EL156 AUDIO POWER

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Thanks to its robustness, the legendary EL156 audio power pentode has found its way into many professional amplifier units. Its attraction derives not just from its appealing shape, but also from its impressive audio characteristics. We therefore bring you this classical circuit, updated using high-quality modern components.

AMPLIFIER Return of a legend

The EL156 was manufactured in the legendary Telefunken valve factory in Ulm, near the river Danube in Germany. The EL156 made amplifiers with an output power of up to 130 W possible, using just two valves in the output stage and one driver valve. Genuine EL156s are no longer available new at realistic prices, and hardly any are available second-hand. The original devices used a metal valve base which is still available, but a new design using original valves and metal valve bases would anyway be impractical, given the lack of availability at reasonable prices.

Made in China

Fortunately this valve is still being produced in China, using the original Telefunken machines. A normal octal base is now used, with pinout the same as that of the EL84, 6L6, KT88 and similar valves. The devices are still not exactly cheap, but the price is not too unreasonable and the valves are generally supplied with bases included. Comparison with original Telefunken valves shows that the devices are a successful mechanical and electrical copy and are suitable for use in a hi-fi amplifier.
Before we proceed to describe the design, we should first look at a few special features of these valves. In the text box we compare the basic specifications of the EL156 with those of the well-known and widely-used EL34. This information will to a large extent determine the design of the amplifier. In order to obtain sufficient output power, the anode voltage must be at least twice as high as the screen grid voltage. The driver circuit must be designed to cope comfortably with the comparatively low-impedance load presented by the grid leak resistors. The popular ECC83 (12AX7) is ruled out, since it operates at only around 1 mA. The ECC82 (12AU7) audio double triode can be operated with an anode current of 10 mA, and so would appear to be suitable; however, its open-loop gain is only 17, which is not enough to give adequate sensitivity, even before allowing any margin for negative feedback. The ECC81 (12AT7), however, which has an open-loop gain of 60 and which can be operated with anode currents of up to 10 mA, can be used to build a suitably low-impedance circuit.
Two EL156s can be used to produce an output power of 130 W with only 6 % distortion. To improve reliability and increase the life of the valves, however, we have limited the maximum power. A genuine hi-fi output at 100 W with low distortion is better than 130 W at 6 %, especially when there is a large component at the unpleasant-sounding third harmonic.
The whole circuit is built on four printed circuit boards, forming a monoblock. **Figure 1** shows the power supply and the amplifier together. The power supply capacitors are cascaded to filter the high anode voltage in order to obtain the required voltage stability. To supply the relatively high currents required by the screen grids of the EL156s two separate high voltage supplies are produced using bridge rectifiers from two isolated transformer windings ('hi' and 'lo'). Immediately after the rectifiers these supplies are connected in series and individually filtered. Choke Dr1, with a value of 2.3 H, is rated for a current of 0.3 A and filters the anode supply, while Dr2, with a value of 4 H and rated for 0.18 A, filters the screen grid voltage. The driver valve is also powered from the screen grid supply. The screen grid voltage must be well filtered since any hum present on it will be amplified through to the output: the screen grid has some control effect. The values suggested give good filtering and hence low hum. Radial 100 μF/500 V electrolytic capacitors are recommended to make the power supply compact; a working voltage of 500 V ensures adequate margin to give reliable operation even in the event of mains overvoltage. Note the discharge resistors in parallel with the electrolytics. The negative grid bias voltage is provided by a diode and electrolytic capacitor: this voltage is further filtered on the amplifier board.

