THE HIGH VOLTAGE SUPPLY

The high voltage supply in the EC/130 provides high voltage for the CRT. The supply is basically a series fed voltage multiplier. A block diagram of the high voltage supply used in the EC/130 is shown in Figure 1. An oscillator drives the actual circuit via an isolation transformer. The transformer steps up the oscillator output voltage to reduce the number of sections that must be used in the multiplier circuit. The voltage multiplier circuit is divided in two parts; the lower half develops a positive voltage with respect to the transformer, and this positive end is grounded, putting the transformer at

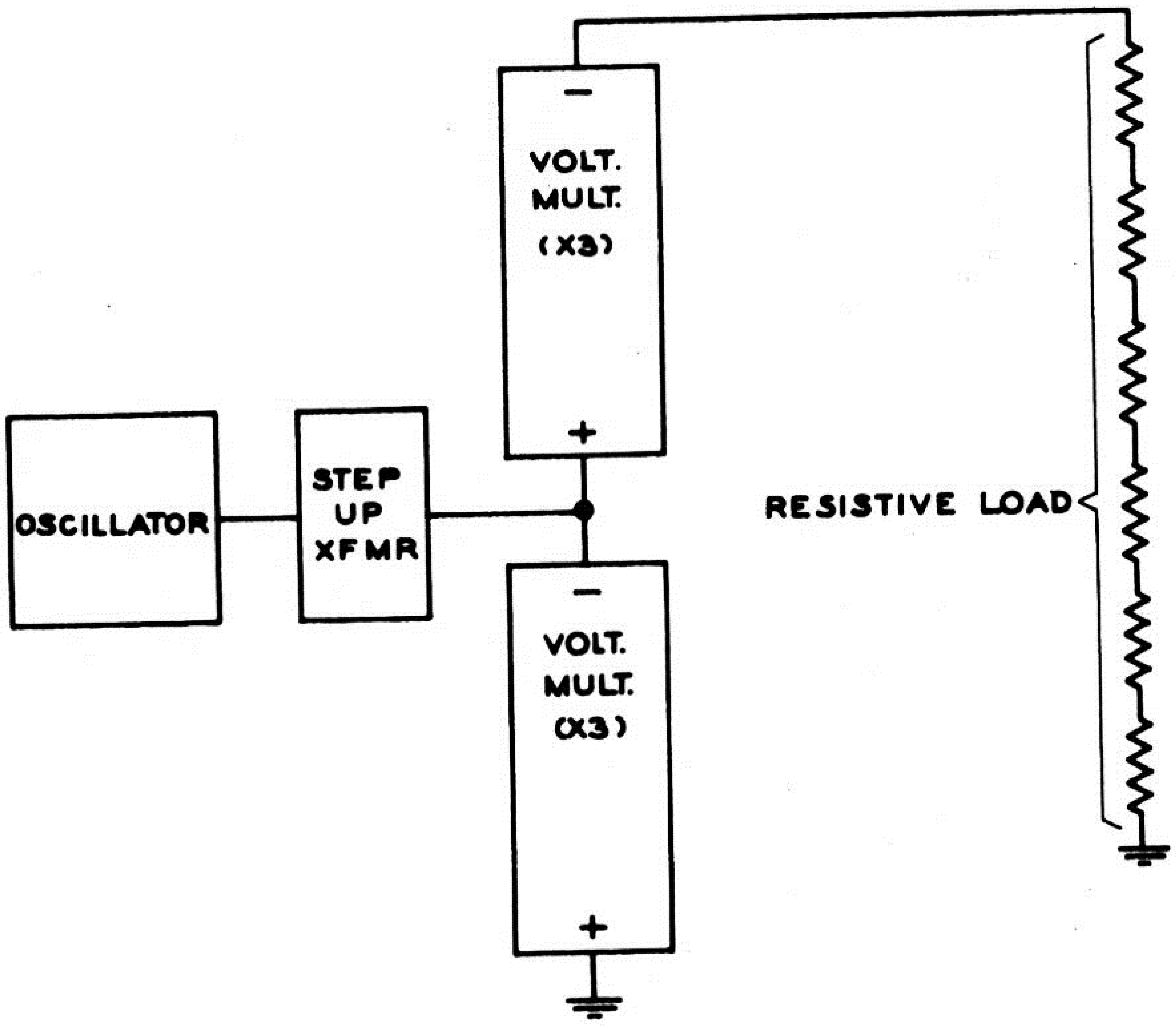


FIGURE 1

some negative potential; the upper half develops a negative voltage with respect to the transformer. This puts the output of the upper half of the circuit at a more negative potential than the transformer, which is more negative than ground. The result is a negative voltage supply with the driver transformer right in the middle. The reason why this configuration is used will become more obvious later.

