APPLICATION NOTE
SEMICONDUCTOR PRODUCTS DEPARTMENT

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Efficient, High-Quality Program Amplifier Circuits Using the Industrial Silicon Series 2N2107, 2N2108 & 2N2196

by
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Recent advances in semiconductor technology has enabled the electronic industry to see an increasing number of power transistors, capable of efficient operation at the upper end of the audio spectrum and above. Diffused semiconductor junctions was the basis for this higher frequency capability and this, combined with the more recent epitaxial process, promises even greater improvements (i. e. lower saturation resistance, etc.)

The power handling capability of a transistor is limited by both its electrical and thermal ratings. The electrical rating limit is a function of the transistor's voltage capability, and its maximum current at which the current gain is still usable. The thermal rating is limited by the transistor's maximum junction temperature. Therefore, it is desirable to provide the lowest thermal impedance path that is practical from junction to air. The thermal impedance from junction to case is fixed by the design of the transistor thus it is advantageous to achieve a low thermal impedance from case to the ambient air.

The 2N2107 and 2N2108 are NPN diffused silicon transistors. They will be limited in their maximum power handling ability by the thermal considerations for many applications unless an efficient thermal path is provided from case to air.

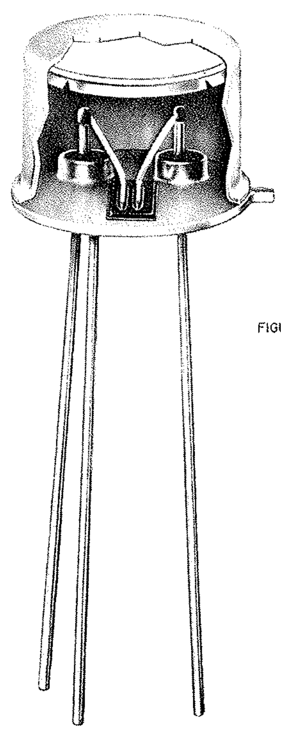
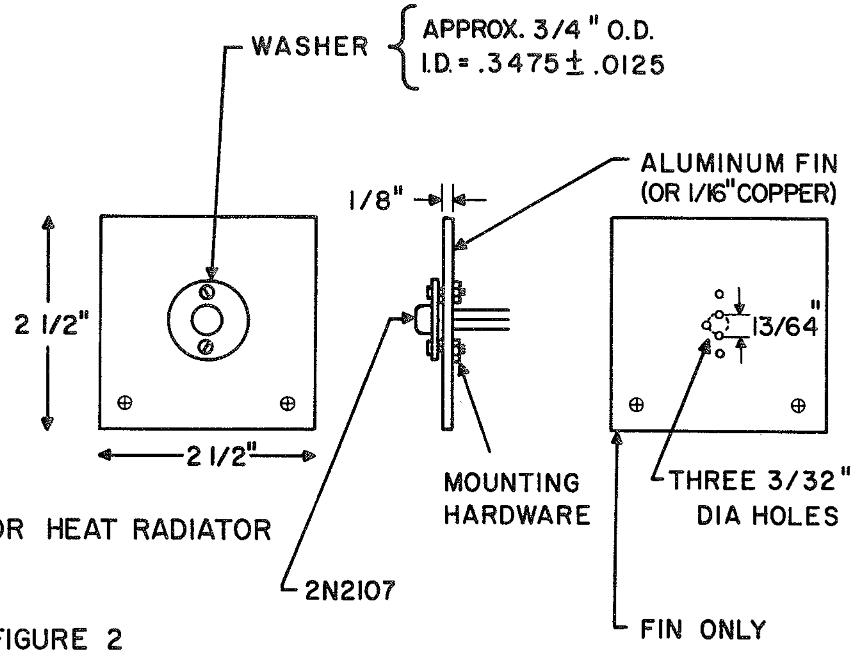


FIGURE 1

These transistors are constructed with the silicon pellet mounted directly on the metal header, see Figure 1, and, therefore, it is more efficient to have an external heat radiator in direct contact with this header than to make contact with the cap of the transistor package. Making contact with the cap for heat transfer means that the variation of the cap's outside diameter makes it difficult to maintain a uniform thermal impedance, and the heat must flow from the header across the welded seam to the cap which also adds to the total thermal impedance from junction to air.