It is not possible to build an ultra-linear amplifier using the EL156 with a high anode voltage. The same goes for the EL34. The output transformer is therefore connected in such a way that the impedance of the grid connection to the output valve is much lower than in conventional valve circuits, and considerably lower than the maximum permissible value of 100 kΩ. This relaxes the requirements on the tolerance of the valves, and select-on-test of the valves is not required.
Coupling capacitors C9 to C11 have relatively large values. This is needed to ensure that sufficiently low frequencies can be handled in the low-impedance circuit. The input and the phase inversion stages (V1 and V2 respectively) have relatively low anode and cathode resistors. The supply voltage for the input and phase-inversion stages is regulated by Zener diodes D1 to D4. The operating point of V1 is therefore independent of supply voltage fluctuations caused by the output driver stage. R1 and C2 block high frequencies. Capacitor C4, connected in parallel with negative feedback resistor R11, suppresses high frequency oscillations. C3, between anode and grid of V1a, performs the same task. R4 and R6 are effectively in parallel to AC signals, and, in combination with negative feedback resistor R11, set the overall gain. The amplifier is designed with only a moderate amount of negative feedback: this improves the resulting sound.
An E-1220 transformer (Tr1) with a 1:2 turns ratio is fitted at the input to the amplifier. This gives adequate input sensitivity as well as providing isolation. Differential or quasi-differential audio connections are in theory less susceptible to interference and prevent earth loops. Also, the 1:2 ratio gives an extra 6 dB of sensitivity without added noise, leaving a little more margin in hand for negative feedback. The printed circuit board also allows for a

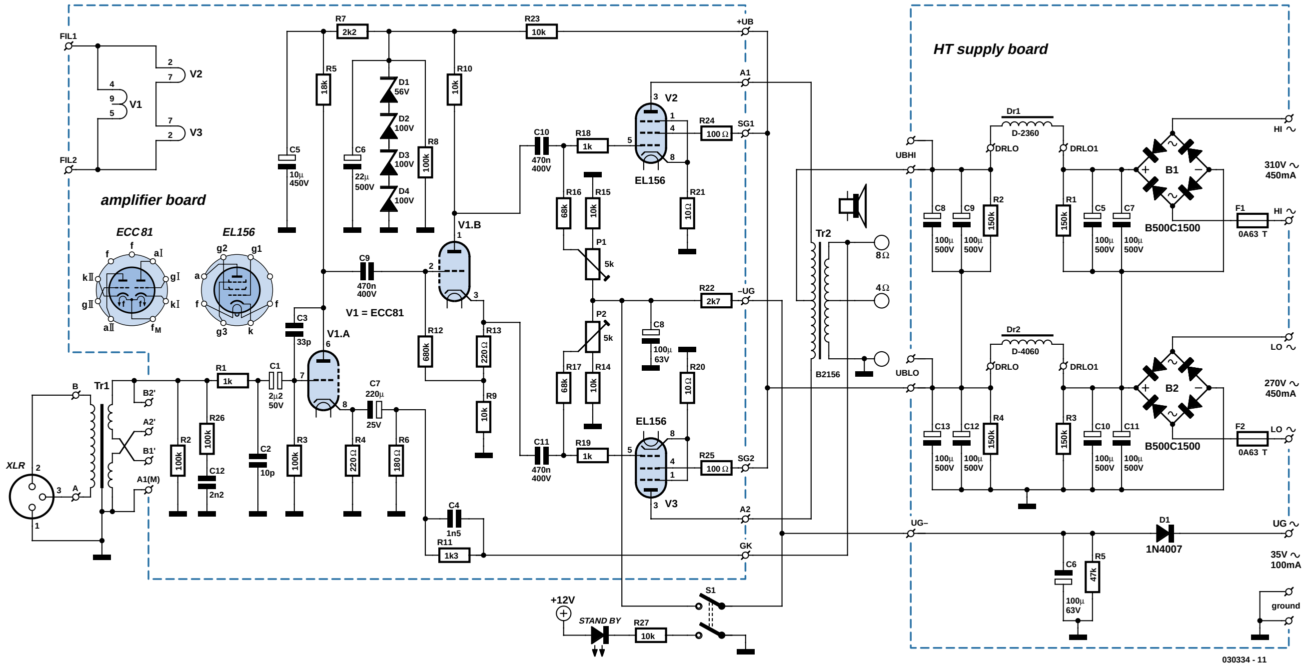


Figure 1. The heart of the valve power amplifier with its output transformer and high-voltage power supply.

1:1 connection, in which case twice the input signal level will be required for full drive. The desired ratio can be selected using wire links. The combination of C12 and R26 compensates for the response of the transformer at higher frequencies.

Stand by me

Valve power output stages are often designed with a stand-by function. This prolongs the life of the output stage valves, normally by switching off the anode supply, while the heater and other voltages remain. On leaving stand-by the amplifier is immediately ready for action.

