Assembly Manual for the

A low-cost utility amplifier
capable of delivering up to 20W.
(PCB and Components Only)

PLEASE READ DISCLAIMER CAREFULLY AS WE CAN ONLY GUARANTEE PARTS AND NOT THE LABOUR CONTENT YOU PROVIDE.

K-3445

DICK SMITH KIT

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This instruction manual describes and compares a low power (1 Watt) amplifier to the 20 Watt amplifier kit supplied. All parts within this kit are ONLY for assembly of the 20 Watt type. For construction details please refer to the appropriate text and diagrams.

Low power audio amplifiers are used in a surprising variety of electronic devices. The TV set in your lounge room uses an audio amplifier, as do transistor radios, tape players, record players, electronic musical instruments, movie sound projectors, and electronic games. For this reason, a general-purpose audio amplifier is a handy device for any hobbyist to add to his workbench.

Some modern audio amplifiers use an integrated circuit module, but a surprising number are still designed around discrete transistors. There are several reasons for this. Discrete designs are usually more reliable, cheaper, and easier to service.

The two designs to be described thus use discrete transistors and are very easy to build and get going. In addition, they present an ideal opportunity for the hobbyist to gain an understanding of how an audio amplifier works. IC "black boxes" are fine, but they don't tell you anything about the circuit operation.

To this end, fairly detailed explanations of the circuit operation are given. In particular, we explain how a complementary symmetry amplifier works and discuss such things as bias stabilisation and Vbe multipliers.

The accompanying specification panels and the graphs give the technical details of the amplifiers, while the physical details can be determined from the photographs. Each amplifier is built on a printed circuit board which, in the case of the 20W version, also carries the heatsinks. They are not intended to be hifi amplifiers, although the 20W version could form the basis of a modest stereo system.

How it works

Before involving ourselves with the details, let's first review the basic theory underlying amplifiers of this general type. Fig. 1 shows a basic complementary symmetry output stage which forms the basis of both amplifiers. Note that the bias components have been omitted for clarity.

The circuit consists of two emitter followers connected together such that each amplifies half of the incoming waveform. The circuit is so biased that the bases of the two transistors, and thus their emitters, are held at half the supply voltage when no signal is present.

Imagine a sinusoidal signal applied to the bases of the two transistors. When a positive half-cycle occurs transistor Q1 is forward biased and thus operates as an emitter follower. Similarly, Q2 is forward biased during negative half-cycles of the input signal. Thus the whole input signal is amplified and applied to the load.

To use the popular jargon, Fig. 1 is known as a class-B output stage. The big advantage of this scheme is that, when no input signal is present, both

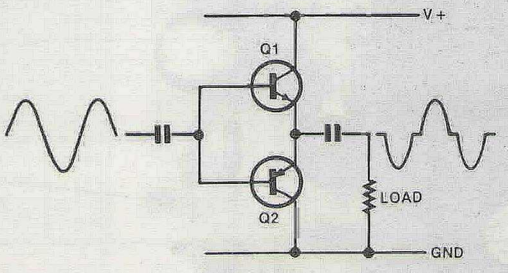


Fig. 1

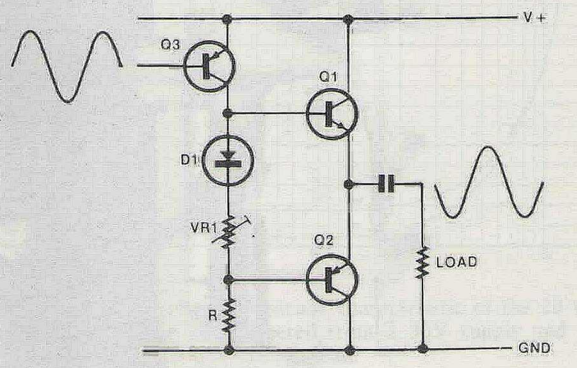


Fig. 2

Fig. 1 (above) shows the basic class B output stage, while Fig. 2 (right) shows the same stage with additional components to eliminate crossover distortion.

transistors are off and so no current is drawn from the supply. Class-B amplifiers are thus quite efficient in terms of current consumption.

