# Class One Sound Amplifier

**A single board, 20W per channel, high quality amplifier with inputs for disk, compact disk, radio, video and tape.**

GRAHAM NALTY

With the Class One Sound Amplifier, the standard of construction you can achieve without the use of specialist tools is equal to the very best manufactured amplifiers. The DM20 (Dual Mono 20W) has been designed as a very special project. It is not simply another amplifier project, but designed to be the best that could be produced using today's technology, in terms of value for money, sound quality, presentation and the education value of construction and testing.

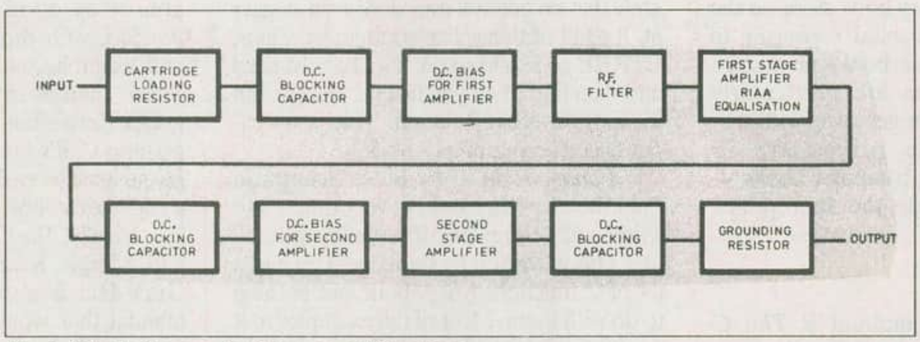



*Fig. 1. Block diagram for the preamplifier stages.*

## Sound Quality

The DM20 has several features which improve its sound quality over amplifiers which the reader might consider comparable.

1. Oversize power transformer, rated at twice the full power output of both channels together.

2. Separate transformer windings, rectifiers and reservoir capacitors for left and right channel for improved stereo performance.

3. Separate rectifiers and reservoir capacitors for low and high current parts of power amplifier and for preamplifier.

4. Large heatsink for low temperature generated distortion as well as reliable operation.

5. T0220 driver transistors for low temperature generated distortion.

6. Cascode circuitry in drive stage of power amplifier for greater linearity and improved high frequency performance.

7. Special two-transistor input stage for improved sound quality (see later explanation).

8. Power amplifier negative feedback AC path taken outside the output capacitor.

9. High quality metal film resistors and plastic film capacitors used extensively.

10. Two stages of power supply filtering for preamp.

11. Special disk circuit designed for good power supply ripple rejection.

12. High quality plated switches used for signal switching.

## Educational Value

The DM20 provides excellent opportunities for electronics teaching. The most attractive feature is the high motivation of students to complete it so they can use it. Also the preamp and power amplifier stages have different levels of complexity and can be used on their own for students at different levels.

Students wishing to gain experience of making printed circuit boards will find the preamp section easy for making their own layout while a single channel of the power amplifier will provide a more exacting challenge for experienced students. A major problem for educational establishments is the cost of purchasing components for a project. Savings can be made by using 5 per cent carbon resistors in place of metal film resistors, and electrolytic capacitors in place of polyester capacitors (provided the correct polarity is observed, but not C3, C4, C103, C104) and substituting the switch system for one four-pole two- way rotary plus a toggle for tape monitor.

Single winding transformers can be used provided one lead is connected to both fused input lines and the other is connected to both non-fused lines. Such measures will reduce the sonic performance of the amplifier but the amplifier will still work. Note: test voltages may be different to those measured using a transformer with separate windings.

The use of separate power supplies for each stage makes testing of the amplifier a more logical process and enhances its value as a training exercise.

## Circuit Design

The circuit uses standard components which are easily obtainable. Many readers might be expected to see the latest audio integrated circuits, but there are several good reasons why discrete components are used. Firstly, the use of integrated circuits would require more complex power supplies. Secondly, building the amplifier with integrated circuits would make the project less useful for educational and training purposes. Thirdly, I see no reason why the use of integrated circuits could improve the sound quality.

Tone controls are not included in this design.

## Preamp

The preamplifier is a simple but very effective circuit. Its operation is very easy to understand and it contains three stages:

Stage 1: common emitter amplifier using *npn* transistor.

Stage 2: common emitter amplifier using *pnp* transistor.

Stage 3: emitter follower.

All other components are included to enable these three stages to work effectively and a full block diagram is shown in Fig. 1. The preamplifier circuit diagram is shown in Fig. 2.

1. Cartridge loading resistor R1. This has two functions. The first is to set the DC potential of the input side of C1 to ground so that no large transients are generated when a cartridge is connected, and the second is to provide the required resistive load to the cartridge to enable the cartridge to perform at its best. The frequency response of the cartridge will vary with varying load resistance.

2. DC blocking capacitor C1. This allows all audio frequency signals to pass, but blocks DC. This is necessary because the circuit requires different voltages between the input and the base of TR1.

