

SIMPLE AUDIO CIRCUITS



Part 1 – Introduction and Power Amplifiers

RAYMOND HAIGH

A selection of "pic-n-mix" low-cost audio circuits – from preamplifier to speaker!

WHATEVER their particular area of interest, most electronics enthusiasts encounter the need to amplify and reproduce audio signals. The final stages of radio receivers, intercom units, security and surveillance installations, or just a hankering for a big sound from a Walkman or portable CD player, all involve audio amplification and a speaker system. And the amplification usually goes hand-in-hand with some form of signal processing.

Music reproduction calls for a wide frequency response and tone-control circuitry. Speech communication, especially

under difficult conditions, is greatly clarified if the frequency response is curtailed.

This short series of articles describes simple, but effective, ways of meeting these different requirements. Although the circuits are capable of a good standard of reproduction, they will particularly interest the constructor who looks for plenty of performance per pound or dollar.

We begin with the power amplifier. Six alternatives are given and, with the requirement of maximum performance for minimum cost and effort, they are all based on widely available integrated circuits (i.c.s):

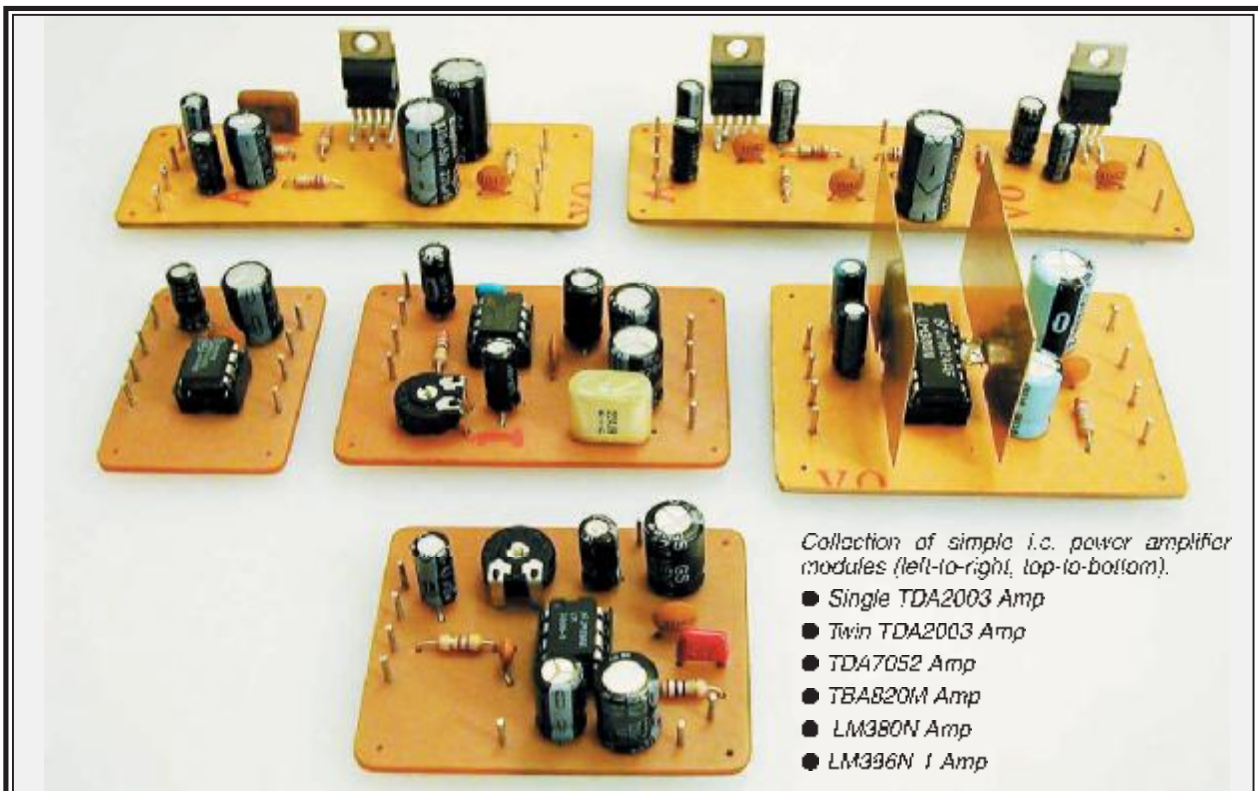
HOW MUCH POWER?

Before considering the various circuits, it is worthwhile to reflect on the amount of power actually needed.

Clear reproduction in Walkman type earphones of reasonable sensitivity can be achieved with a miserly milliwatt (0.001W). When listening to talk programmes in a quiet domestic setting, the power fed to the speaker will hover around 50mW (0.05W), and this is ample for the operator of a communications receiver whose ears are closer to the sound source.

During the valve era, ten watts was considered adequate for the realistic reproduction of orchestral music, and some experts suggested a figure as low as five. One watt of power delivered to a

- LM386N-1
- TDA7052
- TBA820M
- LM380N
- TDA2003.



Collection of simple i.c. power amplifier modules (left-to-right, top-to-bottom).

- Single TDA2003 Amp
- Twin TDA2003 Amp
- TDA7052 Amp
- TBA820M Amp
- LM380N Amp
- LM386N 1 Amp

reasonably efficient speaker will produce a loud sound, a *continuous* five watts is becoming deafening, and ten will rattle windows. This assumes single channel, or mono, reproduction in a normal living room. The impact is, of course, greater with a stereo system.

This is at odds with the high power ratings of many of the quality amplifiers currently advertised. The desire for a big reserve of power, the low efficiency of some modern speakers, and different ways of measuring output, may account for the difference.

Output is variously rated as music power, sustained music, speech and music, and sinewave power. To add to the confusion, the figures are quoted at different distortion levels. The standard most often used when valves were commonplace, and the one adopted in this article, is the r.m.s. (root mean square) value of a continuous sinewave. This gives the lowest rating and is the most realistic expression of the amplifier's ability to deliver power into a load (speaker).

An increase in output power is reflected as much, if not more, in the cost of the power supply as it is in the actual amplifier. Because the theme of this article is good performance at modest cost, the most powerful amplifier described is rated at 12.5W r.m.s.

DISTORTION

Manufacturers of power-amplifier integrated circuits and modestly priced hi-fi systems (which invariably incorporate devices of this kind) usually rate the maximum power output at 10 per cent distortion. At this level there is a very noticeable roughness to the sound and clipping of the waveform on loud passages.

The power output levels quoted here have been measured just before the onset of clipping or any noticeable distortion of the output waveform. They are somewhat lower than the figures quoted by the i.c. manufacturers, but they do represent the highest output, free from audible distortion, that the device can deliver for a particular supply voltage and load.

NOISE

Modern power amplifier i.c.s have a very low noise level. Manufacturers usually define this internally generated electrical noise as an equivalent signal voltage at the input, but this doesn't give the average experimenter an immediate impression of its audible effect.

Accordingly, the devices described here were tested by disconnecting the signal source, turning the input or volume control to maximum, and then listening to the output on a pair of sensitive, Walkman type earphones.

In all cases the noise was no more than barely audible. The two devices which can be configured for high gain (LM386N and TBA820M) did produce a faint, but audible, hiss when the gain was set at maximum. The hiss was also noticeable with a loudspeaker connected.

However, when the gain preset was turned back a little, these i.c.s became as silent as the rest. Some constructors may need the highest possible gain, and details will be given later of measures which can be taken to eliminate the noise.

STABILITY

Provided a few basic precautions are observed, the amplifiers are all unconditionally stable. Most i.c.s of this kind have a ground connection for the input circuitry and a *separate* ground pin for the output stage.

The printed circuit board (p.c.b.) layouts have been designed to maintain this isolation, and care should be taken to ground the signal inputs and connect the negative power supply lead to the designated points on the board. Failure to do this could result in "motor boating" (low frequency instability).

Input leads should be *screened* to avoid mains hum and radio frequency (r.f.) signal pick up. Speaker leads should be twisted together to minimise external fields. Input and output leads should be spaced as far apart as possible: this is particularly important when the LM386N and TBA820M are set for high gain.

All of the circuits include high and low frequency bypass capacitors across the supply rails. The former minimise the possibility of r.f. oscillation: the latter avoid low frequency instability when long power supply leads are used, or when batteries are ageing.

HIGH FREQUENCY RESPONSE

The bandwidth of the amplifiers extends into the r.f. spectrum, and this makes the devices vulnerable

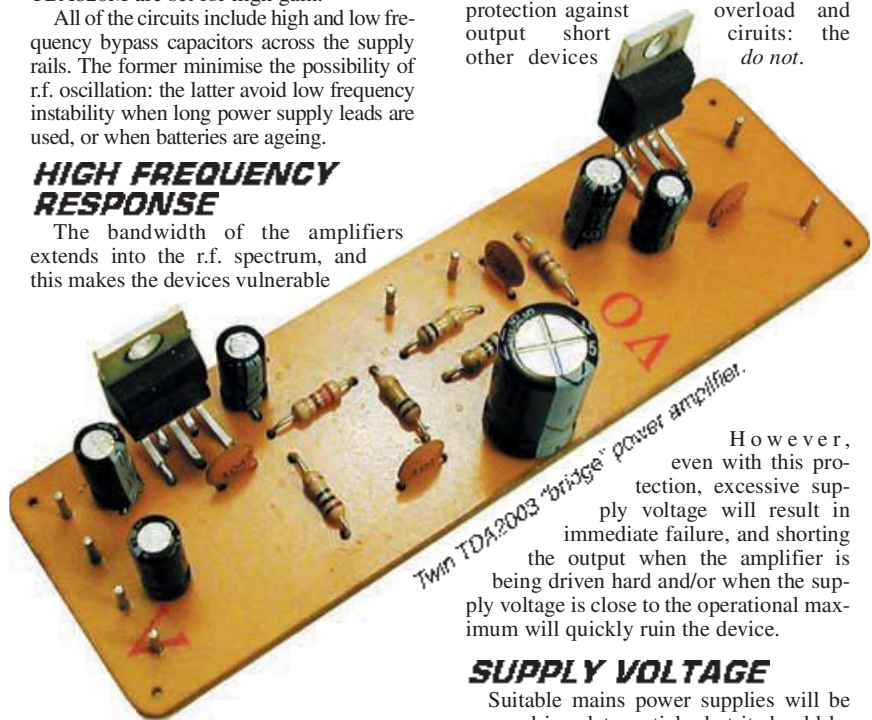
overloads them, causing distortion and loss of clarity.

Indeed, if the amplifier is being used primarily for speech, clarity can be much improved by rolling-off the frequency response below 300Hz, and an even lower value of coupling capacitor, say 100 μ F or even 47 μ F, would be of benefit. Readers seeking quality music reproduction at low power, via a speaker of reasonable size, should increase the coupling capacitor to say 1000 μ F.

This relationship between coupling capacitors and frequency response will be considered more fully in the next article.

DEVICE PROTECTION

The integrated circuits covered here are electrically robust but they are by no means indestructible. The TDA7052, LM380, and the TDA2003 incorporate protection against overload and output short circuits: the other devices do not.



However, even with this protection, excessive supply voltage will result in immediate failure, and shorting the output when the amplifier is being driven hard and/or when the supply voltage is close to the operational maximum will quickly ruin the device.

SUPPLY VOLTAGE

Suitable mains power supplies will be covered in a later article, but it should be mentioned now that, off-load, d.c. output voltages rise to 1.4 times the a.c. voltage delivered by transformer secondaries. When using unregulated mains power supplies care should, therefore, be taken to ensure that the off-load voltage is always less than the maximum safe working voltage of the amplifier. *Never connect a working power supply to an amplifier without first checking its output voltage.*

ELECTRICAL CHARACTERISTICS

The electrical characteristics of the various devices are tabulated alongside the circuit diagrams (except one) for easy reference. Power output figures are based on measurements taken on a single, randomly purchased sample. For reasons already given, they are somewhat lower than the figures quoted by the manufacturers.

Recommendations are made regarding the speaker impedances to use with various supply voltages in order to keep the dissipation of the devices within reasonable limits.

The input resistance, maximum voltage ratings, and frequency response details are those supplied by the manufacturers.

to r.f. interference. Some of the i.c.s provide for the connection of an external capacitor in a negative feedback loop to "roll-off" the high frequency response. Selecting an appropriate value for this component will help to make the device immune.

The problem of r.f. pick up invariably manifests itself when a high value (more than 10 kilohms) input potentiometer (VR1) is used to match the amplifier to the impedance of a signal source. If the potentiometer or volume control must have a high resistance, connecting a 1nF or, at most, 10nF capacitor across its track will shunt unwanted r.f. to ground.

LOW FREQUENCY RESPONSE

The low frequency response of three of the lower powered amplifiers has been curtailed a little by fitting a 220nF speaker coupling capacitor. Amplifiers of this kind are invariably used with small, inexpensive speakers which are incapable of producing an audible output at frequencies below 150Hz or so. Feeding low frequencies to speakers of this kind only

AMPLIFIER PROJECTS

In use, there is little to distinguish between the four, low powered amplifiers, all perform well. There are, however, differences which make one device more suitable than another for a particular application.

Low current consumption is important when equipment is powered from dry batteries. Quiescent current drawn by the small amplifiers is in the region of 6mA (13mA for the LM380).

In the case of the LM386N, TBA820M and LM380, current rises to around 120mA when 500mW is being delivered into an 8 ohm load. Current consumed by the TDA7052 is approximately 220mA, or almost double, under these conditions.

In all cases, the signal input has been connected to the slider (moving contact) of the Volume control potentiometer (via a blocking capacitor in the case of the TDA2003). This minimises hum and noise and ensures that a more or less constant impedance is presented to the signal

source. Potentiometers of 4700 ohms or 10 kilohms (10k) are usual, but the value can be increased to 100k to raise input impedance.

This will, however, make the circuits more vulnerable to mains hum, r.f. interference and instability, and the value should be kept as low as the signal source impedance permits. This applies particularly to the TDA7052, where the value of the Volume control should, if possible, be no more than 10k. Earlier comments regarding stability are of relevance here.

LM386N-1 AMPLIFIER

A circuit diagram for a simple amplifier using the low-voltage LM386N-1 power amplifier i.c. is shown in Fig.1. Also shown are the general performance and electrical characteristics of the circuit.

Blocking capacitor C1 prevents any disturbance of the d.c. conditions in the signal source and potentiometer VR1 (the Volume control) sets the input level. The manufacturers of the chip, National Semiconductor, suggest an input network to roll-off high frequencies and resistor R1 and capacitor C2 perform this function.

The unused non-inverting input (pin 3) is grounded to avoid instability when gain is set high. Capacitors C3 and C4, connected across the supply rails, prevent low and high frequency instability.

FEEDBACK

An internal negative feedback path can be accessed via pin 1 and pin 8. Bypass capacitor C5 reduces the feedback and increases the gain of the chip from 23 to 170 times (as measured: samples will vary). Preset potentiometer VR2 (wired as a variable resistor) controls the bypassing effect of C5 and enables the gain to be set within these limits.

Bypass capacitor C6 makes the device more immune to supply line ripple, and C8 couples the output to the speaker LS1. The Zobel network, formed by resistor R2 and capacitor C7, ensures that the speaker always presents a resistive load to the amplifier. Without these components there is a risk of high level transients causing damage to the output transistors.

Tabulated power output levels for various supply voltages and speaker impedances are included below the circuit diagram. Sustained operation at more than 300mW is not recommended.

CIRCUIT BOARD

The printed circuit board component layout, wiring details and full-size copper foil master pattern are shown in Fig.2. This board is available from the *EPE PCB Service*, code 343 (LM386N-1).

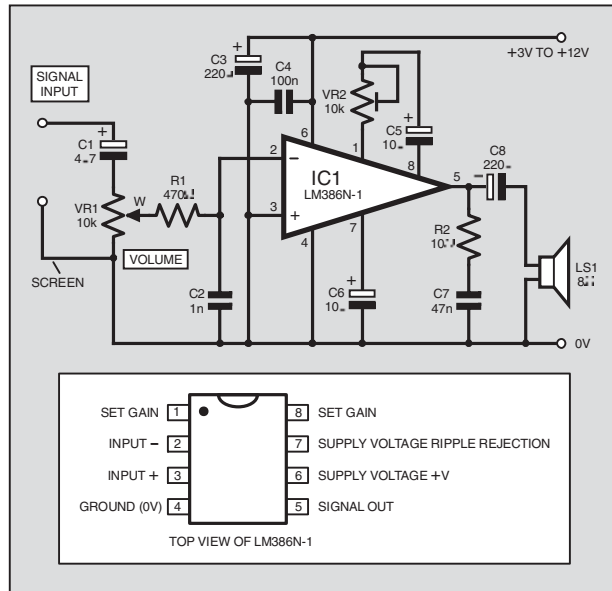
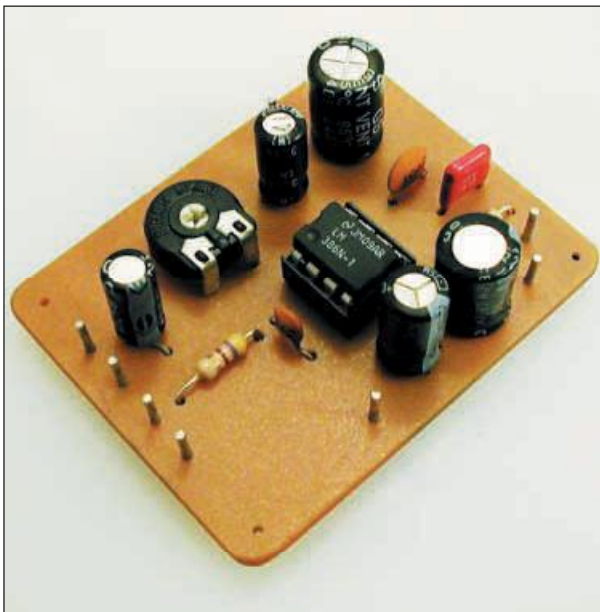


Fig. 1. Circuit diagram and pinout details for the LM386N-1 Power Amplifier.



Completed LM386N-1 circuit board.

LM386N-1 POWER AMPLIFIER R.M.S. power output just before the onset of waveform clipping

Speaker impedance ohms	Supply Voltage				
	3V	4.5V	6V	9V	12V
4	60mW	150mW	320mW	500mW	-
8	26mW	105mW	200mW	560mW	900mW
16	15mW	60mW	110mW	320mW	605mW
32	-	35mW	62mW	170mW	330mW

Quiescent current:

6mA

Input resistance:

50k ohms

Input sensitivity for 560mW

output (8 ohm load, 9V supply),

(a) VR2 set for maximum resistance: 90mV r.m.s. (gain 23)

(b) VR2 set for minimum resistance: 12mV r.m.s. (gain 170)

Absolute maximum supply voltage,

beyond which damage will occur:

15V

Suggested maximum supply

voltage with a 4 ohm speaker

6V

Frequency response

up to 300kHz

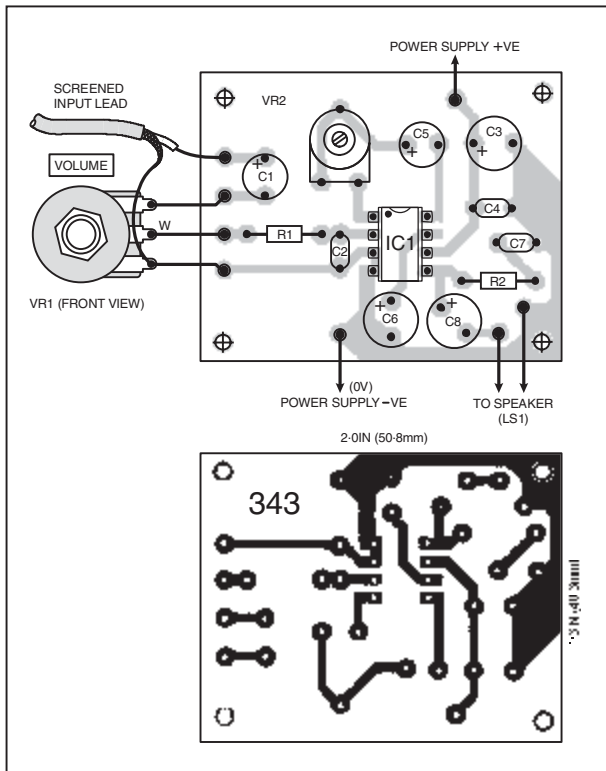


Fig. 2. Printed circuit board, component layout, full size copper foil master and interwiring for the LM386N-1 Amp.

COMPONENTS

LM386N-1 AMPLIFIER

Resistors

R1 470Ω R2 10Ω
All 0.25W 5% carbon film

Potentiometers

VR1 10k min. rotary carbon, log.
VR2 10k enclosed carbon preset

Capacitors

C1 4.7µF radial elect. 25V
C2 1n disc ceramic
C3, C8 220µF radial elect. 25V (2 off)
C4 100n disc ceramic
C5, C6 10µF radial elect. 25V (2 off)
C7 47n polyester

Semiconductor

IC1 LM386N-1 audio power amp i.c.

Miscellaneous

LS1 4 to 32 ohm loudspeaker (see text)

Printed circuit board available from the *EPE PCB Service*, code 343 (LM386N-1); case (optional), size and type to choice; 8-pin d.i.l. socket; multistrand connecting wire; audio screened cable; solder pins; solder etc.

Approx. Cost
Guidance Only

£10.50

excluding case & speaker

See
SHOP
TALK
page

TDA7052 AMPLIFIER

Philips have adopted a bridge arrangement for the TDA7052's output stage. This enables the chip to maintain a good output at low supply voltages and eliminates the need for a speaker coupling capacitor.

Gain is fixed internally, no provision is made for ripple rejection, and there is no Zobel network. This reduces the external component count to the d.c. blocking capacitor C1, Volume control VR1 and the supply line bypass capacitors, C2 and C3. The full circuit diagram, together with a

specification guide, for the TDA7052 amplifier is shown in Fig. 3.

Protection against output short circuits is built in and the device shuts down when the dissipation becomes excessive. This explains the small rise in sustainable output when the speaker impedance is increased to 16 ohms with a 9V supply.

Although usually costing a little more than the other low-power chips, this is the device of choice when the supply voltage

has to be low, a good output is required, and high gain is not important. Current consumption for a given output power is, however, almost twice that of the LM386N and the TBA820M.

CIRCUIT BOARD

The printed circuit board component layout, wiring details and full-size copper foil master pattern are shown in Fig. 4. This board is available from the *EPE PCB Service*, code 344 (TDA7052).

TDA7052 POWER AMPLIFIER

R.M.S. Power output just before the onset of waveform clipping

Speaker Impedance Ohms	Supply Voltage				
	3V	4.5V	6V	9V	12V
4	70mW	500mW	780mW	—	—
8	60mW	455mW	640mW	1W	—
16	40mW	235mW	450mW	1.12W	—
32	24mW	145mW	250mW	600mW	1.26W

Quiescent current	5mA
Input resistance	100k ohms
Input sensitivity for 1W output (8 ohm load, 9V supply)	40mV r.m.s. (gain 70)
Absolute maximum supply voltage beyond which damage will occur	18V
Suggested maximum supply voltage:	
with a 4 ohm speaker	6V
with 8 or 16 ohm speakers	9V
Frequency response at the -3dB points	25Hz - 20kHz

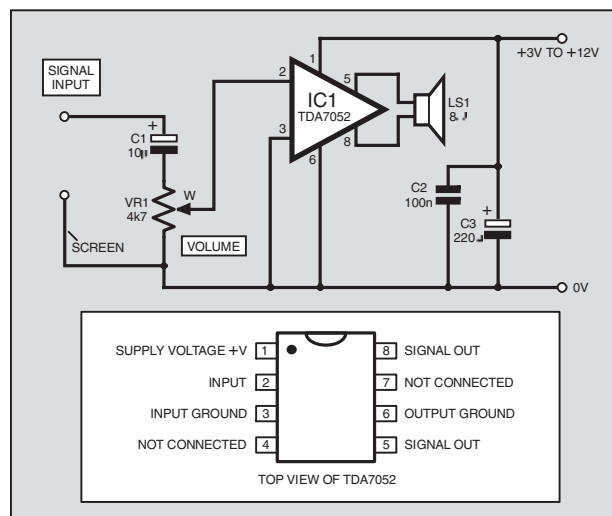


Fig. 3. Circuit diagram and pinout details for the TDA7052 Amp. See left for performance guide.

COMPONENTS

TDA7052 AMPLIFIER

Capacitors

- C1 10 μ radial elect. 25V
- C2 100n disc ceramic
- C3 220 μ radial elect. 25V

See **SHOP TALK** page

Potentiometers

- VR1 4k7 min. rotary carbon, log.