A class-A amplifier, on the other hand, is one in which the active device is turned on for the full input waveform. In other words, the transistor is biased so that it operates over both positive and negative excursions of the cycle. This type of circuit draws considerable quiescent current in the no-signal mode and is thus relatively inefficient.

There is one major problem with class B- amplifiers, however, and that is crossover distortion. This occurs because neither transistor will turn on until the base-emitter junction is forward biased by about 0.7V. Thus, there will be a period when both transistors will be off: ie while the input voltage is between +0.7V and −0.7V. This means that there will be a discontinuity in the output waveform as it passes through the mid-point.

This situation is obviously not acceptable, so some way must be found to eliminate the problem. The most obvious solution is to bias both transistors so that they are just turned on with no signal present. If this is to be the case the bases of the output transistors cannot be connected together but, instead, must have about 1.4V between them. Fig. 2 shows one configuration which provides this condition.

Q3 is biased so that, with no signal present, a small current flows through it. This current flows through D1 and VR1 to provide the 1.4 volts difference between the bases of Q1 and Q2. A variable resistor is used in this position so that the bias current can be adjusted to the minimum value required to eliminate crossover distortion.

The diode is used to provide temperature compensation. The voltage which we are trying to match, the voltage across the base-emitter junctions of the output transistors, does not remain constant with temperature. Thus a diode, with its similar voltage-temperature coefficient, is used to compensate for the change in base-emitter voltage with temperature.