3. DC bias circuit D1, D2, R3, R4.

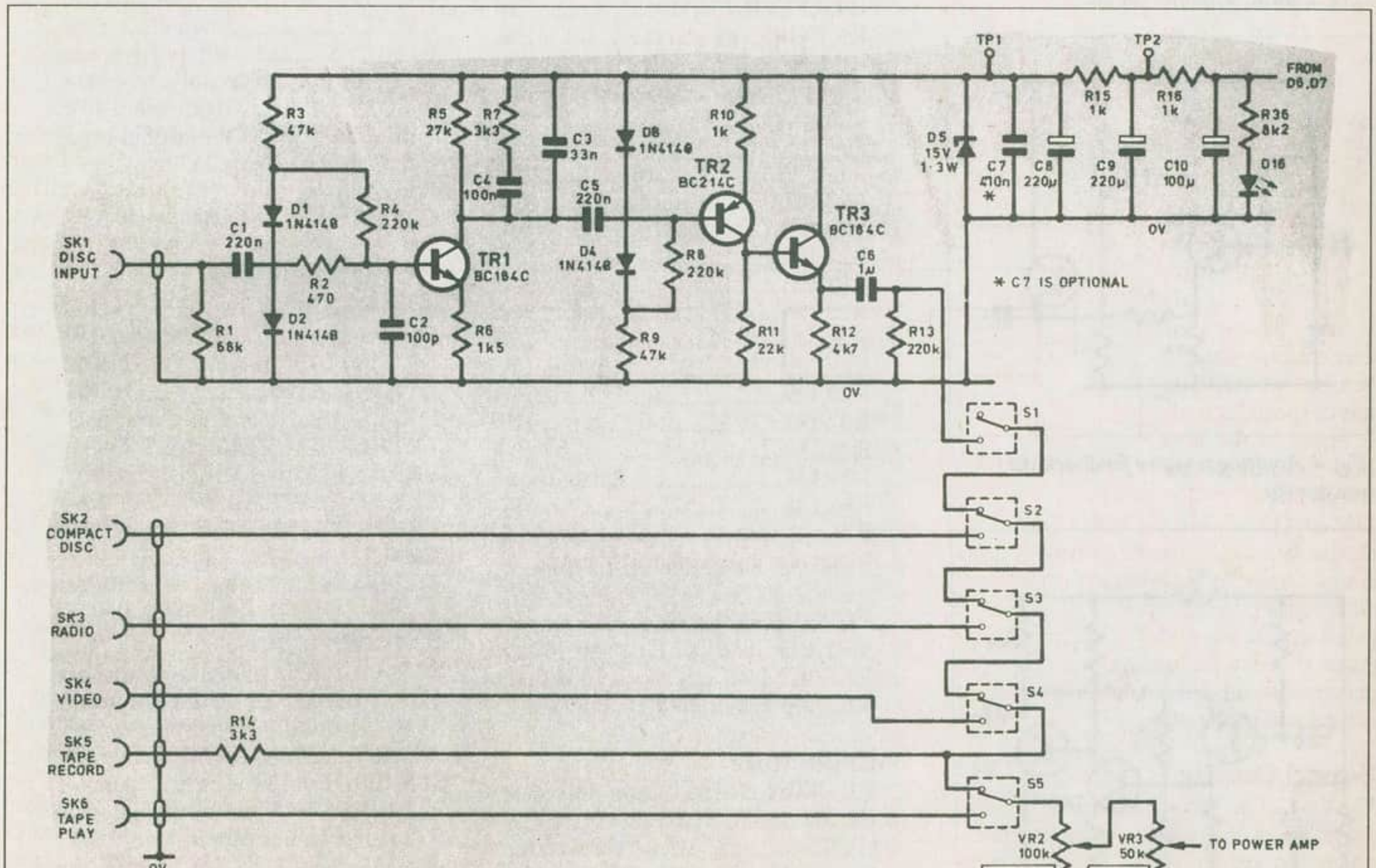



*Fig. 2. The schematic for the preamplifier stages, showing inputs for disk, CD, tuner, and tape.*

Transistor TR1 requires a DC voltage of around 0.8V to 1.0V to work properly. Diodes D1 and D2 are conducting with a current taken from the supply via R3. This gives a voltage close to 1.2V at the anode of D1. Current flows via R4 to the base of TR1. The product of TR1 base current XR4 gives a voltage of around 0.3V to set the base of TR1 at around 0.9V.

4. Radio frequency filter R2, C2. This prevents any radio frequency signals which see the leads from the cartridge as an aerial being demodulated by TR1.

5. First amplifier stage TR1, R5, R6, R7, C3, C4. The DC current through TR1 is determined by the DC voltage at the base. The base emitter junction will have a volts drop of 0.6V and so the voltage across R6 will be around 0.3V. As the transistor has a high gain, the DC current through R5 will be the same as through R6. A low frequency AC signal at the base of TR1 will be amplified by the ratio R5/R6, but as the frequency of the signal increases the gain will decrease, due to the effects of C3 and C4/R7. This frequency selective circuit provides equalization for records which are recorded at higher level at high frequencies to reduce the overall noise.

6. DC blocking capacitor C5 enables DC potentials to be different at either side while allowing all audio frequency signals to pass.

7. DC bias D3, D4, R8, R9. Operates as in paragraph 3 above, but is referenced to the supply.

8. Second amplifier TR2, R10, R11. Operates as TR1 but in reverse polarity and constant gain at all frequencies.

9. Emitter follower TR3, R12. This reduces the output impedance of the circuit. If this were omitted and a tape deck were connected at the output, the gain of the circuit would be considerably reduced by the effect of the tape input impedance in parallel with R11.

