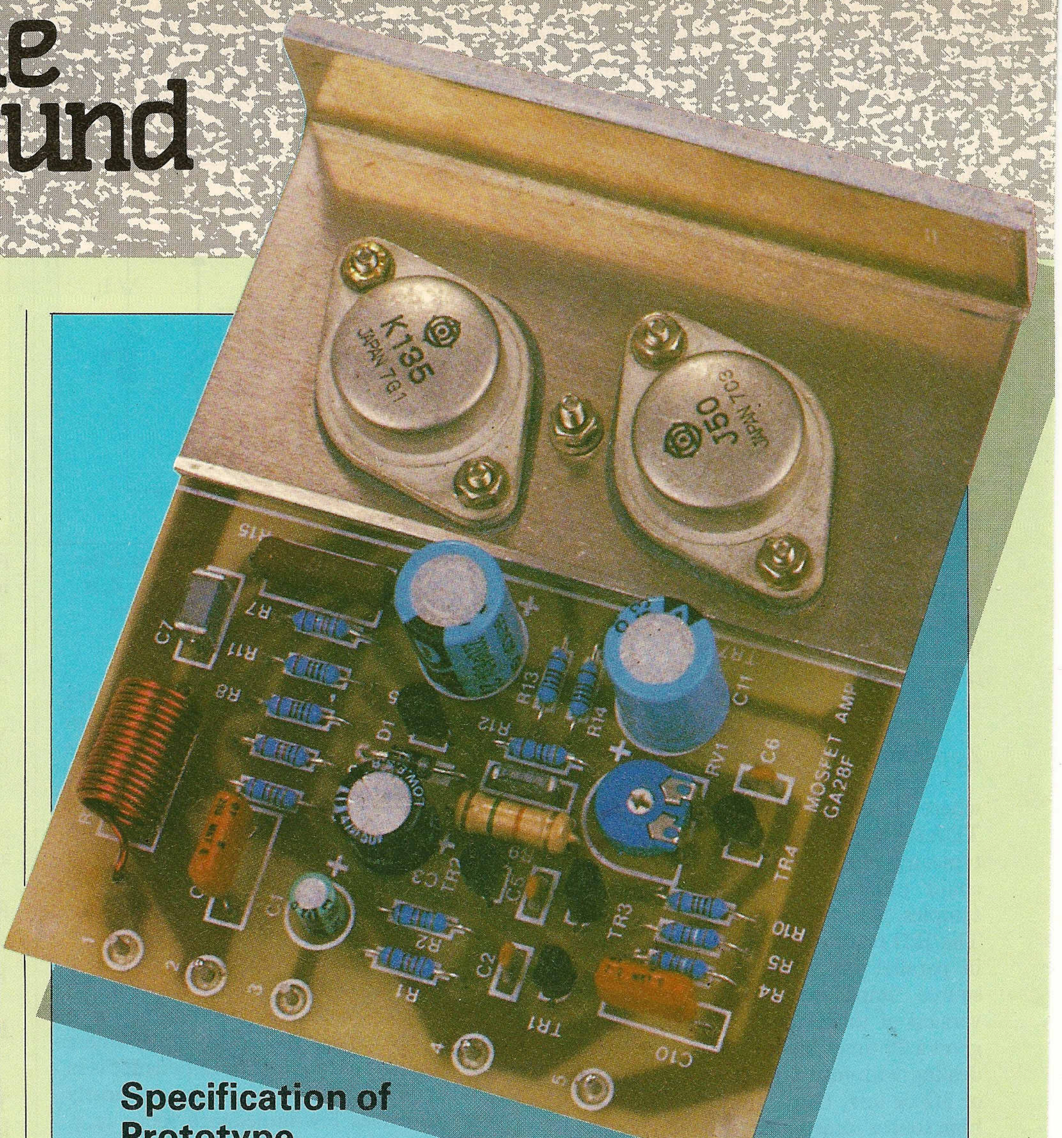
2ND Time Around

MOSFET AMPLIFIER

Introduction

Many projects from the Maplin range have proved to be popular over the years. However, modern technology and electronic components have a habit of changing with the result that some of these projects are in danger of becoming obsolete as the originally specified components become unavailable or standards change. In order for some of the more popular projects to remain available, updates and improvements are necessary, and to this end these projects are being reviewed in the series "2nd Time Around". This time it is the turn of the MOSFET Amplifier.