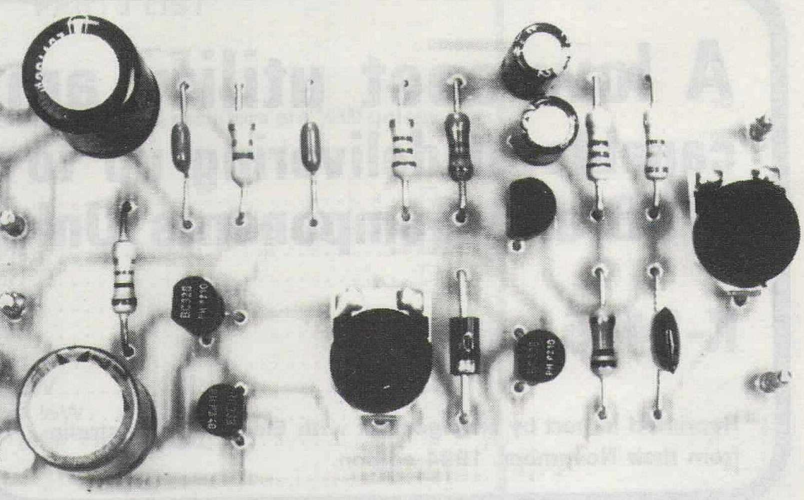
1W amplifier

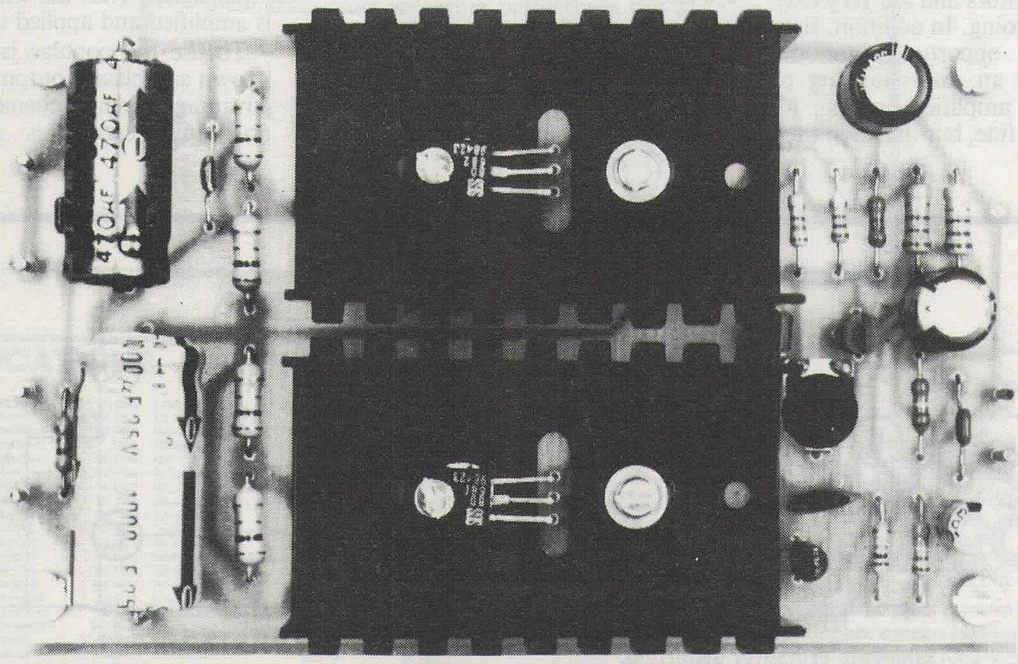
Referring now to the circuit diagram of the one watt amplifier, it can be seen that the output stage of Fig. 2 is used with only one minor variation. The resistor on the base of Q2 is no longer connected to the negative rail but is instead connected to the output terminal.

The reason for connecting one side of the 1kΩ resistor to the output rather than the negative supply is to provide "bootstrapping". Because the output stage is essentially a complementary emitter-follower with almost unity gain, there is almost no difference in AC signal voltage across the 1kΩ resistor. Therefore very little signal current flows in this resistor and so there is less loading on Q3 than there otherwise would be. This translates into slightly more output signal and slightly less distortion.

The only other addition to the circuit is the stage containing Q4. This stage provides some of the voltage gain of the amplifier as well as establishing the bias conditions throughout. The +12V rail is decoupled by the 100kΩ resistor and the

The completed 1 watt amplifier is mounted on a PC board measuring only 44 × 77mm.





This photograph shows the completed 20 watt amplifier. Note the heatsinks on the board.

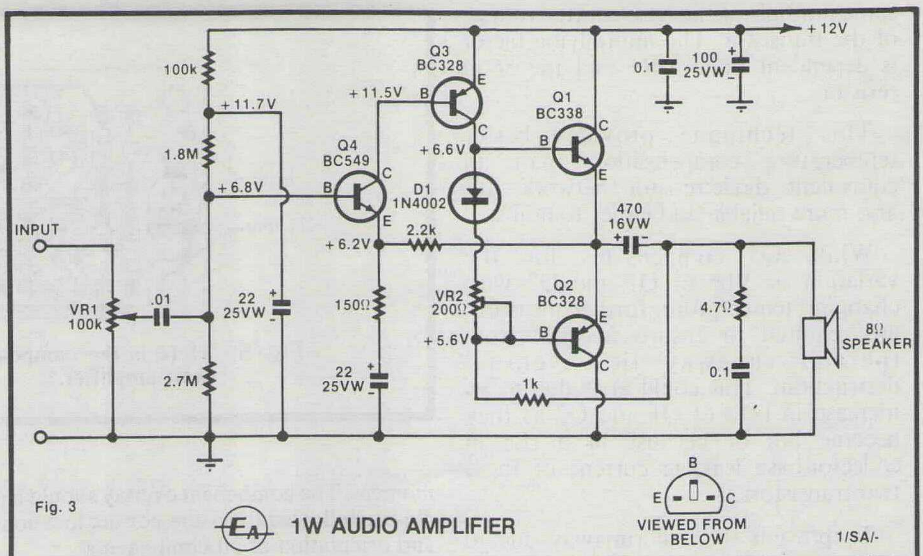


Fig. 3: The voltages shown on this circuit diagram are measured with no signal present. They clearly illustrate the DC conditions under which the amplifier operates.

