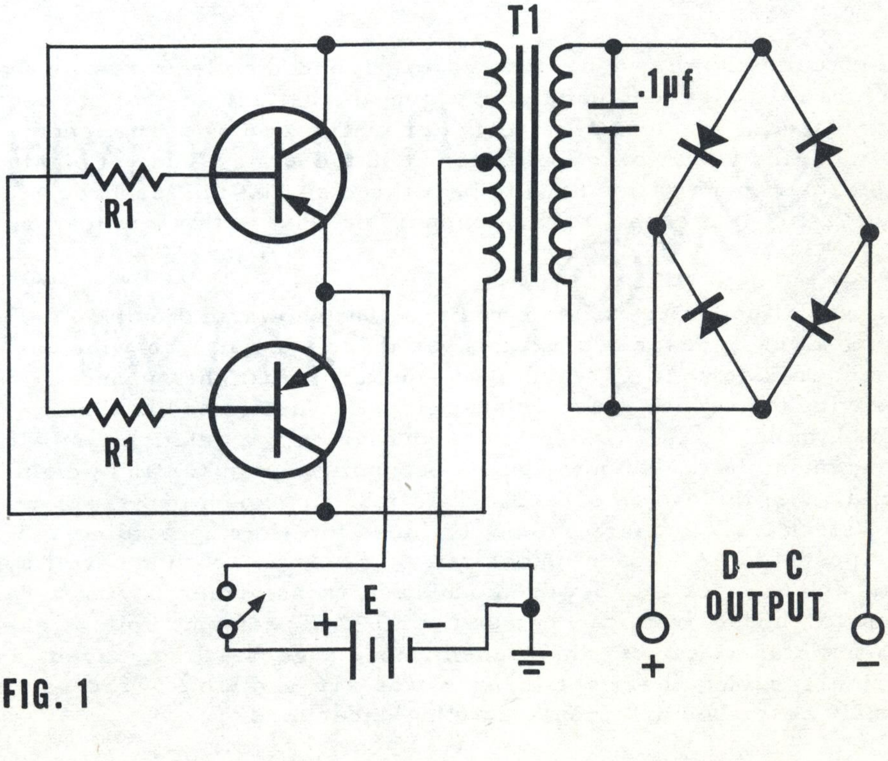

FIG. 1

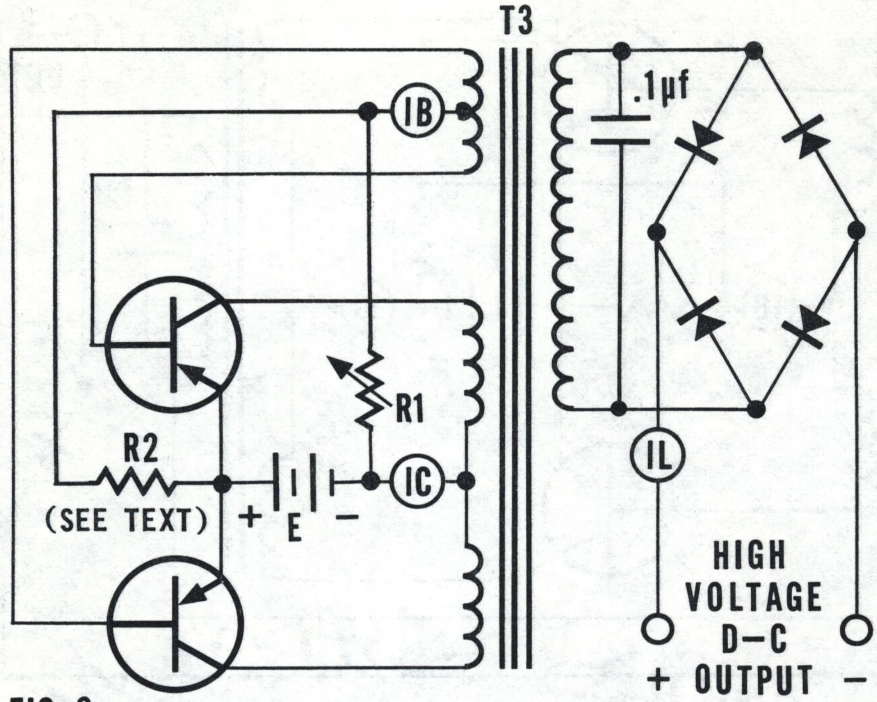
T3
IB
.1µf
R1
R2
(SEE TEXT)
IC
+ E –
IL
HIGH
VOLTAGE
D–C
+ OUTPUT –

FIG. 2

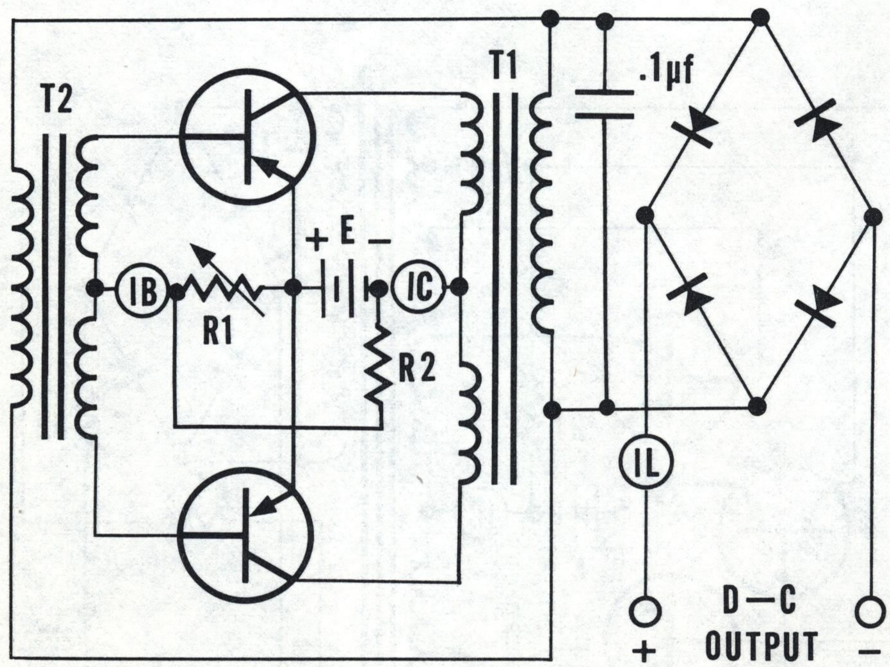
T1
T2
.1µf
+ E –
IB
R1
IC
R2
IL
D–C
+ OUTPUT –