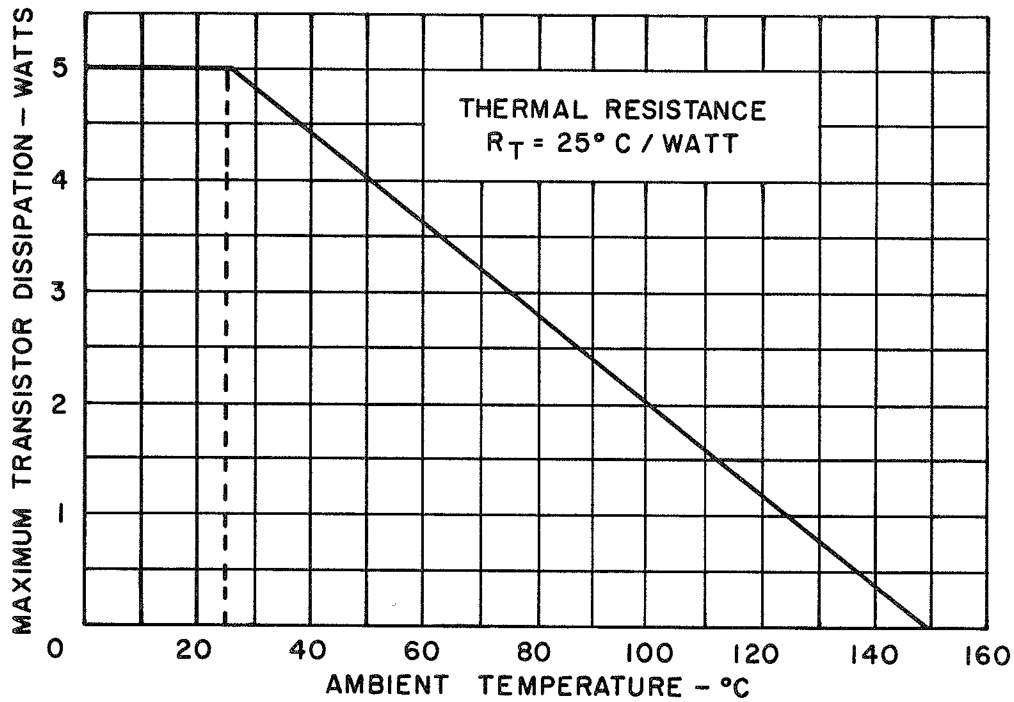
NOTE: APPLY A LAYER OF G.E. SILICONE DIELECTRIC GREASE # SS-4005 OR EQUIVALENT BETWEEN THE TRANSISTOR AND THE FIN.



TRANSISTOR HEAT RADIATOR

FIGURE 2

Figure 2 shows a practical method of achieving a maximum area of direct contact between the metal header and an aluminum fin for efficient heat transfer to the surrounding air. A plain washer with two holes drilled for the mounting hardware is simple but quite adequate for securing the transistor header to the fin. Since air is relatively poor thermal conductor, the thermal transfer can be improved by applying a thin layer of G-E Silicone Dielectric Grease #SS-4005 or equivalent between the transistor and the radiating fin before assembly. This heat radiating fin has two holes for vertical mounting to a chassis. The fin may be anodized or flat paint may be used to cover all the surface except for the area of direct contact with the transistor header. An anodized finish would provide the insulation needed between the base and emitter leads and the sides of the feed-through holes in the aluminum fin.



THERMAL CHARACTERISTIC OF ASSEMBLY IN FIGURE 2

FIGURE 3

Figure 3 shows a thermal rating for the 2N2107 as assembled on the radiating fin in Figure 2. The beta (current gain) hold-up is quite good at one ampere for both the 2N2107 and 2N2108. This means that considerable peak power can be handled.

