

"The Rocker" — 140W of rich, warm valve sound!

We have had so many requests for a valve power amplifier in the last year or so, from readers and project suppliers alike, that we finally succumbed. Turn back the clock, heat up your 100 watt iron and read on . . .

Phil Wait
Ron Keeley

FASHIONS CHANGE, styles come and go, but some things remain the same ... one of the constants is the preference of many musicians for the warm, deep-throated sound of an old-fashioned valve amplifier.

The "valve vs transistor" argument may never be settled conclusively. Despite all the obvious advantages of solid-state, musicians prefer valves because, they say, valve amps simply sound 'better', subjectively — like the preference of some people for an old Harley-Davidson or Triumph motorbike, rather than a modern, high-revving performance machine. On the other hand, there are definite technical reasons why a valve amp will sound 'different'.

The reason most often advanced is that valves produce predominantly second harmonic distortion, whereas transistor amp distortion is mainly third harmonic. While this is true, it is not the whole truth; the distinctive sound of valves is caused by the synergy of many factors, and the spectral balance of the distortion components is just one of them. Other important factors are the shape of the distortion/power curve, the fact that valve amps are transformer-coupled to the load (which affects the overall response of the amp), the high output impedance of valve amps (resulting in reduced damping of the loudspeaker and a more 'colourful' sound), and the higher 'dynamic output' capability of valve amps (the ability to deliver relatively constant power to a varying load, i.e. a speaker).

If all these factors could be built into a transistor amp, then possibly it would sound, subjectively, like a valve amp. Many have tried to do this — most have failed. We've taken the opposite approach, and built a good, old-fashioned, high power valve amplifier, the "Rocker".

Circuit design

This amplifier circuit is the result of many hours of experimentation and



incorporates suggestions from many people, staff and friends of both ETI and sister magazine Sonics, and particularly John Burnett of the School of Electronics, whose suggestions prompted quite a few changes,

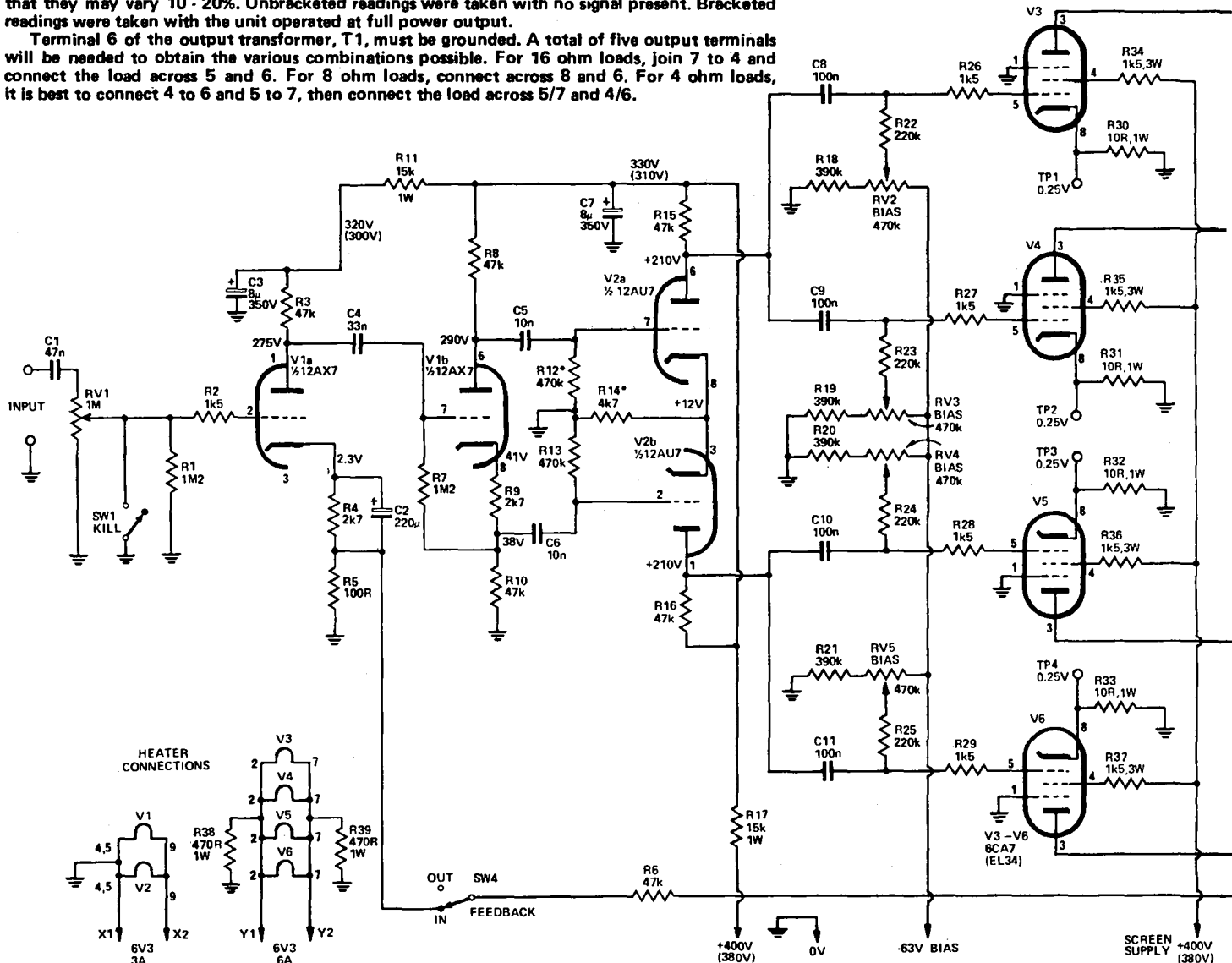
especially around the input stage. Overall, the circuit uses a triode voltage amplifier stage followed by a phase splitter, a pair of drivers and the output stage, consisting of four valves in push-pull-parallel. The amplifier is ▶

SPECIFICATIONS OF PROTOTYPE — ETI 456 VALVE AMPLIFIER					
Power Bandwidth	- 1 dB	- 3 dB			
140 watts	22 Hz to 12 kHz	18 Hz to 17 kHz			
50 watts	18 Hz to 22 kHz	14 Hz to 27 kHz			
Distortion at 1 kHz	100 mW	5 watts	50 watts	100 watts	140 watts
open loop:	1%	0.7%	1.9%	3%	15%
closed loop:	0.4%	0.22%	0.65%	1%	5%
Power output for 5% THD	Input Sensitivity				
140 watts (8 ohm load)	with feedback: 200 mV (adjustable)				
Maximum power output	without feedback: 80 mV				
200 watts (8 ohm load)	Feedback Ratio:				
Hum and Noise	10 dB				
- 62 dB with respect to 140 watts output					

Project 456

NOTES: Various voltage readings are given on this drawing as a guide to constructors, but note that they may vary 10 - 20%. Unbracketed readings were taken with no signal present. Bracketed readings were taken with the unit operated at full power output.

Terminal 6 of the output transformer, T1, must be grounded. A total of five output terminals will be needed to obtain the various combinations possible. For 16 ohm loads, join 7 to 4 and connect the load across 5 and 6. For 8 ohm loads, connect across 8 and 6. For 4 ohm loads, it is best to connect 4 to 6 and 5 to 7, then connect the load across 5/7 and 4/6.