10. DC blocking capacitor C6 prevents

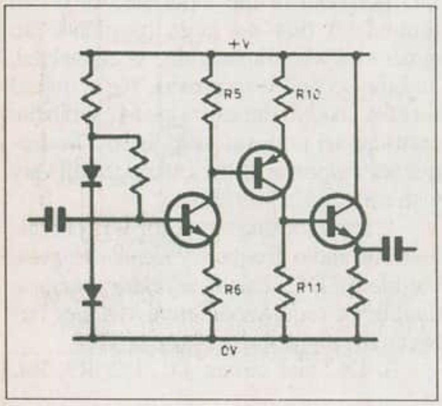



*Fig. 3. Basic amplifier circuit.*

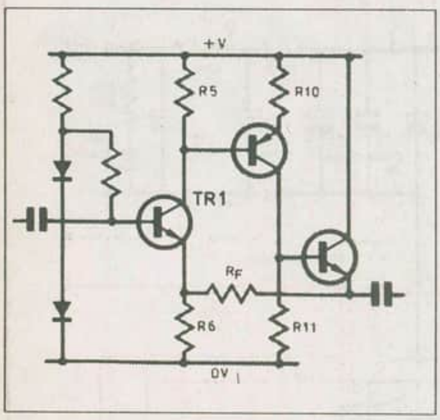



*Fig. 4. Applying negative feedback via resistor $R_F$.*

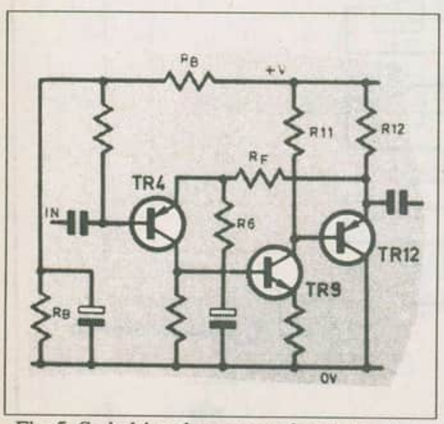



*Fig. 5. Switching the npn and pnp transistors around.*

# PARTS LIST

### Resistors

R1,101 .......... 68k
R2,102 .......... 470
R3,9,24,103,104,124 .......... 47k
R4,9,13,104,108,113 .......... 220
R5,19,105,119 .......... 27k
R6,106 .......... 1k5
R7,14,107,114 .......... 3k3
R10,15,16,17,21,
110,115,116,117,121 .......... 1k
R11,20,30,111,120,130 .......... 22k
R12,112 .......... 4k7
R18,118 .......... 100k
R22,122 .......... 1M
R23,123 .......... 100
R25,125 .......... 22
R26,31,126,131 .......... 220
R27,28,127,128 .......... 1 ohm 1W
R29,129 .......... 10
R32,132 .......... 680 1W
R33,133 .......... 330
R34,134 .......... 22k carbon
R35,135 .......... 47 5W
R36 .......... 8k2
Metal film unless otherwise stated.

### Potentiometers

VR1,101 .......... 1k trimmer
VR2,102 .......... 100k dual
VR3,103 50k or 100k dual audio

### Capacitors

C1,5,101,105 .......... 220n polyester
C2,102 .......... 100p polystyrene
C3,103 .......... 33n 5% polyester
C4,104 .......... 100n 5% polyester
C6,14,106,114 .......... 1u polyester
C7,107 470n optional bypass
C8,9,108,109 220u elect. 35V
C10,19,21,110,119,121 100u elect. 63V
C11,22,111,122 .......... 470n polyester
C12,112 .......... 220p polystyrene
C13,113 .......... 47u elect. 63V
C15,115 .......... 10p polystyrene
C16,116 .......... 100n polycarbonate
C17,117 .......... 1000u elect.40V
C18,20,118,120 470n optional bypass
C23,123 100u elect.63V elect. optional bypass
C24,124 .......... 3300u elect.63V

### Semiconductors

D1-4,8,9,101-104,108,109 .. 1N4148
D5,105 .......... 15V Zener 1W
D6,7,10,11,106,107,110,111 1N4002
D12-15,112-115 .......... 1N5401
D16 .......... red LED
TR1,3,5,9,101,103,105,109 2N3904
TR2,4,6,102,104,106 .......... 2N3906
TR7,107 .......... BD244C or TIP42A
TR8,10,108,110 BD243C or TIP41A
TR11,111 .......... TIP121
TR12,11 .......... TIP126

### Miscellaneous

SK1-6,101-106 Quad phono sockets
S1-5,101-105 .. 2-pole pushbuttons
S6 rotary double pole power switch
SK7,107 ...... 4mm socket terminals
SK8,108 stereo headphone socket
FS1,101 5A PCB mount pigtail fuses
FS2 panel mount fuse holder, 2.5A fuse
T1 toroidal transformer, Hammond 180J70 35-0-35 volt, 90VA (see text for substitution).

the DC at TR3 emitter reaching the output.