The first portion of the detailed description will cover the oscillator. This oscillator is an A-Stable multivibrator with a symmetrical square wave output. A review of flip-flops and the circuit description of flip-flops is suggested at this point, because certain points will be merely stated here that are fully explained in the article on flip-flops.

An a-stable multi similar to the one used in the high voltage supply is shown in Figure 2. Its design frequency is 2KC but this isn't critical at all, and no attempt is made to insure that it is exactly 2KC. A 15% variation either way is of no consequence whatever except for one result which will become apparent later. The main difference between the a-stable in Figure 2 and a flip-flop is the biasing arrangement. This a-stable could be made into a flip-flop by the addition of a resistor from each base to a+6 volt supply (Refer to the article on flip-flops for circuit). This enables one transistor of a flip-flop to be biased off when the other transistor is on. In the a-stable, neither transistor can be biased off, but must depend upon a signal on the base to turn it off, and KEEP it off for a finite period of time. For this reason, the bases of the transistors of an a-stable multi are not returned to 6 volts as they are in the flip-flop. Instead, they are returned only to -12 volts through the cross-coupling resistors. This biases both transistors on, and the only way one of the transistors can be turned off is by a positive signal from the coupling capacitor connected to its base. Take

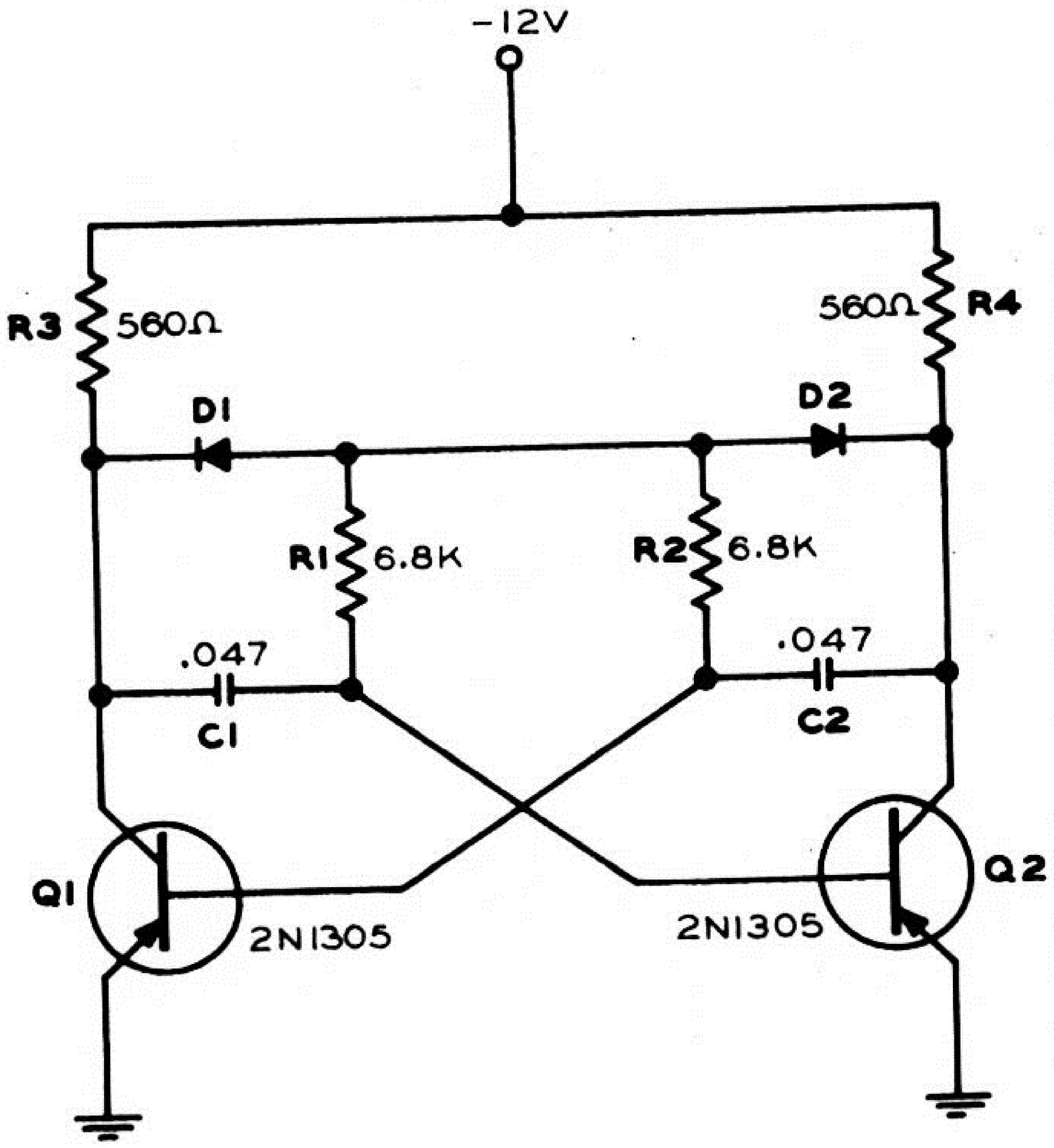


FIGURE 2

the example of Figure 2 as Q1 just turns on. Its collector goes from -12 volts to 0 volts very quickly and the .047 u f capacitor (C1) couples this transistion to the base of Q2 as a +12 volt pulse. + 12 volts on the base of Q2 turns it off and its collector goes to -12 volts. This -12 volt pulse is coupled to the base of Q1 and tries to turn Q1 on harder. Alas, Q1 is already in saturation, its base is clamped to about -.2 volts, so C2 charges to -12 volts. Meantime C1, which was charged with 0 volts on its left side, and +12 volts on its right side, begins to discharge through R1, D2, and R4 back to -12 volts. (It won't discharge through D1 because it's back biased due to R1 and R4 