FIG. 3

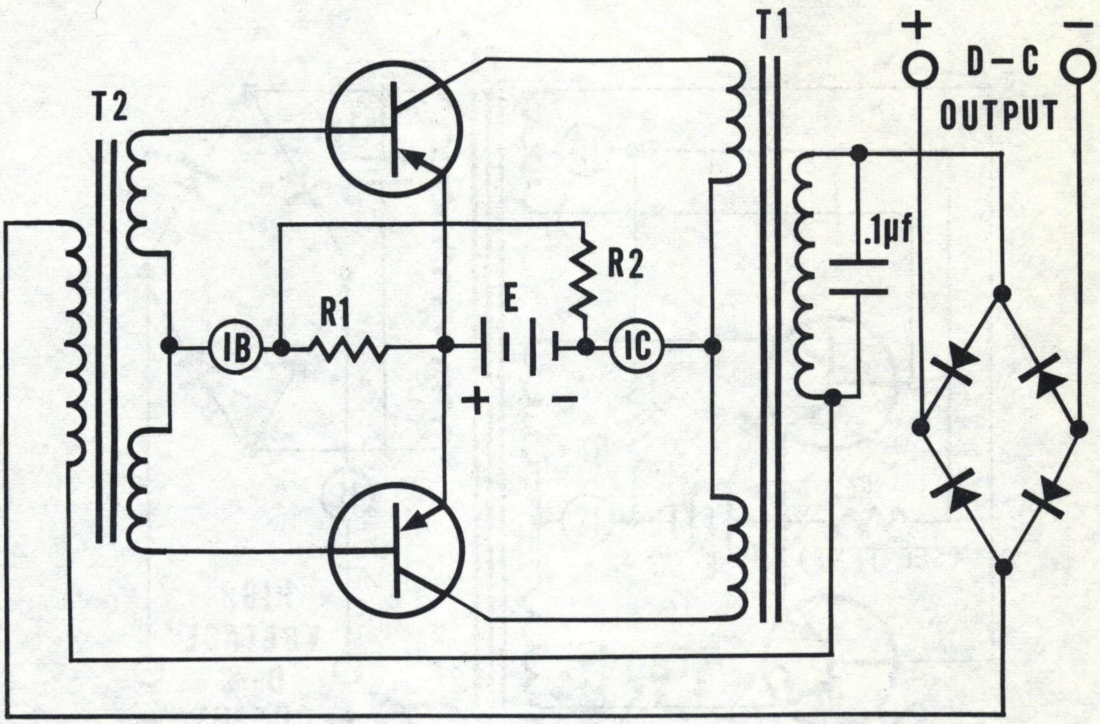

FIG. 4

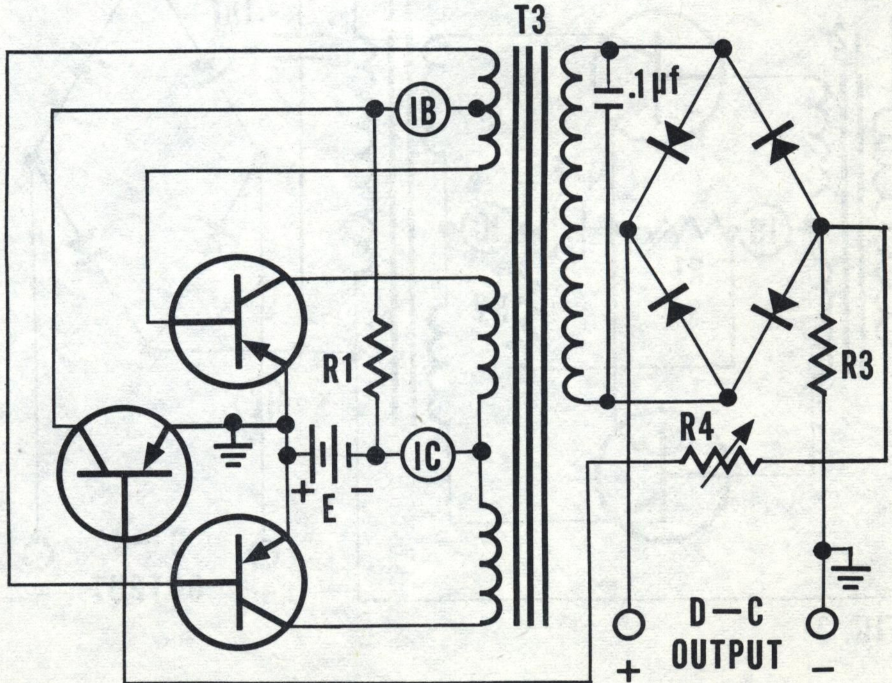

FIG. 5