Semiconductor

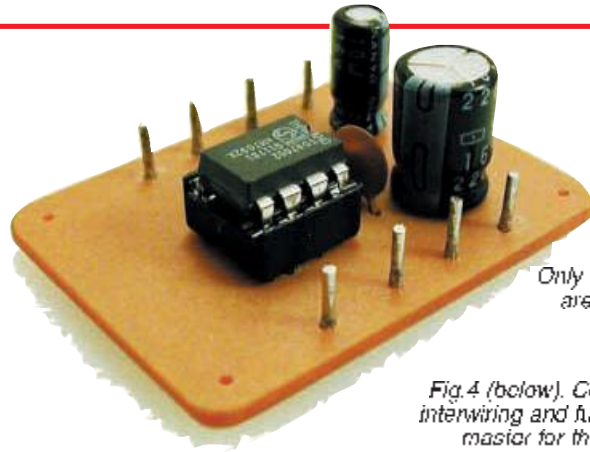
- IC1 TDA7052 power amp i.c.

Miscellaneous

- LS1 4 to 32 ohm loudspeaker (see text)

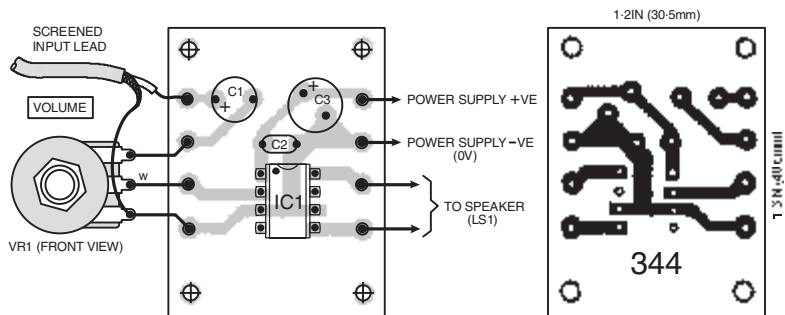
Printed circuit board available from the *EPE PCB Service*, code 344 (TDA7052); case (optional), size and type to choice; 8-pin d.i.l. socket; multistrand connecting wire; audio screened cable; solder pins; solder etc.

Approx. Cost
Guidance Only **£9.50**
excluding case & speaker



Only four components are mounted on the TDA7052 p.c.b.

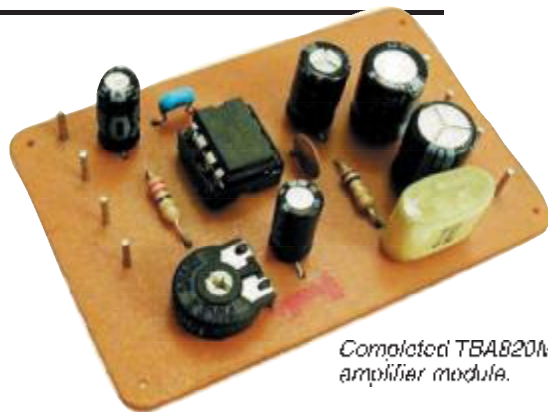
Fig.4 (below). Component layout, interwiring and full-size copper foil master for the TDA7052 Amp.



TBA820M AMPLIFIER

A circuit diagram incorporating the TBA820M audio amp i.c., which is manufactured by SGS-Thomson, together with a general performance guide, is given in Fig.5. The input arrangements, supply line bypassing, speaker coupling and Zobel network are conventional, and the relevant components can be identified from previous circuit descriptions.

Gain can be controlled by shunting an internal negative feedback loop, which is accessed at pin 2. Preset potentiometer VR2, placed in



Completed TBA820M amplifier module.

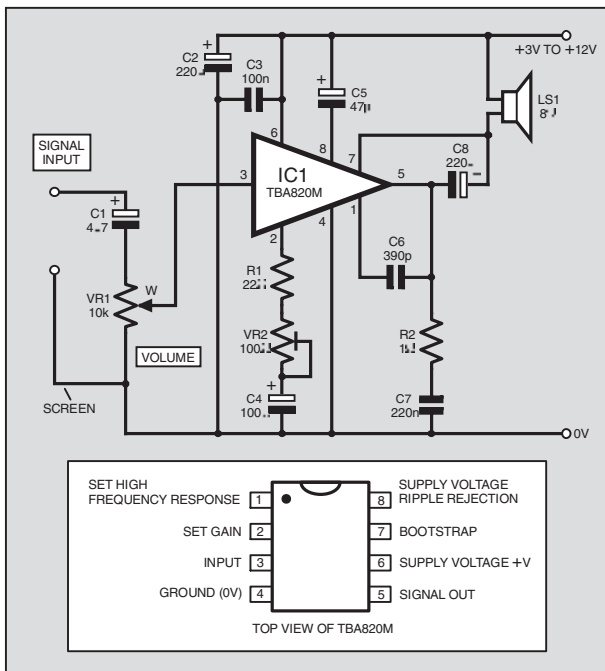


Fig.5. Circuit diagram and pinout details for the TBA820M power amplifier. See right for general performance details.

TBA820M POWER AMPLIFIER

R.M.S. power output just before the onset of waveform clipping

Speaker Impedance Ohms	Supply Voltage				
	3V	4.5V	6V	9V	12V
4	10mW	320mW	405mW	980mW	—
8	20mW	200mW	300mW	680mW	1.1W
16	30mW	115mW	180mW	405mW	720mW
32	20mW	60mW	90mW	225mW	390mW

- Quiescent current 6mA
- Input resistance 5M ohms
- Input sensitivity for 680mW output (8 ohm load, 9V supply):
 - (a) VR2 set for maximum resistance 56mV r.m.s. (gain 40)
 - (b) VR2 set for minimum resistance 10mV r.m.s. (gain 230)
- Absolute maximum supply voltage beyond which damage will occur 16V
- Suggested maximum supply voltage:
 - with a 4 ohm speaker 9V
 - with an 8 ohm speaker 12V
- High frequency response at -3dB point:
 - with C6 220pF 20kHz
 - with C6 680pF 7kHz

COMPONENTS

TBA820M AMPLIFIER

Resistors

R1 22 Ω
R2 1 Ω

All 0.25W 5% carbon film

See
SHOP
TALK
page

Potentiometers

VR1 10k min. rotary carbon, log.
VR2 100 Ω enclosed carbon preset

Capacitors

C1 4 \times 7 radial elect. 25V
C2, C8 220 μ radial elect. 25V (2 off)
C3, 100n disc ceramic
C4 100 μ radial elect. 25V
C5 47 μ radial elect. 25V
C6 390p ceramic
C7 220n polyester

Semiconductor

IC1 TBA820M audio power amp i.c.

Miscellaneous

LS1 4 to 32 ohm loudspeaker (see text)

Printed circuit board available from the *EPE PCB Service*, code 345 (TBA820M); case (optional), size and type to choice; 8-pin d.i.l. socket; multistrand connecting wire; audio screened cable; solder pins; solder etc.

Approx. Cost
Guidance Only
excluding case & speaker

£10

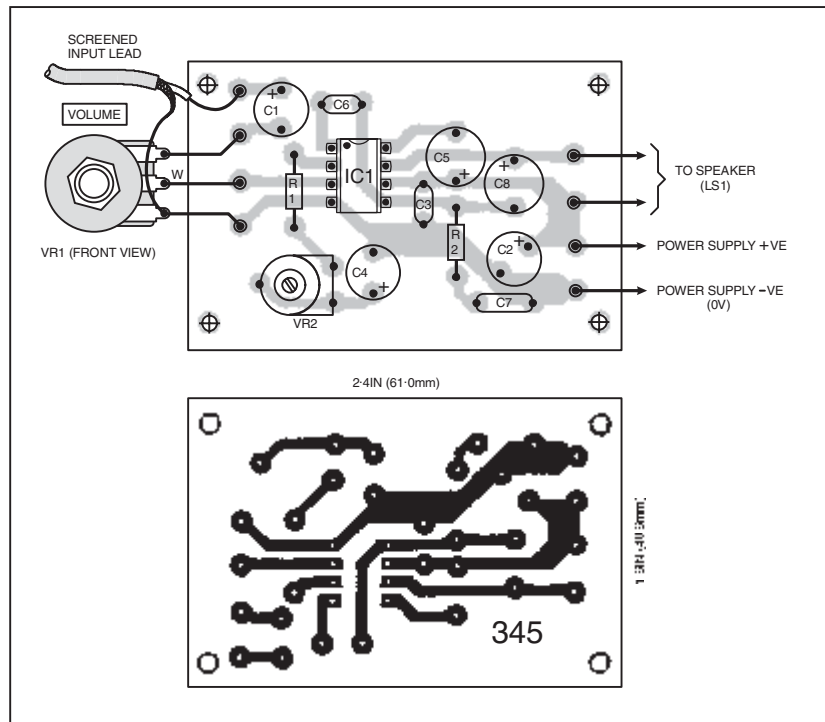


Fig.6. Topside component layout, off board wiring details and full size copper foil master for the TBA820M Amplifier.

series with capacitor C4, controls the shunting effect and, with the sample tested, gain could be set between 40 and 230.

High frequency response is determined by capacitor C6. The response at the -3dB points for different capacitor values is also listed in the table. If desired, the value of C6 can be increased to reduce the upper frequency response even more.

In this application, the speaker LS1 is

connected to the positive supply rail as this reduces the component count (a capacitor and resistor are saved).

CIRCUIT BOARD

The printed circuit board component layout, wiring details and full-size copper foil master pattern are shown in Fig.6. This board is available from the *EPE PCB Service*, code 345 (TBA820M).

LM380N AMPLIFIER

An amplifier circuit diagram incorporating the LM380N audio i.c. is shown in Fig.7. A general specification guide is shown below.

The manufacturers, National Semiconductor, have made provision for optional heatsinking via some of the pins, and this makes the package larger (14-pin). The output is short-circuit proofed and there is dissipation limiting. Gain is fixed.

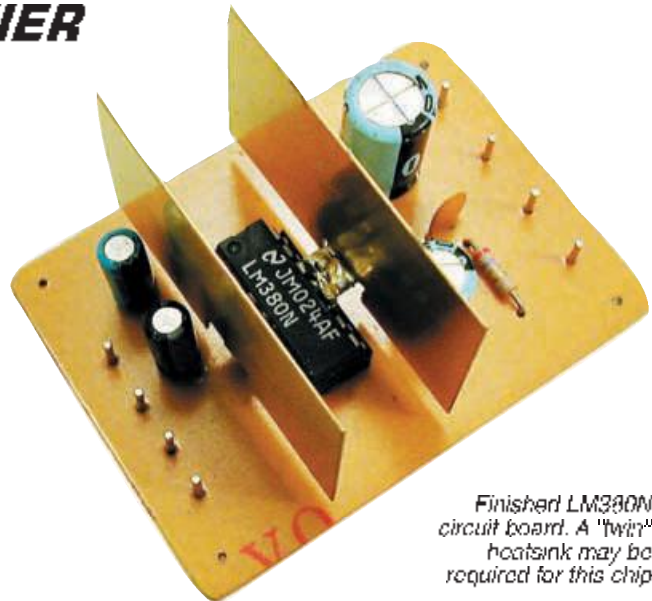
Again, the purpose of the various components will be evident from earlier descriptions. In this version of the circuit, the signal

LM380N POWER AMPLIFIER

R.M.S. power output just before the onset of waveform clipping

Speaker Impedance Ohms	Supply Voltage			
	9V	12V	15V	18V
4	400mW	1.12W	1.62W	-
8	275mW	720mW	1.32W	2.25W
16	137mW	405mW	720mW	1.32W
32	68mW	202mW	360mW	765mW

Quiescent current	13mA
Input resistance	150k ohms
Input sensitivity for 720mW output (8 ohm load, 12V supply)	50mV r.m.s. (gain 50)
Absolute maximum supply voltage beyond which damage will occur	22V



Finished LM380N circuit board. A "twir" heatsink may be required for this chip

A heatsink should be fitted if the device is to be operated, other than intermittently, at output levels in excess of 1W.

Without a heatsink, the suggested maximum supply voltages are:

with a 4 ohm speaker 12V
with an 8 ohm speaker 15V

Frequency response up to 100kHz

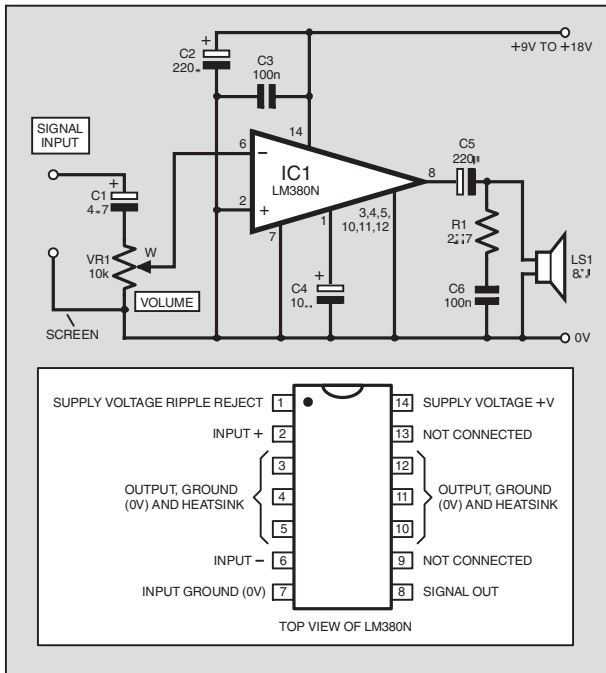


Fig.7. Circuit diagram for the LM380N Amplifier.

is applied to the inverting input (pin 6) and, to avoid instability, the non-inverting input (pin 2) is grounded (0V).

The manufacturers quote a minimum supply voltage of 10V. The sample tested worked with a 9V supply, but performance became erratic at lower voltages. Quiescent current, although modest, is

double that of the other low-power devices, and this, together with the higher operating voltage, makes the i.c. more suitable for mains-powered equipment.

CIRCUIT BOARD

Details of the printed circuit board

COMPONENTS

LM380N AMPLIFIER

Resistors

R1 22Ω 0.25W 5% carbon film

Potentiometers

VR1 10k rotary carbon, log.

Capacitors

C1 4.7µ radial elect. 50V
C2, C5 220µ radial elect. 50V (2 off)
C3, C6 100n disc ceramic (2 off)
C4 10µ radial elect. 50V

Semiconductor

IC1 LM380N audio power amp i.c.

Miscellaneous

LS1 4 to 32 ohm loudspeaker (see text)

Printed circuit board available from the *EPE PCB Service*, code 346 (LM380N); case (optional), size and type to choice; 14-pin d.i.l. socket; heatsink (see text); multistrand connecting wire; audio screened cable; solder pins; solder etc.

Approx. Cost
Guidance Only

£11

excluding case & speaker

component layout, wiring and copper foil master are given in Fig.8. This board is also available from the *EPE PCB Service*, code 346 (LM380N).

Although the board has been kept small, as much copper as possible has been retained to afford some heatsinking.

TDA2003 AMPLIFIER

Produced by SGS-Thomson, the TDA2003 low-cost i.c. is mainly for use in car radios. Although chips designed specifically for "hi-fi" amplifiers are available, they usually require higher voltage and/or split rail power supplies. This makes them less easy and more expensive to use.

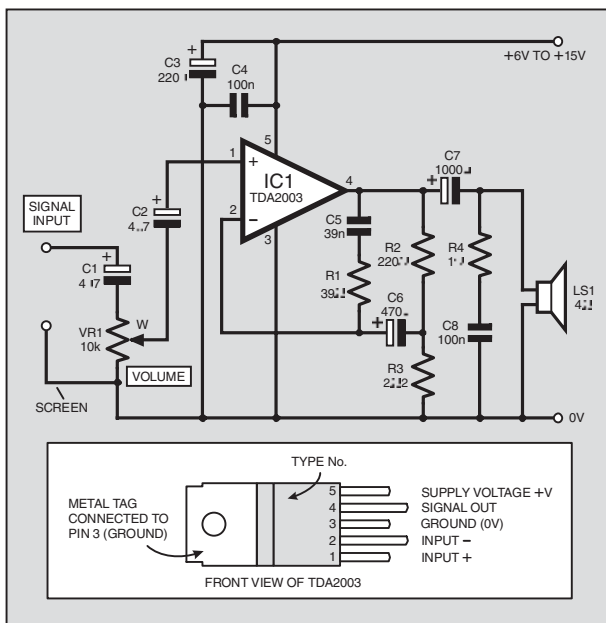
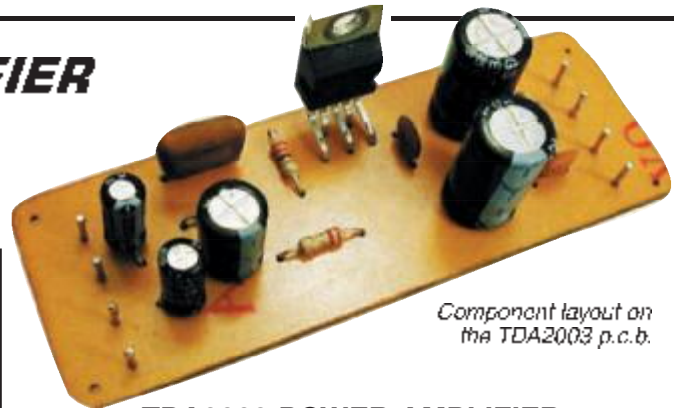


Fig.9. Circuit diagram for a single TDA2003 Amp.



Component layout on the TDA2003 p.c.b.

TDA2003 POWER AMPLIFIER

R.M.S. power output just before the onset of waveform clipping

Speaker Impedance Ohms	Supply Voltage		
	9V	12V	15V
2	2.25W	4W	5.75W
4	1.28W	2.6W	3.9W
8	720mW	1.44W	2.1W

Quiescent current 45mA
Input sensitivity for 2.6W output (4 ohm load, 12V supply) 42mV r.m.s. (gain 80)
Absolute maximum supply voltage beyond which damage will occur 28V
Absolute maximum operating voltage 18V
Frequency response: 40Hz to 15kHz at the -3dB points.
The upper frequency limit can be extended by reducing the value of C5.

COMPONENTS

TDA2003 AUDIO AMPLIFIER

Resistors

R1	39Ω
R2	220Ω
R3	2kΩ
R4	1Ω

All 0.25W 5% carbon film

Potentiometers

VR1	10k rotary carbon, log.
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Capacitors

C1, C2	4μ7 radial elect. 50V (2 off)
C3	220μF radial elect. 50V
C4	100n disc ceramic
C5	39n polyester
C6	470μF radial elect. 50V
C7	1000μF radial elect. 50V
C8	100n polyester

Semiconductor

IC1	TDA2003 audio power amp i.c.
-----	------------------------------

Miscellaneous

LS1	4 to 32 ohm loudspeaker (see text)
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Printed circuit board available from the *EPE PCB Service*, code 347 (TDA2003); case (optional), size and type to choice; heatsink (see text); audio screened cable; multi-lead connecting wire; solder pins; solder etc.

Approx. Cost
Guidance Only

£11

excluding case & speaker

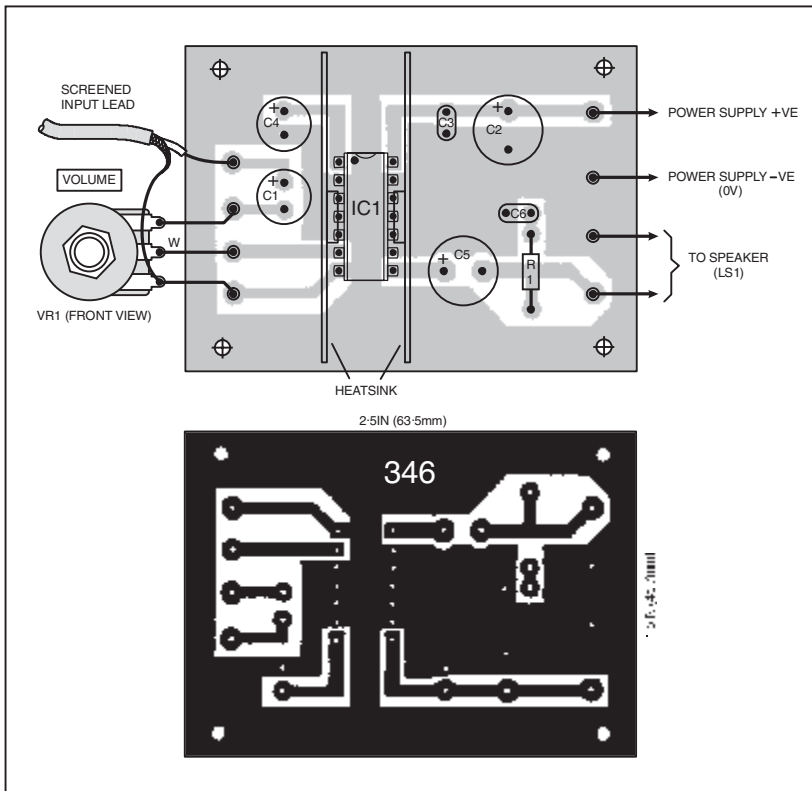


Fig. 8. The LM380N printed circuit board component layout, off board inter-wiring and full size copper foil master pattern. Note the heatsinks.

HEATSINKS

For those readers who wish to get the most out of the chip, a suitable heatsink for the LM380 (Fig.7 and Fig.8) can be formed from two, 40mm (1⁵/₈in.) lengths

of 25mm × 0.4mm (1in. × 1/64in.) brass strip. Make two shallow cuts, 5mm (3/16in.) apart, close to the centre, and bend out a tag which can be soldered to the relevant pins of the i.c. Thin brass strip can be purchased from almost all model shops.

The TDA2003 incorporates short circuit and overload protection, and is extremely rugged. It will deliver a worthwhile output at modest supply voltages, and the suitability of car batteries as a power source may make it of particular interest to some readers. The

circuit diagram of a single chip TDA2003 audio amplifier is given in Fig.9.

Grounding the input (pin 1) of this device would upset the internal biasing arrangements, so a second blocking capacitor C2 must be provided. The high

frequency response is set by capacitor C5 in conjunction with resistor R1. The response can be extended by reducing the value of C5. Supply line ripple rejection is afforded by capacitor C6.

The outputs which can be delivered at various supply voltages are tabulated in the accompanying table. The current drawn from a 15V supply when 4W are dissipated into a 4 ohm load is around 500mA. The 2 ohm load is obtained by connecting two 4 ohm speakers in parallel.

At these power levels, the device must, of course, be connected to an adequate heatsink, and this is discussed later.

The printed circuit board component layout, wiring and full-size copper foil master pattern for the single chip TDA2003 amplifier are shown in Fig.10. This board is available from the *EPE PCB Service*, code 347 (TDA2003).

TWIN TDA2003 AMPLIFIER

A circuit diagram using two TDA2003 chips in a bridge configuration is shown in Fig.11, together with a general performance guide.

Drawing around 1.7A from a 15V supply, this combination will deliver a clean 12.5W into a 4 ohm load. The case for this being adequate for domestic listening has already been argued, but individual constructors will, of course, decide whether or not it will meet their needs.

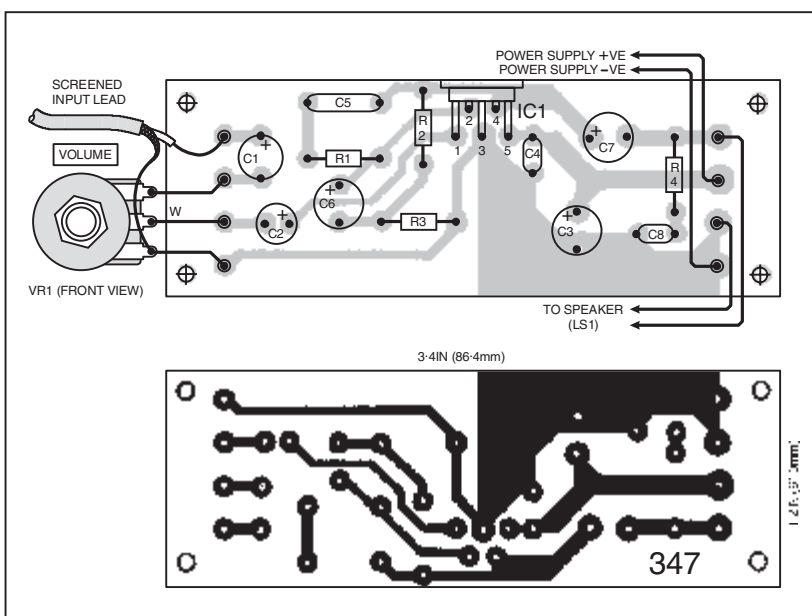


Fig. 10. Printed circuit board component layout, full size foil master and off board wiring for the single TDA2003 Amplifier.