voltage divider action.) When the voltage on the right side of C1 reaches -.2 volts, Q2 begins to turn on. The collector of Q2 begins to fall from about -11.1 volts toward 0 volts. (A stimulating project for the interested reader would be to determine why the collector of Q2 is at -11.1 volts instead of -12 volts, and to determine what the collector voltage was immediately after Q2 turned off.) This positive transition is coupled to the base of Q1 through C2. Q1 turns off and the negative transition is coupled to the base of Q2 through C1 and jams Q2 on. In shorter words, the circuit is highly regenerative, as all oscillator circuits are.

The period (pulse width) of one half cycle of the oscillator is dependent upon the length of time Q2 is off. The length of time Q2 is off is dependent upon the length of time C1 takes to discharge from +11.1 volts to -.2 volts through R1 and R4 in series to -12 volts. The formula for determining this time is

$$T = R \times C \times L_N \frac{E}{E-E_c}.$$

R equals 7.36K because R1 and R4 are in series. C equals .047 uf, of course; L_N means "natural log" or "log to the base 2.71828." E equals 23.1 volts because the capacitor is charged to +11.1 volts and the resistors return to -12 volts. Ec is the instantaneous voltage on the capacitor referenced to -12 volts, and thus is 12-.2 or 11.8 volts. Hence the formula now looks like this:

$$\begin{aligned} T &= 7.36 \times 10^3 \times .47 \times 10^{-6} \times L_N \frac{23.1}{23.1-11.8} \\ &= 346 \times 10^{-6} \times L_N\, 2.05 \\ &= 346 \times 10^{-6} \times .716 \\ &= 248 \text{ u sec} \end{aligned}$$

Since 248 u sec is the period for one half cycle, and the circuit is symmetrical (that is, the two load resistors are equal, the two base resistors are equal, and the two capacitors are equal), then the next half cycle, the period of which is determined by the off time of Q1, is also 248 u sec long. Then the length of one complete cycle is 248+248 or 496 u sec. Frequency equals the inverse of the period of one cycle, so

$$\begin{aligned} F &= \frac{1}{P} \\ &= \frac{1}{496 \text{ u sec}} \\ &= 2.01 \text{ KC} \end{aligned}$$

and 2KC is the design frequency. The above calculations fall well within slide rule accuracy, and component tolerances permit a spread of 1.9 KC to 2.2 KC anyway.