In view of the high anode voltage, an ordinary switch or relay is not suitable. We take a different approach, shorting out R22 using the stand-by switch, so that the negative grid bias voltage on the output stage valves is raised. Only a very small quiescent current now flows. According to the valve data books this is if anything preferable to switching off the anode supply as prolonged operation with the heater on without applying an anode voltage gradually reduces the emissivity of the cathode. An LED connected to the second pole of the double-pole switch indicates when stand-by mode is active. The LED can be powered from the heater supply.

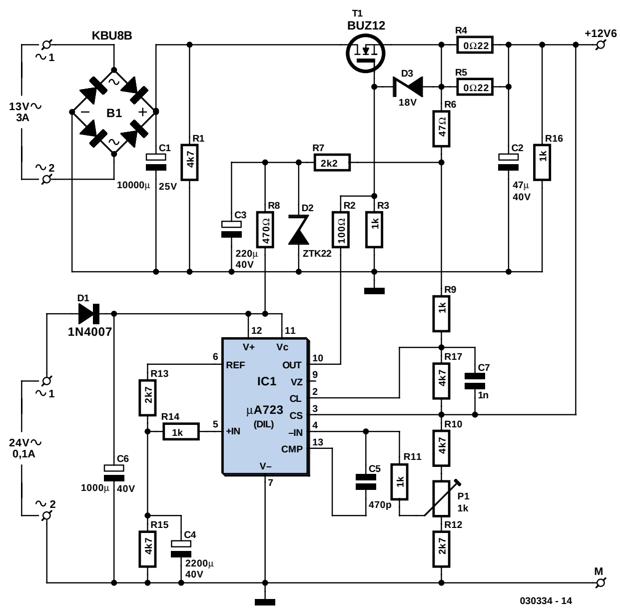


Figure 2. This low drop-out DC regulator provides the heater supply.

DC heater supply

To minimise hum a regulated low drop-out DC heater supply is provided, using the familiar 723 voltage regulator and a MOSFET (**Figure 2**). The supply has been designed to minimise losses, and to this end the heater filaments of the two EL156s are connected in series. The ECC81 can be arranged so that it operates from a 12.6 V heater supply. At double the voltage (using 12.6 V rather than 6.3 V) only half the current flows, which means that losses in the bridge rectifier are considerably reduced. With the given component values power losses in T1 will be kept low.

A further trick is used to reduce the voltage drop due to the current limit circuit. The 723 includes a silicon transistor for current limiting, whose base-emitter junction senses the voltage across the current limit sense resistors R4 and R5. Normally the silicon transistor would switch off at