TWIN TDA2003 AMPLIFIER

COMPONENTS

TWIN TDA2003 POWER AMP

Resistors

- R1, R4 1.5k (2 off)
- R2 220k
- R3, R5 10k (2 off)
- R6 470k

See **SHOP TALK** page

All 0.25W 5% carbon film

Potentiometers

- VR1 10k rotary carbon

Capacitors

- C1, C2 4.7µF radial elect. 50V (3 off)
- C3, C8 100nF disc ceramic (2 off)
- C4 22µF radial elect. 50V
- C5, C6 100nF polyester (2 off)
- C7 10µF radial elect. 50V
- C10 220µF radial elect. 50V

Semiconductor

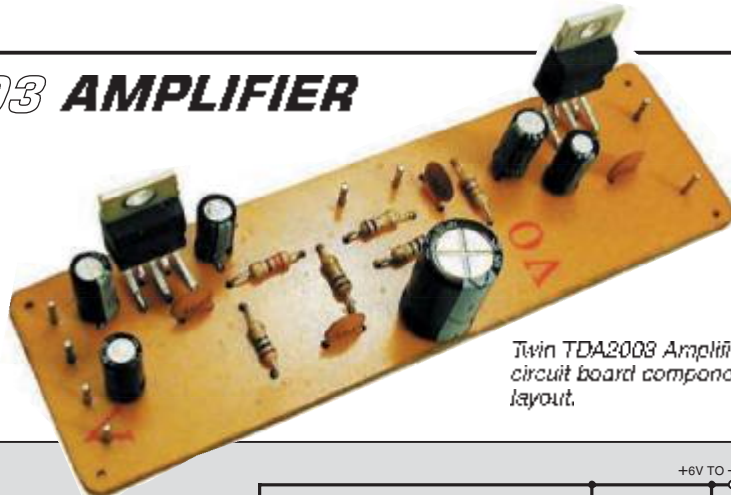
- IC1, IC2 TDA2003 audio power amp i.c. (2 off)

Miscellaneous

- LS1 2 to 8 ohm loudspeaker (see text)

Printed circuit board available from the **EPE PCB Service**, code 348 (TDA2003); case (optional), size and type to choice; heatsink (see text); audio screened cable; multistrand connecting wire; solder pins;

Approx. Cost **£14**
Guidance Only
excluding case & speaker



Twin TDA2003 Amplifier circuit board component layout.

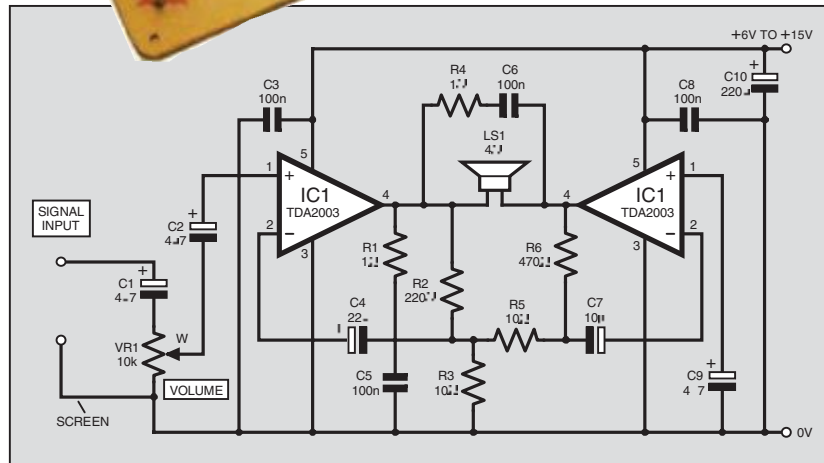


Fig.11 (above). Circuit diagram for the Twin TDA2003 Power Amplifier.

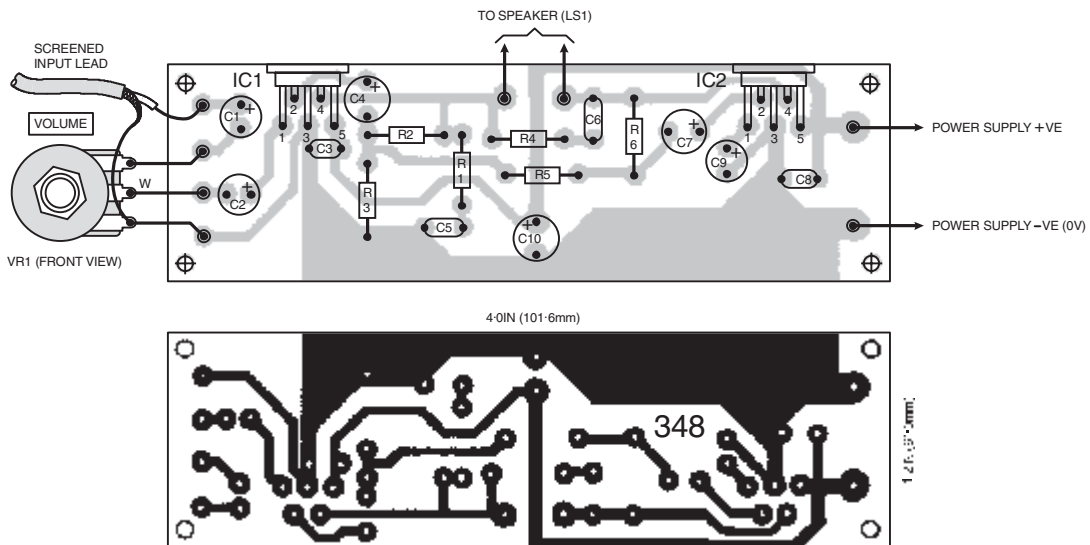
TWO TDA2003 BRIDGE CONFIGURATION POWER AMP

R.M.S. power output just before the onset of waveform clipping

Speaker Impedance Ohms	Supply Voltage		
	9V	12V	15V
2	6.25W	10.5W	—
4	3.78W	8W	12.5W
8	2W	5W	8.2W

Quiescent current 80mA
Input sensitivity for 8W output (4 ohm load, 12V supply) 70mV r.m.s. (gain 40)
See single TDA2003 for details of absolute maximum ratings.

Fig. 12 (below). Component layout, off board inter wiring and full-size copper foil master for the Twin TDA2003 Amp. You will need a heatsink for these devices.



The printed circuit board component layout, wiring and copper foil master are detailed in Fig.12. Again, combined or separate heatsinks must be fitted to the integrated circuit's metal tabs. The p.c.b. is obtainable from the *EPE PCB Service*, code 348 (Twin TDA22003).

HEATSINKS

A large area metal heatsink is required for the TDA2003 (Fig.9 and Fig.11). Because the device incorporates overload protection, the actual size is not too critical (the i.c. will shut down when it begins to overheat), but sustained high output will only be developed if the heatsink is adequate. At the very least use 40sq. cm (6.5sq. in.) of 16s.w.g. aluminium per chip, or fit a proprietary heatsink with a thermal resistance not greater than 7°C per watt.

The i.c.s are arranged on the p.c.b. (see Fig.10 and Fig.12) so that they can be bolted to the back of a metal case by their metal tabs. A 50mm x 150mm x 200mm (2in. x 6in. x 8in.) aluminium box would be more than adequate as a heatsink. Insulating washers are not required, but a smear of heat transfer compound should be applied.

COMPONENTS

Slight differences in the i.c. type numbers can cause confusion. The LM386N-1 has the lowest power rating of this group of devices. The suffixes "N-3" and "N-4" indicate devices rated at 700mW and 1W respectively. The suffix "M" indicates surface mounting. Suppliers offering the

LM386 are usually referring to the N-1 version.

The TDA7052 is sometimes given the suffix "A". This indicates that the chip contains a d.c. volume control and is *not* suitable for the circuit described here.

Some suppliers give the LM380 the suffix "14" to indicate the 2.5W 14-pin version, and the suffix "8" for the 8-pin 600mW alternative. When ordering, make it clear that the 14-pin chip is required.

The suffix "P" or "V" is sometimes added by suppliers to the TDA2003 to indicate that it is for vertical, and "H" for horizontal, mounting. There is no electrical difference, but the p.c.b.s illustrated here have been designed for vertical chips.

CONSTRUCTION

All the amplifiers covered in this part are assembled on printed circuit boards and construction is reasonably straightforward. The use of an i.c. holder will permit the substitution and checking of the low power amplifiers. However, if reliance is to be placed on the p.c.b. foil for minimal heatsinking of the LM380, the device should be soldered directly in place. Solder pins, inserted at the lead-out points, will simplify off-board wiring.

It may help to start construction of the chosen circuit board by first placing and soldering the i.c. holder

on the p.c.b. to act as an "orientation" guide. This should be followed by the lead-off solder pins, and then the smallest components (resistors) working up to the largest, electrolytic capacitors and presets. Finally, the lead-off wires (including the screened input cable), off-board Volume control and loudspeaker should be attached to the p.c.b.

On completion, check the board for poor soldered joints or bridged tracks. Check the orientation of the electrolytic capacitors and the i.c.(s).

If using a mains power supply, make sure the voltage delivered does not exceed the safe working voltage of the amplifier for the load impedance being used.

If all is in order, connect the power supply and check the quiescent current consumption. Inject a signal and re-check the current drain and supply voltage.

Next Month: Transistor preamplifiers



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651.581	150W Continuous	12V	£36.39
651.578	150W Continuous	24V	£36.39
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651.585	300W Continuous	24V	£50.64
651.583	600W Continuous	12V	£101.59
651.593	600W Continuous	24V	£101.59
651.587	1000W Continuous	12V	£177.18
651.597	1000W Continuous	24V	£177.18
651.602	1500W Continuous	12V	£314.52
651.605	1500W Continuous	24V	£314.52
651.589	2500W Continuous	12V	£490.54
651.599	2500W Continuous	24V	£490.54



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SIMPLE AUDIO CIRCUITS

Part 2 – Preamplifiers, Tone Controls and Filters



RAYMOND HAIGH

A selection of "pic-n-mix" low-cost audio circuits from preamplifier to speaker!

ALTHOUGH the power amplifiers described last month have a respectable amount of gain, some signals may be too weak to produce an adequate loudspeaker output without additional amplification. They can also be further weakened by an excessive mismatch between signal source and amplifier. Tone controls are usually required when music is being reproduced, and restricting the bandwidth will clarify speech signals, especially under noisy conditions.

These three issues: preamplification, impedance matching and tailoring the frequency response, are covered in this article.

TRANSISTOR AMPLIFIERS

Impedances

The impedances presented by the input and output ports of transistor amplifier stages are extremely variable. Load and bias resistors exert a major influence, as do the gain of the transistor and its emitter current. Negative feedback can either raise or lower impedance and, to further confuse the issue, the load connected across one port influences the impedance presented by the other.

The impedance figures quoted are, therefore, intended as no more than a guide when selecting the best circuit for a particular application.

Biasing

Transistor amplifier stages are usually biased so that the output (collector or emitter; drain or source) rests at half the supply voltage under no-signal conditions. This enables the stage to deliver the greatest possible signal swing; i.e. the highest output, before the onset of clipping.

Transistor gain (h_{fe}), and supply voltage, affect the biasing. However, over a wide range of h_{fe} values (at least 200 to 600), and supply voltages from +9V to +12V, the circuits described here will deliver a low distortion output that is more than

sufficient to fully drive the power amplifiers described last month.

Experimenters who require the stages to have the highest possible signal-handling capability for a given supply voltage may have to adjust the bias resistors. Guidance on this is given later.

Cascading

The various preamplifiers, tone controls and filters can be combined to suit individual requirements. Blocking capacitors have been provided at the inputs and outputs, and the units can be used safely with any equipment.

Cascading makes one of these capacitors redundant. Similarly, when they are connected to the power amp described last month, the output blocking capacitor can be omitted (C1 on the power amplifier p.c.b. duplicates this component).

Decoupling

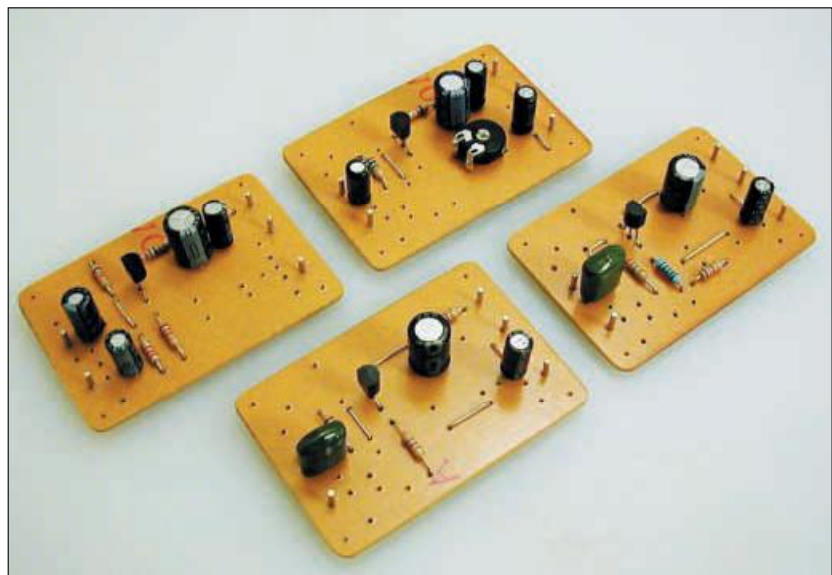
All of the preamplifier circuits are decoupled from the power supply by a resistor and capacitor. Failure to include these components will almost certainly result in motor boating (low frequency instability).

The main cause of this instability is the wide swing in power amplifier current drain: even with small units this can range from 10mA to 150mA. These signal-induced current swings cause variations in the voltage of dry batteries or badly regulated mains power supplies. When high gain preamplifiers share the same supply rail, the resulting feedback causes low-frequency oscillation.

If problems are encountered, increase the value of the decoupling resistor, or capacitor, or both, by a factor of ten. A capacitor of 2000 μ F or more, connected across a dry battery power supply, will also help to eliminate instability at high volume levels.

R.F. Interference

The single transistor preamplifiers described here have an extended high



Four single-transistor preamplifiers (left-to-right): ● Low Impedance ● Medium Impedance ● High Impedance ● F.E.T. High Impedance.

frequency response, and problems with r.f. interference may be encountered. Connecting a low value ceramic capacitor between the input (emitter or base) and the 0V rail will cure the problem, and the accompanying printed circuit board (p.c.b.) makes provision for this.

SINGLE TRANSISTOR CIRCUITS

In many cases, all that is required is the additional gain and/or impedance matching afforded by a single transistor stage. Four circuits will now be considered.

Low Input Impedance Pre-amplifier

It is convenient, with simple intercom units, to make the speaker double up as a microphone. Voice coil impedance and output are very low: a few ohms and less than 1mV at a close speaking distance. Transformers are often used to increase the impedance and voltage of this signal

source, but a transistor can be made to do the job just as well.

The "grounded base" stage illustrated in Fig.1 has an input impedance of around 50 ohms, an output impedance roughly equal to the collector load resistance (R2) of 10 kilohms, and a voltage gain of around 100. Although more commonly encountered at the front-end of a radio receiver, this configuration is suitable for matching low source impedances to the power amplifier and, at the same time, providing a useful amount of voltage gain.

In the circuit diagram for the Low Input Impedance Pre-amplifier shown in Fig.1, C1 is a d.c. blocking capacitor, R1 and R2 are the input and output load resistors, and resistors R3 and R4 bias the transistor. The base (b) is grounded at audio frequencies by capacitor C3.

Supply line decoupling is effected by C4 and R5, and C2 is the output coupling and d.c. blocking capacitor.

CIRCUIT BOARD

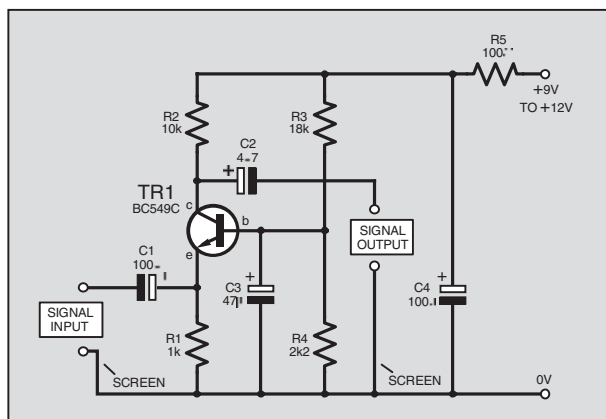
The printed circuit board component layout, wiring details and full-size copper foil master pattern are shown in Fig.2. This board is available from the *EPE PCB Service*, code 349 (Single Trans.).

Before commencing assembly, check the component, construction and interconnection notes at the end of the article.

VARIATIONS

Readers wishing to operate the stage from lower supply voltages should check the voltage on the collector (c) of transistor TR1 under no-signal conditions. If it is much more than half the supply voltage, reduce the value of resistor R3 to increase the bias current. With 3V on the supply rail, R3 will need reducing to around 6-8 kilohms and, with a 6V supply, its value will be in the region of 12k.

Because of its very low input impedance, the circuit of Fig.1 is not prone to capacitive hum pick up, and the input lead can be



VOLTAGE GAIN 100 OVER AN h_{fe} SPREAD OF 110 TO 600.
CURRENT DRAIN AT 9V SUPPLY 0.75mA.

Fig. 1. Circuit diagram for the single transistor Low Input Impedance Pre-amplifier.

LOW INPUT IMPEDANCE PREAMPLIFIER



Low Input Impedance Pre-amplifier components mounted on the "single" p.c.b.

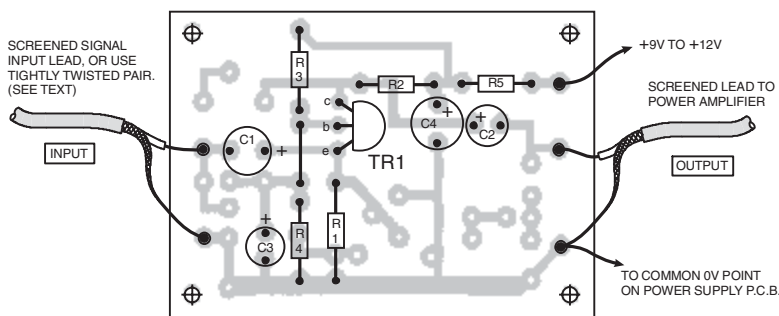
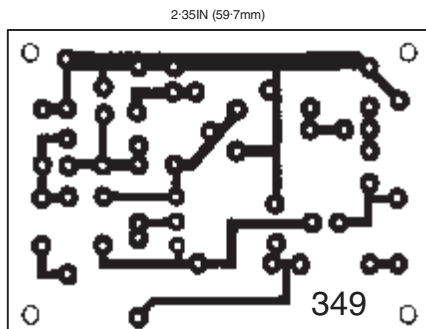


Fig. 2. Printed circuit board component layout, wiring and full-size copper foil master pattern for the Low Input Impedance Pre-amplifier.



COMPONENTS

LOW INPUT IMPEDANCE

Resistors

R1	1k	See SHOP TALK page
R2	10k	
R3	18k (see text)	
R4	2k2	
R5	100Ω	

All 0.25W 5% carbon film

Capacitors

C1, C4	100μ radial elect. 25V (2 off)
C2	4μ7 radial elect. 25V
C3	47μ radial elect. 25V

Semiconductors

TR1	BC549C npn transistor (or similar - see text)
-----	---

Miscellaneous

Printed circuit board available from the *EPE PCB Service*, code 349 (Single Trans.); audio screened cable; multi-strand connecting wire; input and output sockets, type to choice; solder pins; solder etc.

Approx. Cost
Guidance Only

£7

tightly twisted flex rather than screened cable. If r.f. interference problems are encountered, connect a 100nF capacitor between the emitter (e) of TR1 and the 0V rail: provision is made for this on the p.c.b.

Combining this low impedance circuit (Fig.1) with the LM386N-1 or the TBA820M power amplifiers (fully described in Part 1, last month) will produce a decent intercom unit, but more amplification is needed for surveillance purposes. Cascading the grounded base stage with the medium impedance preamplifier described next (Fig.3) is one possible answer.

Medium Input Impedance Preamplifier

The input impedance of the single transistor, common emitter preamplifier

illustrated in Fig.3 is approximately 1500 ohms (1.5k), and the output impedance roughly equal to the value of the load resistor, R2; i.e. 4700 ohms (4.7k).

Base bias resistor R1 is connected to transistor TR1 collector (c) rather than the supply rail. The resulting d.c. negative feedback makes the biasing more immune to transistor gain spreads and variations in supply voltage.

Preset potentiometer VR1 acts as the emitter bias resistor. Connecting capacitor C2 to the slider (moving contact) enables part of it to be left un-bypassed. This introduces varying levels of negative feedback and, with the specified transistor, the gain of the stage can be set between 10 and 160 times to suit different applications.

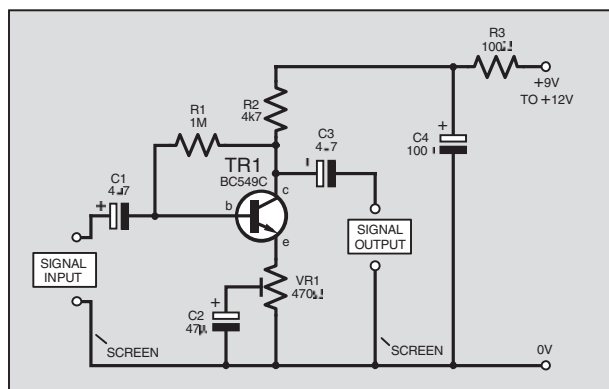
Comment has already been made about supply rail decouplers, R3 and C4, and blocking capacitors, C1 and C3.

CIRCUIT BOARD

The printed circuit board component layout, wiring details and full-size copper foil master pattern are shown in Fig.4. This board is available from the EPE PCB Service, code 349 (Single Trans.).

Before undertaking assembly work, see the component, construction and inter-connection details at the end of the article.

Provision is made for connecting an r.f. bypass capacitor across the input. A 1nF or 10nF ceramic component should be adequate if problems arise.



VOLTAGE GAIN WITH VR1 SLIDER AT 0V RAIL, 8 TO 10 OVER AN h_{fe} SPREAD OF 110 TO 600.
VOLTAGE GAIN WITH SLIDER AT TR1 EMITTER, 80 TO 600 OVER AN h_{fe} SPREAD OF 110 TO 600.
CURRENT DRAIN AT 9V SUPPLY: 1.25mA.

Fig.3. Circuit diagram for the Medium Input Impedance Preamplifier.

MEDIUM INPUT IMPEDANCE PREAMPLIFIER



Medium Input Impedance preamplifier components mounted on the "single" p.c.b.

COMPONENTS

MEDIUM INPUT IMPEDANCE

Resistors

R1	1M
R2	4k7
R3	100k

All 0.25W 5% carbon film

See
SHOP
TALK
page

Potentiometers

VR1	470k enclosed carbon preset
-----	-----------------------------

Capacitors

C1, C3	4.7µF radial elect. 25V (2 off)
C2	47µF radial elect. 25V
C4	100µF radial elect. 25V

Semiconductors

TR1	BC549C NPN transistor (or similar - see text)
-----	---

Miscellaneous

Printed circuit board available from the EPE PCB Service, code 349 (Single Trans.); audio screened cable; multi-strand connecting wire; input and output sockets, type and size to choice; solder pins; solder etc.

Approx. Cost
Guidance Only

£7

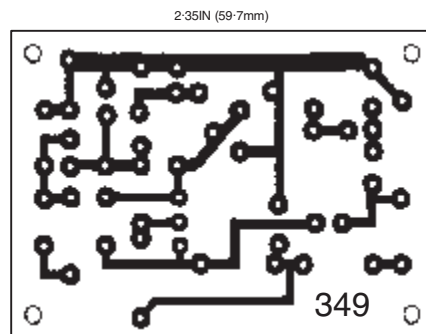
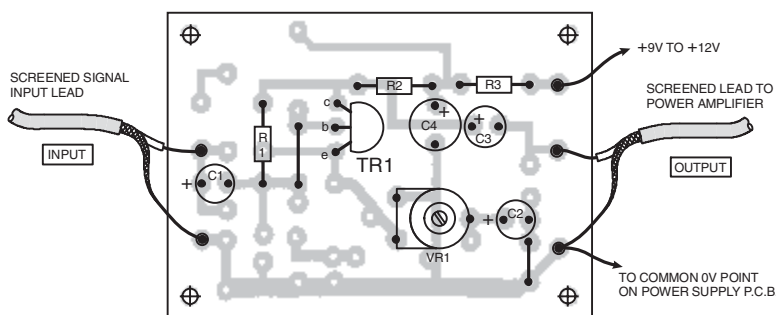


Fig.4. Medium Input Impedance Preamplifier printed circuit board component layout, wiring and full size copper foil master.

High Input Impedance Preamplifier

Crystal microphones and ceramic gramophone pick-ups (there are still a few in use) require an amplifier with a high input impedance, and a stage of this kind is useful when the damping on a signal source has to be kept low.

Configuring a bipolar transistor in the emitter-follower (common collector) mode results in a high input and low output impedance, and a typical High Input Impedance Preamplifier circuit diagram is shown in Fig.5. The input impedance is roughly equal to the gain of the transistor (h_{fe}) multiplied by the value of the emitter load resistor R2.

This is, however, limited by the bias resistor R1, and the output load, which shunts the emitter resistor. Nevertheless, a high gain transistor will still produce an input impedance of about 100 kilohms.

Often the low output impedance is the sought after feature, either for matching purposes or for avoiding high-frequency losses and hum pick-up when long screened cables have to be used. Output impedance is

directly related to the impedance presented by the signal source, and is usually in the region of 1000 ohms. The voltage gain of the circuit is a little less than unity.