11. DC grounding resistor R13 holds the output at zero DC voltage.

## Power Amplifier

To the newcomer the power amplifier may look rather complex. It is quite simple, but has a number of features added to make it work exactly as we require it. If we look at the circuit of Fig. 3, we see a circuit that looks like the preamp, but omits the frequency selective network on TR1 collector and the DC blocking capacitor between the two transistors. The gain of the circuit can be calculated:

$$\text{Gain} = (-R5/R6)(-R11/R10)$$

Now look at Fig. 4. Negative feedback is applied to the input via $R_F$. If the current fed back via $R_F$ is much greater than the current through TR1, the voltage at the emitter of TR1 can be approximated at $R6/(R6+R_F)$ times the output voltage. If the open loop gain defined by equation (1) is much greater than $(R6+R_F)/R6$ then we have a negative feedback amplifier which has the advantage of less harmonic distortion and a wider frequency response than the circuit without feedback. The theory of negative feedback is an important part of any basic electronics course and can be covered far better by op amp theory, so I do not wish to go into it here. Comparing Fig. 4 with Fig. 5, you

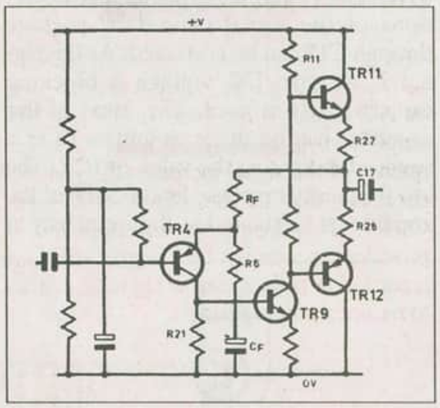



*Fig. 6. Adding a complementary output stage (TR11, 12).*

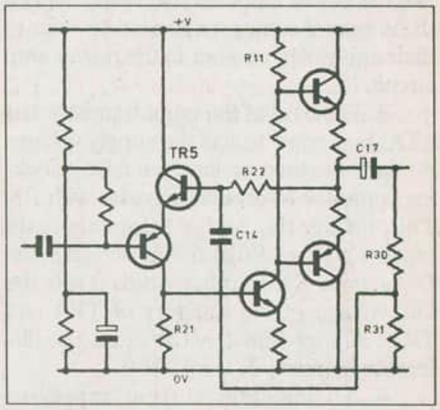



*Fig. 7. Improving the distortion factor of Fig. 6.*

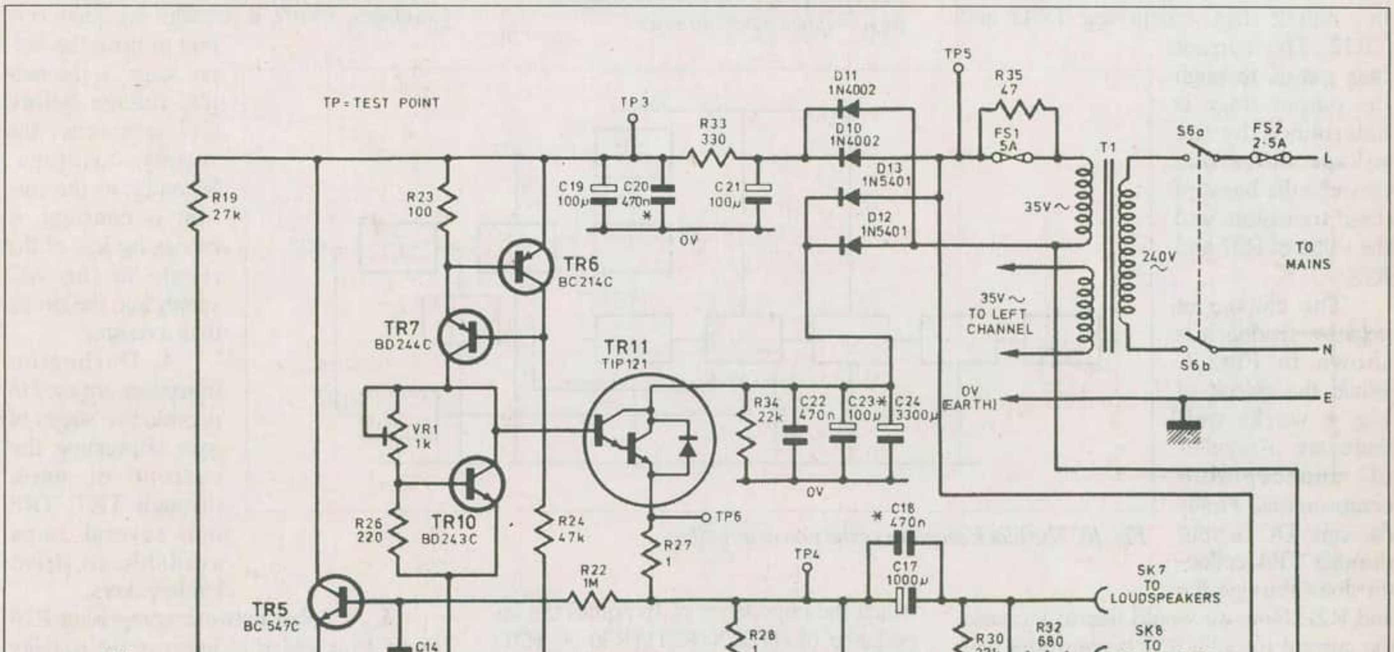



*Fig. 8. Complete circuit schematic for the power amplifier section.*

will notice that Fig. 5 has a number of changes:

1. The circuit has been inverted by changing the *pnp* and *npn* transistors around.

2. As the circuit is now looking more like the power amplifier, we have changed the names of some components to refer to their equivalent number in the power amp circuit.

3. The base of the input transistor has a DC bias equal to half the supply voltage. At the same time we have put a DC blocking capacitor to ground in series with R6. This makes the audio frequency gain equal to $(R_F+R6)/R6$ but reduces the DC gain to X1. In other words it sets the DC voltage of the emitters of TR4 and TR12 at approximately the same, the difference being $R_F \times I_C$(of TR4).