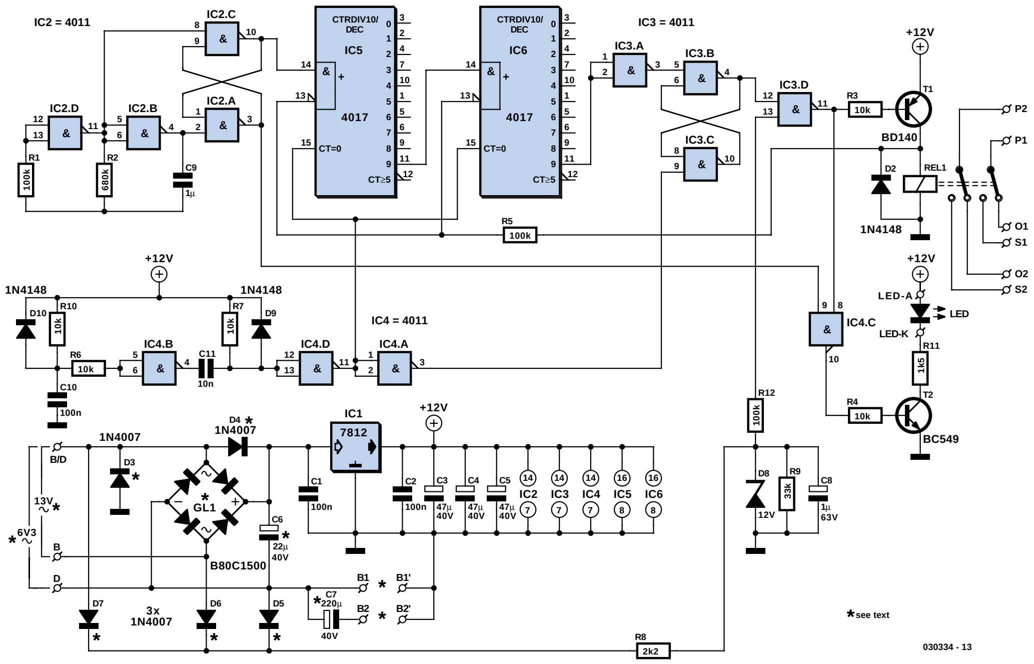


Figure 3. This clever switch-on delay circuit prevents clicks, hum and rumble.

about 0.6 V. Here, however, the base is provided with a stabilised bias voltage from temperature-compensated Zener diode D2 via R7 and R8. This results in a smaller voltage drop across R4 and R5 being needed to trigger current limiting.

The reference voltage produced by the 723 is divided down by R13 and R15. C4 is in principle necessary to filter out any noise on the reference voltage, but could be made considerably smaller. Because of the relatively high value of the capacitor, the voltage at pin 5 rises slowly, providing a 'soft start' to the heater supply. A BUZ12 FET with an R_{DSON} of just 28 mΩ is used for T1.

It is important to ensure that the voltage difference between the cathode and the heater is not too high as otherwise arcing can occur. The negative side of the heater supply **must** therefore be connected to the negative side of the high voltage supply.

Rattle and hum

When the output stage is switched on and while it is warming up the various reservoir and coupling capacitors may charge at different rates. This can give rise to hum and rumble. The circuit in **Figure 3** can suppress these sounds effectively. The normally-closed relay contact shorts out the output transformer for a set time (which the valve output stage can comfortably cope with). Only after a certain interval does the relay pull in, removing the short circuit. This approach avoids putting relay contacts in the signal path. The layout of the printed circuit board allows a relay with two changeover contacts to be fitted so that the circuit can be used for other applications, including with a stereo output stage.

In our case the circuit runs from the 13 V heater supply, from which it will draw a maximum of 200 mA. If the switch-on delay circuit is to be connected to an existing amplifier, the circuit will work equally well from a 6.3 V heater supply winding, as long as there is sufficient spare current capacity. In this case a voltage doubler circuit is used. Depending on the choice of power supply voltage a number of components must be added to or removed from the circuit, as indicated on the component mounting plan and in the parts list.

Switching on

When power is applied C8 immediately starts to charge via R8, taking the pin 13 input of IC3.D high. At the same time C10 charges via R10. As soon as the input threshold voltage of IC4.B is reached its output goes low and, via the high-pass network formed by C11 and R7, generates a brief low pulse at the input to IC4.D. This signal is inverted and then used to reset the 4017 counter to zero, and then inverted again and used to reset the flip-flop formed by IC3.B and IC3.C. The output of this flip-flop at pin 4 thus goes low (if it was not already low). The output of IC3.D is consequently high, T1 does not conduct and the relay does not pull in. The output of the amplifier is therefore short-circuited.

IC2.B and IC2.D form a 1 Hz clock generator, the frequency being determined by C9 and R2. The flip-flop formed by IC2.A and IC2.B makes this clock available to the cascaded counters IC5 and IC6. After 100 counts the flip-flop comprising IC3.B and IC3.C is set via inverter IC3.A. The output of IC3.D then goes low, T1 conducts and the relay pulls in. The short-circuit is removed and the audio signal is now passed through to the loudspeaker. At the same time this high signal is used to disable to counters via R5.

During the switch-on process the pin 8 input to IC4.C is high, and a 1 Hz signal is present on pin 9. The output on pin 10 will therefore also carry the 1 Hz signal, and so the LED flashes. Once the switch-on delay is complete pin 8 goes low, forcing the output of the NAND gate high. The LED now glows continuously.