22μF capacitor, and then applied to a voltage divider consisting of 1.8MΩ and 2.7MΩ resistors. This sets the voltage on the base of Q4 to just over half supply.

The emitters of the output transistors are held close to half the supply voltage by means of DC feedback provided by the 2.2kΩ resistor. In simple terms this is how it operates. If the voltage on the emitters of Q1 and Q2, and hence the voltage on the emitter of Q4, is lower than 6V, then Q4 turns on harder since it's base is held at just above 6V. This means that Q3 also turns on harder, and so the voltage at the emitters of the output transistors is forced to rise.

In the same way, if the voltage at this point rises above 6V, Q4 reduces the drive to the output stage, thereby lowering the voltage at the output.

Now let's consider what happens when a signal is applied to the input. Trimpot VR1 sets the signal level into the amplifier while a .01μF capacitor provides AC-coupling to the base of Q4. Note that since the impedance at the base of Q4 is about 1MΩ, VR1 determines the overall input impedance of the amplifier (ie, the amplifier has an input impedance of 100kΩ).

Q4 is configured as a common-emitter amplifier. The 2.2kΩ resistor provides overall AC feedback around the whole amplifier, as well as the DC feedback mentioned earlier. Feedback is used in this way to increase the stability of the amplifier and to reduce dependence on the gain of individual transistors.

The load for the common emitter stage is provided by Q3, which is the driver transistor for the output stage (Q1 and Q2). The output stage provides the necessary current gain to drive low impedance loads such as loudspeakers.

A 470μF capacitor is used to block the DC component present on the output. The 4.7Ω resistor and 0.1μF capacitor across the output form a Zobel network to ensure the amplifier remains stable into all types of loads. Filtering of the supply is provided by the 100μF and 0.1μF capacitors connected from the +12V rail to ground.

Using the components shows in Fig. 3, the voltage gain of the circuit is approximately 15.6. This can be adjusted to suit individual needs and is set by the ratio of the 2.2kΩ and 150Ω resistors. For example, reducing the 150Ω resistor to 100Ω increases the gain to 23.