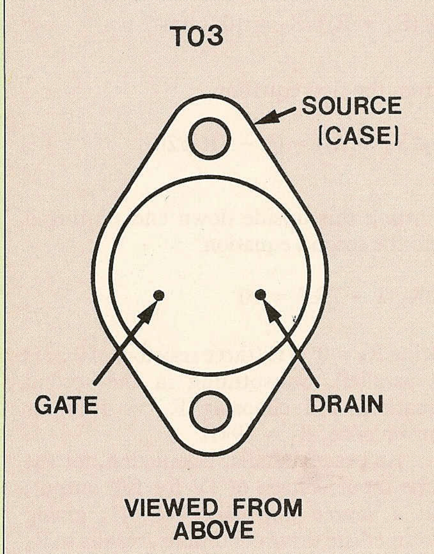


Figure 1. Power MOSFET package.

Specification of Prototype

Power Supply Requirements	
Voltage:	±55V DC (MAX)
Current:	2·5A (8Ω) - 5A (4Ω)
Power Output (1kHz continuous sine wave)	
Rating:	100W RMS into 8Ω 150W RMS into 4Ω (absolute maximum)
Frequency Response:	20Hz to 40kHz
T.H.D.:	0·01% (at 1kHz)
Input Impedance:	47kΩ
Sensitivity:	860mV RMS input (2·43V Pk - Pk) for rated output

Ancient History

The Maplin MOSFET Amplifier was originally developed for use as a guitar amp in the late seventies and first saw the light of day with the 75W Combo Amplifier project ('Electronics' Issue 1). Shortly afterwards – by popular demand – the power amplifier section from the project was published in 'Electronics and Music Maker magazine' and also in the Best of E&MM projects book and has remained one of our biggest selling projects over the last decade!

The amplifier was not intended to reflect a state-of-the-art Hi-Fi design as the requirement was for a rugged, easy to build project that would offer good, reliable performance and – to quote our early advertising – be "virtually bomb-proof like the best valve amps". Journalistic licence maybe, but the enormous success of this project would certainly substantiate this claim!

The MOSFET

Figure 1 shows the terminal connections for a MOSFET, viewed from *above* the TO3 package. The Source terminal, incidentally, is the metal package itself and connections to it are made through both of the case mounting holes. Thermally, the MOSFET has an advantage over the bi-polar transistor. As a bi-polar transistor heats up in use, the collector current increases due to the positive temperature coefficient of the device. If the temperature rise were allowed to continue then thermal runaway would ensue and the transistor could be destroyed. A MOSFET however exhibits a negative temperature coefficient. As the device heats up in use the Drain-Source current decreases (due to increasing internal resistance), the device temperature will also reduce in turn and the Drain-Source current will then rise again. Used in a power amplifier this self regulating effect can be desirable as it offers a high degree of immunity from misuse – or abuse according to your musical taste perhaps?

The symbols given for N and P type MOSFETs in Figure 2 relate to the Gate voltage and Drain current transfer characteristics and show the MOSFET to be an enhancement type.

Figure 3 shows the output characteristics of typical MOSFET devices.

These particular qualities of the MOSFET allow for much simpler designs to be produced, as complex biasing and quiescent current compensation arrangements are not required, which is usually the case with bi-polar transistors. The typical Total Harmonic Distortion (T.H.D.) of the MOSFET is very low for output levels up to 50W. At higher frequencies and power levels approaching 100W the T.H.D. levels increase as can be seen in Figure 4, although these figures remain fairly insignificant in practical terms.

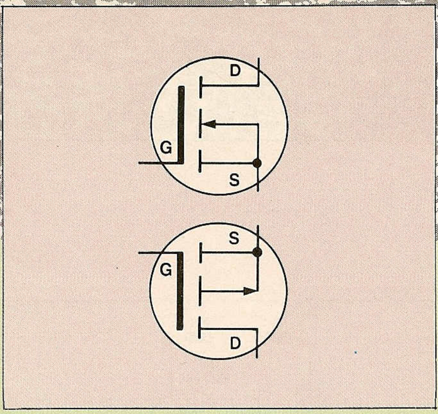


Figure 2. MOSFET symbols.