Switching off

When the amplifier is turned off, there is no longer any voltage present on the transformer. The transformer voltage is monitored continuously by D5 and D6 (13 V operation) or by D5 and D7 (6.3 V operation). If the voltage is not present,

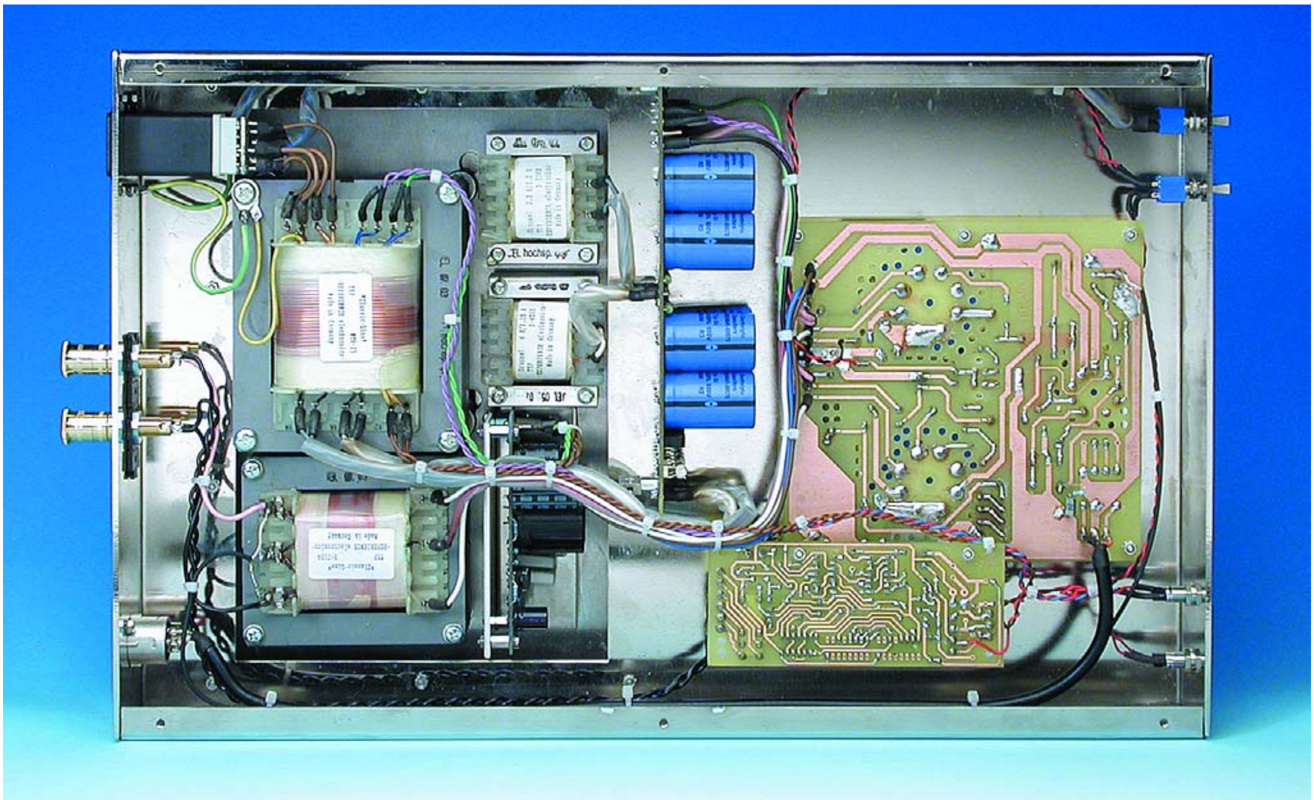


Figure 4. The amplifier seen from below.

the relay drops out immediately. Diodes D1 and D9 ensure that capacitors C10 and D11 discharge quickly. If power is applied again, the whole cycle must be repeated. This ensures that the output is once again muted, ensuring that the unwanted effects mentioned earlier are avoided.

Construction

The monoblock amplifier comprises a total of three printed circuit boards and several wound components fitted into

A valve is a valve is a valve...