CIRCUIT BOARD

The printed circuit board component layout, wiring details and full-size copper foil master pattern for the High Input Impedance Preamplifier are shown in Fig.6. This board is the same one used for all the single transistor preamplifiers, and is available from the *EPE PCB Service*, code 349 (Single Trans.). See the component, construction and inter-connection notes at the end of the article.

High input impedance makes the stage very vulnerable to hum pick up. Careful attention must, therefore, be paid to screening the input leads and, possibly, the entire unit.

VARIATIONS

It is possible to obtain higher input impedances with a bipolar transistor by applying positive feedback from the emitter to the base bias network. This involves an extra pair of resistors and a capacitor, and an alternative solution, if very high

input impedances are required, is to use a field effect transistor (f.e.t.); a device which tends to introduce less noise at audio frequencies.

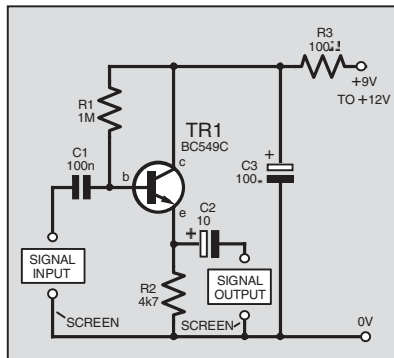
USING A F.E.T.

A circuit diagram for a F.E.T. High Input Impedance Preamplifier is given in Fig.7. The gate resistor R1 is tapped down to the source resistors R2/R3 in order to improve biasing and, hence, signal handling. By this means the f.e.t. develops its gate bias across R2, and R3 drops an additional 3V or so to fix the voltage on the source at around half the supply voltage.

Connecting the gate resistor R1 in this way applies a proportion of the in-phase output signal to its lower end, and the resulting positive feedback, or "bootstrapping", increases its effective resistance, and the input impedance of the circuit, to around 6 megohms (6M).

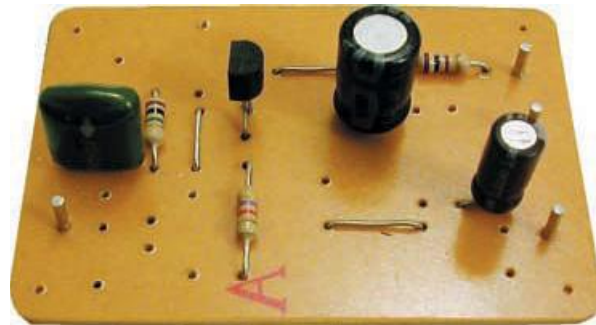
Output impedance is independent of signal source impedance. It is governed by the transconductance (gain) of the device, and is usually of the order of 500 ohms.

HIGH INPUT IMPEDANCE PREAMPLIFIER



VOLTAGE GAIN: UNITY
CURRENT DRAIN AT 9V SUPPLY: 1.25mA.

Fig.5. High Input Impedance Preamplifier circuit diagram.



High Input Impedance Preamplifier circuit board.

COMPONENTS

HIGH INPUT IMPEDANCE

Resistors		See
R1	1M	SHOP
R2	4k7	
R3	100Ω	
All 0.25W 5% carbon film		
		TALK
		page
Capacitors		
C1	100n polyester	
C2	10µ radial elect. 25V	
C3	100µ radial elect. 25V	
Semiconductors		
TR1	BC549C npn transistor (or similar - see text)	

Miscellaneous

Printed circuit board available from the *EPE PCB Service*, code 349 (Single Trans.); audio screened cable; multi-strand connecting wire; input and output sockets, type to choice; solder pins; solder etc.

Approx. Cost
Guidance Only

£7

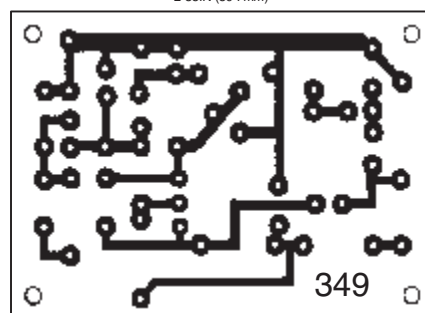
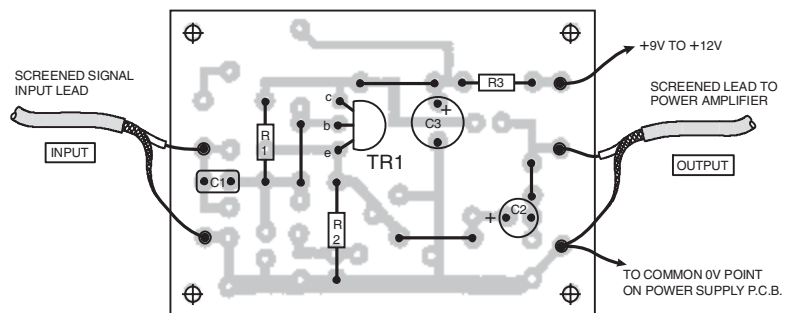


Fig.6. Printed circuit board component layout, wiring and full size copper foil master for the High Input Impedance Preamplifier.

This is the circuit of choice when a high impedance source has to be connected to a long screened cable; e.g., a capacitor or crystal microphone. However, f.e.t. characteristics vary widely, and readers wishing to use the circuit of Fig.7 should be prepared to adjust the value of resistor R3, over the range of 1500 to 4700 ohms, especially when low supply voltages are used, in order to optimise signal handling capability.

CIRCUIT BOARD

Details of the printed circuit board component layout, wiring and copper foil master pattern are given in Fig.8. The board is the single transistor version and is available from the *EPE PCB Service*, code 349 (Single Trans).

Before assembly, check the component, construction and interconnection details at the end of the article.

LOW-NOISE PREAMPLIFIER

Amplifiers introduce unwanted noise and, as gain increases, more care has to be taken to prevent the noise becoming too intrusive. The noise generated by a bipolar transistor can be reduced by operating it at a low collector current, typically between 10 μ A and 50 μ A. This technique has been adopted for the first stage of the directly-coupled, two transistor, Low-Noise Preamplifier shown in Fig.9.

Overall gain is stabilised by negative feedback applied via preset VR2. With the value shown, gain is approximately 300. If a 47k potentiometer is used instead, gain will be reduced to around 150, and it can be taken down to 70 or so with a 22k component.

Rotating the slider (moving contact) of preset VR2 causes it to be progressively bypassed by capacitor C6, increasing the

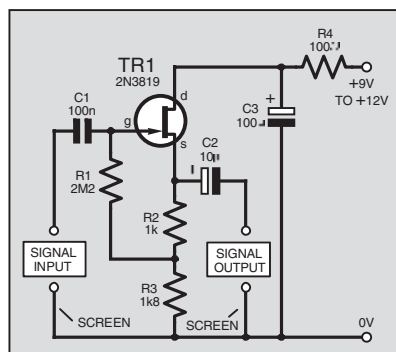
negative feedback, and reducing gain, at high frequencies. This feature is useful for reducing noise and for correcting the recording characteristic of long playing records. It is usual to incorporate more complicated RC networks in the VR2 position for the latter purpose but, unless the listener has a very refined ear, there will be little or no discernible difference.

Operating conditions are stabilised by d.c. negative feedback applied via resistor R5. This, together with the high value collector load, R3, fixes the collector current of transistor TR1 at around 50 μ A with a 12V supply.

Input impedance is around 50k, but the optimum signal source resistance for lowest noise is between 5k and 10k. This has influenced the value of the input potentiometer, VR1.

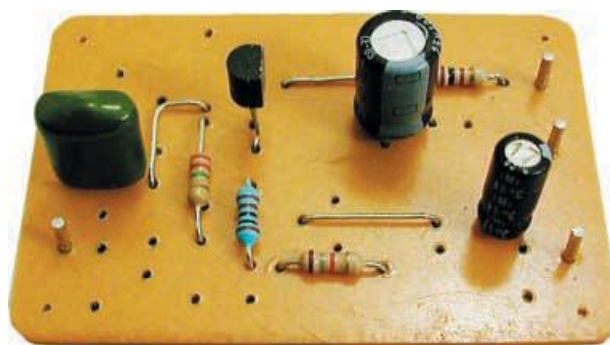
The purpose of the remaining components will be evident from earlier circuit descriptions. However, because of the

F.E.T. HIGH INPUT IMPEDANCE PREAMPLIFIER



VOLTAGE GAIN: UNITY
CURRENT DRAIN AT 9V SUPPLY: 1.75mA.

Fig.7. Alternative circuit diagram for a High Input Impedance Preamplifier using a field effect transistor (f.e.t.).



F.E.T. High Input Impedance Preamplifier p.c.b.

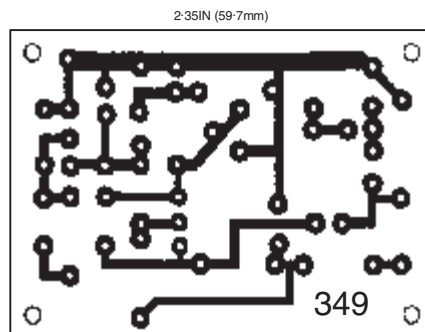
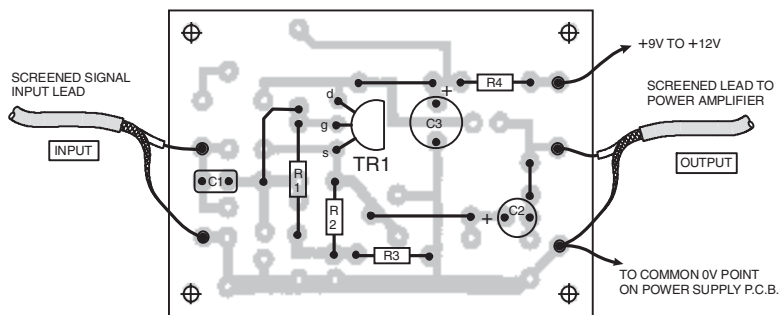


Fig.8. Printed circuit board component layout, wiring and full size copper foil master for the F.E.T. High Input Impedance Preamplifier.

COMPONENTS

HIGH INPUT IMPEDANCE (F.E.T.)

Resistors

R1	2M2
R2	1k
R3	1k8 (see text)
R4	100 Ω

All 0.25W 5% carbon film

See
SHOP
TALK
page

Capacitors

C1	100n polyester
C2	10n radial elect. 25V
C3	100 μ radial elect. 25V

Semiconductors

TR1	2N3819 n-channel field effect transistor (f.e.t.)
-----	---

Miscellaneous

Printed circuit board available from the *EPE PCB Service*, code 349 (Single Trans); audio screened cable; multi-strand connecting wire; input and output sockets, type to choice; solder pins; solder etc.

Approx. Cost
Guidance Only

£7

higher gain, the supply line decoupling capacitor C7 has been increased in value to ensure stability.

CIRCUIT BOARD

The printed circuit board component layout, wiring details and full-size copper foil master pattern for the Low-Noise Preamplifier are shown in Fig.10. This board is available from the *EPE PCB Service*, code 350 (Dual Trans.).

See the general construction, component and interconnection guide-lines on the last page.

VARIATIONS

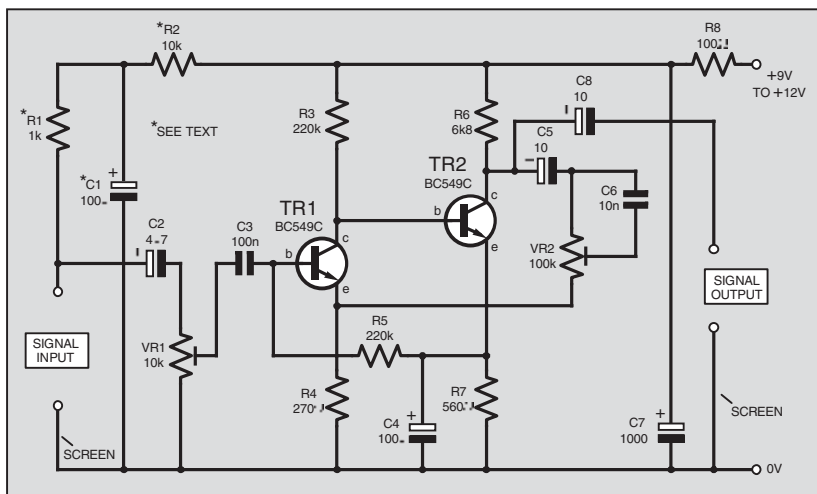
Some readers may wish to use this circuit with electret microphones which contain an internal line-powered f.e.t. amplifier. The load for this remote device is provided by resistor R1, and the supply voltage is reduced to around 4.5V, which is optimum for most microphones of this kind, by resistor R2. Decoupling is by means of capacitor C1.

These components (R1, R2 and C2) should only be fitted if an electret microphone is used, as the circuit maintains a

LOW-NOISE PREAMPLIFIER



Completed p.c.b. for the Low Noise Preamplifier.



VOLTAGE GAIN 300 OVER h_{fe} SPREAD OF 450 TO 600. CURRENT DRAIN AT 9V SUPPLY: 1mA.

Fig.9. Circuit diagram for the Low Noise Preamplifier. Components marked with an asterisk are only needed if an electret microphone is used. Increase the value of R2 to 10k with 12V supplies.

COMPONENTS

LOW-NOISE PREAMPLIFIER

Resistors

R1*	1k	See SHOP TALK page
R2*	10k	
R3, R5	220k (low-noise metal film preferred) (2 off)	
R4	270Ω	
R6	6k8	
R7	560Ω	
R8	100Ω	

All 0.25W 5% carbon film, except R3 and R5.

*Only required if electret mic. used

Potentiometers

VR1	10k enclosed carbon preset
VR2	100k enclosed carbon preset

Capacitors

C1*, C4	100μ radial elect. 25V (2 off)
C2	4.7 radial elect. 25V
C3	100n polyester
C5, C8	10μ radial elect. 25V (2 off)
C6	10n polyester
C7	1000μ radial elect. 25V

*Only required if electret mic. used

Semiconductors

TR1, TR2	BC549C npn transistor (or similar - see text) (2 off)
----------	---

Miscellaneous

Printed circuit board available from the *EPE PCB Service*, code 350 (Dual Trans.); audio screened cable; multistrand connecting wire; input and output sockets, type to choice; solder pins; solder etc.

Approx. Cost
Guidance Only

£8

excluding microphone

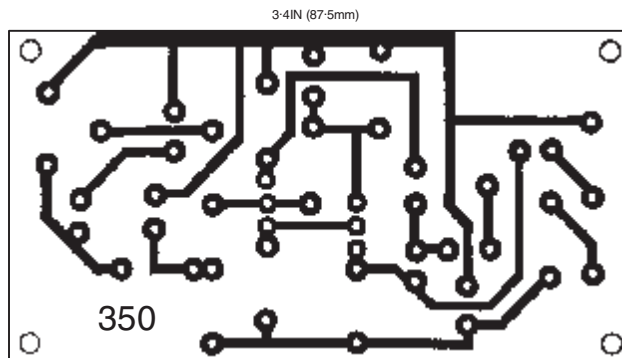
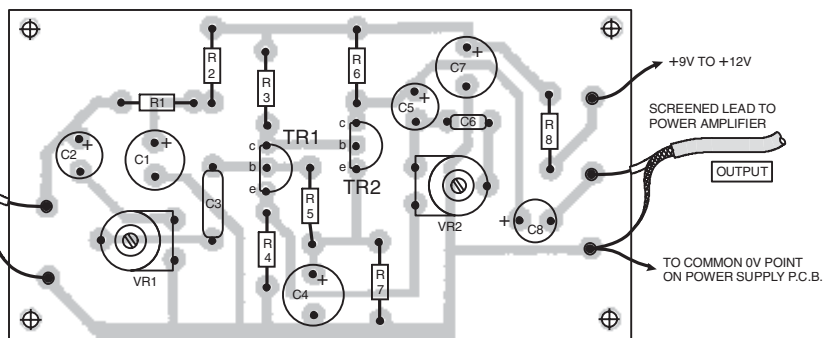


Fig.10. Printed circuit board component layout, wiring and full size copper foil master for the Low Noise Two Transistor Preamplifier.

d.c. voltage on the input which could disturb the action of some signal sources.

This circuit, and variations of it, form the basis of the front-ends of most high quality preamplifiers. With the component values shown, 3-3mV r.m.s. input will produce a 1V output before the onset of clipping.

The noise introduced by the amplifier is about the same, or a little less, than that generated by the single transistor amplifier set for a gain of 150. The noise level could be further reduced by using low-noise, metal film resistors for R3 and R5.

FREQUENCY RESPONSE

Although inductors are sometimes used for "tailoring" the frequency response, the key components in networks which modify audio frequency response are normally capacitors.

The resistance presented by a capacitor to the flow of alternating current (a.c.) decreases as frequency rises. This frequency dependant resistance is known as *reactance*.

Capacitors combined with resistors form frequency dependant potential dividers which can be used to tailor the response.

These RC networks can, of course, only attenuate signals. So called "bass boost" is obtained by reducing the response of the system to the higher audio frequencies.

Table 1 lists the reactances of a range of standard capacitor values, at spot frequencies, across the audio spectrum. Referring to it, an 0.1 μ F (100nF) capacitor presents a resistance of 5300 ohms at a frequency of 300Hz. This rises to 32000 ohms at 50Hz and falls to 320 ohms at 5kHz.

Fitting a blocking capacitor of this value to an amplifier with an input impedance of 5000 ohms will result in signal levels at 300Hz being halved. (Capacitor and input impedance act as a potential divider). This attenuation will increase as the frequency is lowered, and reduce as frequency is raised, at a rate of 6dB per octave.

Fitting low value d.c. blocking capacitors to one or more stages will, therefore, roll-off the low frequency response. Capacitors connected from signal lines to ground; e.g. across the tracks of volume controls, will progressively attenuate high frequencies. Although simple, these measures can make a significant improvement in clarity and signal-to-noise ratio.

Refer to Table 1 when selecting a capacitor to give the desired roll-off with a particular input impedance, then refine its value by trial and error.

FEEDBACK NETWORKS

Capacitors are used to make gain-reducing negative feedback networks frequency dependant; for example, capacitor C6 in the two-transistor Low-Noise Preamplifier shown in Fig.9.

Reducing the emitter bypass capacitor C2, in the single transistor preamplifier shown in Fig.3, to 4-7 μ F, will progressively increase feedback, and reduce gain, as frequency lowers. This is another simple, but effective, way of securing low frequency roll-off.

TONE CONTROLS

Some means of continuously varying the frequency response is desirable when music is being reproduced, and a suitable Tone Control circuit diagram is given in

Table 1: Reactance, in Ohms, of standard value capacitors at stated audio frequencies

Cap. μ F	50 Hz	100 Hz	200 Hz	300 Hz	400 Hz	500 Hz	1 kHz	2 kHz	3 kHz	4 kHz	5 kHz	10 kHz	20 kHz
1000	3182	1591	795	530	400	318	251	196	159	126	100	79	63
470	6328	3164	1582	1061	796	633	501	396	316	251	196	159	126
100	32	16	8	5	4	3.18	2.51	1.96	1.59	1.26	1.00	0.79	0.63
47	68	34	17	11	8.5	6.3	5.0	3.9	3.2	2.5	1.9	1.6	1.3
10	320	160	80	53	40	32	25	19	15	12	10	7.9	6.3
4.7	680	340	170	110	85	68	54	42	33	26	20	16	13
1	3k2	1k6	800	530	400	320	250	196	159	126	100	79	63
0.47	6k8	3k4	1k7	1k1	850	680	540	420	330	260	200	160	130
0.1	32k	16k	8k	5k3	4k	3k2	2k5	1k9	1k6	1k2	950	750	600
0.047	68k	34k	17k	11k	8k5	6k8	5k4	4k2	3k3	2k6	2k0	1k6	1k3
0.01	320k	160k	80k	53k	40k	32k	25k	19k	15k	12k	10k	7.9k	6.3k
0.0047	680k	340k	170k	110k	85k	68k	54k	42k	33k	26k	20k	16k	13k

Reactance values rounded off

Fig.11. This is the medium impedance transistor preamplifier illustrated in Fig.3 with negative feedback applied, via a frequency dependant network, from transistor TR1 collector to base. First published by P J Baxandall in 1952, the circuit has since been used, with minor variations, in most high quality preamplifiers.

Potentiometers VR1 (Bass), and VR2 (Treble), control the impact of capacitors C1, C2 and C3 on the feedback network. Resistors R2 and R3 minimise interaction between the controls, and the circuit affords 15dB of "boost" or cut at 100Hz and 10kHz.

CIRCUIT BOARD

The printed circuit board component layout, wiring details and full-size copper foil master pattern are shown in Fig.12. This board is available from the *EPE PCB Service*, code 351 (Tone).

Before undertaking any assembly work, see the general component, construction and interconnection notes at the end of the article.

IN-CIRCUIT

When circuits are cascaded, the Tone Control unit should always be the last in the chain; i.e. the one connected to the power amplifier. Most high quality preamplifiers consist of the two transistor circuit illustrated in Fig.9 followed by this Tone Control circuit.

BANDPASS FILTERS

Reducing bandwidth to around 300Hz to 3kHz greatly improves the clarity of speech signals, and the practice is adopted by tele-

phone companies around the world. Limiting the frequency response in this way significantly improves the signal-to-noise ratio. This is particularly desirable with sensitive radio equipment and surveillance systems, where the high level of amplification needed for the weakest signals brings with it a good deal of background and equipment generated noise.

For best results, roll-off beyond the pass band should be fairly steep: the 6dB per octave afforded by a single RC combination is not sufficient.

The Bandpass Filter circuit diagram shown in Fig.13 cascades three high-pass (low frequency cut) sections between transistors TR1 and TR2, and three low-pass (high frequency cut) sections between TR2 and TR3. By this means, a roll-off of 18dB per octave is achieved above and below the desired frequency range.

Filter networks of this kind need to be fed from a comparatively low impedance, and feed into a high impedance. The emitter follower stages, TR2 and TR3, are thus eminently suitable, and amplifiers of this kind have already been discussed. The input stage, transistor TR1, overcomes signal losses, or, with the slider of VR1 at TR1 emitter (e), ensures an overall circuit gain of around 25.

Emitter to base feedback around TR2 and TR3, via the RC networks, improves the action of the filters. Component values have been selected to start the roll-off just within the pass band, and the response falls steeply below 300Hz and above 3kHz.

Two capacitors have to be combined to produce a difficult-to-obtain value. To avoid confusion they are shown separately on the circuit diagram as C8 and C9.

CIRCUIT BOARD

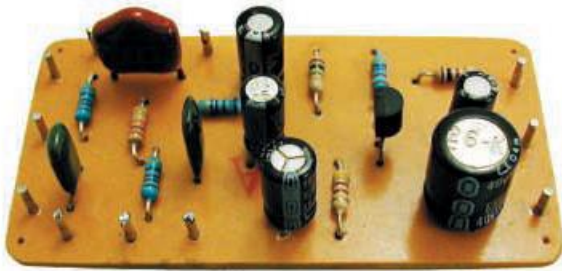
Details of the printed circuit board component layout, wiring and copper foil master are given in Fig.14. The Bandpass Filter board is also available from the *EPE PCB Service*, code 352 (Filter).

See component, construction and interconnection notes before commencing building.

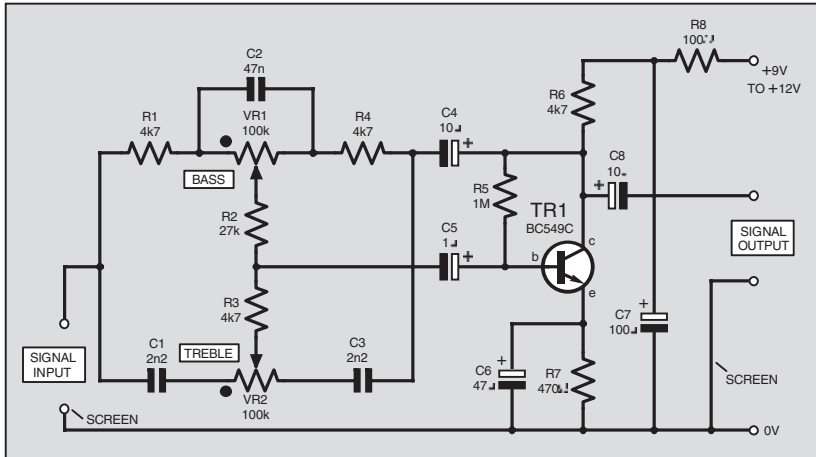


Bandpass Filter (top) and Tone Control p.c.b.s.

TONE CONTROL



Tone Control printed circuit board.



● = BOOST END OF POTENTIOMETERS (VR1, VR2) MOVING CONTACT (SLIDER).
 VOLTAGE GAIN UNITY WHEN VR1 AND VR2 SET AT MID TRAVEL.
 BOOST AND CUT $\pm 15\text{dB}$ AT 100Hz AND 10kHz.
 CURRENT DRAIN AT 9V SUPPLY: 1.25mA.

Fig. 11. Circuit diagram for the Tone Control (bass, treble boost and cut).