4. To maintain current supply to TR12, R12 has been reinstated.

In Fig. 6, emitter followers TR12 and R12 have been replaced by a complementary output stage comprising TR11 and TR12. The current that passes through the output stage is determined by the voltage difference between the bases of these transistors and the value of R27 and R28.

The change in negative feedback is shown in Fig. 7. While the circuit of Fig. 6 works well there are a number of unacceptable compromises. Firstly the same DC current through TR4 collector flows through $R_F$ and R21. Now we would like to increase the current through R21 because this will increase the slew rate (the fastest change of voltage with time, which is related to the highest frequency that can be reproduced) of the amplifier. But this will give a large DC voltage drop across $R_F$, which will reduce the maximum output voltage. Secondly, we have two electrolytic capacitors $C_F$ and C17 in the signal path. As electrolytic capacitors are known to distort sound quality, we would really like to eliminate them or reduce their effects.

The circuit of Fig. 7 achieves all these objectives, and tests with a completed amplifier show that the sound quality is considerably improved. The addition of TR5 enables the current through R21 to be increased. At the same time the current through R22 is greatly reduced by a factor of the HFE (DC gain) of TR5. This enables R22 to be increased. R30 and R31 provide a fraction of the output after C17 to be fed back to the input so that distortions of the signal caused by passage through C17 can be corrected. As this signal is at zero DC voltage a blocking capacitor C14 is used. The value of this capacitor can be made as low as 1u as a result of increasing the value of R22. The low frequency response limit (-3dB) of the amplifier is calculated at the frequency at which the impedance of 1u equals the impedance of (R22 X R31)/(R30 + R31). This is equal to 16Hz.

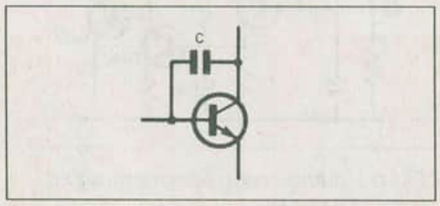



*Fig. 9. Adding a capacitor to maintain high frequency performance.*

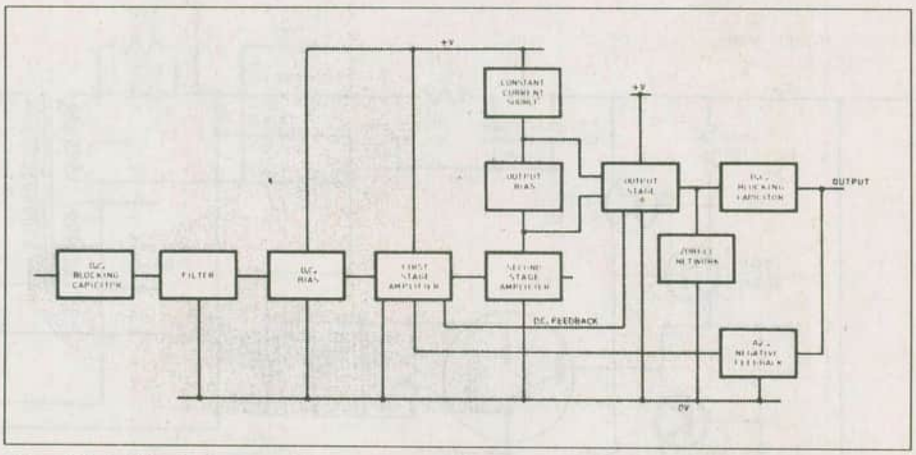



*Fig. 10. The block diagram of the power amplifier.*

## Power Amp Circuit

The completed power amplifier circuit is shown in Fig. 8. If we compare this with Fig. 7 we see a number of further changes, which all contribute to the high performance of the circuit.

1. TR8 is added; this has several advantages. The cascode connection improves both the linearity of TR7 and its high frequency performance. By maintaining the collector voltage of TR9 almost constant, we improve the linearity because the gain of the transistor changes by a small amount due to large changes in collector voltage. Also, transistors have capacitive effects between collector and base, and the effect of varying the collector voltage is to apply feedback (see Fig. 9).

In the actual circuit a real capacitor C15 is used to control the high frequency performance in order to maintain stability. Another advantage is that while a high gain low power transistor is used for TR9, a high power transistor can be used for TR8, and its gain is not so crucial, but the thermal sinking effect of its metal tab reduces temperature generated distortion.

2. A network comprising VR1, R26 and TR10 provides accurate biasing of the output transistors. Mounting TR10 on the heat sink not only improves reliability by reducing the bias voltage when the output transistors get hot, but also improves the sound as a result of lower temperature generated distortion.

3. R11 is replaced by a constant current circuit TR6, TR7, R23; this has two advantages. Firstly, it provides adequate current to drive the output stage as the output voltage before C17 approaches the supply voltage. Secondly, as the current is constant, it carries far less of the ripple in the AC supply into the circuit than a resistor.

4. Darlington transistors are used to provide two stages of gain converting the current of 6mA through TR7, TR8 into several amps available to drive loudspeakers.

5. A Zobel network comprising R29 and C16 is added to improve the stability of the amplifier at high frequencies. Without it the amplifier could turn into a high frequency oscillator under some adverse load conditions.

A block diagram of the power amplifier is shown in Fig. 10. As all the information on how each stage works has been covered, a summary is not required. However, it would prove an excellent teaching exercise to identify each part in each block and describe its function as we did earlier in the preamps.

*The amplifier project will be continued next month, with final details of construction, wiring and testing.* ■

# Class One Sound Amplifier Part2

## Constructional details for last month's audio amp.

GRAHAM NALTY

Last month we discussed the problems associated with amplifier design and looked at the circuit stages in detail. This month we conclude by setting out the construction procedure and final testing.