Parameter	Symbol	EL34	EL156	Units
Heater voltage	U_f	6.3	6.3	V
Heater current	I_f	1.5	1.9	A
Maximum anode voltage	U_{amax}	800	800	V
Maximum cathode current	I_{kmax}	150	180	mA
Maximum anode power dissipation	P_{Vmax}	25/27,5	40	W
Maximum screen grid power dissipation	P_{vg2}	8	8/12	W
Screen grid current	I_{g2}	11/22	5/25	mA
Maximum screen grid voltage	U_{g2max}	425	450	V
in class AB operation		425	350	
Grid bias voltage	U_{g1}	–39	–24	V
AC grid driving voltage	U_{g1AC}	23	18	V
Transconductance	S	11	13	mA/V
Internal resistance	R_i	15	20	kΩ
Maximum grid leak resistor	R_{g1max}	700	100	kΩ

In some cases quantities have been rounded or guideline values shown, since not all data books exactly agree on all the figures. Values shown after an oblique are at maximum drive.

The EL34 and EL156 are genuine audio power pentodes rather than beam power tetrodes like the 6L6, KT88 or 6550. They are similar to one another, but not identical in all respects. The EL156 requires approximately 27 % more heater power, while offering a maximum cathode current about 20 % higher. Its maximum anode power dissipation is about 60 % higher than that of the EL34. The EL156 also features a higher internal resistance, higher transconductance, higher current and slightly lower grid bias voltage. Maximum drive can also be obtained using a smaller grid

Figure 5. The comforting glow of an EL156 in action.

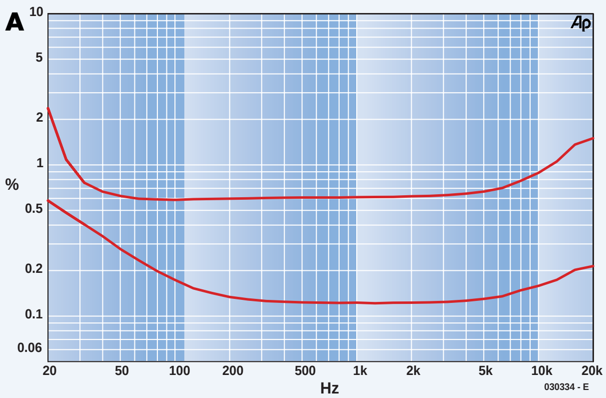
an enclosure as shown in **Figure 4**. Our prototype amplifier was housed in a seamlessly-welded nickel-plated aluminium enclosure polished to a glossy finish. The use of aluminium provides shielding from magnetic interference which mostly originates in the fields produced by the transformers. All the ground connections must be brought together at the amplifier board and bonded to the enclosure at a single point using a bolt and solder tag. If this

driving voltage. Because of these characteristics, greater gain can be achieved using the EL156 than with the EL34, and as a consequence we only need a double triode in the driver stage, despite our high output power.

For both valves a number of details must be observed in high power operation. At higher supply voltages the screen grid voltage must be fixed at a given maximum value. It is also in general necessary to provide a fixed grid bias voltage. The maximum permitted grid leak resistor is considerably lower for the EL156 than for the EL34. The maximum value of the grid leak resistor is specified in the data sheet for each valve. In theory a valve can be driven without dissipating power, but in practice a small grid current flows which must be drained away. Account must be taken of this when designing the driver circuit. The EL156 can only be driven efficiently when the anode voltage is sufficiently high: power has its price! In a triode circuit using class AB push-pull operation dissipation can reach 30 W. The screen grid voltage for the EL156 in high power class AB push-pull operation must be at least 350 V; for the EL34 at least 400 V is required.

On the test bench

Measured characteristics (all measurements taken with an 8 Ω load)				
Parameter	**Conditions**		**Value**	**Units**
Input sensitivity	90 W, 1 % THD+N		1.4	V_{eff}
Input impedance	20 Hz 1 kHz 20 kHz		4 9 1.08	kΩ
Sine wave output power	1% THD+N		90	W
Bandwidth	–3 dB, 1 W		41	kHz
Slew rate	10 µs step		5	V/µs
Signal-to-noise ratio	at 1 W, bandwith = 22 Hz to 22 kHz		88 102	dB BA
Harmonic distortion and noise over 80 kHz bandwidth	1 W	1 kHz 20 kHz	0.12 0.21	%
	50 W	1 kHz 20 kHz	0.6 1.43	
Intermodulation distortion	50 Hz : 7 kHz = 4:1	1 W 50 W	0.5 2.6	%
Dynamic intermodulation distortion	3.15 kHz square and 15 kHz sine wave	1 W 50 W	0.064 0.33	%
Damping factor	1 kHz 20 kHz	2.9 2.3	–	