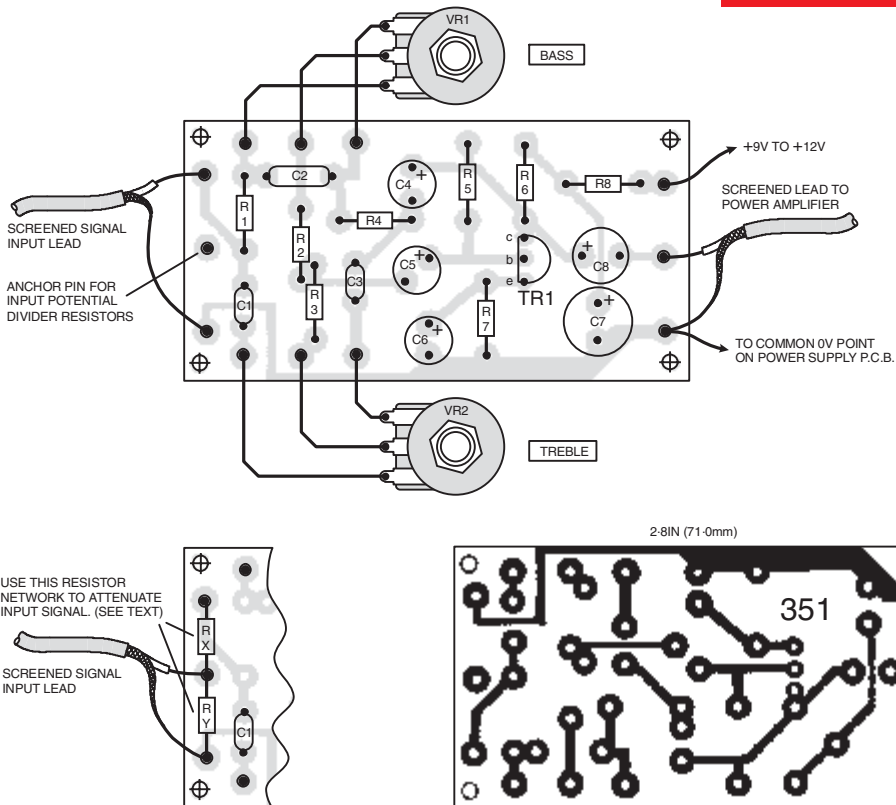


Fig. 12. Tone Control printed circuit board component layout, interwiring and full-size copper foil master. The tape and CD player signal input attenuation resistors (see text) are shown in the inset diagram (left).

COMPONENTS

TONE CONTROL

Resistors
 R1, R3, R4, R6 4k7 (4 off)
 R2 27k
 R5 1M
 R7 470 Ω
 R8 100 Ω
 All 0.25W 5% carbon film

See **SHOP**
TALK
 page

Potentiometers
 VR1, VR2 100k min. rotary carbon, linear (2 off)

Capacitors
 C1, C3 2n2 polyester (2 off)
 C2 47n polyester
 C4, C8 10 μ radial elect. 25V (2 off)
 C5 1 μ radial elect. 25V
 C6 47 μ radial elect. 25V
 C7 100 μ radial elect. 25V

Semiconductors
 TR1 BC549C npn transistor (or similar – see text)

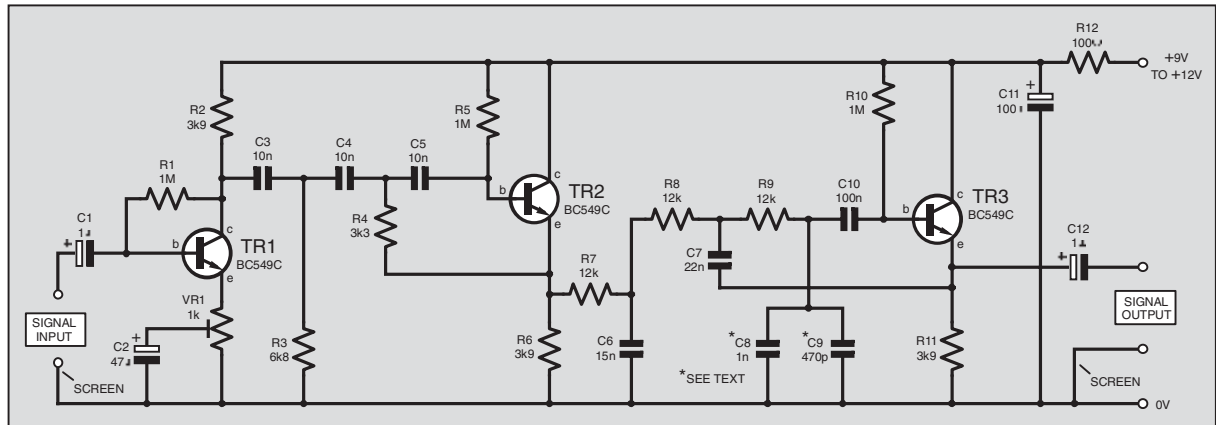
Miscellaneous

Printed circuit board available from the *EPE PCB SERVICE*, code 351 (Tone); metal case (optional), size and type to choice – see text; audio screened cable; multistrand connecting wire; input and output sockets, type to choice; solder pins; solder etc.

Approx. Cost
 Guidance Only

£9
 excluding case

SPEECH FREQUENCIES (300Hz TO 3kHz) BANDPASS FILTER



VOLTAGE GAIN WITH PASSBAND, UNITY WITH VR1 SLIDER AT 0V RAIL; 25 WITH SLIDER AT TR1 EMITTER END.
ROLL-OFF 18dB PER OCTAVE BELOW 30Hz AND ABOVE 3kHz. CURRENT DRAIN AT 9V SUPPLY: 4mA.

Fig. 13. Circuit diagram for the Bandpass Filter for speech frequencies (300Hz - 3kHz).

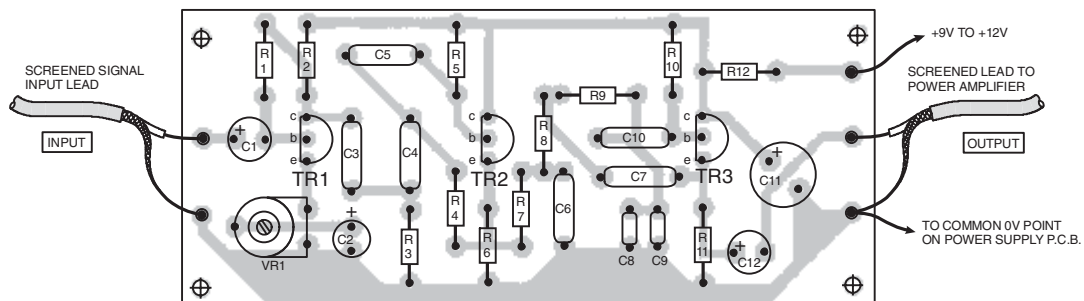
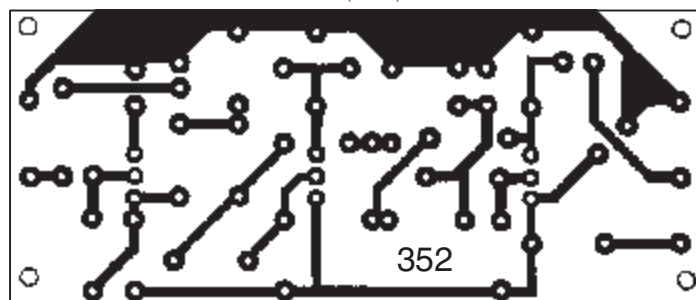


Fig. 14. Printed circuit board component layout, wiring and full size copper foil master for the Bandpass Filter.



COMPONENTS

BANDPASS FILTER

Resistors

- R1, R5, R10 1M (3 off)
 - R2, R6, R11 3k9 (3 off)
 - R3 6k8
 - R4 3k3
 - R7 to R9 12k 1% metal film (3 off)
 - R12 100k Ω
- All 0.25W 5% carbon film, except R7 to R9

Potentiometers

- VR1 1k carbon preset

Capacitors

- C1, C12 1 μ radial elect. 25V (2 off)
- C2 47 μ radial elect. 25V
- C3 to C5 10n polyester (5% or better) (3 off)

- C6 15n polyester
 - C7 22n polyester
 - C8* 1n polyester
 - C9* 470p ceramic
 - C10 100n polyester
 - C11 100 μ radial elect. 25V
- *Combined (parallel) to give 1n5

Semiconductors

- TR1 to TR3 BC549C npn transistor (or similar - see text) (3 off)



Bandpass Filter printed circuit board.

See
SHOP
TALK
page

Miscellaneous

Printed circuit board available from the EPE PCB Service, code 352 (Filter); audio screened cable; multistrand connecting wire; input and output sockets, type to choice; solder pins; solder etc.

Approx. Cost
Guidance Only

£9

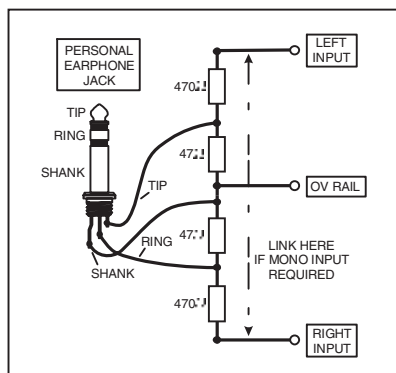


Fig. 15. Method of connecting a "Walkman" tape or CD player.

SUMMARY

Operational amplifiers (op.amps) are more commonly used in filters of this kind but, when the need is simply for a unity gain buffer with a high input and low output impedance, the ubiquitous bipolar transistor can be made to serve our purpose just as well.

SIGNAL SOURCES

Radio Receivers

The output from the detector or f.m. discriminator in a superhet radio receiver should fully load the power amplifiers described last month. After the usual filtering, the signal can be fed directly to the power amplifier, or via the Tone Control unit shown in Fig. 11 and Fig. 12.

Microphones

The single transistor preamplifiers shown in Fig. 1 to Fig. 8 will provide appropriate matching and sufficient gain for dynamic (moving coil), electret and crystal microphones when they are used for intercom purposes. (A circuit for line-powering electret microphones can be taken from Fig. 9). The common emitter circuit given in Fig. 3 should be used with moving coil units as these present an impedance of around 600 ohms.

When electret or dynamic microphones are deployed for surveillance or "sound capturing" purposes, the two transistor circuit of Fig. 9 will ensure a good degree of sensitivity. Electret microphones have an extended low frequency response. If this proves troublesome, reduce the value of the d.c. blocking capacitor C2. Try 47nF (0.047µF) as a starting point.

Gramophone Pick-ups

The low output of moving-coil pick-ups necessitates the use of the two transistor preamplifier detailed in Fig. 9. Omit preset VR1 and feed the signal to the base of transistor TR1 via capacitor C3. Low output ceramic pick-ups should be connected via a 1M (megohm) or 2M2 series resistor to preserve low frequency response.

The F.E.T. Preamplifier circuit illustrated in Fig. 7 is more suitable for high output ceramic and crystal pick-ups.

Personal Tape and CD Players

An arrangement for extracting the signal from personal cassette players and headphone radios is given in Fig. 15. The 47 ohm resistors substitute for the 32 ohm earpieces, and the 470 ohm resistors attenuate the signal path.

Pre-amplification is not required, but readers may wish to use the Tone Control unit to process the signal. Provision is accordingly made, on the Tone Control p.c.b. illustrated in Fig. 12, for a signal attenuating network; resistors Rx and Ry.

STEREO

The chosen system must, of course, be duplicated if stereo operation is required. Tone and Volume controls are usually ganged, and an additional potentiometer is provided to balance the gain of the two channels.

With the simple circuit arrangement shown in Fig. 16, the Balance potentiometer is connected across the ganged Volume controls at the inputs to the two power amplifiers (VR1 on the power amplifier circuit diagrams).

COMPONENTS

All of the components, for this part of the series, are readily available from a variety of sources. Transistor types are not critical and almost any small-signal npn device will function in the circuits.

A low-noise, high gain transistor will, however, ensure the best performance, and the base connections for some alternative types are given in Fig. 17. With European transistors, the suffix "C" indicates the highest gain grouping.

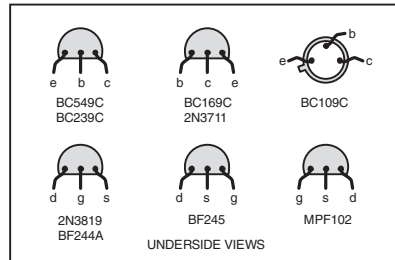


Fig. 17. Base connections for suitable transistors and f.e.t.s.

If possible, use transistors with an h_{fe} of at least 450 for the input stage of the Low-Noise Preamplifier and for the various emitter follower stages (where high input impedance depends on the use of a high gain device).

CONSTRUCTION

All the preamplifiers covered in this part are assembled on printed circuit boards and construction is reasonably straightforward. Solder pins, inserted at the lead-out points, will simplify any off-board wiring. Remember to earth the metal bodies of rotary potentiometers and to use screened audio (mic.) cable for the leads to tone and volume controls to minimise hum pick-up.

The single transistor preamplifiers all use the same p.c.b. and wire links are required. If units are cascaded, and coupling capacitors deleted, remember to install wire links to maintain the signal path.

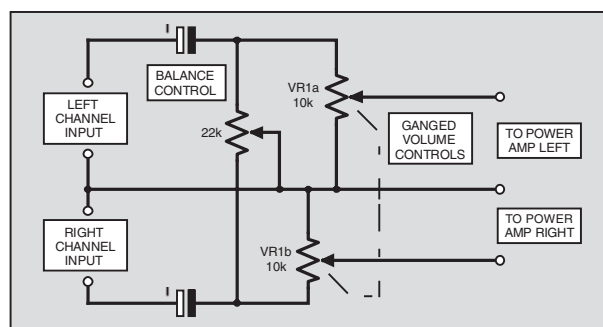


Fig. 16. Circuit arrangement for a stereo Balance control.

It may help to start construction by first placing and soldering in position the various wire links on the chosen preamplifier p.c.b. This should be followed by the lead-off solder pins, and then the smallest components (resistors) working up to the largest, electrolytic capacitors and presets. Finally, the lead-off wires (including the screened cables) should be attached to the p.c.b.

On completion, check the orientation of electrolytic capacitors and transistors, and examine the board for poor connections and bridged tracks, before connecting the power supply. The approximate current drains are included with the circuit diagrams.

INTERCONNECTIONS

Overall voltage gain can be in excess of 2000, and care must be taken to avoid hum pick-up and instability.

Hum pick-up is of two kinds, capacitive and inductive. High impedance circuits are prone to the former, and low impedance to the latter. Housing the pre- and power amplifiers in a metal case will do much to minimise these problems.

If hum increases when a finger is brought near to the preamplifier, the pick-up is capacitive. It can usually be cured by providing an earthed metal screen around the input wiring or even the entire preamplifier board.

All mains and a.c. power leads within the metal case of the unit must be tightly twisted to minimise external fields, and the mains transformer should be sited at least 150mm (6in) from the input circuitry. Tightly twist power amplifier output leads, and keep them as far away as possible from preamplifier inputs. Keep all leads as short as possible.

Run a separate negative power supply connection from each of the p.c.b.s to a common 0V point on the power supply board, or to the negative battery terminal. Do not connect one circuit board via another to supply negative, or rely upon screened cable braiding or a metal case to provide this connection. Make only one connection to any metal case, close to the negative terminal on the power supply p.c.b.

If all of the above measures have been adopted and hum problems still persist, try disconnecting, one by one, the screens of the audio cables, at one end only. Reorientating the mains transformer can also effect a cure.

Next Month: Mains power supplies, loudspeakers and signal filtering will be discussed.

SIMPLE AUDIO CIRCUITS

Part 3 – Power Supplies, Loudspeakers, Crossover Networks and Filters

RAYMOND HAIGH

A selection of "pic-n-mix" low-cost audio circuits from preamplifier to speaker!

If a modest output from one of the smaller power amplifiers (May '02) is all that is required, dry batteries represent a suitable power supply. However, when the output is expected to exceed the half-watt level for sustained periods, a mains power unit is more appropriate. Savings in the cost of batteries will quickly cover expenditure on components.

Compromises, inherent in the design of loudspeakers, give rise to limitations which are normally overcome by the use of two or more units and a crossover.

Power supplies, loudspeakers and associated networks are the topics to be covered this month.

SUPPLY REGULATION

A simple mains power supply comprising a full-wave rectifier and capacitor input filter will deliver an off-load voltage of around 1.4 times the transformer secondary voltage.

With a secondary rated at 12V a.c., the off-load d.c. output voltage will, therefore,

be almost 17V. If the power supply output is close to the maximum safe operating voltage of the amplifier i.c., there is a danger that, under no-signal conditions, the device will be ruined.

When fully loaded, the d.c. output voltage will fall to around 14V with an adequately rated transformer; lower when the transformer specification has been skimped. Voltage will, therefore, be low at the very moments when the power amplifier is being called upon to deliver a high output.

These voltage variations are a cause of distortion and impair the performance of the power amplifier. Moreover, when high-gain preamplifiers or radio tuners are fed from the same supply, the variations can also result in instability, even when substantial decoupling is provided.

POWER SUPPLY

These problems can be avoided by regulating the output of the power supply, and a versatile circuit, which can be adapted

for single or stereo pairs of any of the amplifiers described in Part 1 (May '02), is given in Fig.1. The mains voltage is stepped down by transformer T1, and a full-wave bridge rectifier arrangement, D1 to D4, produces the d.c. output. Reservoir capacitor C5 reduces supply ripple.

Voltage regulators IC1 and IC2 virtually eliminate any voltage swings caused by load variations. The regulators also remove any residual 100Hz ripple on the supply voltage rails and permit the use of a lower value reservoir capacitor (C5). Low level electrical noise, extending into the r.f. spectrum, is present in the output of the i.c.s, and bypass capacitors, C6, C7, C8 and C9, shunt this to the 0V rail.

The voltages required by amplifiers, preamplifiers and auxiliary equipment are often different, and provision is made for two regulated outputs. Alternatively, each output can supply a separate channel of a stereo system in order to double the current rating.

The switching action of the rectifier diodes (D1 to D4) modulates any r.f. (radio frequencies) present in the mains input. This modulated r.f. can be picked up by radio receivers connected to the supply and it manifests itself as a 100Hz hum which only appears when a station is tuned in. Capacitors C1 to C4, connected across the diodes, suppress this interference, which is known as modulation hum. If radio tuners are to be powered from this circuit, these capacitors must be fitted.

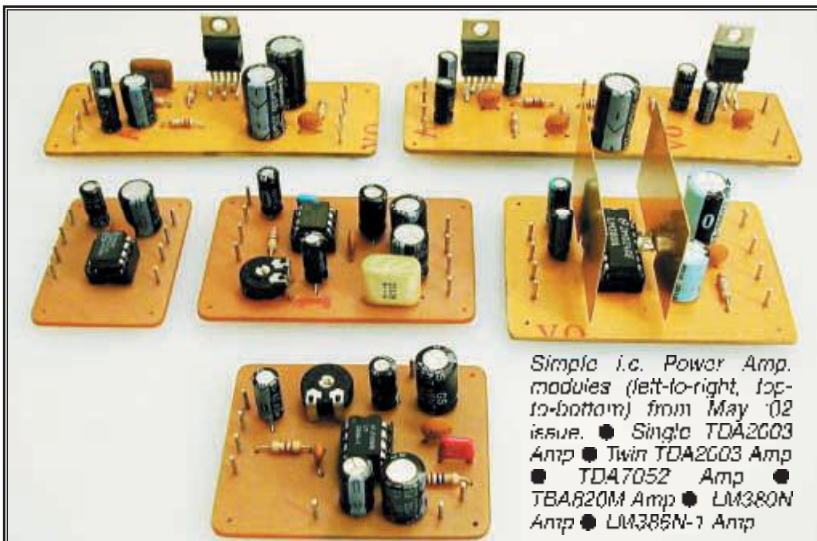
COMPONENT RATINGS

Fuse

It is good practice to protect the equipment with an internal fuse of the lowest possible rating. Because of the nature of the load, this should be of the anti-surge or slow-blow type, and a component rated at one amp (1A) would be suitable for power supplies serving the amplifiers described in this series of articles.

Transformer

The rectified d.c. voltage across the reservoir capacitor (C5) must be at least 3V more than the regulator output when



Simple i.c. Power Amp. modules (left-to-right, top-to-bottom) from May '02 issue. ● Single TDA2003 Amp ● Twin TDA2003 Amp ● TDA7052 Amp ● TBA820M Amp ● LM380N Amp ● LM385N-1 Amp

maximum current is being drawn from the supply. Further, the maximum input voltage to the regulator i.c., which is usually 35V for devices with a 2A rating, *must not* be exceeded. It is also desirable for the voltage drop across it to be no more than 10V or so, or power dissipation within the chip will be increased and more elaborate heatsinking will be required.

These requirements can best be met if the mains transformer secondary voltage is 3V more than the regulated d.c. output.

To determine the required current rating of the secondary winding, add together the demands of the amplifiers and ancillary equipment to be connected to the power supply, and increase this by at least 25 per cent to allow for the reactive load presented by the reservoir capacitor (C5). The current requirements of the power amplifiers were given in Part 1. For convenience, they are repeated here in Table 2.

Manufacturers usually indicate the current delivering capacity of their mains transformers by quoting a VA rating. This is, of course, the secondary output voltage multiplied by the maximum current which the transformer can supply.

In Europe, mains transformers often have two 115V primary windings and two identical secondary windings. The primary windings must be series or parallel connected to suit the local supply voltage, and the secondary connected to deliver the desired output. Parallel connecting the secondary will, of course, double the current available. *Connect the windings in phase or the transformer will be short circuited.*

Rectifiers

With a capacitor input filter, the rectifiers (D1 to D4) must have a p.i.v. (peak inverse voltage) rating at least three times the secondary voltage of the mains transformer. Their current rating should be at least 50 per cent greater than the maximum load on the power supply.

Reservoir Capacitor

The value of the reservoir capacitor, in microfarads (μF), should be at least 2500 times the maximum load current in amps when the supply is regulated, and double this value when unregulated. The working voltage should be at least double the secondary voltage of the mains transformer.

Regulators

The current rating of the voltage regulators (IC1 and IC2) must, of course, be equal to or greater than the maximum current demand on the power supply. The maximum input voltage rating (usually 30V to 35V) must be at least 1.5 times the secondary voltage of the mains transformer.

Regulator i.c.s are available in a range of output voltages suitable for the audio amplifiers (May'02) and preamplifiers (June'02) described in this

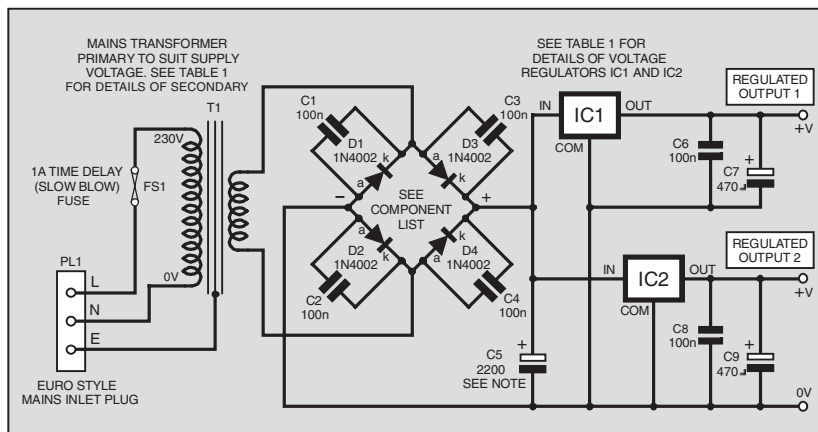


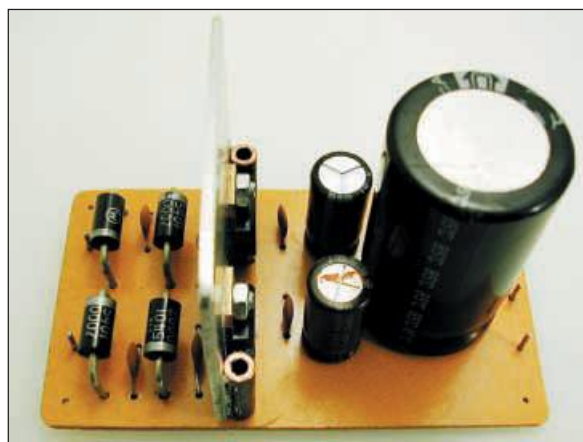
Fig. 1. Circuit diagram for a Dual Output Regulated Power Supply.