Now that the a-stable multivibrator is completely understood, the next item of concern is that of getting the signal to the transformer. Obviously, the transformer can't be connected directly to the a-stable, because that would drastically change circuit parameters. The solution is to use the a-stable to control a power transistor which acts as a driver for the transformer. The method used to do this is shown in Figure 3. Here, the emitter current for Q2 is the base current for Q3;

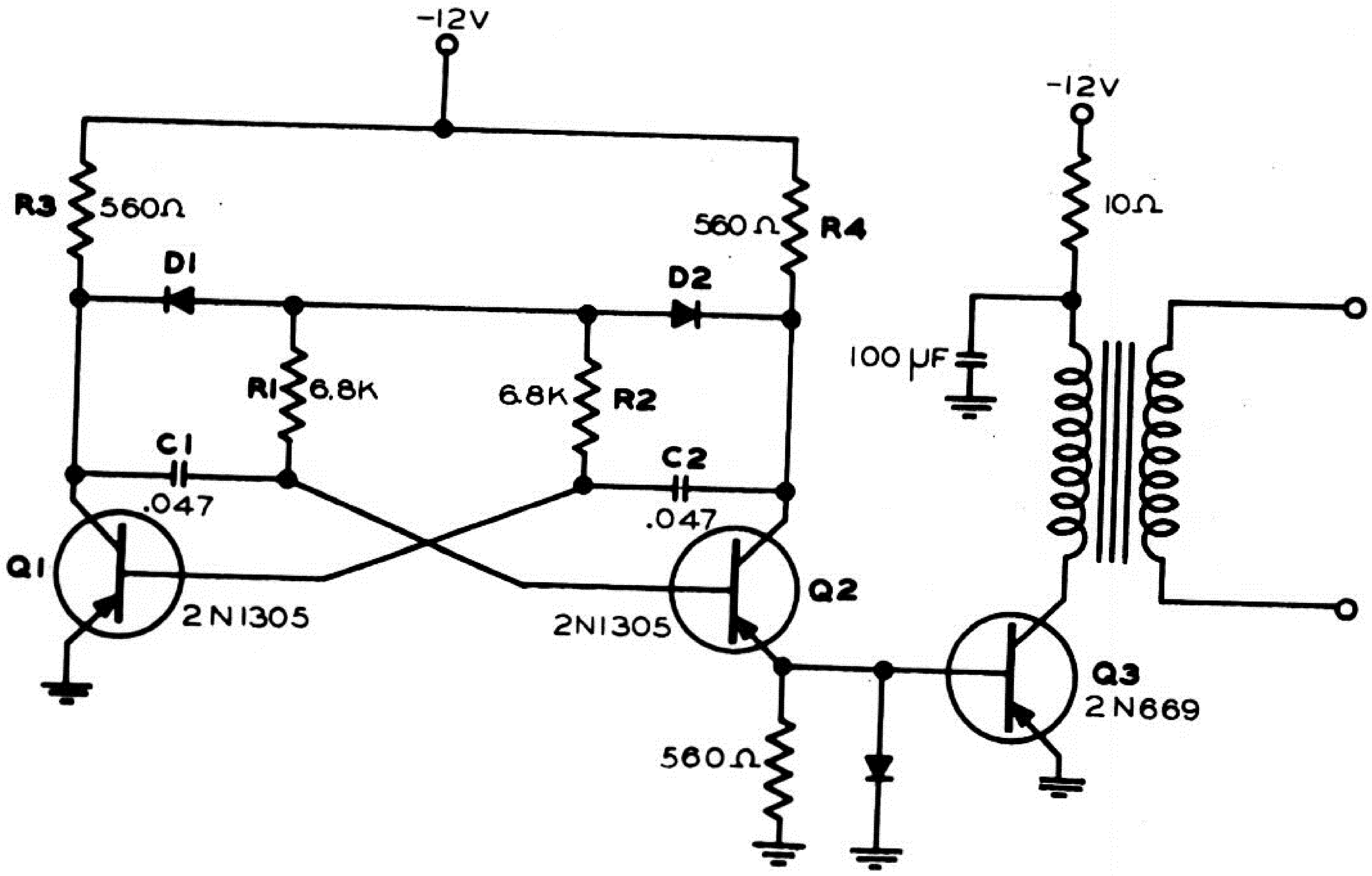


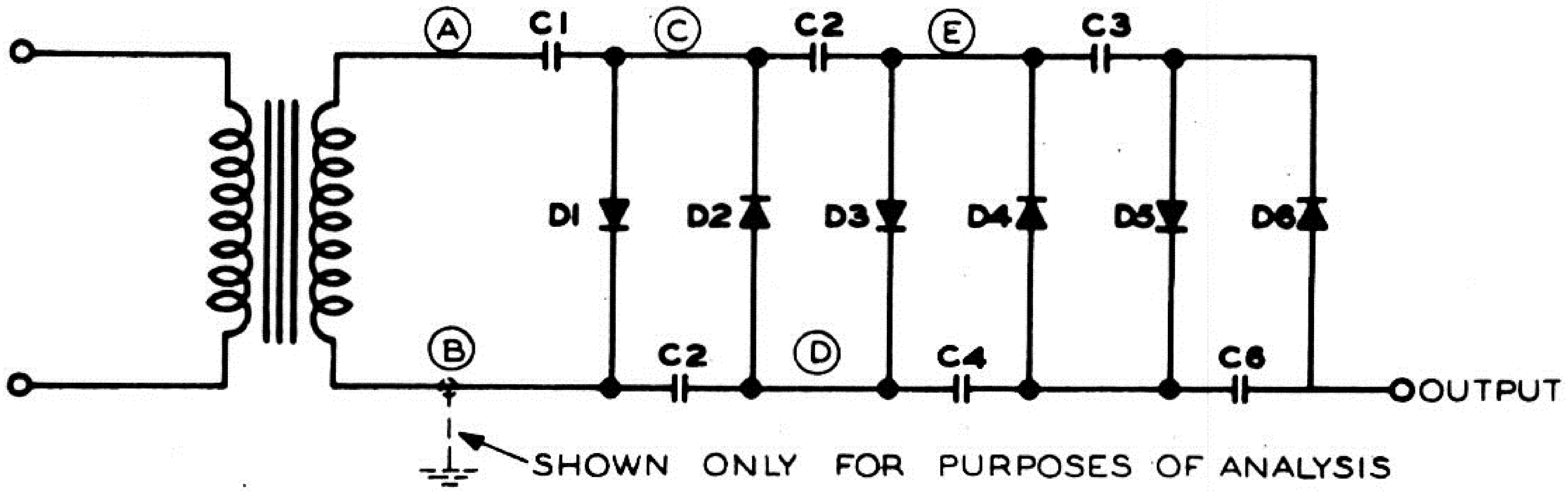
FIGURE 3

hence Q2 controls Q3, and Q3 drives the transformer. The 10 ohm resistor and the 100 uf capacitor insure that none of the 2KC gets back into the -12 volts supply, and you can bet your boots that, if there is a lot of 2KC ripple on the -12 volt supply, it's because the 100 uf capacitor is open!

There is an interesting thing about the step-up transformer. It was desired to have a turns ratio of about 25 to 1 and, coincidentally, there is an audio output transformer available that gives that ratio, so it was decided to use that transformer turned around and used as a step-up transformer. A little extra insulation was added to give it a 3KV rating, but it's still basically a little 5 watt audio output transformer. The transformer acts strictly as a coupling device and does not seriously distort the square wave input or output signal. However, the transformer is still an inductive device and, like all inductors, it develops a counter electromotive force which opposes changes in current. As a result, although only 8 volts of the total 12 volts supply is used, a 16 volt square wave will be developed because of the counter EMF built up. (Also see the article on the Master Oscillator for a little more complete discussion on inductors). Hence, with a 16 volt square wave on the primary, the secondary will yield a square wave output equal to 25 times 16, or 400 volts peak-to-peak.