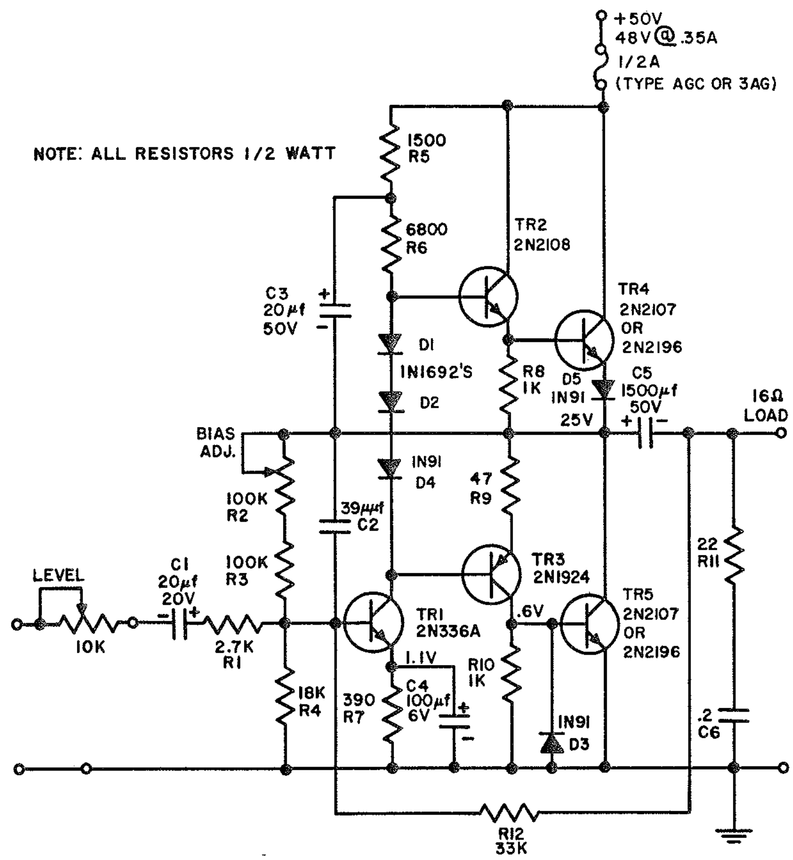
Power Amplifiers:

It is difficult to attain faithful reproduction of a square wave signal with a transformer amplifier. A high quality transformer is required and it must be physically large to have a good response at the low frequencies. Thus, a great deal of effort has gone into developing transformerless push-pull amplifiers using vacuum tubes. Practical circuits, however, use many power tubes in parallel to provide the high currents necessary for direct-coupling to a low impedance load (i. e. 8 to 100 Ω).

The advent of power transistors has sparked new interest in the development of transformerless circuits since the transistors are basically low voltage, high current devices. Some of the transistor power amplifiers to date have been lacking in their high frequency performance and their temperature stability. The diffused junctions of the 2N2107 permit good circuit performance at high frequency. Silicon transistors are desirable for power output stages because of their ability to perform at much higher junction temperatures than germanium. This means smaller heat radiating fins can be used for the same power dissipation. On the negative side, silicon has higher saturation resistance which gives decreased operating efficiency that becomes appreciable when operating from low voltage supplies.

Circuit Analysis:

Figure 4 is a direct-coupled power amplifier with excellent low frequency response, and also has the advantage of a D. C. feedback arrangement for temperature stabilization of all stages. This feedback system also stabilizes the voltage division across the power output transistors TR4 and TR5 which operate in a single-ended Class B push-pull arrangement. TR2 and TR3 also operate Class B in the Darlington connection to increase the current gain. Using a PNP for TR3 gives the required phase inversion for driving TR5 and also has the advantage of push-pull emitter follower operation from the output of TR1 to the load. Emitter follower operation has lower inherent distortion and low output impedance because of the 100% voltage feedback.