Table 1: Component Ratings

Regulated Output V d.c.	Transformer Sec. V r.m.s.	Regulator i.c. (1A max output)	C5 Working Voltage
6	9	L7806	25
9	12	L7809	25
12	15	L7812	35
15	18	L7815	35

NOTES:

- (1) To determine the transformer current rating, add together the current demands of pre and power amplifiers and any ancillary equipment, then increase the total by at least 25% to allow for the reactive load presented by C5.
- (2) A bridge-connected pair of TDA2003 i.c.s with a 4 ohm load will draw 1.7A from a 15V supply and the ratings of the rectifiers, regulator and reservoir capacitor must be increased. Use 1N5401 rectifiers, an L78S15 regulator and a 4700 μF capacitor for C5 (35V working).
- (3) For two, bridge-connected pairs of TDA2003 i.c.s in a stereo combination, fit a 10000 μF (or two 4700 μF) 35V reservoir capacitor, two L78S15 regulators, (one for each stereo channel) and use P600D rectifiers.



Completed power supply board.

Table 2: Power Amplifier Current Requirements

Power Amp i.c.	Speaker Imp Ohms	Supply volts V d.c.	Current drain A	Power output W
LM386N-1	4	6	0.13	0.32
LM386N-1	8	9	0.12	0.56
TDA7052	4	6	0.42	0.78
TDA7052	8	9	0.39	1
TBA820M	4	9	0.23	0.98
TBA820M	8	12	0.17	1.1
LM380N	4	12	0.23	1.12
LM380N	8	15	0.19	1.32
TDA2003	4	15	0.5	3.92
TDA2003	8	15	0.27	2.1
TDA2003 x 2	4	15	1.7	12.5
TDA2003 x 2	8	15	0.96	8.2

Current drain and power output measured just before the onset of clipping.

series. Maximum current ratings are 5A for 12V and 3A for 15V units, but chips rated at more than 2A can be difficult to obtain. When the current demand exceeds 2A; e.g. when two, bridge-connected, pairs of TDA2003 audio power amplifier modules are used in a stereo combination, fit a 2A regulator to each output of the power supply and use one for each stereo channel.

Suppressor Capacitors

The working voltage of capacitors C1 to C4, connected across the rectifier diodes, should be at least four times the secondary voltage of the mains transformer. Bypass capacitors C6, C7, C8 and C9, should have a working voltage at least 1.5 times the transformer secondary voltage to protect them in the event of regulator failure.

DUAL OUTPUT REGULATED POWER SUPPLY

COMPONENTS

POWER SUPPLY

Capacitors

C1 to C4	100n ceramic, 100V (4 off)
C5	2200µF radial elect. (see Table 1)
C6, C8	100n ceramic, 50V (2 off)
C7, C9	470µF radial elect. 50V (2 off)

See
**SHOP
TALK
page**

Semiconductors

D1 to D4	1N4002 rect. diode for 1A max. output (4 off)
	1N5401 rect. diode for 3A max. output (4 off)
	P60D rect. diode for 4A max. output, limited by regulators (4 off)
IC1, IC2	78 series for 1A; 78S series for 2A maximum output. See Table 1 (2 off)

Miscellaneous

T1	mains transformer – see text and Table 1
FS1	1A 20mm slow-blow fuse to suit holder
PL1	Euro fused mains inlet, chassis mounting, plug with line socket

Printed circuit board available from the EPE PCB Service, code 356 (PSU); metal case, size and type to choice; multistrand connecting wire; mains cable; aluminium sheet or proprietary heatsink and heatsink compound; solder pins; nuts, bolts and washers; stand-off pillars (4 off); solder etc.

Approx. Cost
Guidance Only

£20
excluding case

CONSTRUCTION

Any readers who have no experience of building or commissioning mains-powered equipment are reminded that the voltages involved can kill! Anyone who feels unsure of his or her ability to complete a project of this kind MUST seek help and guidance from an experienced constructor.

The small components are assembled on the printed circuit board (p.c.b.) as illustrated in Fig.2, together with a full-size copper foil master and the interwiring to off-board components. This board is available from the EPE PCB Service, code 356.

Commence construction by first soldering in position on the p.c.b. the rectifier diodes and non-electrolytic capacitors. This can be

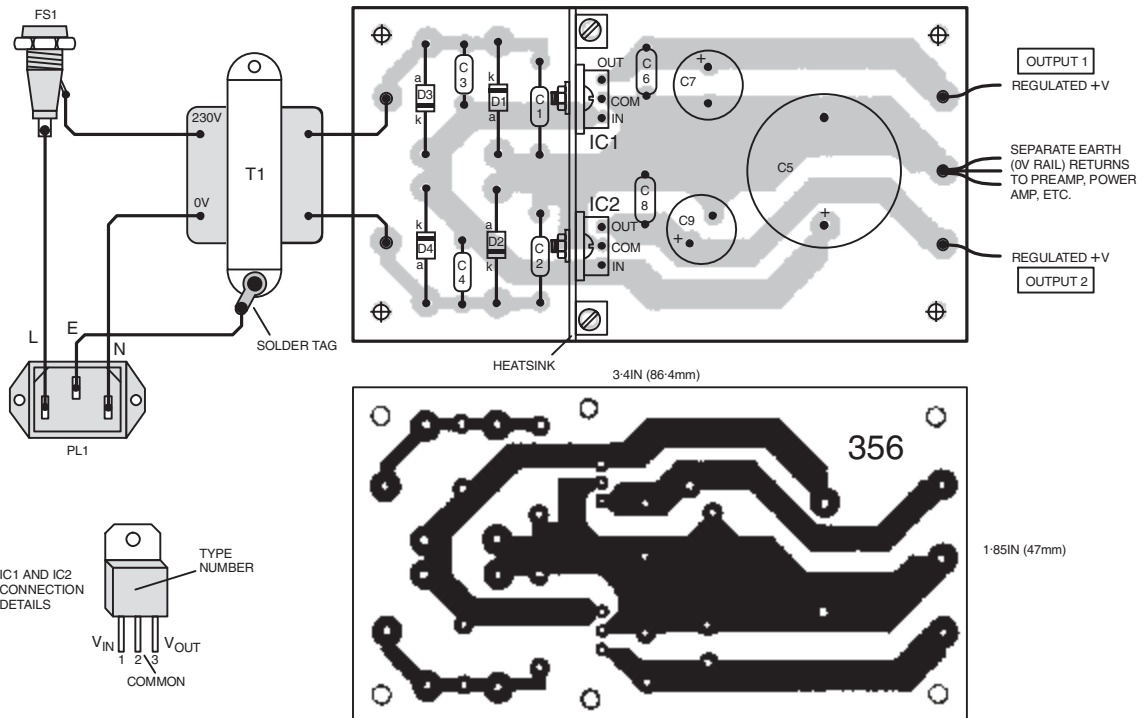
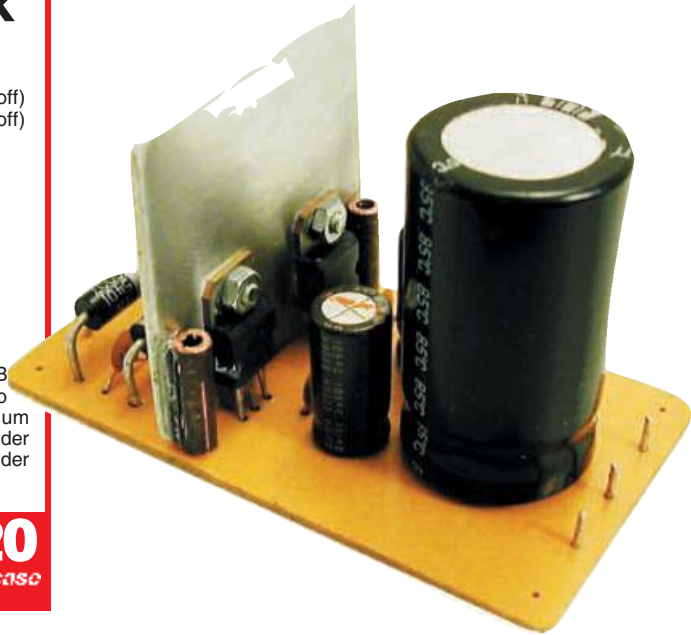


Fig.2. Power Supply printed circuit board, full-size copper master and suggested mains transformer and separate panel fuseholder interwiring. The 16 s.w.g. aluminium heatsink measures 45mm x 45mm.

LOUDSPEAKERS

followed by the larger electrolytic types and the voltage regulators IC1 and IC2. Finally, you will need to bolt a heatsink to the regulators and details of choosing a suitable heatsink will be given shortly. Solder pins, inserted at the lead-out points, simplify the task of off-board wiring.

Diodes D1 to D4, the reservoir capacitor, C5, and the regulators, IC1 and IC2, have to be chosen to suit the voltage and current to be delivered by the power supply. The requirements are summarised in Table 1 and the associated notes. Details of the modest current needs of the various preamplifiers were given in Part 2 of the series, and the current demands of the power amplifiers are scheduled in Table 2.

Dimensions and fixing arrangements for mains transformers vary and this heavy component should be mounted directly into or on the metal equipment case bottom or chassis panel. A Euro-style mains inlet plug, with a built-in fuseholder for FS1, is strongly recommended. You can, of course, use a separate panel-mounting fuseholder if you wish, see Fig.2.

Mains Earth should be connected to any metal case and to the core and cladding of the transformer. (A solder tag bolted under one of the mains transformer mounting lugs makes a good earthing point for the mains Earth lead.)

Interwiring details to off-board components are also shown in Fig.2. Leads connecting the mains transformer to the inlet plug and the p.c.b., and any mains switch wiring, should be tightly twisted to minimise external fields. Keep the transformer at least 150mm (6in.) away from signal input wiring.

Toroidal transformers have a smaller external field than units with conventional cores. They are the component of choice when the equipment is particularly compact and/or high gain preamplifiers are used.

HEATSINKING

Unless the current drain is to be very low (say 20mA or less), the regulator i.c.s must be bolted to a heatsink. The 45mm x 45mm sheet of 16s.w.g. aluminium shown on the drawing (Fig.2) is sufficient for current drains up to 1A when the voltage drop across the regulators is not too extreme.

For larger current loads it is suggested that the heatsink be extended and bolted to the metal case or chassis of the unit to ensure adequate heat transfer. Failure to properly dissipate heat from the regulators will result in the devices shutting down.

COMMISSIONING

Once construction has been completed, check the p.c.b. for poor soldered joints and bridged tracks. Check the orientation of electrolytic capacitors, diodes and regulators.

Make sure that the primary windings of the mains transformer are connected to suit the local supply voltage, and that the secondary windings are connected, in phase, to deliver the correct voltage to the power supply p.c.b. It is a good idea to connect the transformer to the mains and check the secondary voltage with a test meter before linking it to the p.c.b. **Extra care must be taken when carrying out this last task.**

Check the voltage across the reservoir capacitor C5, and that the voltages delivered by regulators (IC1 and IC2) are correct before using the supply to power any equipment.

Loudspeaker (speaker) designers have to make compromises. Sensitivity, good transient and good high frequency response call for a lightweight cone and speech coil assembly. Power handling and an extended low frequency response require a large, strong (and heavy) cone and coil.

For good sensitivity, the magnetic field cutting the voice coil must be intense. Unfortunately, this increases the impedance at the cone's resonant frequency. However, this impedance rise can be controlled by the speaker enclosure, and a powerful magnet is always preferable.

The reproduction of low frequencies involves large cone excursions and the suspension must be highly compliant. High compliance also lowers the cone's resonant frequency, and this extends the speaker's low frequency response. However, the need to maintain control of the position of the voice coil in the magnet gap imposes limits on how free the suspension can be.

Cone movement for a given sound output reduces with increasing speaker size but, as we have seen, greater diaphragm mass impairs transient and high-frequency response.

HORSES FOR COURSES

To avoid performance being excessively degraded by these conflicting requirements, domestic "hi-fi" systems usually combine two or more speakers, each being designed to reproduce part of the audio frequency spectrum.

The low frequency unit, or *bass* speaker, has a comparatively heavy cone and voice coil with a highly compliant suspension. Clever designers have managed to obtain reasonable results with small speakers, but an extended low frequency response and good power handling are more easy to achieve with speakers of 200mm (8in.) or more in diameter.

Mid-range units are sometimes provided when the low frequency speaker is large (300mm to 450mm or 12in. to 18in. diameter). As one would expect, cones are lighter, the compliance is often stiffer, and the chassis can form a sealed enclosure.

High-frequency units, or "*tweeters*", have a very small diaphragm, which is commonly dome shaped to improve sound dispersal. Units of this kind always have sealed backs.

Whilst moving coil tweeters are the preferred option for hi-fi applications, horn-loaded piezoelectric units are often fitted in the high power speaker systems used by musicians. The impedance of these devices rises, and their power consumption falls almost to zero, as the applied frequency is lowered. They do not, therefore, require a "crossover unit", and are easy to connect into multiple speaker systems.

COMMUNICATIONS

Loudspeakers intended primarily for speech reproduction in communications equipment have to perform well over a restricted frequency range, usually around 300Hz to 3000Hz.

Inexpensive speakers of the type manufactured for portable receivers are better suited for this purpose, and, if space is available, a 102mm (4in.) diameter unit is

to be preferred. Clarity will be impaired if low frequencies are allowed to excite the cone of a speaker of this kind, and measures to prevent this were discussed in Part 1 (May '02).

IMPEDANCE

Speech coil impedance is usually measured at around 400Hz. At this frequency, the inductance of the coil has a minimal effect, and its impedance is only one or two ohms more than its d.c. resistance. As frequency rises, the inductance of the speech coil has a growing impact and impedance mounts steadily.

The movement of the speech coil in the magnetic field induces in it a voltage which opposes the signal voltage. At the cone's resonant frequency, very little energy is needed to sustain it in motion, and it vibrates readily, over larger distances, for a comparatively small power input.

These larger cone excursions generate a greater opposing voltage, or back-e.m.f., and speech coil impedance, at resonance, increases by as much as a factor of ten over its nominal value. The more powerful the magnetic field, the more dramatic the rise in impedance.

Impedance peaking at cone resonance (between 30Hz and 100Hz for low frequency speakers), and the gradual rise in impedance with increasing frequency, makes the response of the speaker non-linear. (The power which can be fed to a speaker system falls as its impedance rises). Fortunately, the former can be tamed by good enclosure design, and the latter can be overcome by the use of filter networks and the addition of a tweeter.

Care must always be taken to ensure that the rated impedance of a speaker system is not too low for the power amplifier. Too low an impedance will cause excessive dissipation in the output transistors and, if there is no overload protection circuitry, the power amplifier will be ruined.



Safe supply voltage and speaker impedance combinations for the various i.c. power amplifiers were given in Part 1. They are summarised here in Table 2.

CROSSOVERS

When two or more speakers are used to improve performance, arrangements must be made to allocate the audio spectrum between them.

The resistance presented by capacitors to the flow of alternating current decreases as frequency rises. With inductors, resistance increases with rising frequency. This frequency-dependant opposition to current flow is known as *reactance*.

Capacitors and inductors can be combined in simple networks which utilise this phenomenon to allocate frequency bands to different speakers. Circuits and design data are given in Fig.3 and inductor and capacitor values for common speaker impedances, and a range of crossover frequencies, are set out in Table 3. The reactances of standard value capacitors, at

Table 3: Crossover Network Inductor and Capacitor Values

Crossover frequency Hertz		500	1000	1500	2000	2500	3000	3500	4000	4500
4 ohm Speaker	L	1.3	0.63	0.42	0.32	0.25	0.21	0.18	0.16	0.14
1st Order Filter	C	80	40	26	20	16	13	11	10	8
4 ohm Speaker	L	1.8	0.9	0.6	0.5	0.35	0.3	0.25	0.22	0.2
2nd Order Filter	C	56	28	18	14	11	9	8	7	6
8 ohm Speaker	L	2.6	1.26	0.84	0.64	0.5	0.42	0.36	0.32	0.28
1st Order Filter	C	40	20	13	10	8	6.5	5.5	5	4
8 ohm Speaker	L	3.6	1.8	1.2	1	0.7	0.6	0.5	0.44	0.4
2nd Order Filter	C	28	14	9	7	6	4.5	4	3.5	3

Inductance values, L, are given in mH (millihenries).

Capacitor values, C, are given in μ F (microfarads).

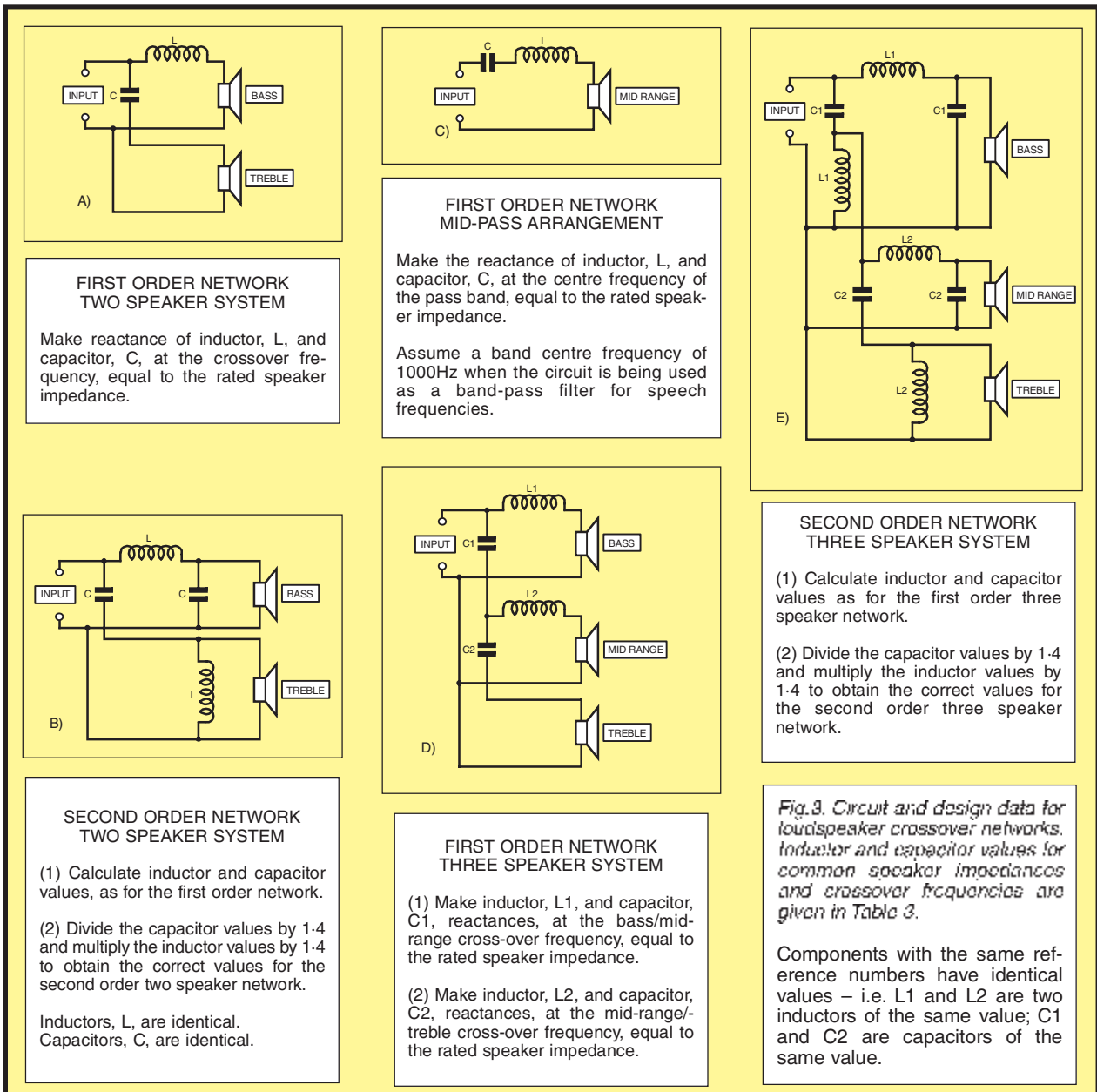
See text for guidance on rounding figures up or down to nearest standard value.

various audio frequencies, were tabulated in Part Two.

FILTER ORDERS

The simple "first order" filters shown in Fig.3a and Fig.3d are perfectly suitable for domestic systems rated at up to 15W.

Low frequency roll-off above the crossover frequency is 6dB per octave and this may not be sufficient to protect some tweeters when higher powered amplifiers are used. In these cases, the second order filters, shown in Fig.3b and Fig.3e, which produce a 12dB roll-off, are safer options.



CROSSOVER FREQUENCY

With two-speaker systems the crossover frequency is usually between 1kHz and 4.5kHz, and the tweeter manufacturer's recommendations should be followed. If the unit is of uncertain origin, adopt a crossover frequency of around 2.5kHz: this will normally be satisfactory.

When the bass speaker is large (12 inches diameter or more), a crossover at 1kHz or even lower can produce a more even frequency response. Suitable tweeters tend to be rather costly, but an inexpensive alternative will be described later.

THREE SPEAKERS

Another way of ensuring a more even response when a large bass speaker is used is to install a third, mid-range unit. Suitable circuits are given in Fig.3d and Fig.3e.

The bass/mid-range crossover point is usually around 500Hz with open chassis mid-range speakers, and 1000Hz with sealed back units. The mid-range/treble crossover is generally between 4.5kHz and 6kHz. Again, the recommendations of the speaker manufacturer should be followed.

PHASING

Parallel connected bass speakers must be wired in phase to avoid cancellation of the lower audio frequencies. Use a 1.5V dry cell to test for phasing on unmarked speakers by noting the battery positive connection for the outward movement of the cone.

Crossover networks introduce phase shift, but, as frequency increases, phasing becomes less important. Readers can try reversing the connections to mid-range units. However, unless they have a very refined ear, they are not likely to detect any difference.

CROSSOVER COMPONENTS

Inductors

Inductors for home-made crossovers have to be hand wound. The amount of wire, and the resistive losses, can be greatly reduced by winding the coils on short lengths of ferrite aerial rod. Core saturation problems should not arise at the power levels encountered in domestic installations.

Bobbin construction is illustrated in Fig.4. Winding details for the inductor values likely to be encountered are given in Table 4.

The wire should be wound on evenly, and masking tape, applied over each layer, will make the task a little easier. Constructors who have difficulty producing neat windings should increase the diameter of the bobbin ends for the larger inductance coils.

Capacitors

The bipolar electrolytic capacitors used in crossover networks are available in a limited range of values. Capacitors of this kind can be formed by connecting two ordinary electrolytics back-to-back, and this makes possible the production of non-standard values. The details are given in Fig.5. Capacitors rated at 50V working

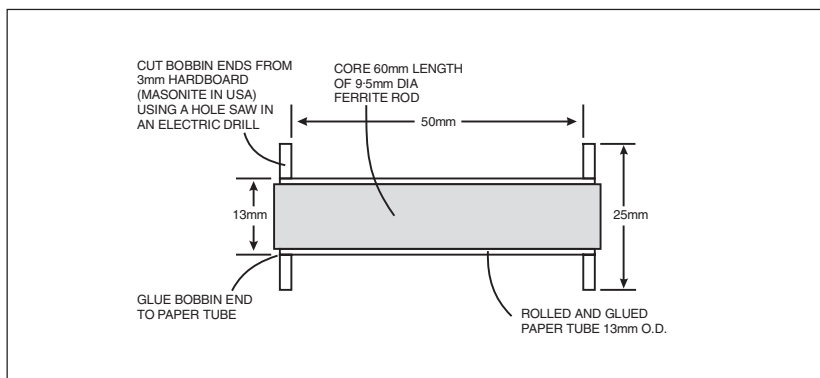


Fig.4. Inductor bobbin construction details.

Table 4: Inductance of Ferrite-cored Coils

Induct mH	0.1	0.2	0.3	0.4	0.5	0.75	1	1.5	2	2.5	3	3.5
No. of turns	45	60	75	90	100	125	150	175	200	225	250	275

Use 20 s.w.g. (19 a.w.g.) enamelled copper wire for coils up to 2mH.

Use 22 s.w.g. (21 a.w.g.) enamelled copper wire for 2.5mH to 3.5mH coils.

See illustration for details of bobbin and core.

will be suitable for all of the power amplifiers described in Part 1.

The performance of electrolytic capacitors can become uncertain at high audio frequencies, and the best crossover networks use components with a paper, polyester or polypropylene dielectric.

Tolerances

Variations in the composition of ferrite rod will affect the tabulated inductor values shown in Table 4 by plus or minus 10 per cent or so. Bipolar electrolytics, whether purchased or homemade, have a tolerance, at best, of plus or minus 20 per cent.

Fortunately, loudspeaker crossover networks are very forgiving, and component spreads even greater than this produce no audible difference. When calculated values are being rounded up or down, it is prudent to err on the high side with inductors and on the low side with capacitors.

BANDPASS FILTERS

Mention has already been made of the desirability of restricting the audio bandwidth of speakers used primarily for speech communication. An inductor and capacitor can be combined to produce a bandpass effect, and a typical circuit is given in Fig.3c.

As a starting point, select the inductor and capacitor values for a centre frequency of 1000Hz (1kHz). If a more severe attenuation of frequencies below 300Hz and above 3000Hz (3kHz) is required, reduce the capacitor and increase the inductor value. When using this network with earphones, connect both earpieces in parallel to produce an impedance of 16 ohms, and perform the calculations on this basis.

Although extremely simple, this measure will greatly improve the clarity of speech, especially when signals are overlaid by received or generated noise within the amplifiers.