The amplifier has four separate stages: the input voltage amplifier, a phase-splitter, a push-pull driver stage and a push-pull power output stage.

The input stage, V1a, uses one section of a 12AX7 of a high-u twin triode. The input enters via a dc-isolating capacitor, C1, and the gain control, RV1. The 'grid stopper' resistance, R2, is placed directly in series with the grid to reduce susceptibility to RF interference.

The phase-splitter uses the other half of V1 (V1b), its grid being coupled to the anode of the input stage by C4. This stage has no gain. The signal at the grid of V1b appears at the anode inverted, i.e.: 180° out of phase. The signal also appears at the junction of the cathode bias resistors R9 and R10, in the same phase. Thus, the signals coupled to the push-pull driver stage via C5 and C6 are 180° out of phase. Grid bias for the phase-splitter is obtained by returning the grid resistor, R7, to the junction of the cathode bias resistors, R9 and R10, effectively placing the grid at about -3 V with respect to the cathode.

The driver stage consists of a 12AU7 low-u twin triode. Resistor R14 provides common cathode bias, while R12 and R13 are the two

HOW IT WORKS — ETI 456

grid returns. The anode supply for this stage comes from the 400 V supply (screen voltage supply for the output stage) via a decoupling network consisting of R17 and C7. Each driver (V2a and V2b) has a gain of 10, defined by the ratio of R15 to R14 and R16 to R14.

The output stage consists of four valves in a push-pull parallel arrangement. V3 and V4 are in parallel and V5 and V6 are in parallel, the two pairs connected in push-pull via the output transformer. The anode of V2a drives the grid circuits of V3-V4 while the anode of V2b drives the grid circuits of V5-V6. The output stage is operated in class AB, which affords good gain, low distortion and good power output.

Bias for output stage is provided from a common bias supply from the power transformer, the bias for each valve being individually adjusted. As the characteristics of the 6CA7 output valves can vary widely, this adjustment is provided to ensure proper operation from unit to unit.

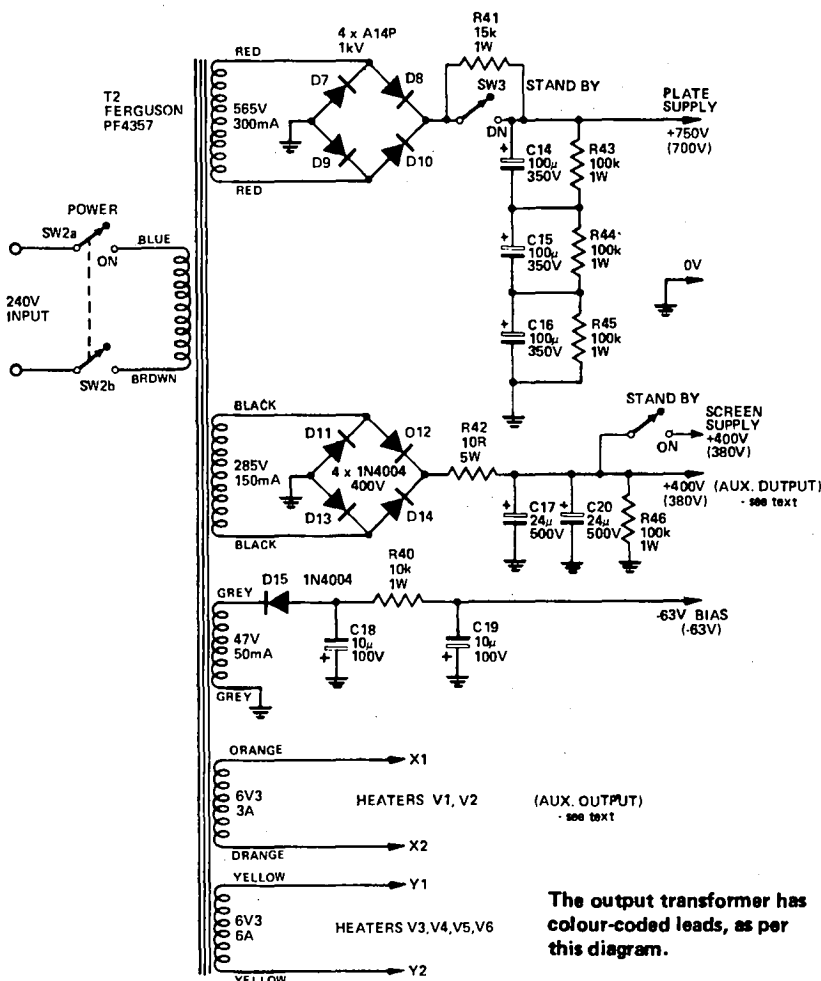
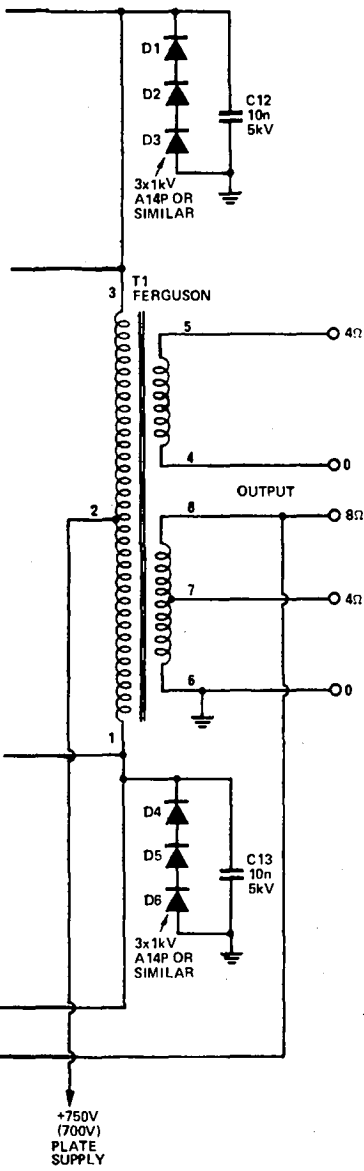
The output transformer matches the plate-to-plate impedance of the push-pull output pairs, about 5500 ohms, to the low impedance

speaker load. Several output windings are provided: a single 4 ohm winding and an 8 ohm winding, tapped at 4 ohms. Feedback to the cathode of the input stage is taken from one end of the 8 ohm winding, the other end being grounded.

During each half cycle of the signal waveform, one 'side' of the output stage (i.e.: V3-V4 or V5-V6) will 'turn off'. This will allow that side of the output transformer primary to develop enough back emf to cause arcing across the valve socket pins. To prevent this, the reverse cycle emf is shunted via a set of diodes to ground — D1 — D3 and D4 — D5.

The power supply is fairly conventional. The power transformer has five secondary windings: one 6.3 V/3A heater winding, one 6.3 V/6A heater winding, one 47 V/50 mA bias winding, one 285 V/150 mA HT winding and one 565 V/300 mA HT winding.

Bridge rectifiers with capacitor-input filters are used to provide the appropriate HT voltages: 750 V for the output stage anodes, 400 V for the output stage screens and HT for the driver stages. A half-wave rectifier and pi-section filter is used to derive the -63 V bias supply.