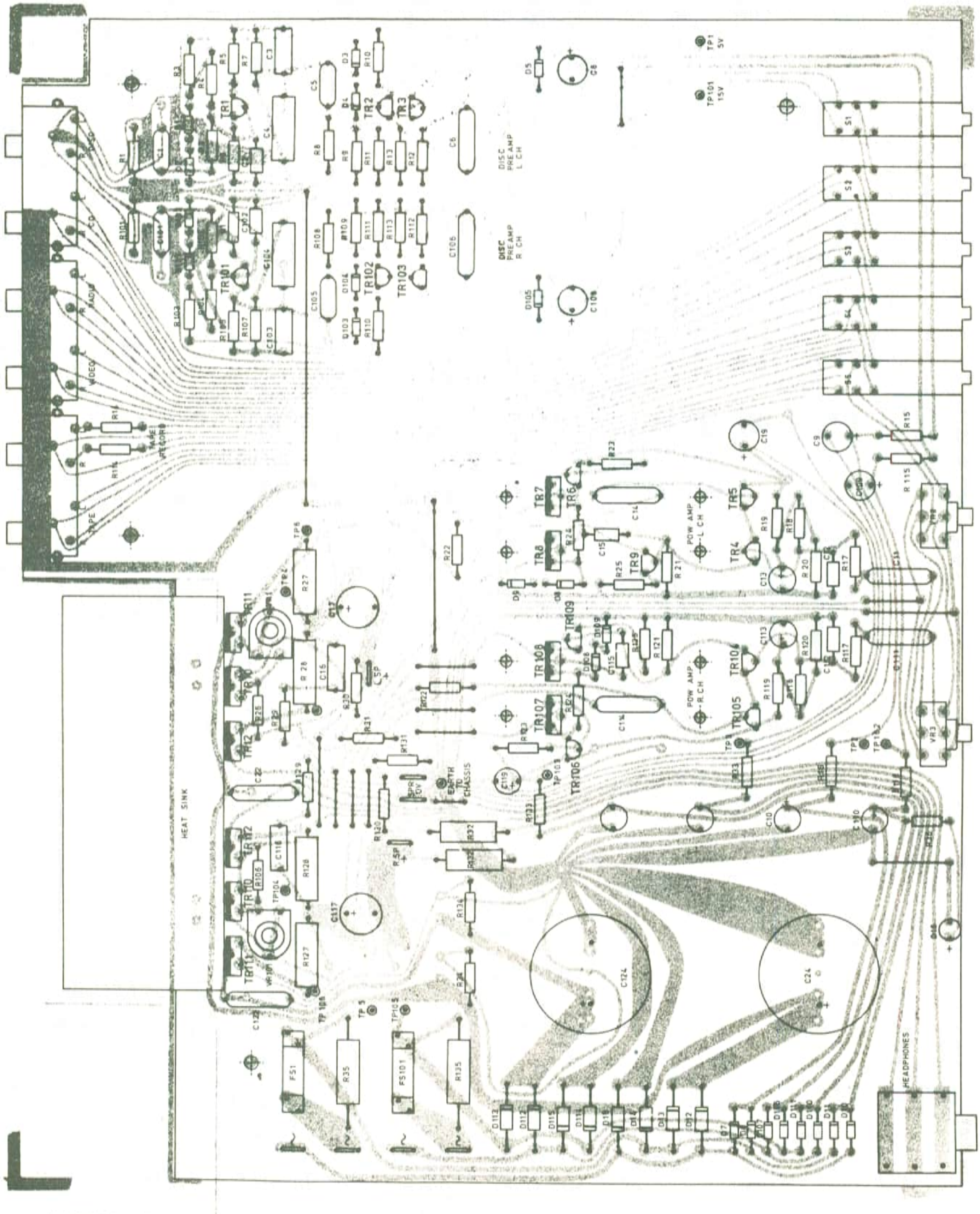
### Grounding

In audio amplifiers the grounding circuits are a very important part of the design. Ideally, every single ground return should be taken separately to a central "star" ground. In practice, some grouping is permissible, but poor grounding techniques in an amplifier will result in hum, instability and degradation of the sound. In this amplifier, all the ground returns have been looked at in far more detail than I can write about here, and the result can be seen in the way in which they have been connected in the printed circuit board (PCB) layout.