With 2400 volts required, and 400 volts to start with, the voltage multiplier circuit must increase this 400 volts by a factor of 6. If the multiplier circuit is divided into two equal parts as shown in Figure 1, then each half must step up the 400 volt input signal by a factor of 3. Since the two parts are almost identical, only one half will be analyzed, and only one half is shown in Figure 4.

For purposes of analysis, consider a 400 volt peak-to-peak square wave input with point B at 0 volts and point A varying from -400 volts to 0 volts as shown. At the input frequency (2KC) C1 is a coupling capacitor because the RC time constant



SHOWN ONLY FOR PURPOSES OF ANALYSIS

FIGURE 4

is so high ($R \longrightarrow \infty$). The signal at point C then, should be a 400 volt square wave signal going from 0 volts to -400 volts. Diode D1 is for DC restoration and assures that point never goes more positive than 0 volts. C2 is a storage capacitor that charges up to the peak voltage (-400 volts) at point C, and D2 prevents C2 from discharging back to C1. Hence, at point D, a steady -400 volts DC is seen. C3 is another coupling capacitor and serves to couple the 400 volt square wave from point C to point E, so there is a 400 volt square wave signal at point E. However, point E is DC restored to the DC level at point D, by diode D3. Therefore, the maximum positive voltage that point E can attain is -400 volts. So the square wave signal at E varies from -400 volts to -800 volts. C4 is the next storage capacitor that charges up to -800 volts through diode D4, which also prevents C4 from discharging back into C3 when point E drops from -800 volts to -400 volts. By now it should be apparent that C5 is another coupling capacitor, and C6 is the next storage capacitor and that D5 is for DC restoration, and D6 is a coupling diode. The output of this multiplier is -1200 volts DC. The effective source that the load sees is three capacitors connected in series and charged up to -1200 volts. The three capacitors in series are C2, C4, and C6. If these three capacitors are .1 uf each, then the effective capacitance is .033 u . Thus, in loose terms, the multiplier acts like a .033 uf capacitor being charged to -1200 volts at a 2KC rate. If the load resistance is infinite, the output will be exactly -1200 volts. But an infinate load resistance is a little impractical, so some load resistance is necessary. The minimum resistance that can be used commensurate with the particular supply can be roughly determined by a "rule of the thumb" law, to wit; the RC time constant should be at least 100 times as great as the period of one cycle of the signal input. The signal input is 2KC, so the period of one cycle is 500 u sec. It has already been determined that the effective capacitance of one half of the supply is .033 uf.

$$RC = 100 \times P \qquad (P = \text{period})$$

$$R = \frac{100 \times P}{C}$$

$$= \frac{100 \times .5 \times 10^{-3}}{.033 \times 10^{-6}}$$

$$R = 1.5 \text{ megohms}$$

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So the maximum practical resistance of the load on one half the supply is 1.5 megs. (As R goes up, the high voltage goes up because of less sagging. What happens if frequency goes up?) This is because the effective capacitance is .033 uf. HOWEVER, the supply consists of TWO equal halves, connected series aiding. (See Figure 5) This means that there are TWO effective .033 capacitances connected in series, which makes the effective capacitance of the WHOLE supply equal to .0167 uf $(\frac{.033}{2})$. Therefore, in order to keep the RC time constant equal to 100 times the period, the resistance must be doubled. So the minimum practical resistance becomes 3 megs. As a check,