7 1/2 TO 10 WATT AMPLIFIER
FIGURE 4

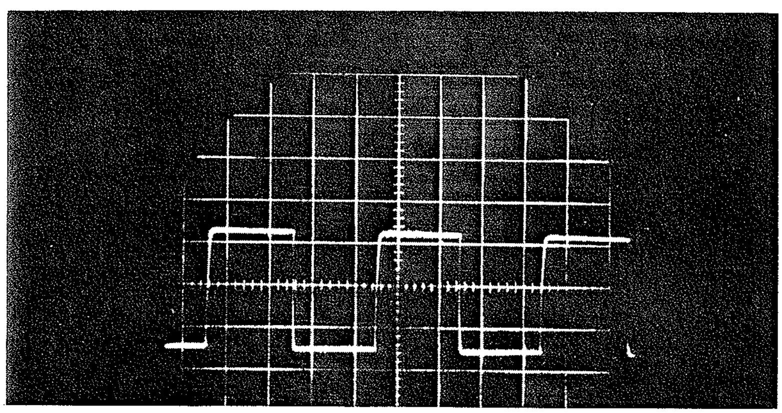
TR4 and TR5 have a small forward bias of 10 to 20 ma to minimize crossover distortion and it also operates the output transistors in a more favorable beta range. This bias is set by the voltage drop across the 1K resistors that shunt the input to TR4 and TR5. TR2 and TR3 are biased at about 1 ma (to minimize crossover distortion) with the voltage drop across the two 1N1692 silicon diodes and the 1N91 Germanium diode. The junction diodes have a temperature characteristic similar to the emitter-base junction of a transistor. Therefore, the three diodes also give compensation for the temperature variation of the emitter-base resistance of TR2, TR4 and TR3. These resistances decrease with increasing temperature, thus the decrease in forward voltage drop of approximately 2 millivolts/degree centigrade for each of the diodes provides temperature compensation. The 1N91 connected to the emitter of TR4 gives additional stabilization for this stage for variations in transistor beta and temperature.

The 47Ω resistor in the emitter of TR3 aids the stabilization of this germanium transistor stage and also decreases distortion through local feedback. The 1N91 diode at the base of TR5 has a leakage current which increases with temperature in a manner similar to the I_{CO} of TR3. The 1N91 can thus shunt this temperature sensitive current to ground, whereas, if it were to flow into the base of TR5, it would be amplified in the output stages.

TR2 requires a transistor with a minimum h_{fe} of 30 at 1 to 30 ma collector current. Of the two output transistors, the higher beta unit should be used for TR4 to help compensate for the unsymmetrical output circuit.

TR1 is a Class A driver with an emitter current of about 3 ma. Negative feedback to the base of TR1 lowers the input impedance of this stage and thus requires a source impedance that is higher so the feedback current will flow into the amplifier rather than into the source generator. The resistor R1 of Figure 4 limits the minimum value of impedance. The bias adjust R2 is set for one-half the supply voltage across TR5.

About 11 db of positive feedback is applied by way of C3 across R5. This bootstrapping action helps to compensate for the unsymmetrical output circuit and permits the positive peak signal swing to approach the amplitude of the negative peak. This positive feedback is offset by about the same magnitude of negative feedback via R2 and R3 to the base of TR1. The net amount of negative feedback is approximately 20 db resulting from R12 connecting the output to the input. In addition, there is the local feedback inherent in the emitter follower stages. The value for the C2 feedback capacitor was chosen for optimum square wave response (i. e. maximum rise time and minimum overshoot) as shown in Figure 5.

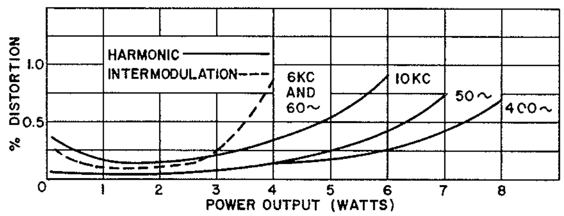


2KC SQUARE WAVE RESPONSE
FIGURE 5

If the load impedance has a reactive component, as with loud-speakers, it should be shunted by R11 and C6 as shown in Figure 4 to prevent the continued rise of the amplifier load impedance and its accompanying phase shift beyond the audio spectrum.

Performance:

The overall result, from using direct-coupling, no transformers, and ample degeneration, is an amplifier with output impedance of .5Ω for good speaker damping, and very low distortion as shown in Figure 6.



DISTORTION VS POWER OUTPUT FOR AMPLIFIER OF FIG. 4
FIGURE 6

The square wave response shown in Figure 5 is indicative of an amplifier with a good transient response and also a good bandwidth. The bandwidth is confirmed by the response curve of Figure 7.