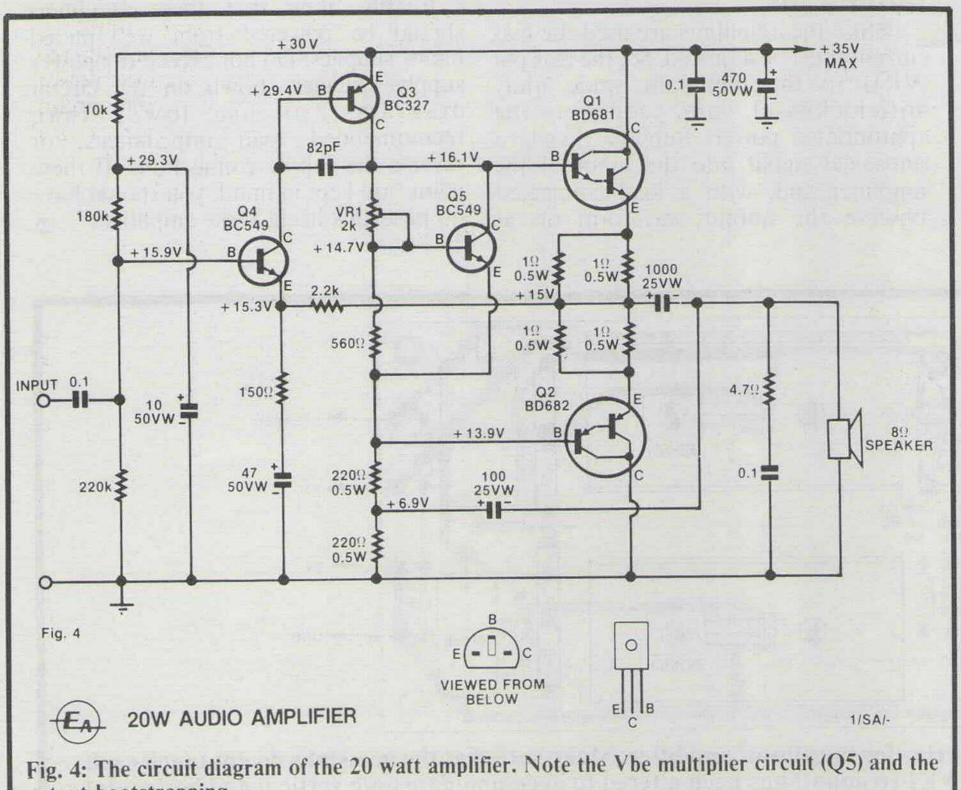


Fig. 4: The circuit diagram of the 20 watt amplifier. Note the Vbe multiplier circuit (Q5) and the output bootstrapping.

20W amplifier

Now let's turn our attention to Fig. 4. Although this circuit is slightly more complex than the lower-powered version, the same general principles apply.

The input stage is virtually identical and bias is provided to the whole amplifier in the same way. The most obvious differences are around the output stage where Darlington transistors have been used. These transistors were chosen because they can supply a higher current without requiring much more drive, since they have a very high beta. They also allow greater power dissipation than the transistors used in the other version.

A different form of load bootstrapping has been used in the bigger amplifier. Instead of connecting one end of the collector load resistor for Q3 direct to the output, we have a split load, consisting of two 220Ω resistors. The junction of these two resistors is connected to the output via a 100μF/25VW capacitor.

From here on, the principle of bootstrapping the collector load of Q3 is the same as for the smaller amplifier. Because of emitter followers Q1 and Q2, there is little difference in signal voltage between the base of Q2 (and Q1) and the output. Therefore, very little signal current flows in the collector load resistors for Q3 and thus it "sees" a much higher value of load.

The advantage of using the split load for Q3 together with the 100μF capacitor is that this amplifier can operate without any load being connected. Thus it can happily drive high value loads such as high impedance headphones. By contrast, the smaller amplifier will cease to operate if the load is disconnected, because that would interrupt the DC current flow through the 1kΩ collector resistor for Q3.

Another obvious change involves the substitution of Q5 for the resistor/diode network of Fig. 3. Q5 is called a Vbe multiplier because the voltage between the collector and the emitter is equal to some multiple of the base-emitter voltage of the transistor. The multiplying factor is dependent upon VR1 and the 560Ω resistor.

This technique provides better temperature compensation than an equivalent diode/resistor network. It's also more reliable and easier to adjust.

While Q5 compensates for the variation in Vbe of Q1 and Q2 with changing temperature, further measures are required to ensure freedom from thermal runaway (ie, eventual destruction). This could arise due to an increase in beta of Q1 and Q2 as they become hot or because of a rise in collector-base leakage current of these two transistors.

To prevent thermal runaway due to these causes, Darlingtons Q1 and Q2 are connected to the output via parallel-connected 1Ω emitter resistors. Now, if the current through Q1 and Q2 tends to rise because of heating effects, the voltage across the emitter resistors will also tend to rise and cancel a portion of the voltage developed across Q5. Thus the output transistors will be partly shut-down and no thermal runaway will occur.

The only other component which is not used in the 1 watt amplifier is the 82pF capacitor between the base and collector of Q3. This capacitor is included to roll off the gain of the amplifier at high frequencies. This is necessary to ensure that the amplifier will remain stable under all load conditions.