The output transformer has colour-coded leads, as per this diagram.

capable of driving four, eight or sixteen ohm loads, or two four ohm loads simultaneously.

Overall feedback is taken from the eight ohm winding of the output transformer to the cathode of the input stage, and is wired via a front panel switch, allowing the feedback to be switched out if desired. This will increase the impedance looking back into the output terminals, reducing the damping factor so that the speaker cone is more influenced by the back emf of the voice coil. Normally, hi-fi amps are designed to have very low output impedance – a high damping factor – to suppress the effect of the back emf and reduce the colouration which would otherwise be introduced by the speaker.

With the feedback in, the 'Rocker' is quite clean, and suitable for PA, bass guitar or even as a hi-fi amp; switching the feedback out, however, makes the amp that much 'dirtier' and will also give it a more 'live' sound. Other front panel controls are provided for the usual functions – power, standby and input gain. The 'kill' switch shorts the input to ground, and is an effective way of temporarily 'switching off' without generating any transients or unwanted thumps.

All inputs and outputs are mounted on the rear panel. Although we have used a phone-jack input socket and a single pair of binding post output terminals, there is sufficient room behind the chassis for Cannon/Switchcraft inputs and multiple binding post or phone jack outputs, if required.

At the input stage, we had a choice between a triode-pentode, such as the 6BL8, or a 12AX7 twin triode. Triodes have the disadvantage of large plate to grid capacitance which, together with the plate resistor and the voltage gain of

the stage, introduces a phase shift at high frequencies, called the Miller Effect. The degree of phase shift depends on the capacitance, gain and value of the plate resistor. All phase shifts add through the amplifier, the first stage having the largest effect, and when feedback is applied from the output to the input, the amplifier may oscillate. The feedback ratio (and the possible reduction in distortion) is therefore limited by the phase change through the amplifier, and must be kept low if a triode is used in the input stage.

Our first design used a 6BL8 pentode which worked well with about 20 dB of feedback, allowing a good stability margin, and looked very promising. Then we started talking to people in the audio business who had experience with valve amplifiers, who all said that a triode-pentode tube was internally fragile and would fail after a few months on the road. Back to the 12AX7 then, and lower amounts of feedback to preserve stability.

We wanted the amplifier to be useful for hi-fi and bass guitar ▶

Project 456

applications as well, so we had to design it carefully for good performance but with a good stability margin, too. Conventional circuits usually drive the output stage directly from the phase splitter, which is inherently high in distortion when run at high signal levels and so requires large amounts of feedback to clean it up. Since the amount of feedback we could apply was limited by stability considerations, we followed the phase splitter with a pair of driver amplifiers, allowing the splitter stage to operate at a lower level for less distortion.

The output stages run in push-pull parallel using 6CA7 power pentodes. We chose four of these tubes, rather than two of the more powerful KT88s, because they are less than one quarter the price and are readily available.

The bias for class B operation is set individually on each tube; this was found to be necessary because of the

large spread in the parameters of unmatched tubes bought over the counter. The bias is set by monitoring the voltage across 10 ohm resistors, in the cathode of each valve, which also help reduce the effects of bad matching.

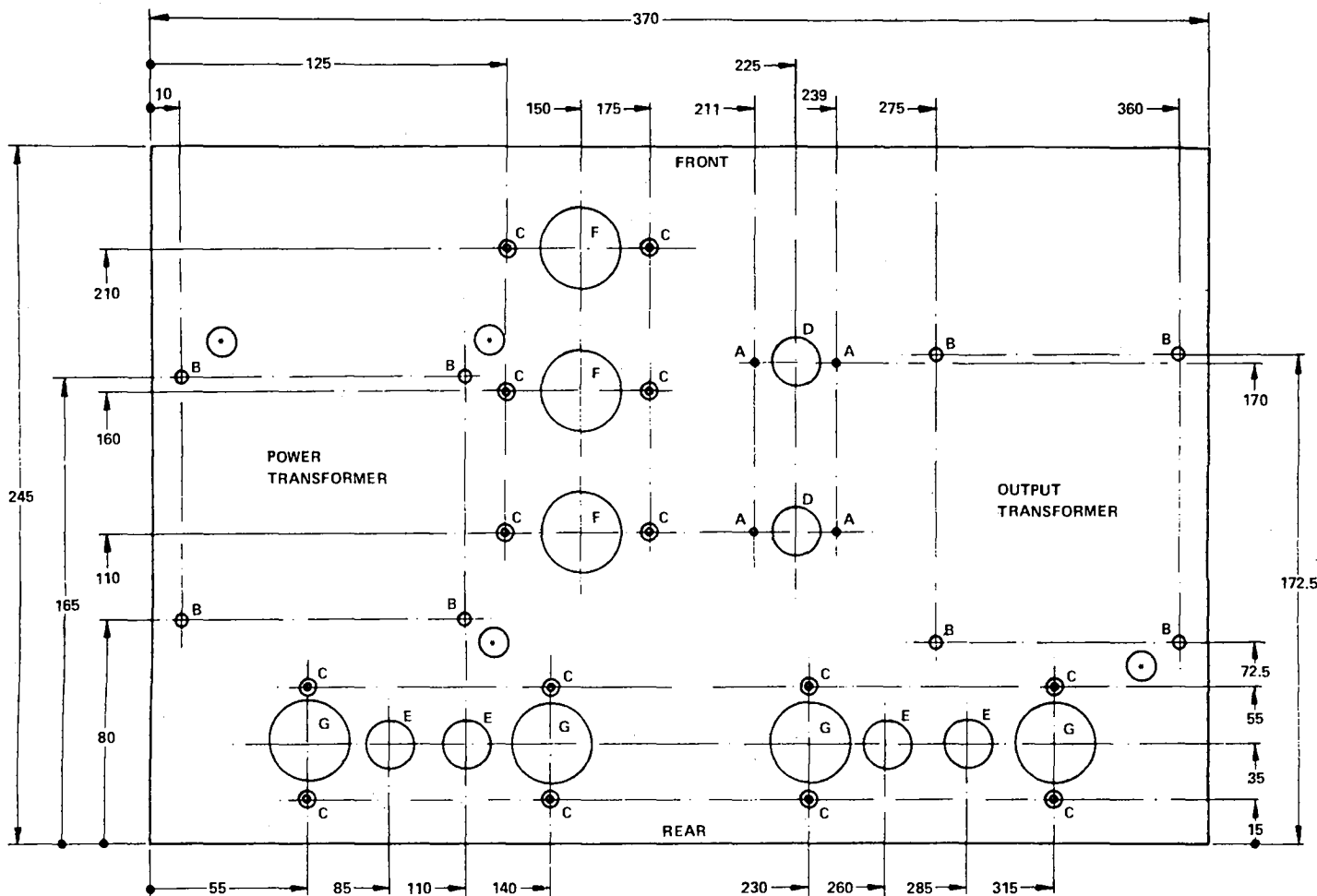
The life of the output valves is increased by placing 1k5 resistors in each of the screen leads to reduce the peak screen dissipation, and parasitic oscillation is avoided by 1k5 resistors on the grids. The possibility of socket flashover is reduced by using diodes and capacitors from each side of the output transformer primary to earth. The back emf from the transformer, when each half of the output stage turns off, is conveniently shunted to ground via the diodes. Three are connected in series to obtain a PIV rating of 3 kV.