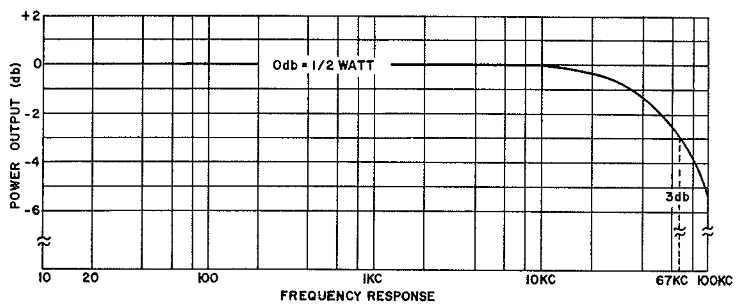


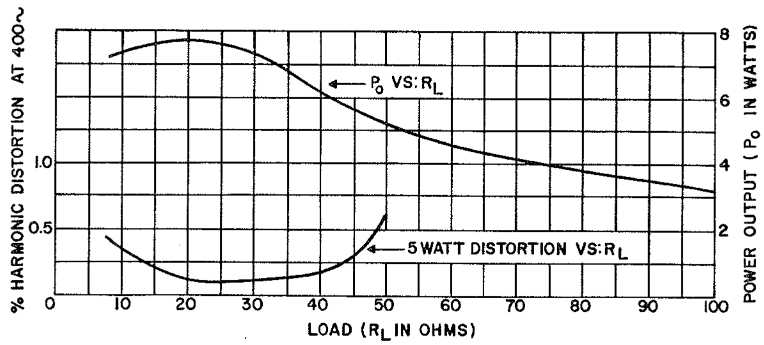
FIGURE 7

The power response at 5 watts output is flat within 1/3 db from 30 cycles to 15Kc. The amplifier exhibits good recovery from overload, and the square wave peak power output without distorting the waveform is 12 watts.

An rms input signal of 1- 1/4 volts is required for 8 watts output with a supply furnishing 350 ma at 48 volts. The 2N2107 output transistors, TR4 and TR5, were mounted on heat dissipating fins as shown in Figure 2 and the amplifier operated successfully delivering 1 watt rms 400 cycle continuous power to the load with no increase in total harmonic distortion from room ambient of 75°C to 175°F (approx. 80°C). At 175°F the DC voltage across TR5 had decreased less than 15% from its room ambient value. Operation at higher temperatures was not attempted because of TR3 being a germanium transistor which has a maximum operation junction temperature of 85°C. For operation at higher junction temperatures a PNP silicon transistor should be used for TR3.

The above performance tests were with a 16Ω resistive load. The performance near maximum power output will vary somewhat with transistors of different beta values giving a range of maximum power output of 7 1/2 to 10 watts before clipping. Varying values of saturation resistance for the output transistors TR4 and TR5 also affect the maximum power output.

Figure 8 shows the load range for maximum performance. It indicates that for a varying load impedance such as a loudspeaker, the most desirable range is 16 to 40 Ω. A 16 Ω speaker system is in this range. At higher impedances (to 100 Ω), 1 to 3 watt servo motors could be driven or an impedance matching auto-transformer would permit higher power. A 20 to 600 Ω auto-transformer should be used for driving a 600 Ω line.