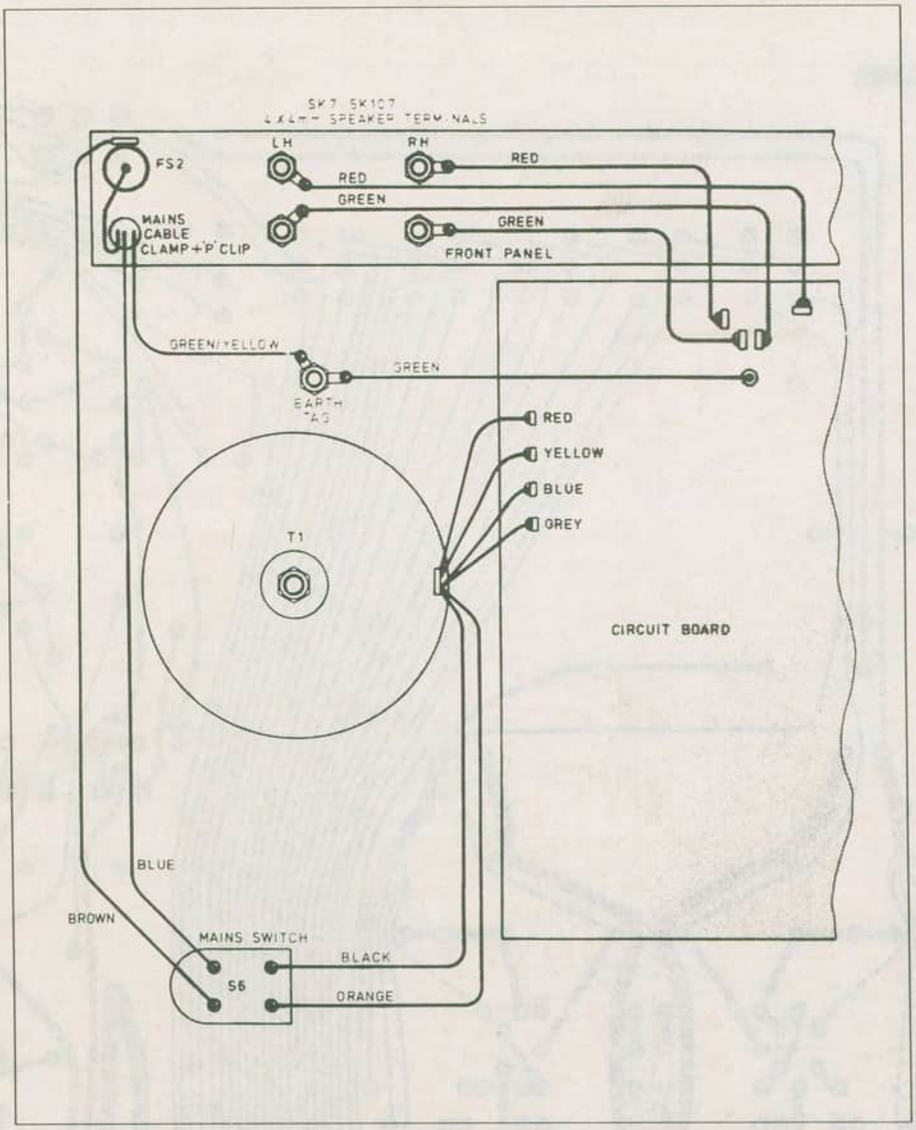
### Building the Amplifier

1. Insert and solder all PCB pins.
2. All diodes except D16 (LED).
3. All 1/4 watt metal film resistors.
4. Insert all wire links using resistor lead offcuts, except for L1 and L10 which should be made from tinned copper wire.
5. All polystyrene capacitors.
6. Attach heat sink to PCB using 3/8 inch bolts and insulating washers.
7. Slot TR-10-TR-12, TR110-TR112 into the board and line up the holes in the tabs with the threaded holes in the heatsink.
8. Attach the transistors to the heatsink using a bolt, washer and nylon bushing, after placing a thermally conducting electrically insulating washer or silicone heatsink compound between transistor and heatsink.
9. Attach VR1, VR101, C22, C116, C122 to PCB
10. Attach R27, R28, R127, R128 to PCB
11. Attach all remaining semiconductors including D16.
12. Attach all polyester capacitors (NB, C7, C18, C20, C23, C107, C118, C120, C123 are optional).
13. Attach all 1/4 inch blade connectors, fuse and remaining resistors.
14. Attach all electrolytic capacitors.
15. Make certain that each and every electrolytic is connected in the right polarity. Check a second time because a wrongly connected capacitor can be damaged when the power is connected.
16. Attach phono sockets, switches, potentiometers and headphone socket.

Now that the board is complete, set



*The printed circuit board component layout for the Class One amplifier, not full size.*




*Interwiring from case mounted components to the PCB.*

VR1 and VR101 fully clockwise and remove fuses FS1 and FS101.

## Case

Next assemble the case, leaving the rear panel off, and attach the mains transformer and all the parts shown in Fig. 11. The PCB can now be attached to the floor of the case using 3/4 inch threaded pillars with bolts at each end. Attach the rear panel to the case and make all the necessary connections to the PCB (Four 1/4 inch blade connections from the transformer, four 1/4 inch blade connections from the speaker terminals and the chassis ground connection, which is soldered to the 1mm dia. pin.

## Testing the Amplifier

Check that fuses FS1 and FS101 have been removed from the board and that VR1 and VR2 are turned fully clockwise.

Switch on and measure the voltages at test points TP1 to TP4 and TP101 to TP104. The slightly lower readings on the right channel (TP101 to PT104) are due to the effect of the LED drawing current from the right channel supply only.

The most difficult part of building the amplifier is setting the output stage quiescent current. This is achieved on the left channel by turning VR1 counterclockwise, and on the right channel by turning VR101 counterclockwise. If you have a digital meter or oscilloscope you can set the current by turning VR1 (VR101) until about 40mV is observed across R27/R28 and R127/R128. Alternatively, you can set the output stage quiescent current using only a moving coil meter on its AC voltage range. Connect the meter across R35 (left channel) and R135 (right channel) and adjust VR1(L) and VR101(R) until the reading across each register increases by one volt AC. This will give a quiescent current of 20mA through the output stages. If all the readings appear correct, switch off, replace fuses FS1 and FS101, switch on again and start listening.

## Sound Quality

Readers who are interested in building the amplifier will be interested in how it sounds, so I borrowed a pair of Richard Allen CD5 loudspeakers to assess its performance with a high quality speaker of recent design. The results were very rewarding. Stereo imagery was really good compared with one of my earlier designs, which shared the same power supplies for each channel.