Construction

The 20 watt amplifier is assembled on a printed circuit board coded 84pa11. All components are mounted on this board, including the heatsinks.

Start by mounting all the low lying components such as resistors and capacitors, and then mount the transistors Q3, Q4 and Q5 to the board, leaving the output transistors (Q1 and Q2) off for the moment. The component overlay should be closely followed to ensure correct location and orientation of all components.

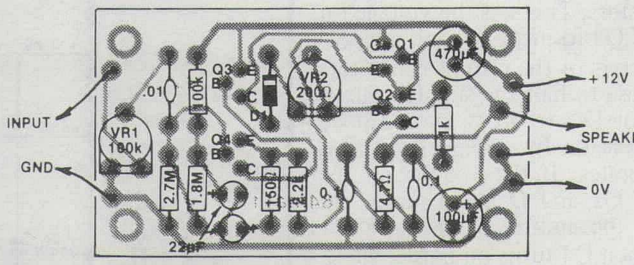


Fig. 5: Here is the component overlay for the 1 watt amplifier.

The heatsinks can now be mounted onto the board. Each heatsink should be mounted using a bolt through the hole not used for the transistor.

Make sure that the slot in the heatsink is directly over the transistor mounting holes, and that the heatsinks are not touching each other. The transistor leads can then be bent through 90 degrees, about 8mm from the body of the transistor. This done, smear the mating surfaces with heatsink compound, bolt the transistors to their respective heatsinks, and solder the leads.

There is no need to use mica insulating washers but note that the heatsink for the BD681 will sit at the supply voltage. This is because the metal tab of each output transistor is at collector potential. Whatever you do, don't let the heatsinks touch.

Setting up

Before the amplifiers are used the bias current must be adjusted. Set the bias pot (VR1) to the minimum value (fully anticlockwise), and connect the appropriate power supply. Feed a sinusoidal signal into the input of the amplifier and, with a load connected, observe the output waveform on an oscilloscope. Some crossover distortion should be apparent. Turn the pot clockwise until the distortion just disappears.

If you do not have access to test equipment, the quiescent current may be set in the following way. First, connect a jumper lead between the bases of Q1 and Q2. With a load connected (in the case of the 1W amplifier) measure the current drain at 12V and no signal. It should be close to 6mA. Now remove the jumper lead between bases of Q1 and Q2 and adjust VR2 so that the total current increases to 10mA.

In the case of the 20W amplifier, no load needs to be connected to set the quiescent current. Again with a jumper lead between the bases of Q1 and Q2, the current with 30V supply and no signal should be close to 31mA. Now remove the jumper and adjust VR1 to give a total current of 40mA. **Please note that the above quiescent current adjustment should only be measured at no signal with the input shorted to ground.**

Finally, note that these amplifiers should be powered from well-filtered mains supplies. Do not exceed the power supply voltages shown on the circuit diagrams, or use lower than recommended load impedances, or reverse the supply connections. If these points are kept in mind, you should have no problems using these amplifiers.