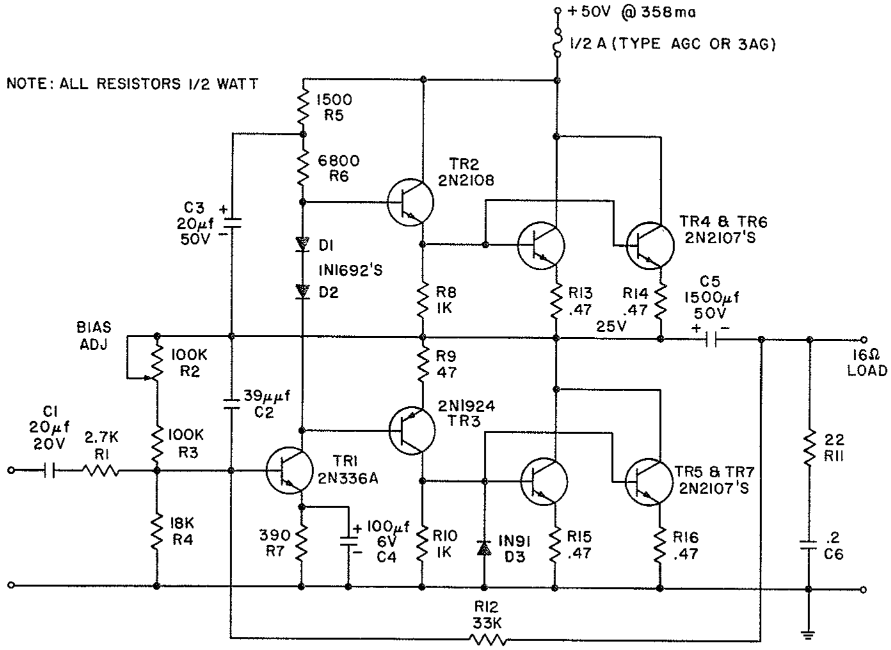
AMPLIFIER PERFORMANCE VS LOAD
FIGURE 8

The amplifier of Figure 4 operates with an efficiency of 47 to 60% and has a signal-to-noise ratio of better than 98 db. The amplifier of Figure 4, when operated with the 2N2107 heat radiator assembly as shown in Figure 2, can safely deliver up to 10 watts rms of continuous power to the load at room temperature. When driving a loudspeaker with program material at a level where peak power may reach 10 watts the rms power would generally be less than 1 watt. This amplifier when operated with 2N2196's in the outputs, can be mounted on a smaller 2" x 2" fin because of its increased power capabilities. The 2N2196 has a case that simplifies the mounting on a heat radiator, and it has electrical characteristics that equal or excell the 2N2107 for this application.

The power supply for this amplifier should have low impedance (less than 15 Ω) attained either by regulation or output capacitance as in Figure 11. This power supply has diode decoupling which provides excellent isolation between two stereo amplifier channels. (Ref. 2)

12 Watt Amplifier:

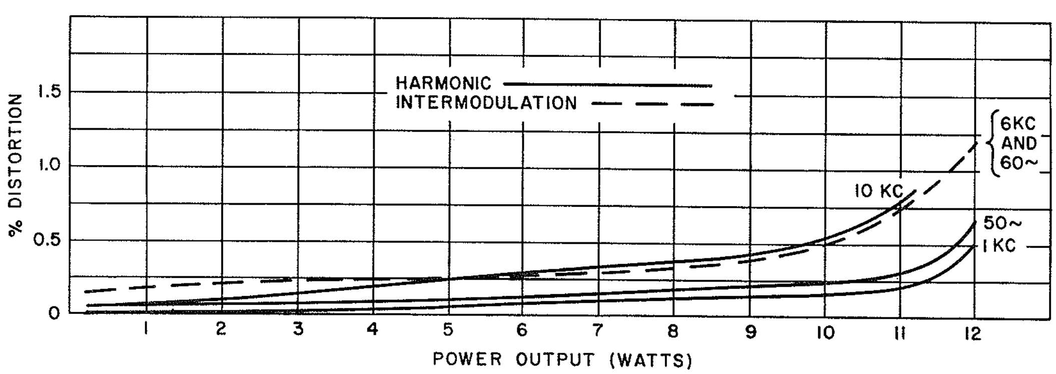
The amplifier of Figure 4 is limited in its maximum power output by the supply voltage and the saturation resistance of the output transistors, TR4 and TR5. The supply voltage can not be increased much beyond 50 volts at maximum amplifier signal swing without making the V_{CE} rating for TR1 marginal. Under these conditions the saturation resistance becomes the limiting factor for obtaining increased power output.



12 WATT AMPLIFIER
FIGURE 9

The circuit of Figure 9 uses two transistors in parallel for each of the outputs. This enables the saturation resistance to be reduced in half and gives 12 watts output. The .47 ohm resistor used in the emitter of the paralleled transistors gives a more uniform input characteristic for sharing of the input currents. These emitter resistors also give increased bias stabilization. The rest of the circuit is the same as Figure 4 except the 1N91 (D4) is not used in the collector of TR1 since there is no diode voltage to offset in series with output emitter (D5).