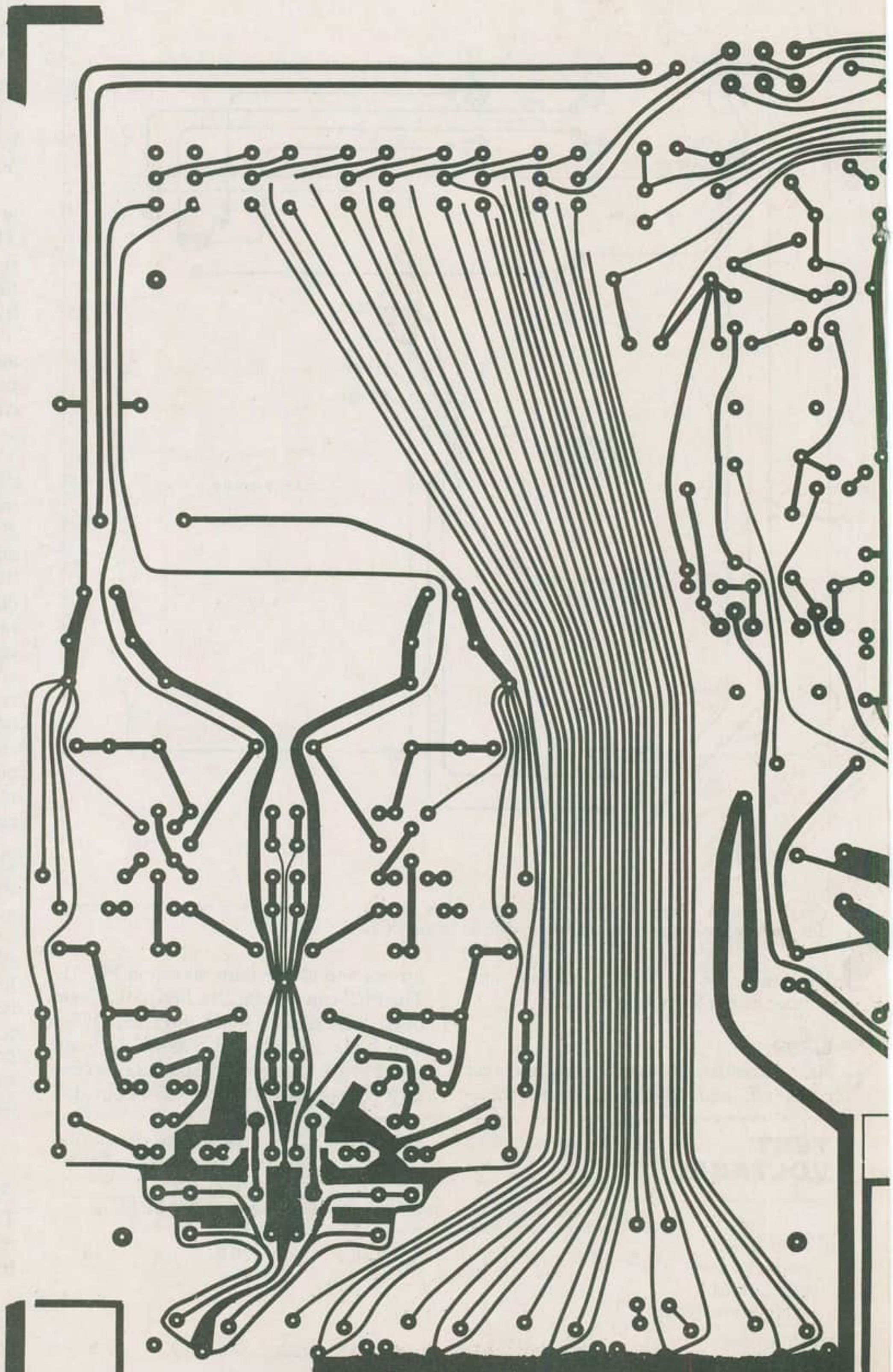
## Parts Availability

The printed circuit diagram is enclosed for reference; it is copyrighted by Audiokits Inc.

Complete amplifier kits, plus individual components, special component packs and printed circuit boards are available from Audiokits, 6 Mill Close, Borrowash, Derby DE7 3G0, England. Send a large envelope plus three International Reply Coupons for details.

| TEST VOLTAGES | TP1 L | TP101 R | TP2 L | T201 R | TP3 L | TP103 R | TP4 L | TP104 R | Across R35 L | Across R135 R |
|---|---|---|---|---|---|---|---|---|---|---|
| A With fuses removed and VR1, VR101 set fully clockwise | 14.5 | 14.7 | 31.5 | 31.3 | 45.7 | 45.2 | 23.2 | 28.8 | 1.4 | 1.55 |
| B With fuses removed and VR1, VR101 set to 20mA output stage current | 14.6 | 14.7 | 30.2 | 30.1 | 42.9 | 42.8 | 22.0 | 22.0 | 2.4 | 2.5 |
| C With fuses inserted and 20mA output stage current | 14.6 | 14.7 | 33.5 | 33.5 | 49.5 | 49.5 | 24.9 | 24.7 | | |

* All measurements from TP1 to TP4, TP01 to TP104 are made using a digital meter. Measurements across R35, R135 with a moving coil meter on a.c. volts range.



*The main board for the Class One power amp; see text for availability.*

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