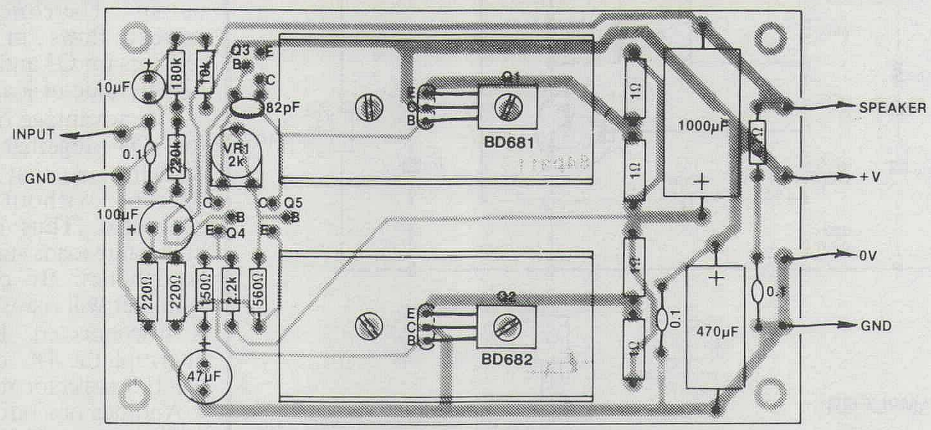
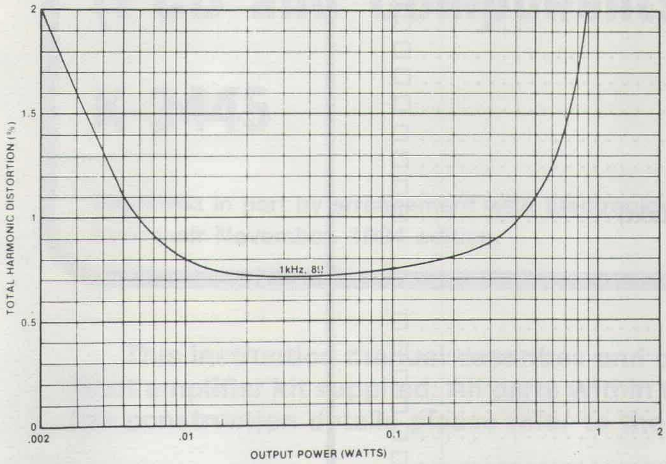


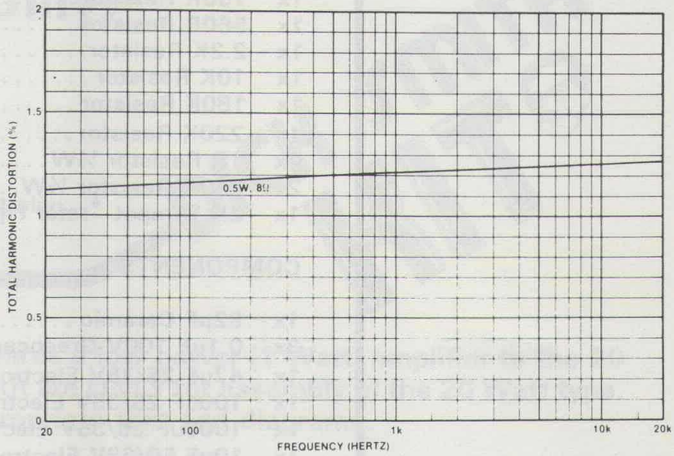
Fig. 6: Here is the printed circuit overlay for the 20watt amplifier. Make sure that the heatsinks do not touch each other. The copper tracking beneath VR1 (trimpot) has been altered to accommodate both vertical and horizontal trimpots.

Specifications: 1W Amplifier

Supply voltage	12 volts
Power output	1 watt RMS
Input impedance	100kΩ approx
Output impedance	0.7Ω approx
Signal-to-noise ratio	64dB with respect to 1 watt
Frequency response	3dB at 75Hz, −0.5dB at 100kHz
Load impedance	8Ω or greater
Quiescent current	5.6mA with 8Ω load



This graph shows the power versus distortion characteristic for the 1 watt amplifier. The measurements were made using a 12V supply.