$$R = \frac{100 \times .5 \times 10^{-3}}{.0167 \times 10^{-6}}$$

$$= 3 \text{ megohms}$$

The load on the high voltage is constant at about 3.9 megohms,

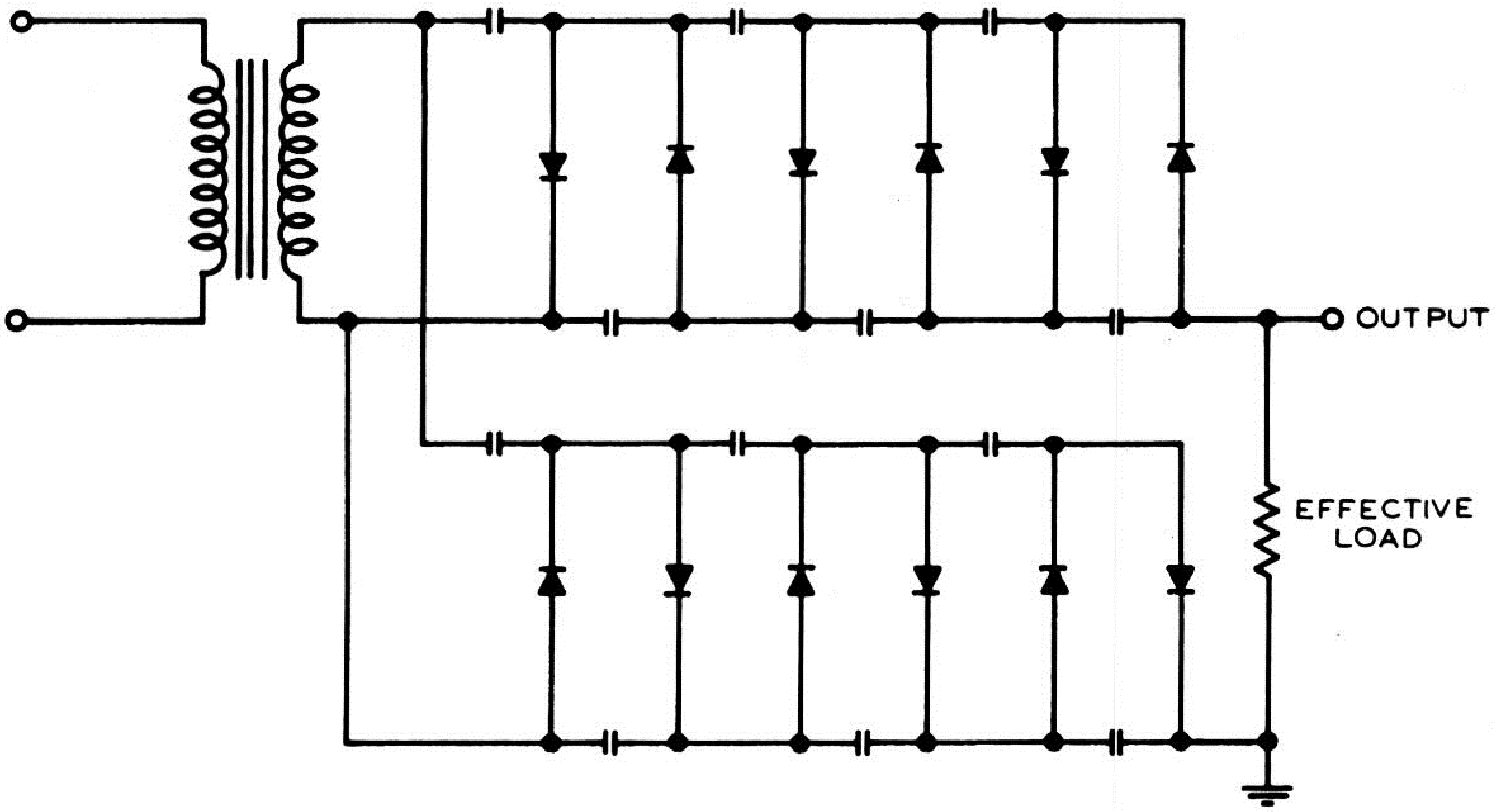

FIGURE 5

which is better than the minimum acceptable value. Be aware though, that there is still some sagging of the supply voltage; the only time the voltage is really at its peak value is when there is NO load at all. Another thing to be aware of, is that when the high voltage supply is unloaded, the output is at its peak value, and is pure DC; but when there is a load, and the supply sags, ripple appears. The heavier the load, the less the high voltage, and the greater the ripple component will be. It would be nice if the ripple could be eliminated. This can be done by driving the multiplier from the center. That way, there is a ripple component developed by each half of the multiplier, but these two components are 180 degrees out of phase. In theory, they are also equal in amplitude and thus cancel completely, but in practice, there will always be some ripple. The net effect though, is a ripple component greatly reduced in amplitude, and this is effected by driving the multiplier from the center instead of from one end. For this reason the transformer must be insulated for a much higher voltage than if it were used as an audio transformer.

That's the high voltage supply in a nutshell. It's simple, reliable, and does its job well. No one can ask more of a circuit than that.