The output transformer is probably the most important component effecting the performance of the amplifier. It must have sufficient

winding inductance for good bass, but low leakage inductance for good high frequency performance. These are conflicting requirements and the transformer must be well made to achieve both.

In this transformer, the secondary windings are placed either side of the primary, sandwich fashion, to reduce leakage inductance. For maximum flexibility, the output transformer has two separate secondary windings, an eight ohm winding tapped at four ohms and a separate four ohm winding. A 16 ohm load can be run from the two four ohm windings in series (linking pins 4 and 7, taking the output from 5 and 6), an eight ohm speaker is run from the eight ohm winding, and either one or two four ohm speakers can be run by connecting the four ohm windings in parallel for one speaker, or independantly for two.

Throughout the circuit, the values



HOLES MARKED	A	6BA x 4
" "	B	4BA x 8
" "	C	6BA x 14 or 3mm pop rivet
" "	D	18mm x 2
" "	E	9mm x 4
" "	F	28mm x 3
" "	G	30mm x 4

ALL DIMENSIONS IN MILLIMETRES
UNLESS OTHERWISE SPECIFIED
MATERIAL 1-1.5mm ALUM. OR STEEL

*DRILL AND INSULATE TO SUIT
FOR THROUGH WIRING FROM
TRANSFORMER

Drilling details for the chassis,
looking down from the top.
Refer to the picture on the page
opposite.

of coupling capacitors have been kept as low as possible. If the capacitors are large and if the preceding stage is driven into clipping, there will be a time delay while they discharge, causing a short drop-out in the sound.

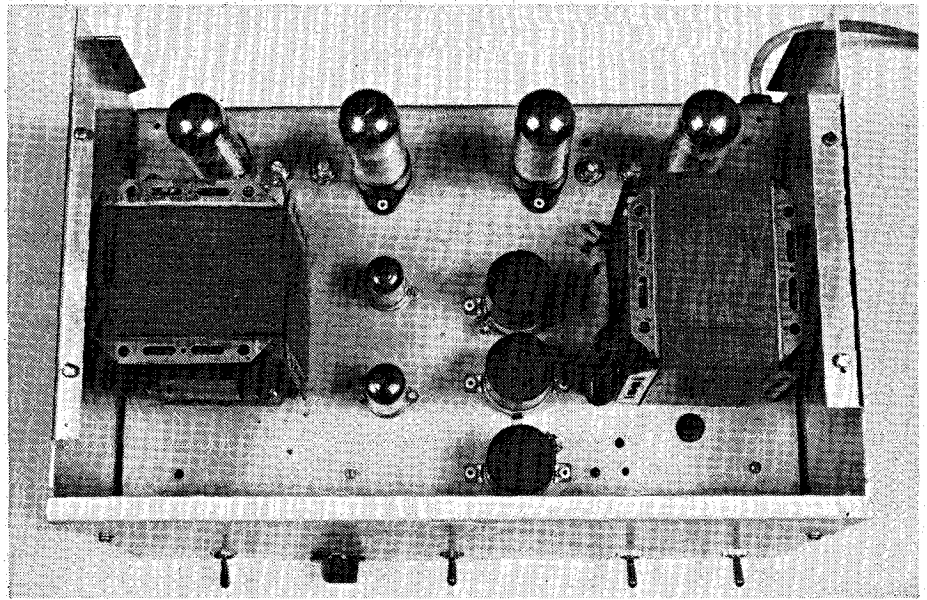
When you look at the power supply circuit, it may seem a little large. It is! It must be, to allow the amplifier to run into hard distortion, especially when used for bass guitar amplification.

The bias supply must be both free from ripple, and must reach its normal value immediately after turn on. If the power to the amplifier is momentarily interrupted (somebody tripping over a cord then quickly plugging it back in) the heaters in the tubes will still be hot; if the bias supply then takes time to come up to value, the output tubes will draw excessive current and may destroy themselves. The bias supply filter capacitors should be quite small and used with a fairly small value resistor in a pi-section filter to remove ripple. Regulation of the screen supply is ensured by using a separate transformer winding for the 400V (screen supply) rail.

One of the heater lines should be earthed to reduce the risk of hum caused by heater to cathode leakage, but you will notice that the output stage heater lines are earthed through two 470 ohm resistors, rather than having one side connected directly to earth. Why? Imagine this: an output tube goes short circuit; the cathode resistor won't last long, and the tube will arc over internally from cathode to heater, and then to earth through the heater line.

Now the output transformer has the full supply voltage across it and the current is limited only by the dc winding resistance, with the result that the output transformer burns up! The same thing will happen if a valve socket arcs over from pin 3 to pin 2. If resistors are placed from either side of the heater line to earth, however, they act as fuses protecting the output transformer while still preventing hum problems.

As in any amplifier, the mechanical design is just as important as the electrical. Looking at the layout, you will notice that the two transformers are the same size and are placed at either end of the chassis for correct weight distribution, and the four output valves are spaced along the back of the chassis for good ventilation — an important consideration to ensure them a long life. All power supply components are at the power transformer end of the chassis, while amplifier components are at the other. Bias controls are situated next to



Looking into the unit. **WARNING:** keep all the covers on in use as lethal voltages are present. The multimesh cover fits under the front panel lip and is secured by the PK screws at either side.

each output valve so that all wiring is short and direct.

Construction

Since most of the components are mounted either on the chassis or on the valve sockets, a pc board is of little advantage. The method we used requires some care in wiring, however, and careful cross checking with the circuit diagram to ensure you haven't made any mistakes! Remember that the unit has lethal voltages present and if you make a mistake you may not have the chance to make another.

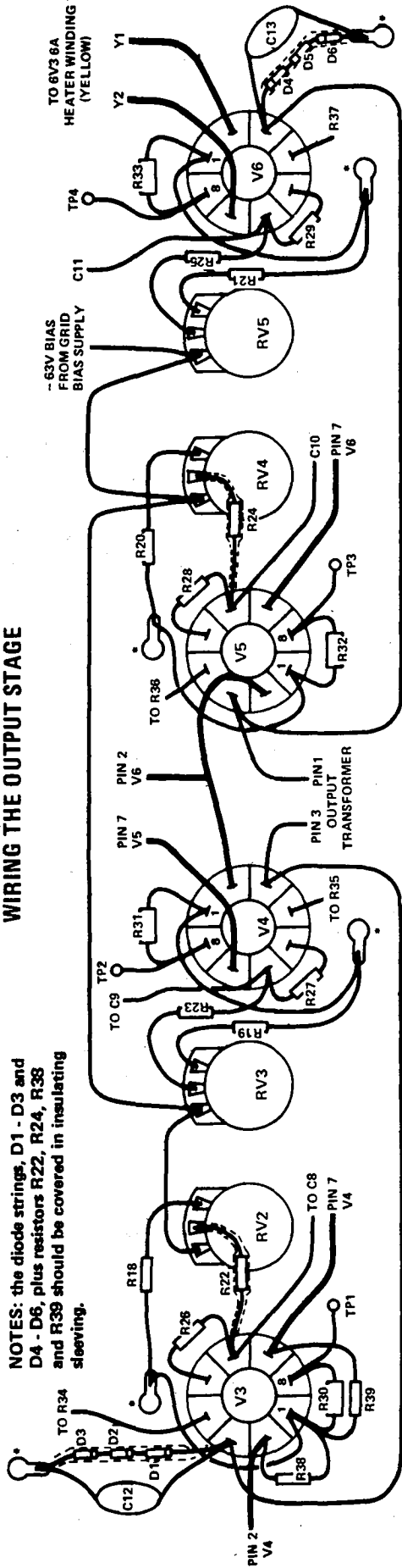
As the amplifier will be a relatively expensive project, you may wish to save a few dollars by making your own

chassis. Hence we have produced a complete set of metalwork drawings. If you have the patience, the tools and the skill, quite a professional-looking unit can be produced. Many component suppliers sell sheets of aluminium, as well as useful things like hole-punch tool sets. Aluminium sheet and expanded aluminium may also be obtained from hardware stores, don't forget.