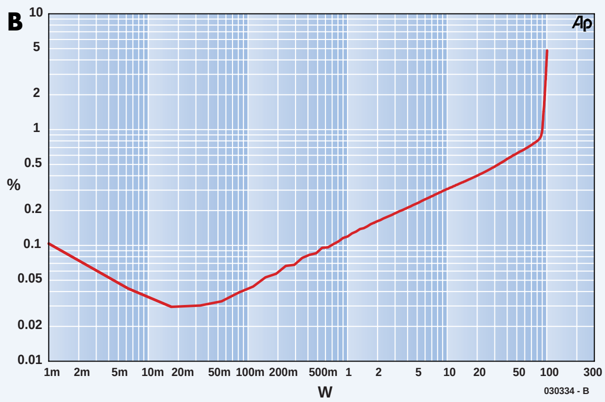


Figure A shows the total harmonic distortion plus noise (THD+N) as a function of frequency when the amplifier is driven at 1 W and at 50 W. The measurement was carried out using a bandwidth of 80 kHz. As is to be expected from a valve amplifier, the distortion increases as the core in the output transformer approaches saturation. This is not a particular disadvantage as the human ear is insensitive to low frequencies and does not find higher distortion levels unpleasant.

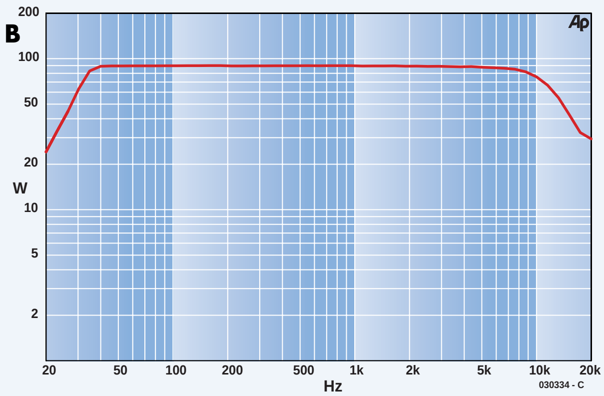
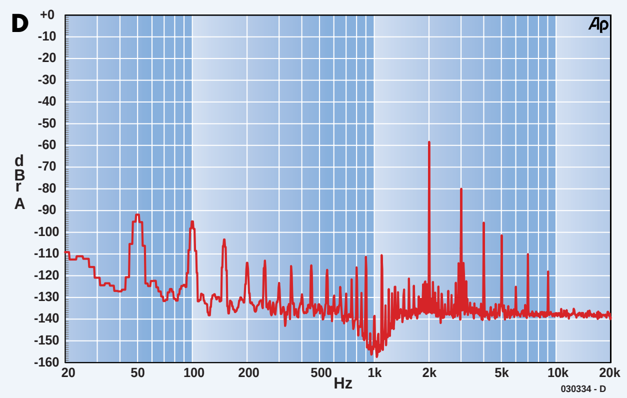
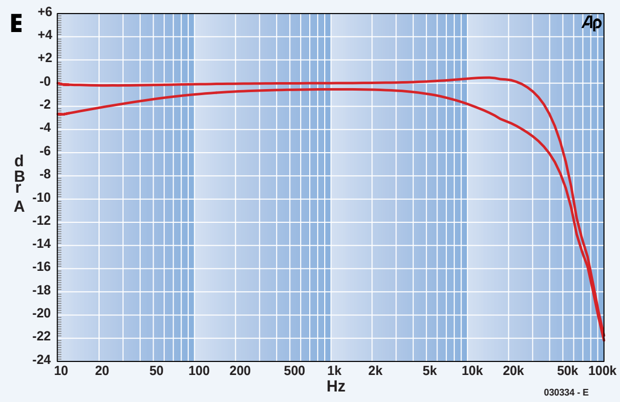


Figure B shows distortion as a function of drive level. The distortion rises from about 50 mW onwards, being dominated by harmonic components. The measurement was taken using a bandwidth from 22 Hz to 22 kHz in order to show more clearly the effect of harmonic distortion at low power levels. At 90 W the amplifier starts to clip.