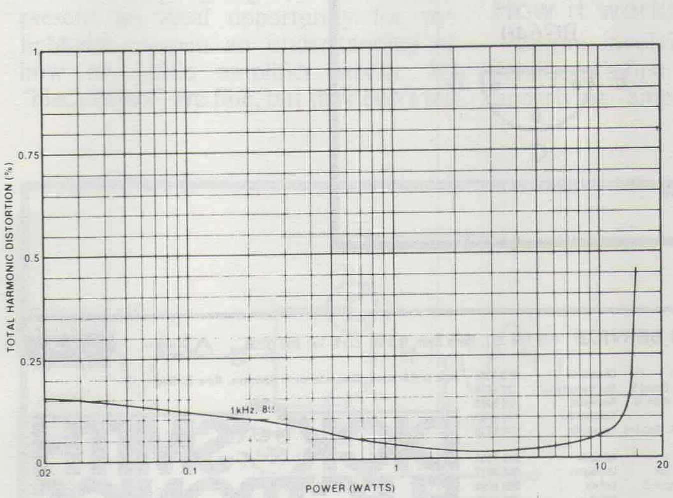


Here is the distortion versus frequency characteristic for the 1 watt amplifier.

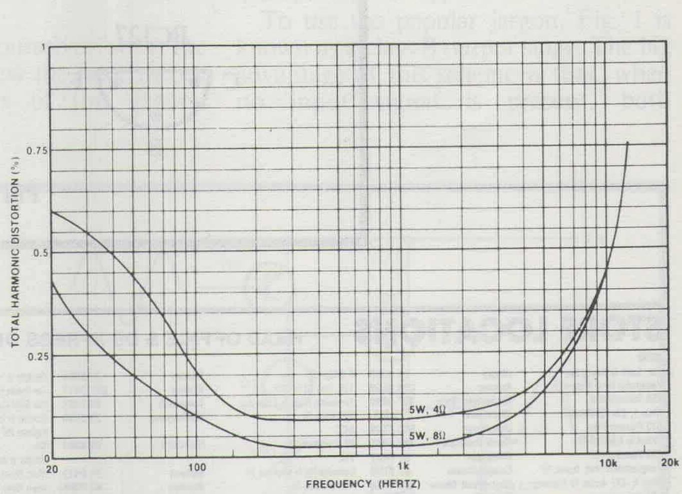
Specifications: 20W Amplifier

Input impedance		100kΩ approx
Output impedance		0.1Ω approx
Signal-to-noise ratio		58dB with respect to 1 watt
Frequency response		−3dB at 45Hz and 68kHz
Load impedance		4Ω or greater
Quiescent current		22mA with 8Ω load
Supply voltage	Power into 8Ω	Power into 4Ω
20V	4W	6.6W
30V	8W	12W
35V	15W	19W

Note: 35 volts is the maximum supply permitted.



This graph shows the distortion versus power characteristic of the 20 watt amplifier. The measurements were taken with the amplifier powered from a 30V supply.



Here is the distortion versus frequency characteristic of the 20 watt amplifier. The amplifier was powered from a 30V supply and was delivering a power of 5 watts into the load.

PARTS LIST

RESISTORS

Constructors please note that all resistors are ¼W unless specified.

- 1x 4.7R Resistor ☐
- 1x 150R Resistor ☐
- 1x 560R Resistor ☐
- 1x 2.2K Resistor ☐
- 1x 10K Resistor ☐
- 1x 180K Resistor ☐
- 1x 220K Resistor ☐
- 4x 1R Resistor ½W ☐
- 2x 220R Resistor ½W ☐
- 1x 2K Trimpot *refer Fig. 6 (text) ☐

COMPONENTS

- 1x 82pF Ceramic ☐
- 3x 0.1uF 100V Greencap ☐
- 1x 47uF 25/35V Electro ☐
- 1x 100uF 25/35V Electro ☐
- 1x 1000uF 25/35V Electro ☐
- 1x 10uF 50/63V Electro ☐
- 1x 470uF 50/63V Electro ☐
- 1x BD681 Transistor ☐
- 1x BD682 Transistor ☐
- 2x BC549 Transistor ☐
- 1x BC327 Transistor ☐

MISCELLANEOUS

Screws, nuts, washers, PCB pins, solder, heatsink compound, PCB, heatsinks

Constructors Please Note.

If you have been supplied with a BC640 instead of a BC327, please note pin orientation as shown below. Both these transistors will work perfectly in this kit.

Pin View