Examine the photos and the wiring diagrams and note carefully the positions of the components. The layout should be followed exactly, and all wiring should be of the highest standard. The power supply circuitry is located around the power transformer while the voltage

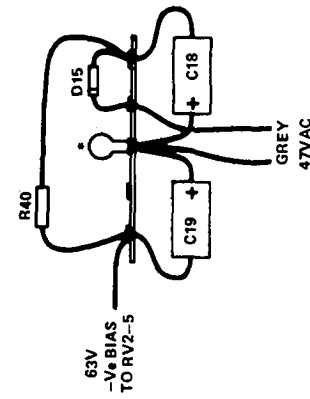
WIRING THE OUTPUT STAGE

NOTES: the diode strings, D1 - D3 and D4 - D6, plus resistors R22, R24, R38 and R39 should be covered in insulating sleeving.



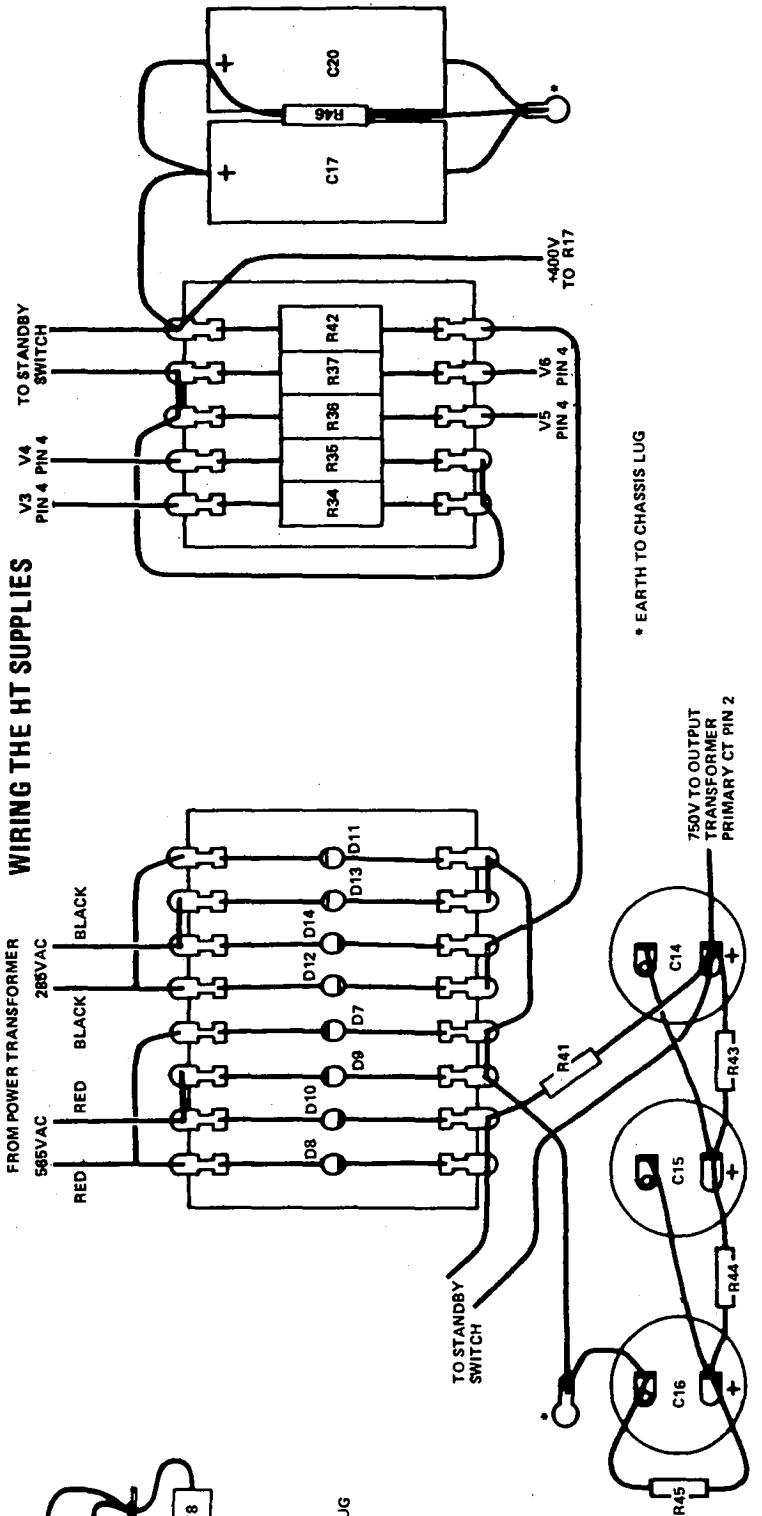
* EARTH TO CHASSIS LUG

WIRING THE BIAS SUPPLY



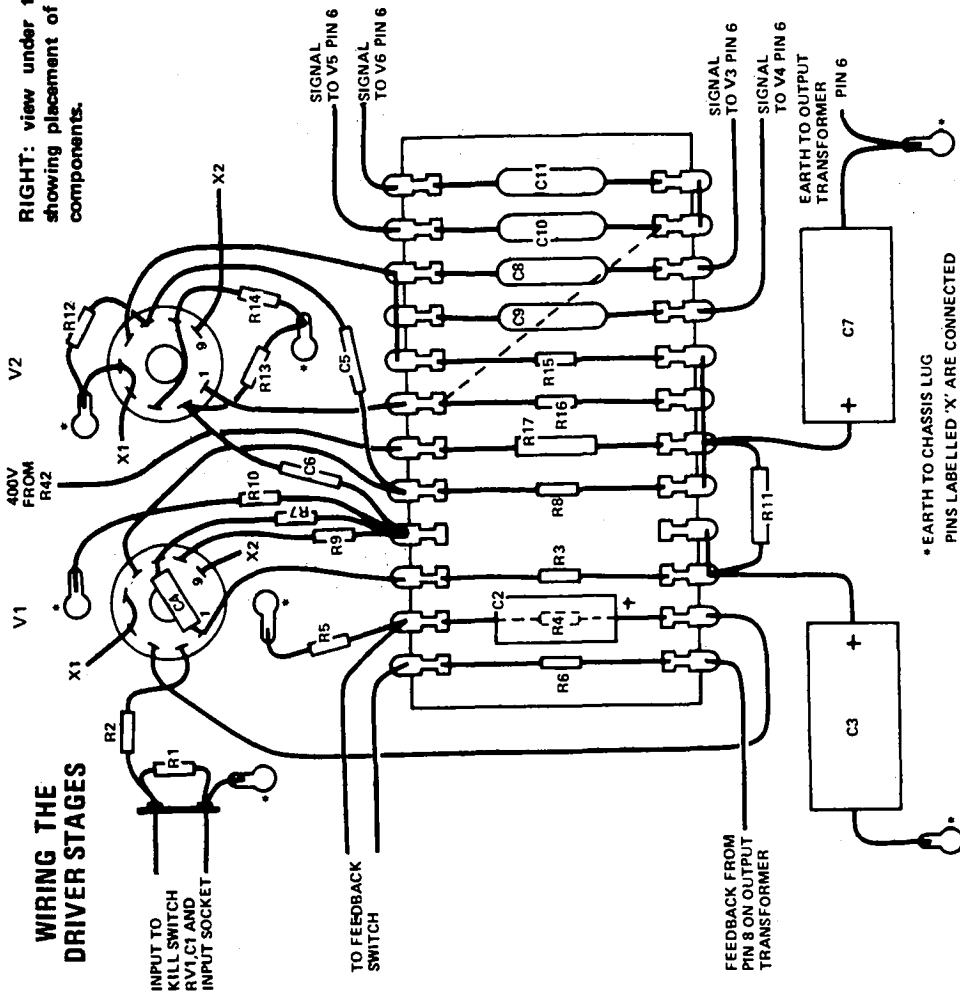
* EARTH TO CHASSIS LUG

WIRING THE HT SUPPLIES

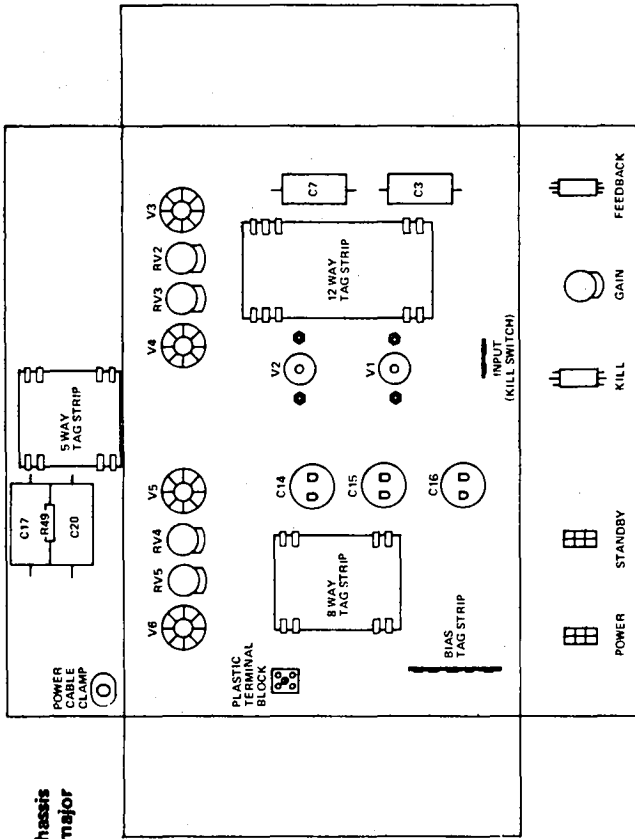


* EARTH TO CHASSIS LUG

WIRING THE DRIVER STAGES



RIGHT: view under the chassis showing placement of the major components.



PARTS LIST — ETI 456

Resistors	
R1, R7	all 1/2W, 5% unless noted
R2, 26, 27, 28, 29	1M2
R3, 6, 8, 10, 15, 16	47k
R4, R9	2k7
R5	100R
R11, R41	15k, 1W, 5%
R12, 13	470k
R14	4k7
R17	15k, 1W, 5%
R18, 19, 20, 21	390k
R22, 23, 24, 25	220k
R30, 31, 32, 33	10R, 1W, 5%
R34, 35, 36, 37	1k5, 3W, 10%
R38, 39	470R, 1W, 5%
R40	10k, 1W, 5%
R42	10R, 5W, 10%
R43, 44, 45, 46	100k, 1W, 5%
RV1	1M, log. pot. (GAIN)
RV2, 3, 4, 5	470k, lin. pot. (BIAS)

Capacitors	
C1	47n greencap
C2	220u, 16V electro. (pigtail)
C3, 7	8u, 350V electro. (pigtail)
C4	33n greencap
C5, 6	10n greencap