CROSSOVER UNIT

The circuit diagram for an inexpensive 8ohm Crossover/Filter unit suitable for a multi-purpose workshop speaker is shown

FORMULAE FOR THE REACTANCE OF INDUCTORS AND CAPACITORS

$$X_L = 0.00628 f L \text{ ohms}$$

$$X_C = \frac{159000 \text{ ohms}}{f C}$$

where

f is in Hertz

L is in millihenries (mH)

and C is in microfarads (μF)

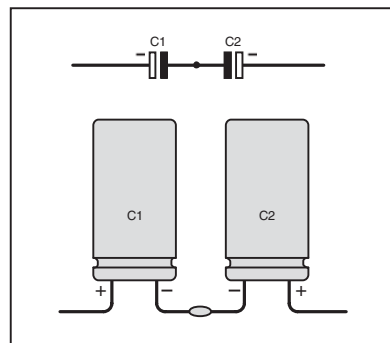


Fig.5. Creating a bipolar electrolytic from two capacitors.

FORMULAE FOR COMBINING CAPACITORS

Two capacitors in series:

$$C_x = \frac{C_1 \times C_2}{C_1 + C_2}$$

Capacitors in parallel:

$$C_x = C_1 + C_2 + C_3 \dots$$

The working voltage of each capacitor should be at least 1.5 times the peak-to-peak signal voltage developed across the loudspeaker at maximum input.

CROSSOVER/AUDIO FILTER

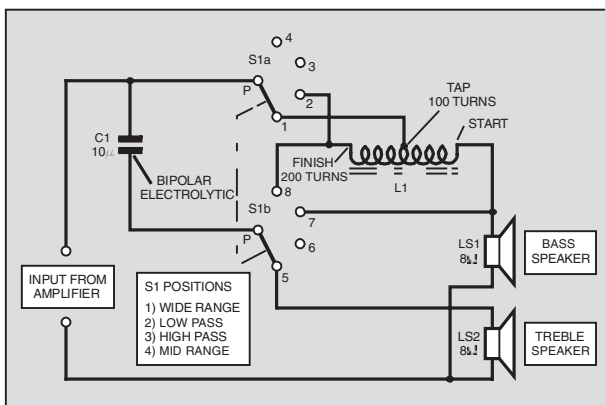


Fig.6. Circuit diagram for the Loudspeaker Crossover/Audio Filter.

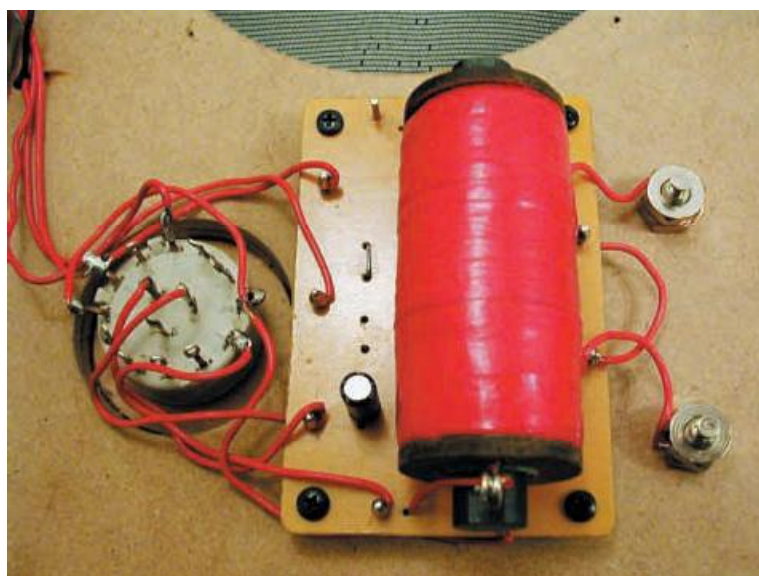
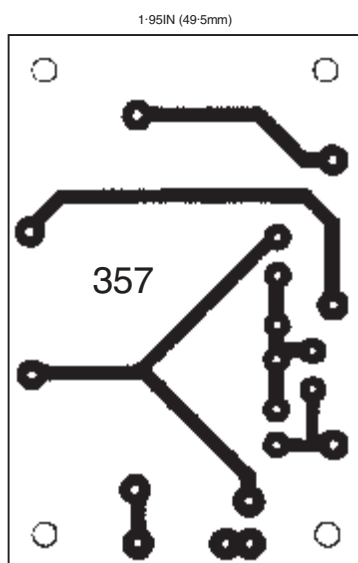
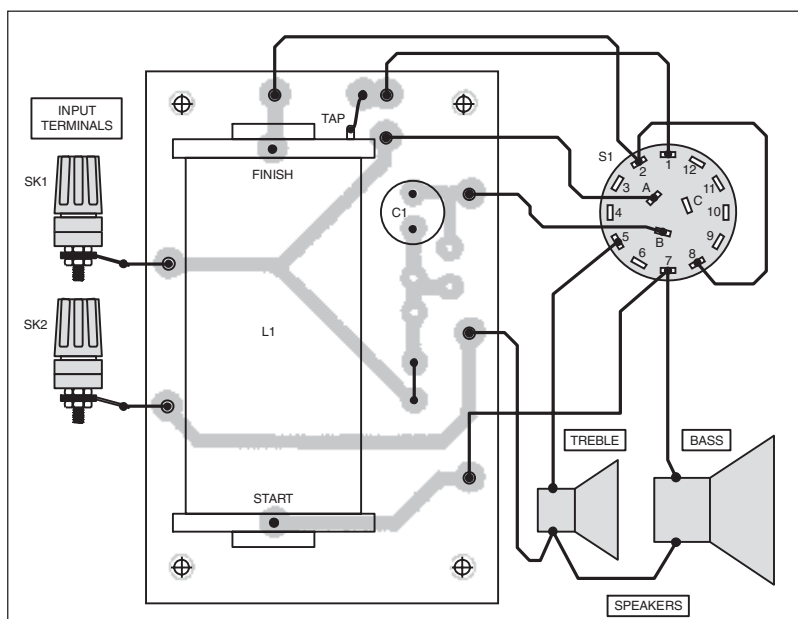


Fig.7. Crossover/Audio Filter printed circuit board component layout, interwiring to off-board components and full size copper foil master. The completed crossover is shown in the above photograph.

COMPONENTS

CROSSOVER/AUDIO FILTER

Capacitors

- C1 10µF bipolar radial elect. 50V (Alternatively, two 22µF standard elect. connected back-to-back – see text and Fig.5)

Inductor

- L1 9.5mm (3/8in.) dia. ferrite rod, length 63mm (2½in.); card, hardboard and glue for bobbin. Enamelled copper wire: Crossover only – 100 turns 20 s.w.g. (19 a.w.g.). Crossover and Filter – 200 turns 22 s.w.g. (21 a.w.g.). See Fig.4 and text

Miscellaneous

- S1 3-pole 4-way rotary switch (only two poles used)
SK1, SK2 4mm screw terminal post/socket (2 off)

Printed circuit board available from the *EPE PCB SERVICE*, code 357 (Crossover/Filter); multistrand and connecting wire; plastic control knob; speaker terminals; solder pins; solder etc.

Approx. Cost
Guidance Only

£9
excluding speakers

in Fig.6. The first order filter serves as a basic crossover when the speaker is being used for testing or listening to "hi-fi" equipment.

Switching out the Treble speaker and connecting the inductor in series with the Bass speaker gives a low-pass (top cut) effect. Connecting the capacitor in series with the speaker provides a high-pass (bass cut) arrangement. With the inductor and capacitor in series with the speaker, response to speech frequencies is emphasised, making the unit suitable for use with a communications receiver or for surveillance work.

Rotary switch S1 selects the required function, and the inductor is tapped to provide appropriate values for the crossover and speech filter.

CONSTRUCTION

Construction of the Crossover/Filter Unit is based on a small single-sided printed circuit board (p.c.b.). This board is available from the *EPE PCB Service*, code 357.

The topside component layout, full-size copper foil master and off-board wiring details are illustrated in Fig.7. Again, solder pins at the lead-out points will simplify off-board wiring. The p.c.b. makes provision for series and parallel combinations of capacitors, and a wire link must be inserted

if capacitor C1 is a single, bipolar electrolytic.

Constructors interested only in "hi-fi" applications can ignore the switching arrangements and simply connect a 100-turn (0.5mH) inductor and the capacitor as shown in Fig.3a.

Next Month: The final part will deal with speaker enclosures and include a low-cost, high-performance design



Low Frequency Oscillator for loud speaker resonance checking.

which incorporates this month's Crossover/Filter unit.

The construction of a simple and inexpensive oscillator and resonance detector, which can be used to match any speaker to an enclosure and optimise performance, will also be described.



SHOP TALK

with David Barrington

Infra-Red Autoswitch

As the *Infra-Red Autoswitch* project is mains powered, all the components have been specially selected to fit directly on the small printed circuit board (p.c.b.). If alternative, non-board mounting components, such as the mains transformer and relay, are used you must take extra care when building and testing this unit. In this case, it is very important that the p.c.b. and any off-board parts be mounted in its case before testing and that a separate power supply is used for checking its operation, prior to mains connection.

The special Sharp IS471F infra-red sensor/detector came from **RS Components** and carries the order code 564-396. They also supplied the p.c.b. mounting, short-circuit proof, mains transformer with twin 9V 0.027A (0.5VA total) secondaries, code 310-1263. These components can be ordered from any of our RS stockists, including some of our advertisers. You can order direct from RS (see above) on ☎ 01536 444079 or on the web at rswww.com. A post and handling charge will be made.

The 12V d.c. low-profile relay, with 12A 250V a.c. rated single-pole changeover contacts, used in the model was purchased from **Rapid Electronics** (☎ 01206 751166 or www.rapid-electronics.co.uk), code 60-4630. We understand that RS (see above) also stock a similar relay, code 198-6933.

The specified low-profile case came from **CPC** (☎ 08701 202530, code EN55028). A post and packing charge is made on all orders under £30. The Autoswitch printed circuit board is available from the *EPE PCB Service*, code 358 (see page 539).

Teach-In 2002 - Lab 9

Once again, it's only the sensor and semiconductor devices called for in this month's *Teach-In 2002 Lab 9* that will give some readers sourcing grief. Starting with the Nemoto NAP-7AU gas sensor/compensator pair, these were obtained from **Maplin** (☎ 0870 264 6000 or www.maplin.co.uk), code FM87U and are sold as a pair.

We have found two listings for the precision low off-set op.amp type OP177 and it can be ordered from **Rapid Electronics** (☎ 01206 751166 or www.rapid-electronics.co.uk), code 82-0092, or **RS Components** (☎ 01536 444079 or on the web at rswww.com), code 127-2868. Expect to pay a handling and postage charge.

If readers experience any difficulty in finding a local source for the 4093 quad 2-input NAND Schmitt trigger (Rapid 83-0420) and the ADC0804 8-bit analogue-to-digital chip (Maplin QQ00A or RS 411-674) they should contact the above mentioned companies. The relevant code numbers are shown in brackets.

The Linear Technology LTC1062CN8 5th order switched capacitor low-pass filter i.c., used in the *Anti-Aliasing Filter (Lab 5.5)* appears to be listed only by RS (see above), code 633-880.

EPE Stylopic

A couple of items proved hard to find when tracking down parts for the *EPE StyloPIC* project. The National Semiconductor LM13600 transconductance amplifier i.c. and the SGS-Thompson L272 dual power op.amp i.c. only appear to be listed by **RS**, codes 304-453 and 635-167 respectively. You can order

them direct from RS (credit card only) on ☎ 01536 444079 or on the web at rswww.com. A post and handling charge will be levied.

The above company supplied the Texas TLC7524CN 8-bit digital-to-analogue converter chip, code 650-087. It is also currently listed by **Rapid** (☎ 01206 751166 or www.rapid-electronics.co.uk), code 82-0764, but double check it is the 16-pin device being supplied.

For those readers unable to program their own PICs, a ready-programmed PIC16F877-20 microcontroller can be purchased from **Magenta Electronics** (☎ 01283 565435 or www.magenta2000.co.uk) for the inclusive price of £10 each (overseas add £1 p&p). It is the 20MHz version you require. The software is available on a 3.5in. PC-compatible disk (*EPE* Disk 5) from the *EPE* Editorial Office for the sum of £3 each (UK), to cover admin costs (for overseas charges see page 539). It is also available from the *EPE* web site: [ftp://ftp.epemag.wimborne.co.uk/pub/PIC/StyloPIC](http://ftp.epemag.wimborne.co.uk/pub/PIC/StyloPIC).

The printed circuit board/keyboard is available from the *EPE PCB Service*, code 359 (see page 539).

Simple Audio Circuits - 3

Most of our components advertisers should be able to supply all the parts needed to construct the circuits in this month's instalment of the *Simple Audio Circuits*. A suitable Bulgin fused Euro-style mains inlet, chassis mounting, plug (code MK18U or FT37S) together with an insulation, rear tag, protective cover (code JK67X) and line socket (UL16S) is listed by **Maplin** (☎ 0870 264 6000 or www.maplin.co.uk). They also list the 6A 200V P600D rectifier diode for one version of the Power Supply Unit, code UK60Q.

If problems are experienced in obtaining a ferrite rod for the Crossover unit, we understand, from the author, that one is obtainable from **JAB, PO Box 5774, Birmingham, B44 8PJ** (☎ 01522 520767). You will need to cut the rod down to size (take care, it is brittle!). These two firms can also supply 50g (2oz) reels of enamelled copper wire for the Crossover.

The two printed circuit boards are available from the *EPE PCB Service*, codes 356 (PSU) and 357 (Crossover) - see page 539.

Rotary Combination Lock

Probably the most expensive item when purchasing components for the *Rotary Combination Lock* project is likely to be the heavy-duty power solenoid. The one in the model cost about £15 and came from **RS** (☎ 01536 444079 or rswww.com) and is their 12V d.c. standard pull action, spring return type, code 250-1303. They also supplied the Omron 12V d.c. ultra-min., p.c.b. mounting relay, code 369-359.

The two printed circuit boards are available from the *EPE PCB Service*, code 260 (Lock) and 361 (Interface).

PLEASE TAKE NOTE

L.E.D. Sequencer (Ingenuity Unlimited)

June 02

Page 406. To prevent the i.c. outputs (IC2, IC3) from adversely affecting each other, 1N4148 signal diodes should be inserted between each i.c. pin and the respective l.e.d. The anode on the pin and cathode on the l.e.d.

World Lamp

Where it is said that VR1 should be turned clockwise, this should read anti-clockwise, and where anti-clockwise, clockwise.

Toolkit TK3

Updated files for V1.2 are now on our FTP site. Only files Disk 1 and Disk 3 are affected.

SIMPLE AUDIO CIRCUITS



Part 4 – Loudspeaker Enclosures, Tuning Oscillator and Resonance Detector

RAYMOND HAIGH

A selection of "pic-n-mix" low-cost audio circuits – from preamplifier to speaker!

ART and science collide in the design of loudspeaker enclosures and, transcending all the conflicting opinions, is the way a vibrating paper cone can reproduce sounds ranging from the human voice to a symphony orchestra with vivid realism.

Last month we discussed speakers and crossover networks. In this final instalment, enclosures and the simple test equipment needed to optimise performance are covered.

WHY AN ENCLOSURE?

Sound waves formed by the front of the speaker cone are out of phase with those at the back. If the pressure variations can leak around the cone there will be cancellation, particularly at low frequencies, and sound output will be reduced. The primary duty of the enclosure is, therefore, to prevent this leakage.



Speaker cones have a natural *resonant* frequency (just like a guitar string). The greater the mass of the cone, and the freer its suspension, then the lower the resonant frequency.

At resonance, very little energy is required to make the cone vibrate vigorously. This has electrical drawbacks, which were discussed last month. It is also undesirable from an acoustical point of view for speaker sensitivity to peak sharply at one frequency.

The second requirement of the enclosure is, therefore, to retain a volume of air which damps the cone and evens out the response of the system.

ENCLOSURE TYPES

Ignoring simple open baffles, there are four basic types of enclosure.

Infinite Baffles.

Infinite baffles are no more than sealed boxes filled with acoustic wadding to

absorb the sound output from the rear of the speaker. Air trapped inside the box damps the cone, raising its resonant frequency by up to an octave (a doubling). Low frequency output falls off rapidly below resonance, and special speakers with high mass, high compliance (very low resonance) cones are sometimes used to offset the rise in resonant frequency.

Absorption of the energy delivered by the rear of the cone, together with the high cone mass, result in an acoustic efficiency as low as 1 per cent. Our Twin TDA2003 12.5W Amplifier (8.2W into 8 ohms: see Part One) requires a more efficient speaker than this if windows are to rattle.

Acoustic Labyrinth

Acoustic labyrinth enclosures are, in effect, a duct one quarter of a wavelength long at the speaker's resonant frequency (e.g., 7ft at 40Hz). Folding the fibreboard or plywood duct into a box shape produces a labyrinth, hence the name. Some designers fill the duct with acoustic wadding; others just line the interior surfaces.

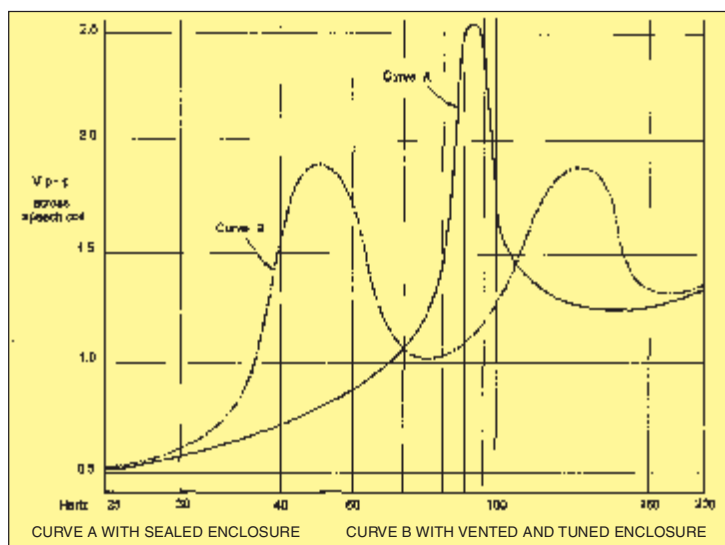


Fig. 1. Speech coil impedance in region of resonance.

The quarter wavelength air column imposes the desired heavy damping on the cone at its resonant frequency. As frequency rises through an octave (i.e., towards 80Hz in our example) the air column approaches half a wavelength. The phase of the radiation from the rear of the cone is then inverted, and it emerges from the duct to reinforce that from the front, thereby increasing output.

Enclosures of this kind are not easy to construct or tune to suit different speakers. In our quest for good performance for a modest outlay of cash and effort, this highly regarded system has, therefore, to be rejected.

Horns

Loading the speaker cone with an expanding column of air in the shape of a horn results in very high efficiencies; of the order of 40 per cent to 50 per cent. The horn effects an impedance transfer: high at the throat and low at the mouth. The resulting heavy damping on the speaker cone, and the small cone excursions and low power input needed for a given sound output, greatly reduce distortion.

Many ingenious designs have been produced for folding large, low frequency horns into cabinets. However, cost, size, and complexity of design and construction remove this system from our consideration.

Bass Reflex

Bass reflex enclosures, also known as acoustic phase inverters, are based on the work of a German physicist, Herman Ludwig Ferdinand von Helmholtz (1821-1894).

Whilst exploring the nature of sound, he investigated the way air resonates inside vented chambers and close to the vent itself. The idea of mounting a loudspeaker in a Helmholtz resonator was patented, about half-a-century later, by A. L. Thuras.

Enclosures of this kind are simple and cheap to construct and tune. Efficiency is comparatively high: some authorities suggest 15 per cent to 20 per cent depending on the size of the loudspeaker (the bigger the better).

A reflex enclosure is, therefore, the natural choice when cost and effort are to be kept to a minimum and limited amplifier power demands good speaker efficiency.

HOW IT WORKS

A bass reflex enclosure is no more than a box with a small opening known as the "vent" or "port". The mass of air within the box is tuned, by the vent, to resonate at the same frequency as the speaker cone. This imposes heavy damping and results in two smaller resonances, one of lower and one of higher frequency than the unvented cone resonance.

Speaker output falls off rapidly below resonance, and the development of the lower frequency peak extends the speaker's bass response by almost an octave. Phase inversion takes place over most of the low frequency range, and output from the vent augments that from the front of the cone (the operation of the system is complex, and phase inversion does not occur at all frequencies).

Output falls off very rapidly below the lower peak but, in a well designed system, this will be in a region where there is little or no signal content.

The damping effect of the vented enclosure is displayed graphically in Fig.1. A plot of speech coil voltage against frequency, it represents variations in impedance which are intimately related to resonances in the system. The single resonant peak (curve A) developed when the vent is sealed contrasts with the two lower peaks (curve B) which form when the vent is opened. Correct tuning is indicated when the peaks are of equal magnitude (as is the case here).

DESIGN TECHNIQUES

Traditionally, designers matched enclosure resonance to the free-air resonance of the speaker cone on the basis of vent area being equal to effective cone area. This optimised low-frequency reinforcement by the vent but resulted in large enclosures.

Readers who like to build on a grand scale might find the formulae in Table 1 helpful. Much simplified, they relate speaker size and cone resonance to enclosure volume. The relevant speaker parameters are listed in Table 2.

Enclosures as large as this tune very broadly, and sizeable variations in vent area have only a modest effect on performance. As we shall see, enclosures can be too big, and it would be prudent to reduce the volume given by the formulae by, say,



Crossover/Audio Filter selection switch and amplifier input terminals.

25 per cent and tune to resonance by reducing the vent area or providing a duct.

When reflex enclosures are designed in this way, the frequency ratio between the two smaller resonances formed by tuning should be not less than 1.5:1 and not more than 2.4:1.

MODERN PRACTICE

During the 1960's, Australians, Neville Thiele and Richard Small, extended earlier loudspeaker research carried out by American, James Novak.

They were able to show that, for optimum performance, enclosure size is dependant upon the relationship between the damping effect of the enclosed air and the compliance of the cone suspension. If, when the enclosure vent is sealed, the frequency of the single resonant peak is 1.5 to 1.6 times the free-air resonant frequency of the cone, the relationship is correct.

Thiele and Small described an experimental method for determining suspension compliance, and produced formulae relating this, and other speaker properties, to enclosure size and vent area. Known as the Thiele-Small parameters, these speaker characteristics are now published by a number of manufacturers.

TABLE 1: TRADITIONAL ENCLOSURE DESIGN

Formulae relating enclosure volume to speaker cone size and resonant frequency

f res Hz	40	50	60	70	80	90	100	110
Vol cu ft	3R	2R	1.4R	1R	0.8R	0.6R	0.5R	0.4R

Notes:

- (1) **F res** is the free air resonant frequency of the cone, in Hertz.
Vol is the internal volume of the enclosure in cubic feet.
R is the effective radius of the speaker cone in inches (see Table 2).
- (2) These formulae are derived from traditional design procedures. Calculations in accordance with current practice, which relates cone compliance to enclosed air compliance, usually result in a smaller enclosure (see text).
- (3) Although much simplified, the formulae will produce sufficiently accurate results (as size increases towards this maximum, tuning becomes less and less critical).
- (4) Formulae are based on enclosure port area being equal to the effective cone area. See Table 2 for details of effective cone areas.

TABLE 2: LOUDSPEAKER DATA

Speaker Diameter (inches)	8	10	12	15	18
Effective cone radius R in.	3	3.75	4.75	6	7.5
Effective cone area sq. in.	28	44	71	113	177





D. B. Keel subsequently adapted the formulae for processing on a pocket calculator, but the procedure is still complicated. Readers with a mathematical turn of mind who want to optimise their enclosures in this way are urged to study the extensive literature on the subject.

BUILD AND TUNE

Theile-Small parameters are not usually available for the low cost, but often reasonable quality, speakers of Far Eastern origin (or for speakers in spare boxes). Even if they were, it is likely that many readers couldn't face the tedium of the calculations.

An alternative approach is to make an enclosure of manageable dimensions, having regard to the size of speaker, and then tune it to optimise performance.

Quite small enclosures can be tuned to frequencies in the 50Hz to 100Hz range. However, as volume is reduced vent area has to be reduced to secure resonance at a particular frequency.

Eventually, a point is reached when vent output is negligible and the enclosure is performing almost like a sealed box. Moreover, as size is reduced, the smaller, "stiffer" volume of air increases damping on the cone and its resonant frequency rises unacceptably.

The resonant frequency of a given vent and enclosure combination can be lowered by forming a duct or pipe behind the vent. The longer the duct the lower the resonant frequency. Although this involves more constructional effort, it does allow a reasonable vent area to be maintained when enclosure volume is small.

SIZE AND SHAPE

Speaker units were discussed last month, and it was clear that an extended and powerful low-frequency response becomes easier to achieve as speaker size is increased. It was suggested that speaker size ought not to be less than 8in, and this is especially true when an inexpensive unit is to be fitted.