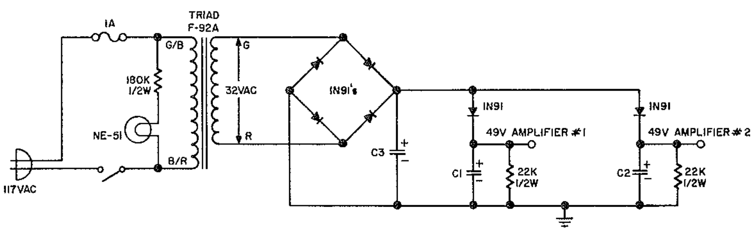
The performance of the 12 watt circuit is like that given previously for the circuit of Figure 4 except for the distortion vs: power output. Figure 10 indicates the increased power output and also the lower distortion which is a second advantage of parallel operation of the outputs. Lower distortion results from parallel operation since the signal current swing in each transistor is approximately halfed and thus confined to the more linear portion of the transfer characteristic.



DISTORTION VS POWER OUTPUT FOR 12 WATT AMPLIFIER
FIGURE 10

The amplifier of Figure 9 operates at maximum power output with an efficiency of 67%. This circuit can be packaged with a minimum volume and weight without component crowding, see Figure 12. One of the paralleled output transistors uses the technique described in Figure 2 and the other makes for simplified mounting using a G. E. transistor, 2N2196 that was discussed previously. All four of the output transistors could be 2N2107's or all 2N2196's. Each mounting fin is 3/32" x 1 1/2" x 4 1/2" aluminum.

A regulated 50 volt supply is recommended for best performance of this circuit. If the amplifier is powered by the supply of Figure 11, it will provide 10 watts of continuous output or 12 watts at Music Power Rating.

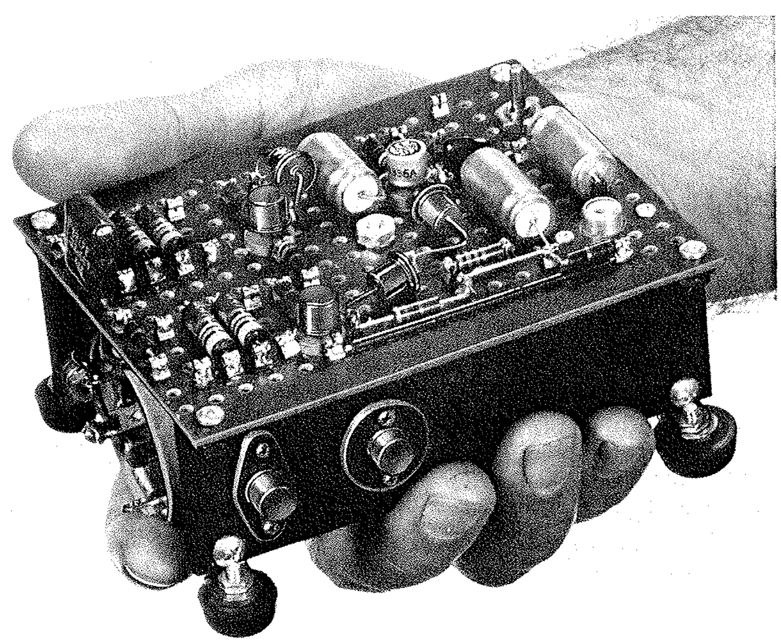


C1, C2, & C3 – 1500µf, 50V

POWER SUPPLY FOR STEREO SYSTEM
FIGURE 11

Either one of the amplifiers described will give superb performance in a stereo system when used to drive a 16Ω speaker that has at least moderate sensitivity.

The generally higher cost of silicon transistors vs. germanium is decreasing and this trend will probably continue along with improved performance as mentioned at the beginning of this article. It was only a few years ago that germanium rectifiers outnumbered silicon, but now the situation has reversed.



12 WATT AMPLIFIER
FIGURE 12