Figure C shows the maximum power as a function of frequency for a fixed distortion (here 1 %). The bandwidth used for the distortion measurement was 80 kHz. The maximum power starts to fall off towards the upper and lower ends of the amplifier's frequency range. At the upper end of the frequency range the situation is not too bad, since generally less power is required here anyway. Things are different below 40 Hz, where deep tones often demand a lot of power.





A spectrum analysis of the distortion to a 1 kHz sine wave signal at an output power of 1 W is shown in **Figure D**. Almost all the distortion is accounted for by the second harmonic at –58.3 dB. The third harmonic lies at –80 dB, and all the remaining harmonics, along with mains hum, are below –90 dB. The hum component is mainly due to the magnetic field of the transformers (50 Hz component); otherwise the 100 Hz component would be expected to be much more significant.

Finally, **Figure E** shows the effect of the input circuit to the amplifier, where a 4.7 kΩ resistor and a 2.2 nF capacitor are effectively connected in parallel across the secondary side of the input transformer. If the output impedance of the preamplifier is greater than 50 Ω, the input impedance of the power amplifier has a clear effect. The upper curve shows the normal frequency response with an impedance of 20 Ω, while at 600 Ω the frequency response falls off markedly at both the upper and lower end of the frequency range.

is not done, the enclosure will act as an antenna and the amplifier will hum. The high voltages used mean that the enclosure **must** be earthed. Input and output connections must be isolated from the enclosure, or else stray earth currents may arise.

Cable with a cross-section of at least 0.5 mm^2 should be used between the relay contacts and the loudspeaker outputs. Thinner cables have too high a resistance, with the result that rumble can be heard faintly through the loudspeakers during the warm-up phase. The heater connections need cable with a cross-section of 1.5 mm^2, the earth connections cable with a cross-section of 0.75 mm^2, the high voltage connections cable with a cross-section of 0.5 mm^2, and finally the auxiliary supply connections cable with a cross-section of 0.25 mm^2.

Operation is relatively straightforward. First check again that all the components are mounted correctly and that the wiring is correct. Next check the auxiliary voltages, leaving out the fuse in the high voltage supply for now. When mains power is applied the negative grid bias voltage should immediately be present on the valve bases, and can be adjusted using the trimmer potentiometers. For the moment, set the voltage to its maximum negative value. Next check the heater voltage and adjust it to 12.6 V. If voltage can be adjusted over a range of two to three volts, but the value of 12.6 V cannot be reached, then resistor R10 or R12 will need to be changed. Next fit the valves. Shortly, the heater filaments should start to glow, as shown in **Figure 5**.

We can now proceed to test the circuit with the high voltage present. It is absolutely essential that a load resistor rated to at least 150 W must **always** be connected. Do not forget to switch off the unit before fitting the high voltage supply fuse!

Turn the unit back on, and connect an oscilloscope across the load resistor to act as an output monitor. Once the warm-up phase is complete the quiescent current of the output valves can be set. Measure the voltage drop across each cathode resistor, R20 and R21, using a multimeter. Alternately adjust the currents through V2 and V3 for a voltage drop of 450 mV, which corresponds to 45 mA per valve. Next connect a signal generator producing a 1 kHz sinewave to the input, and gradually increase the amplitude of the signal. Observe the output signal on the oscilloscope. It should increase in amplitude without distortion or spurious oscillation until the point where it starts to clip. If the amplifier does have a tendency to oscillate, check that the wiring is correct and that the earthing is sound. If the amplifier goes into large-amplitude oscillation as soon as it is switched on, which can be seen on the oscilloscope as a distorted squarewave with a frequency of approximately 100 Hz, and heard as a hum in the transformer and output valves, switch off immediately. The effect indicates that the output transformer has been connected with the wrong polarity, and anode 1 must be interchanged with anode 2, turning positive feedback into negative feedback. As long as the circuit is switched off immediately there should be no damage to the valves or other components.

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Note

For reasons of space, printed circuit board layouts, component mounting plans and parts lists are only available in electronic form on the Internet, downloadable from

www.elektor-electronics.co.uk.

Ready-made unpopulated printed circuit boards and kits can be obtained from the author (experience.electronics@t-online.de).