C8, 9, 10, 11	100n greencap
C12, 13	10n, 5KV ceramic disc or mica
C14, 15, 16	100u, 350V electro. (can)
C17, C20	24u, 500V electro. (pigtail)
C18, 19	10u, 100V electro. (pigtail)

Valves	
V1	12AX7
V2	12AU7
V3, 4, 5, 6	6CA7 (EL34)

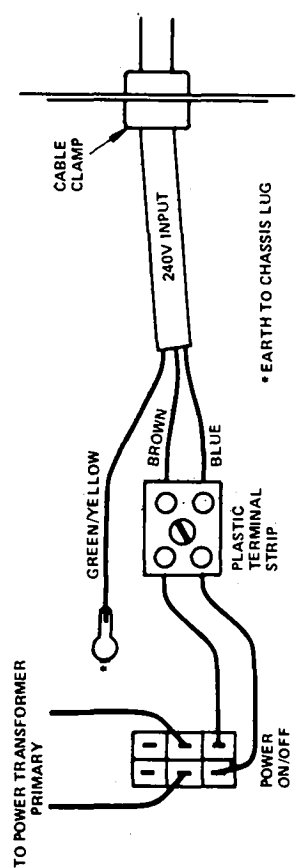
Semiconductors	
D1 to D10	BC548, BC108 or similar
D11 to D15	BC558, BC178 or similar

Transformers	
T1	PF4357, Ferguson power transformer (see circuit)
T2	OP603, Ferguson output transformer; 5k5 p-p impedance to 4 ohm + 8/4 ohm, 200 W.

Miscellaneous	
SW1, SW4	SPST toggle switch
SW2, SW3	DPDT, 250 Vac rated toggle switch

Four octal valve sockets; two nine-pin valve sockets; 6.5 mm input jack; binding post (or other) output terminals; 55 - 60 mm wide double tagboards (one 12 pair, one 8 pair, one 5 pair) with insulated backs; one five-lug tagstrip; one three-lug tagstrip; solder lugs; power cord and plug; chassis as per dimensions given plus panel, side plates and mesh top; base plate with rubber feet; 10 mm grommets; nuts, bolts etc.

NOTES: Greencap capacitors should be 630 V rated types or use polycarbonate types rated at 400 V or more.



MAINS INPUT WIRING

amplifier, phase splitter and driver stages are next to the output transformer.

The first step is to mount the major components on the chassis. Locate the transformers, valve sockets, can electrolytic capacitors and bias pots in their correct positions.