Readers may wish to use even larger speakers for the advantages they offer: some highly regarded studio monitors comprise a 15in bass unit in a 5 cubic foot reflex enclosure.

Cabinet dimensions should not be exact multiples of one another, and some experts maintain that deep enclosures perform better than shallow ones. Greater depth also permits a longer duct.

Chamfers, formed around the enclosure front and reaching almost to the speaker aperture, are said to improve clarity at low frequencies, but this makes construction difficult. Keeping the front panel as narrow as possible is probably the best we can do to achieve this objective.

The vent can be any shape provided its smallest dimension is not less than one inch. Circular vents can be ducted with a length of cardboard tube, but some builders may find rectangular openings and box-form ducts easier to fabricate.

CABINET SIZES

The above requirements, together with the desirability of a reasonable vent area and the obvious influence of speaker diameter, tend to determine the smallest acceptable enclosure size. Suggested internal dimensions to suit standard speakers are listed in Table 3 and the general make-up of the enclosure is shown in Fig.2.

The enclosures for the 15in and 18in units are rather deep, and the speaker aperture and vent opening could be formed on the face with the larger dimension if desired (these cabinets are large enough for the cone to still be an adequate distance from what would then be the back).

Whilst the width of the front is determined by the speaker chassis and cannot be reduced much, the other dimensions can be changed to suit materials that are to hand or a particular space in a room. When making changes, try not to reduce the volume by more than 10 per cent or so (especially with the 8in. and 10in. units); and try to avoid dimension combinations that are exact multiples.

CONSTRUCTION

One of the best materials for cabinet construction, acoustically speaking, is medium density fibreboard (MDF). This material is reasonably heavy, easy to work, has a desirable "dead" quality and is inexpensive. Chipboard, blockboard and ply-wood are also perfectly acceptable.

Enclosures for the 8in., 10in. and 12in. speakers should be formed from 13mm (1/2in.) thick sheet with 19mm (3/4in.) square glued and screwed softwood corner fillets. The two larger enclosures require 19mm (3/4in.) material and 25mm (1in.) square fillets. One or two lengths of 25mm square softwood should be fixed across the larger enclosures, from side-to-side, near mid panel, to inhibit vibrations.

The construction must be air-tight. If any of the joints are less than perfect, apply

liberal quantities of adhesive to fill the gaps. Use plastic foam draught excluder to seal the access panel.

MAKING DUCTS

Ducts need not be as rigid as the enclosures, and hardboard (Masonite in the USA) or very thick cardboard are suitable materials. Circular ducts can be formed by applying paste to a long strip of paper or thin card and winding it around a food or paint container until a thickness of 3mm (1/8in.) or so has been built up.

Slide the duct from the former and place it somewhere warm for the paste to dry. It is not too difficult to combine two pipes to form an adjustable, telescopic duct.

TWEETER MOUNTING

Tweeters can be mounted axially in front of the bass speaker to avoid the need for another hole in the cabinet. Small hooks and eyes and the kind of springy wire used for hanging net curtains are ideal for this purpose.

If the wires are cut short to provide a little tension the speaker will be held firmly in place. Strong rubber bands could be used, but these may perish over time.



Using cut-down curtain wire, hooks and eyes to suspend the treble speaker over the bass speaker.

Bass reflex cabinets are resonators and acoustic treatment should be applied sparingly. The rear and top of the enclosure should, however, be lined with about 50mm (2in.) of cellulose wadding to prevent the reflection of mid-frequency sounds which could otherwise escape through the speaker cone and impair clarity.

Cellulose wadding can be obtained from upholsterers and craft shops (it is used for stuffing soft toys).

TESTBENCH SPEAKER

The accompanying photographs show an enclosure for an 8in. speaker, constructed in accordance with the earlier guidelines, and incorporating the crossover and audio filter unit described last month. It is intended for workshop use, and this is reflected in the style and type of finish. Constructors wanting "hi-fi" speakers will have their own ideas for giving the units a more domestic appearance.

The surface mounted grille is of the type fitted to musician's speakers. The bezel around the vent opening is formed from

TESTBENCH LOUDSPEAKER ENCLOSURE

TABLE 3: RECOMMENDED MINIMUM ENCLOSURE DIMENSIONS

Speaker Diameter	8	10	12	15	18
Width A	9.5	11.5	13.5	17	20
Height B	15	18	21	27	33
Depth C	12	14.5	17	21	24
Speaker Aperture diameter D	7	9	11	13.75	16.5
Vent diameter E	4	5	6	7	8
Vent area sq. in.	12.5	19.5	28	38	50
Minimum distance F	3	4	5	7	8
Enclosure Volume (cu. in.)	1710	3002	4820	9639	15840
Enclosure Volume (cu. ft.)	1	1.75	2.75	5.5	9

Notes:

- (1) All dimensions are in inches unless otherwise stated.
- (2) Enclosure volumes expressed in cubic feet are approximate.
- (3) Enclosures produced to these dimensions must be tuned for optimum performance (see text).

LOUDSPEAKER ENCLOSURE . . . YOU WILL NEED

Bass Speaker: 8in. diameter, 8 ohms impedance, preferably with a free-air resonance below 70Hz (most speakers with a rolled surround will meet this requirement).

Moving coil treble unit, 8ohms impedance (see text).

Sheet of MDF, 1200mm x 600mm x 13mm (4ft x 2ft x 1/2in.) thick; softwood corner fillets 4m x 19mm square (13ft of 3/4in. square); glue and screws.

Speaker and vent grilles; material for any duct (see text); draught excluding strip; springy curtain wire and small hooks for mounting tweeter unit; finishing materials etc.

The parts list for the crossover unit was included with Part 3, last month.

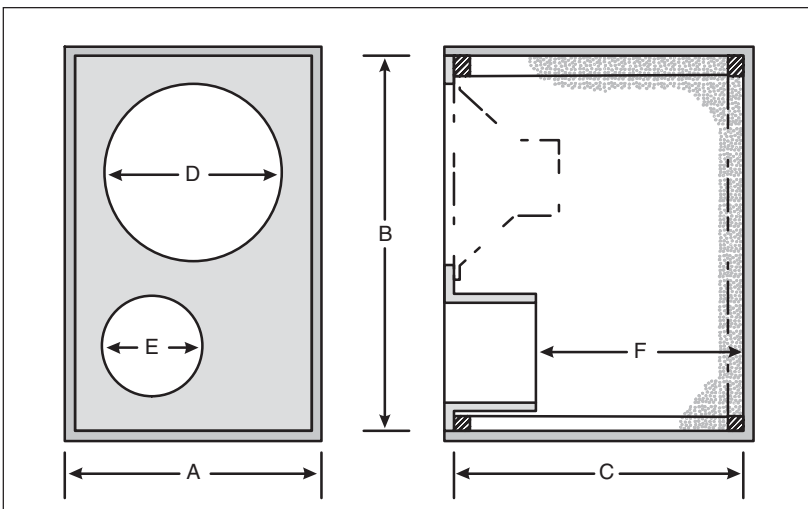


Fig.2. Front and side elevations showing the speaker and vent apertures. Recommended enclosure dimensions are listed in Table 3 above.



Main speaker and crossover filter (last month) mounted on the rear of the enclosure front panel.



Lining the rear of the cabinet with sound absorbent wadding.

hardboard and nylon mesh is used as a screen. Bezel and mesh are spray finished matt black.

Photographs of the tweeter mounting were taken before the suspension wires were painted black to conceal them behind the grille. Car spray paints were used to decorate the cabinet, and the hard, smooth surface of the MDF makes it easy to obtain a good finish (spraying should be undertaken outdoors or where there is plenty of ventilation). Rub-down lettering, protected by varnish, is used for the panel annotations.

SPEAKERS

Manufactured in the Far East, the bass speaker used in the model is an inexpensive 8in. diameter unit with a rolled surround. Speakers of this kind are widely retailed and cost between £8 and £15 (\$12 and \$22).

A compliant suspension and robust cone give these units a free-air resonance in the region of 60Hz. Speakers with a free-air resonance much higher than 70Hz should be avoided if possible.

Suitable tweeters are readily available at a fairly reasonable cost. The paper-coned unit mounted in the prototype is a cheap surplus component.

It is sometimes desirable to adopt a cross-over frequency around 500Hz when large (15in. or 18in.) bass speakers are used. Suitable tweeters can be expensive, and experimentally minded readers may care to try one of the cheap Mylar cone speakers intended for alarm systems. The claimed frequency response extends up to 20kHz, and a 3in. or larger unit should cope with the lower cross-over frequency.

Chassis perforations should be covered with several layers of sticky tape to prevent interaction with the bass speaker. Alternatively, isolate the tweeter by mounting it inside a small box formed within the main enclosure. Fill the box with cellulose wadding. A 3in. diameter Mylar cone speaker performed better than the purpose-made tweeter mentioned above.

TUNING OSCILLATOR

In order to tune our enclosure we need some means of exciting and detecting resonances.

A simple Low Frequency Oscillator circuit diagram is shown in Fig.3, where IC1, a 741 op.amp, provides the necessary gain. A Wien bridge network, formed by C1, C2, R1, R2 and VR1a and VR1b, controls the phase of the positive feedback from IC1 output (pin 6) to the non-inverting input (pin 3). Potentiometer VR1 sets the frequency of oscillation.

Negative feedback, from the output to the inverting input (pin 2), determines the gain, thereby controlling the level of positive feedback. Gain should be as low as possible consistent with reliable oscillation over the full swing of Frequency control VR1. Negative feedback increases, and gain reduces, as the slider (moving contact) of preset potentiometer VR2 is rotated towards resistor R3.

The stabilising circuit usually incorporated into the negative feedback loop has been omitted in the interests of simplicity. Despite this, signal amplitude is constant over the frequency range and waveform is good when VR2 is correctly set.

OSCILLATOR CONSTRUCTION

Most of the oscillator components are assembled on a small single-sided printed circuit board (p.c.b.). This board is available from the *EPE PCB Service*, code 364.

The topside component layout, interwiring and full-size underside copper foil master pattern for the Low Frequency Oscillator board are shown in Fig.4. Solder pins, inserted at the lead-out points,



simplify off-board wiring, and a holder for IC1 facilitates substitution checking.

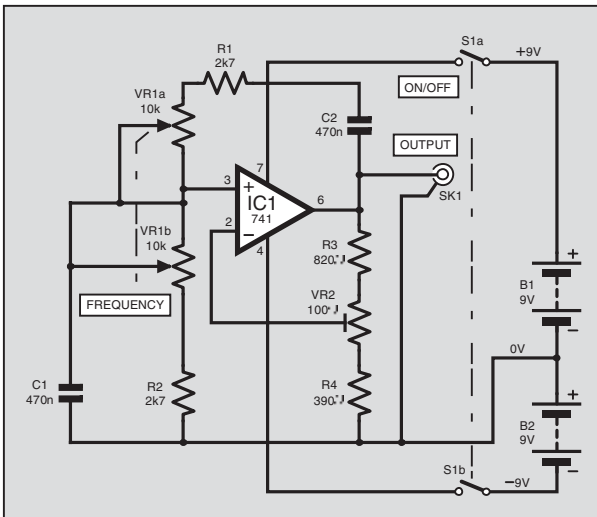


Fig.3. Circuit diagram for a simple Low Frequency Oscillator for loudspeaker resonance checking.



Component layout on the completed circuit board.

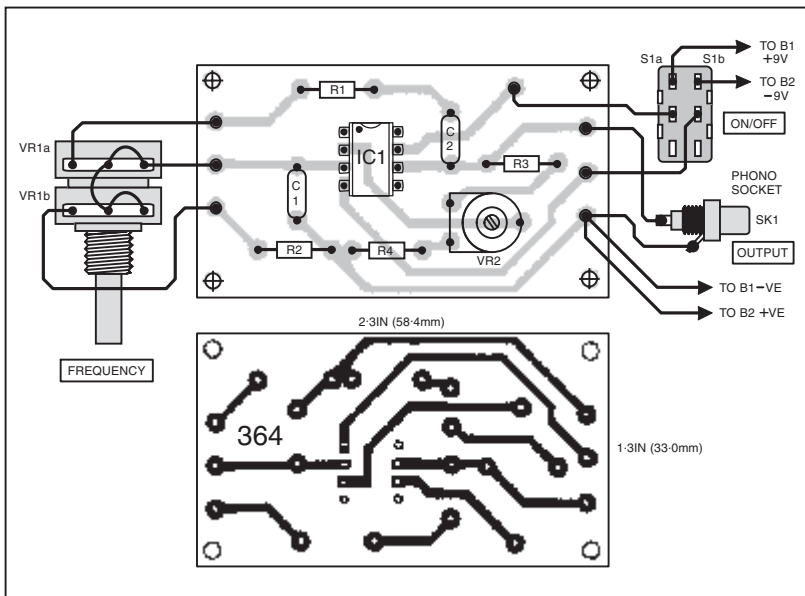


Fig.4. Low Frequency Oscillator printed circuit board component layout, interwiring to off board components and full size underside copper foil master pattern.

COMPONENTS

OSCILLATOR

Resistors

R1, R2 2k7 (2 off)
R3 820Ω
R4 390Ω

All 0.25W 5% carbon film

Potentiometers

VR1 10k dual-ganged rotary carbon, lin.
VR2 100Ω enclosed carbon preset

Capacitors

C1, C2 470n polyester layer, 5% tolerance desirable (2 off)

Semiconductors

IC1 741 gen. purpose op.amp

Miscellaneous

Printed circuit board available from the *EPE PCB Service*, code 364; small plastic case, size and type to choice; PP3 batteries and holders; pointed control knob; 8-pin i.c. holder; solder pins; multistrand connecting wire.

Approx. Cost
Guidance Only

£9
excluding bafts.



Packing the Low Frequency Oscillator components on the rear of the small plastic box lid.

Potentiometer VR1, On/Off switch S1, the p.c.b. and the batteries can be housed in a small plastic box. The compact internal layout inside the prototype unit is shown in the photographs.

It is not necessary to know the precise frequency to tune the enclosure, but an approximate idea is useful. Component

tolerances will affect calibration, but the original dial should provide an approximate guide to the frequency control settings on other units. It is reproduced, full-size, in Fig.5.

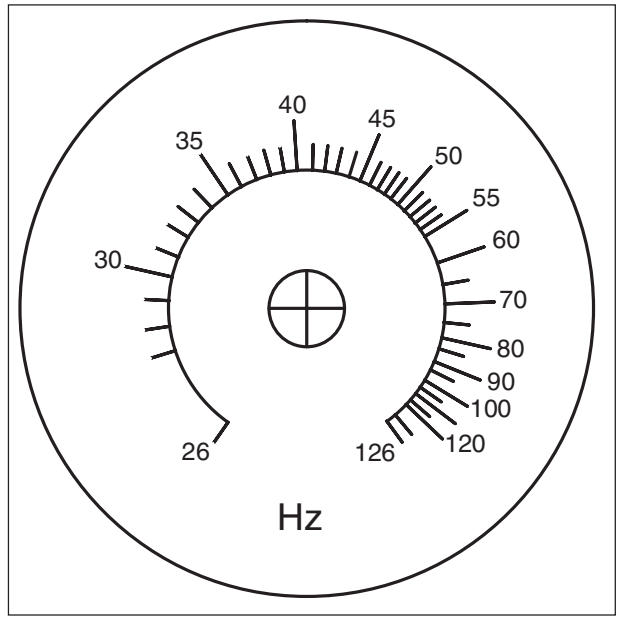


Fig.5. Full size front panel dial as used in the prototype Low Frequency Oscillator.

RESONANCE DETECTOR

Some test meters, set to the lowest a.c. range, could be used to monitor the voltage developed across the speech coil. However, unless the meter is sensitive, the sound level from the speaker under test would be distressingly loud. Further, a

resistor has to be wired in series with the speech coil to facilitate the test. This could make it difficult for the amplifier to deliver sufficient output to produce a reading on an insensitive meter.

Greater sensitivity can be achieved by rectifying the signal and measuring the resultant d.c. on the lowest testmeter range. A suitable loudspeaker Resonance Detector circuit is given in Fig.6, where diodes D1 and D2 are configured as a voltage

doubler delivering almost the peak-to-peak value of the signal.

When the Resonance Detector unit is connected to a high impedance digital meter, reservoir capacitor C2 slows the response to voltage changes, and resistor R2 is included to reduce the delay.

Series resistor R1 increases the impedance of the signal source and magnifies the effect of changes in the impedance of the speech coil. The values of electrolytic capacitors C1 and C2 have been chosen to suit the frequencies involved.

DETECTOR CONSTRUCTION

All the components for the Resonance Detector are assembled on a small printed

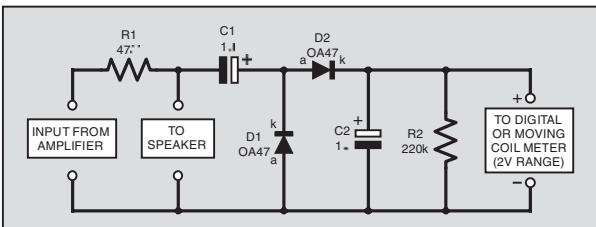


Fig.6. Circuit diagram for the loudspeaker Resonance Detector.

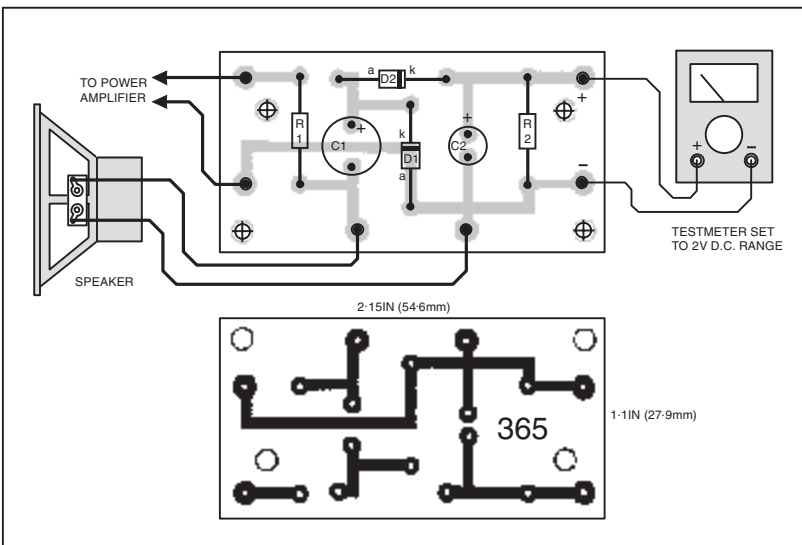


Fig.7. Printed circuit board component layout, interwiring details and full size underside copper foil master for the loudspeaker Resonance Detector.

COMPONENTS

RESONANCE DETECTOR

Resistors

R1 47k
R2 220k

All 0.25W 5% carbon film

Capacitors

C1, C2 1μ radial elect. 25V (2 off)

Semiconductors

D1, D2 OA47 or OA90 germanium diode (1N914 silicon if lower sensitivity can be tolerated – see text) (2 off)

Miscellaneous

Printed circuit board available from the EPE PCB Service, code 365; multi-strand connecting wire; solder pins; solder, etc.

Approx. Cost
Guidance Only

£6

excluding speakers

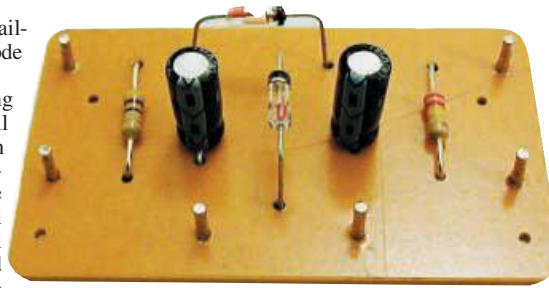
circuit board (p.c.b.). This board is available from the *EPE PCB Service*, code 365.

The p.c.b. component layout, wiring and full-size underside copper foil master pattern details are illustrated in Fig.7. Construction is very straightforward and only the polarity of the capacitors and diodes needs special attention. Also, germanium signal diodes, D1 and D2, can be damaged by excessive heat and it is prudent to leave a good lead length and apply a heat shunt when soldering.

GENERAL SUMMARY

No difficulty should be encountered obtaining any of the materials and components needed for the construction of the loudspeaker enclosure and the setting up equipment. Details of the cross-over unit were given last month.

Silicon diodes (type 1N914) can be used in place of the germanium devices in the voltage doubling rectifier circuit of the Resonance Detector. The higher knee voltage (0.6V instead of around 0.2V) reduces sensitivity, but they will still reveal the resonance peaks when the sound from the speaker is not too loud, and this is the main requirement.



Completed circuit board for the Resonance Detector.

frequency and magnitude of the peak. It will now be at a higher frequency than the free-air resonance.

Open the vent and sweep the oscillator, again noting the frequency and magnitude of the peaks. If the tuning is correct (most unlikely), two peaks of equal magnitude will be revealed on either side of the original, vent-sealed peak.

If the higher frequency peak is of greater magnitude, the vent area is too small (or any duct attached to it too long). Enlarge the vent, or shorten the duct, and test again.

If the lower frequency peak is of greater magnitude (more likely with the

volume, so err on the long side when adjusting its length in this way.

PERFORMANCE

The speaker unit has an extended bass response and, when driven by the 8W amplifier described in Part One (May '02), sound levels are more than sufficient for a domestic "hi-fi" installation.

Vent output makes a significant contribution at low frequencies (it will extinguish a candle held close to the aperture), and there are no audible resonances. The speaker is most certainly not a "boom box" with honking, one-note bass.

The middle range is clear but there is some colouration at high power levels with music that has a heavy bass content. Performance at the higher audio frequencies depends very much on the tweeter used: the enclosure is certainly worth something better than the cheap unit fitted in the prototype.

When the crossover network is switched to act as a "speech frequency bandpass filter", signals overlaid by noise are greatly clarified. Communications enthusiasts, or readers involved in surveillance, may find this circuit of interest. It certainly makes the unit more versatile as a bench speaker.

POWER CHECK

The Low Frequency Oscillator and Resonance Detector units can, of course, be used to investigate any speaker system. The rating of resistor R1 in the Resonance Detector is only sufficient for testing at comfortable listening levels. If speakers are to be checked at high power, fit a 5W component and use silicon instead of germanium rectifier diodes.

Although the test equipment will respond to very slight changes in venting, especially when the enclosure is small, only a refined ear could detect any audible difference, even when quite large adjustments are made.

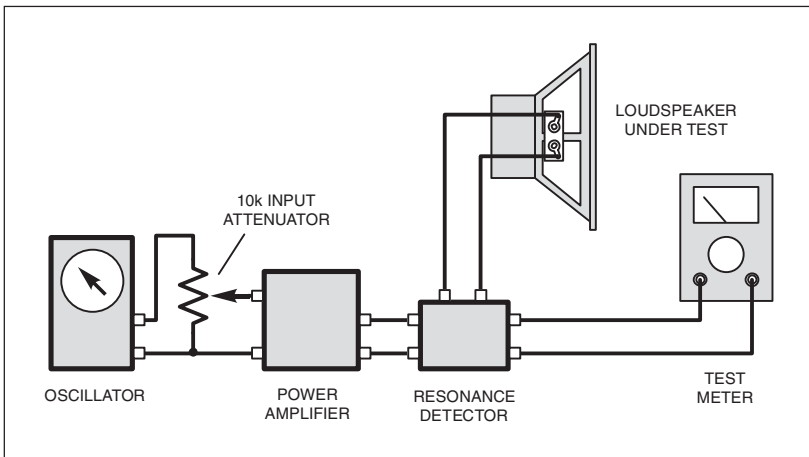


Fig.8. Block schematic diagram showing the interconnecting set up for checking speaker resonances.

FREE-AIR RESONANCE

The free-air resonance of the bass speaker should be checked before embarking on the construction of the enclosure. To do this, wire up the test circuit shown in Fig.8. Details of the connections to the Resonance Detector are given in Fig.7. The Oscillator output is in the region of 4.5V r.m.s., and the 10 kilohm input attenuator potentiometer will have to be turned well down.

Hold the speaker, by the magnet, well away from other objects and sweep the Oscillator until the voltage across the speech coil peaks. The rise will be sudden and dramatic. Note the reading on the Oscillator dial. If an extended low frequency response is important, it ought not to be more than 70Hz.

ENCLOSURE TUNING

With the speaker now in the enclosure, connect it to the test circuit shown in Fig.7 (directly, *not* via the crossover). Seal the vent, sweep the oscillator and note the

design guidance given here), the vent area is too large or any duct is not long enough. Either reduce the vent area, add a duct, or increase the length of any duct already fitted, and test again.

Repeat the procedure until the two peaks are of equal magnitude. Some experts tune to a slightly higher frequency. This depresses the higher frequency peak and, it is claimed, results in a more uniform bass response. The impedance plot of the test bench speaker, after tuning, is given in Fig.1.

DUCTING

It is preferable to install a duct, rather than reduce vent area, in order to lower resonant frequency. Hold ducts in place with sticky tape during the setting up process.

If desired, a duct can be mounted externally and adjusted until its length is almost correct before fixing it behind the vent. Duct volume will then reduce cabinet