Cut three lengths of double-sided tag board, twelve, eight and five tag pairs respectively, making sure the strips are capable of insulating the very high voltages used in this amplifier. We used wide-spaced bakelite tag boards with a bakelite backing piece, so that they can be mounted directly on the chassis without standoffs. Ours came from David Reid Electronics but similar types are widely available. Turn the chassis upside down and mount the tag boards in the appropriate positions. We used the transformer mounting bolts to mount the power supply and amplifier tagstrips. Mount a five-lug single tagstrip for the bias components and a three-lug tagstrip for the input to V1 as shown in the diagrams.

Once the tagstrips and tag boards are mounted, drill holes in the chassis for the leads from the two transformers. We used 10 mm holes with grommets for this, one for the output transformer and three for the power transformer leads. (The holes for the leads are drilled after the tagstrips are mounted to avoid drilling holes under the tagstrips!). Start the wiring with the power supply components and the heater lines. The heavier (six amp) winding supplies the output tubes and the three amp winding supplies V1 and V2? the 12AX7 has a 12 volt centre-tapped heater, and for six volt operation, the two ends of the heater (pins 4 and 5) are joined together and the voltage applied between pins 9 and pins 4/5. All heater wiring is twisted and run above the sockets to keep it

away from other wiring. One side of the 3A heater wiring is earthed at the socket of V2 and the 6A winding is balanced with respect to earth, as already discussed.

Solder the diodes onto the power supply tagstrip and wire the electrolytic capacitors, standby switch, screen resistors, power switch and bias supply. When the power supply wiring is complete check it thoroughly and re-check the polarity of all the diodes and electrolytic capacitors and the connections of the 100k bleed resistors.

Turn the unit on without any valves inserted. If everything seems to be OK (no smoke!) take a meter, with well insulated test probes, and check all the voltages across the electrolytic capacitors. The three electrolytics in series should have equal voltages across them. OK? Turn the unit off and wait for a minute. Then take a screwdriver and short out all the capacitors. If the bleed resistors are working the capacitors should already be discharged. Even so, always repeat this operation when you are working on the amplifier, as bleed resistors sometimes fail and the capacitors can give you a very nasty shock. Now insert the valves and turn on again to check that the heaters are working. Turn it off (and short the capacitors).

If all is well with the power supply, start wiring the circuitry around V1 and V2. The input blocking capacitor, C1, is wired between the gain control and the input socket while the resistor, R2, should be placed as close as possible to the grid pin to reduce the possible pick up of RF interference. We found it unnecessary to use shielded cable between the valve socket, gain pot, kill switch and input socket but if your wiring is longer than ours it may be required to avoid hum pickup. However,

the feedback wiring should be kept well away from the input wiring, or HF instability may occur when the feedback is switched out.

Wire the bias circuitry to each of the output valves, making sure that there is no possibility of components shorting together. Use plastic sleeving over the component leads for insurance, because if the bias supply to any tube fails the result is very dramatic! The 1k5 resistors in the grids of the output valves are wired between pins 5 and 6 of the valve sockets.; pin 6 is not internally connected and is used as a terminal — and also places this resistor nearest the grids for best suppression of parasitic oscillation.

The 10 ohm resistors in the cathodes are wired across the sockets and it is a good idea to wrap the body of the resistor in tape or plastic tube; in the event of a short in one of the valves this resistor will certainly burn up and deposit carbon over the valve socket and surrounding circuitry, which would then have to be replaced. Using the tape to shield the fallout will minimise the damage, should a fault occur.

Be careful not to cross the two out-of-phase signals from the phase splitter; the signal from the cathode must go to the grid of V2b and the signal from the anode must go to the grid of V2a. Also be careful not to cross the primary windings of the output transformer; pin 3 goes to the V3 and V4 anodes and pin 1 goes to V5 and V6 anodes. If these connections are crossed, the phase of the output will be reversed, the feedback will become positive and the amplifier will become a higher power oscillator!

The power supply is quite capable of powering auxiliary equipment such as a valve pre-amplifier, and a power output socket can be mounted on the

rear panel. The 400 V rail will be able to supply about 70 mA and the three amp heater winding will supply 2.4 amps.

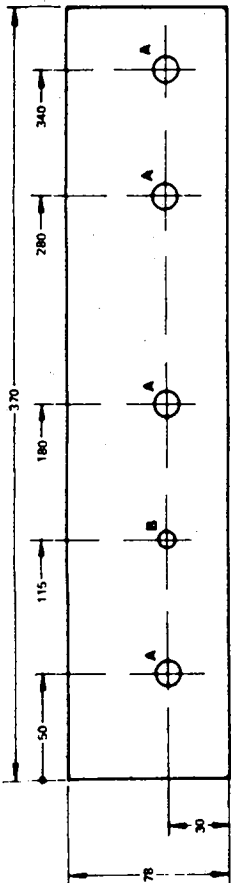
Powering up

There's one good thing about valve circuitry — it's very obvious if something's wrong — but re-check everything thoroughly in any case.

Turn the amplifier on without any valves inserted first, and check the power supply voltages. To check the bias on pin 5 of each output valve, set all pots for maximum bias (counterclockwise), turn down the gain pot, then connect a speaker and plug in the valves. Turn on the amplifier and set each bias pot for 0.25 volts across each of the 10 ohm cathode resistors. If anything unusual happens turn off the amp immediately and re-check the wiring! If not, connect a signal to the input, advance the gain pot and you're ready to rock!

A note on speakers

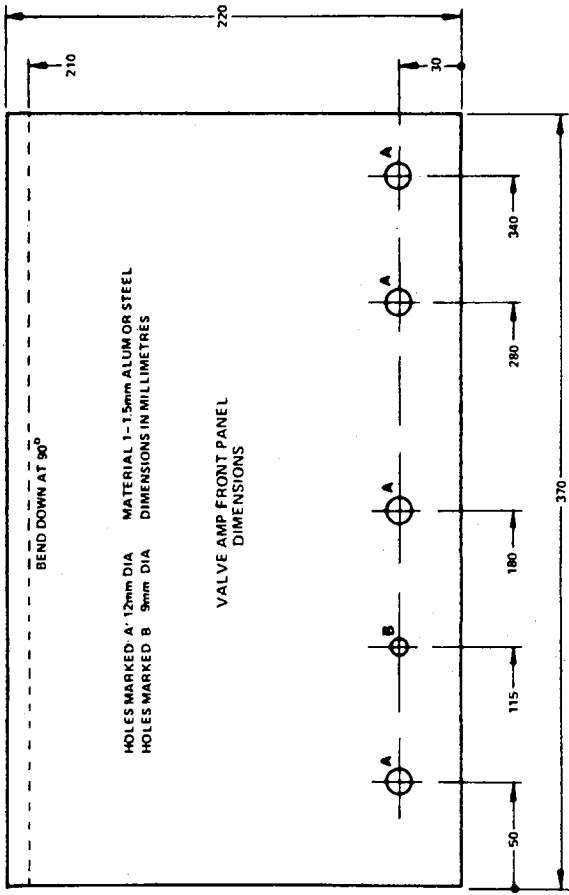
If you plan on using the "Rocker" as a guitar amplifier, we strongly recommend using loudspeakers specifically designed for the purpose, rated to at least 200 watts. These speakers are extremely rugged, with aluminium voice coils designed to withstand the very high power levels generated by guitarists. If you use the amplifier for hi-fi reproduction, be careful not to drive it into clipping. The onset of clipping will not be as harsh and as evident as it would be with a transistor amplifier and you may be doing irreparable damage to your speakers without knowing it. We strongly recommend the ETI-455 speaker protector for any application, as we very quickly blew up a set of 250 watt speakers when the amplifier was overloaded. ●



VALVE AMP CHASSIS FRONT LAYOUT DIMENSIONS

DIMENSIONS IN MILLIMETRES. HOLE MARKED B 9mm DIA HOLE MARKED A 12mm DIA

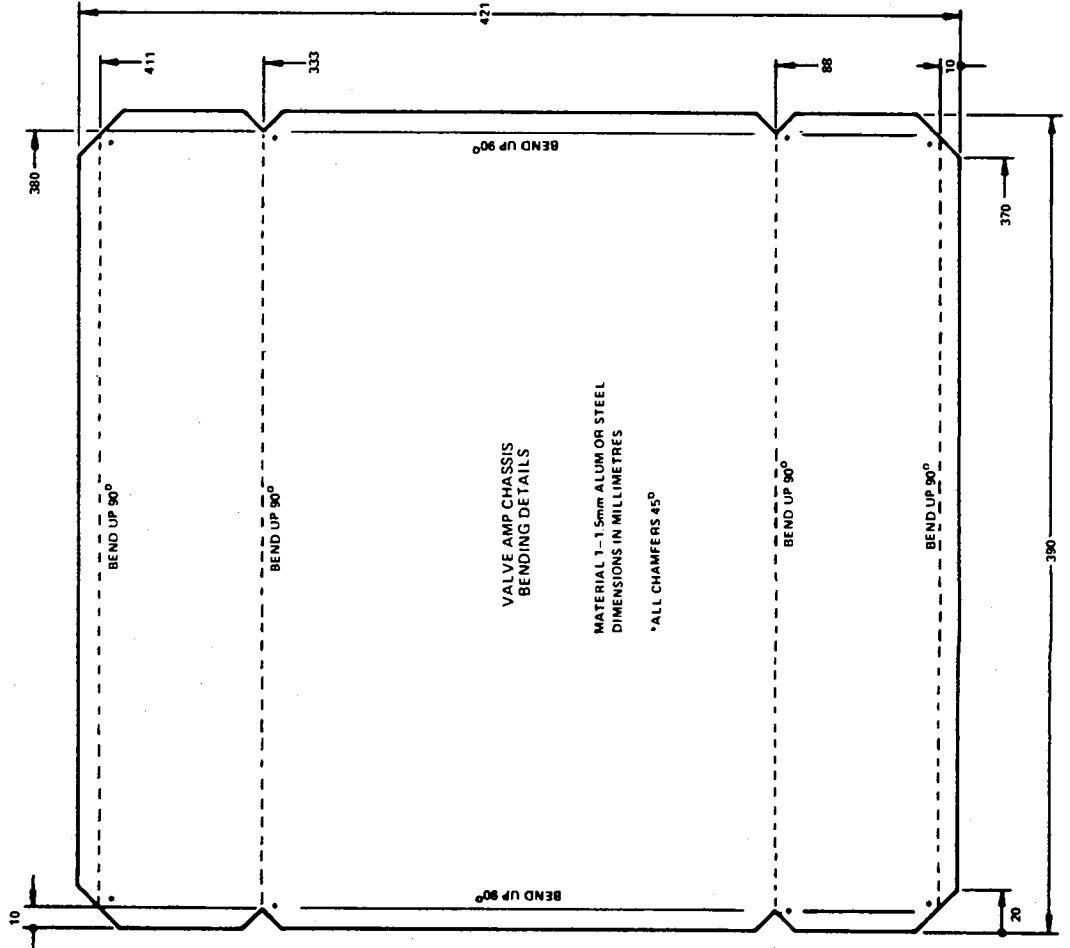
NOTES: a base plate, measuring 370 x 245 mm is necessary. Suitable rubber feet may be mounted on it. The top cover is made from Lysight 'Multimesh' expanded aluminium. It covers the top of the unit and folds down the rear to the chassis top.



VALVE AMP FRONT PANEL DIMENSIONS

HOLES MARKED A: 12mm DIA
HOLES MARKED B: 9mm DIA

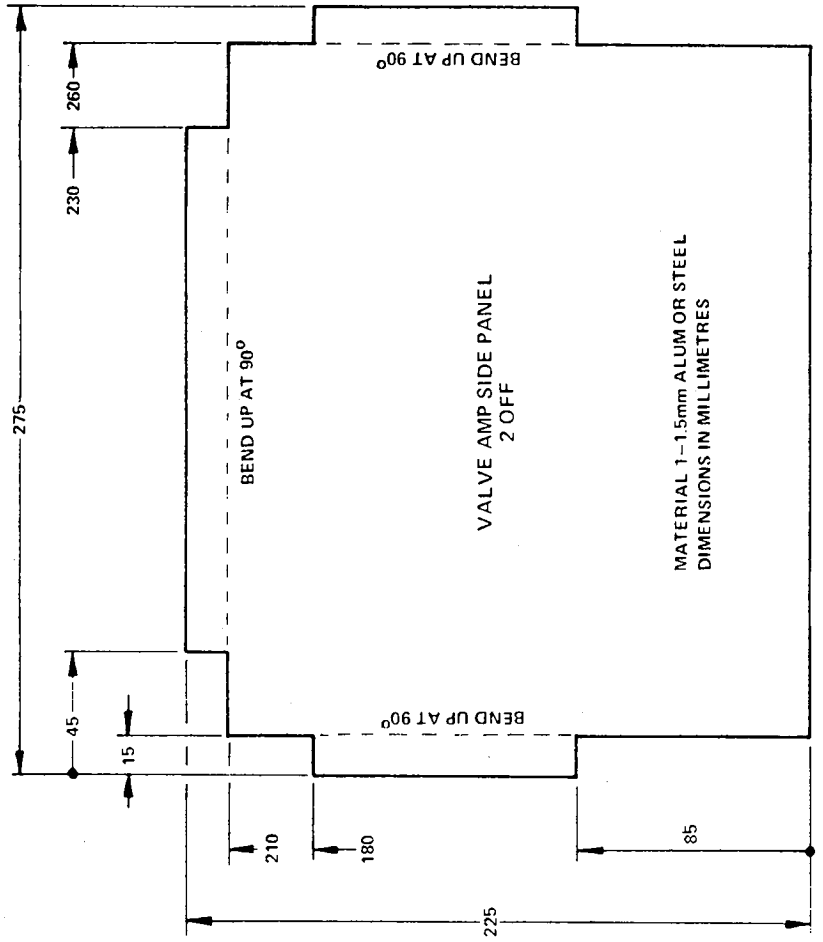
MATERIAL 1-1.5mm ALUM OR STEEL
DIMENSIONS IN MILLIMETRES



VALVE AMP CHASSIS BENDING DETAILS

MATERIAL 1-1.5mm ALUM OR STEEL
DIMENSIONS IN MILLIMETRES

*ALL CHAMFERS 45°



VALVE AMP SIDE PANEL 2 OFF

MATERIAL 1-1.5mm ALUM OR STEEL
DIMENSIONS IN MILLIMETRES