Circuit Description

The amplifier design originates from the late seventies, as previously mentioned and still remains virtually the same, except for a few minor improvements made to ease assembly and improve reliability. In the circuit

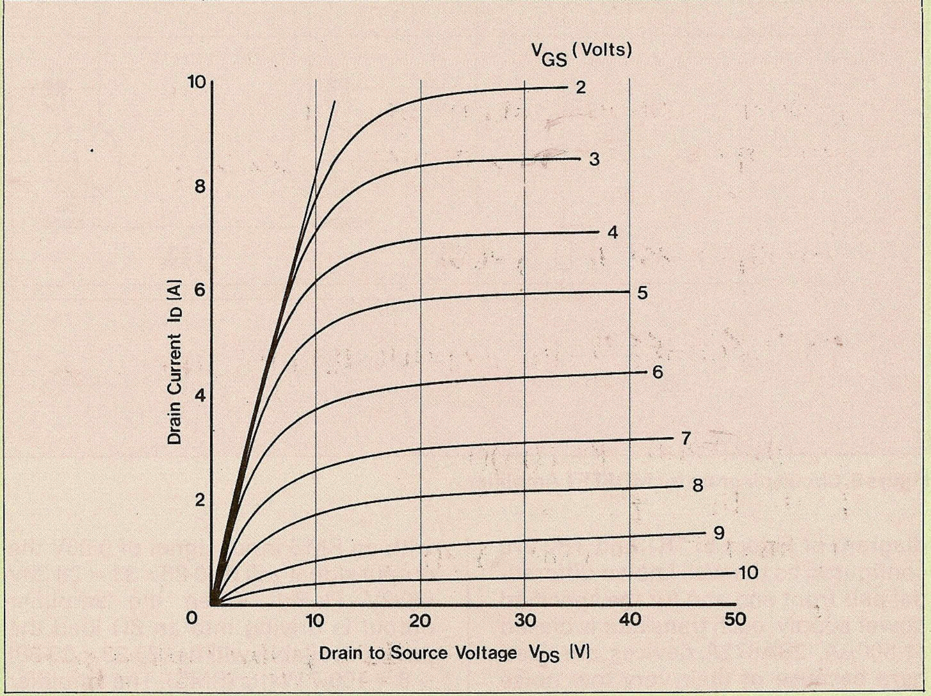


Figure 3. Typical output characteristics (2SK135).

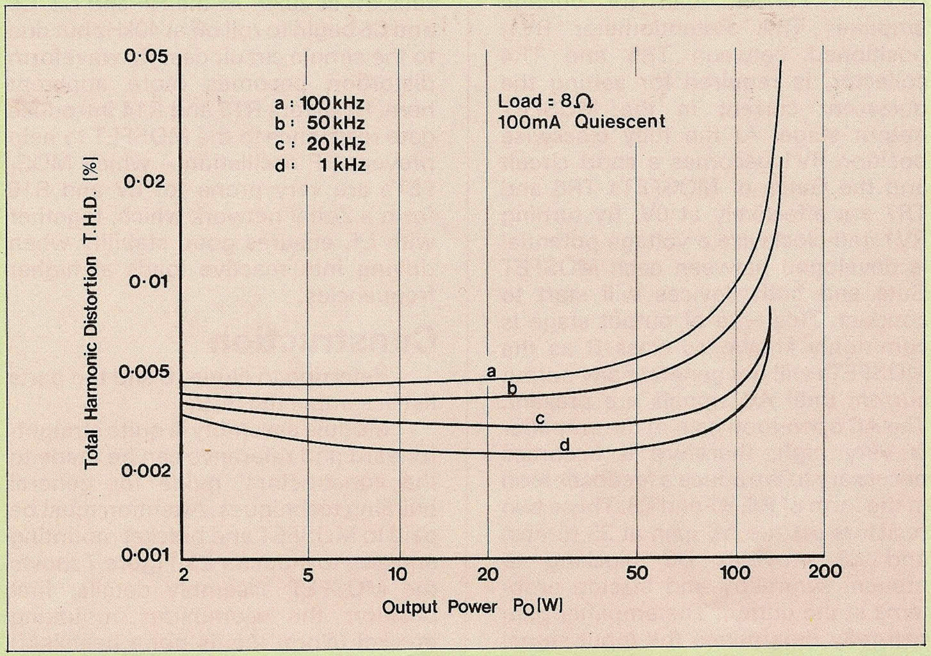


Figure 4. Typical T.H.D. Vs output characteristics.

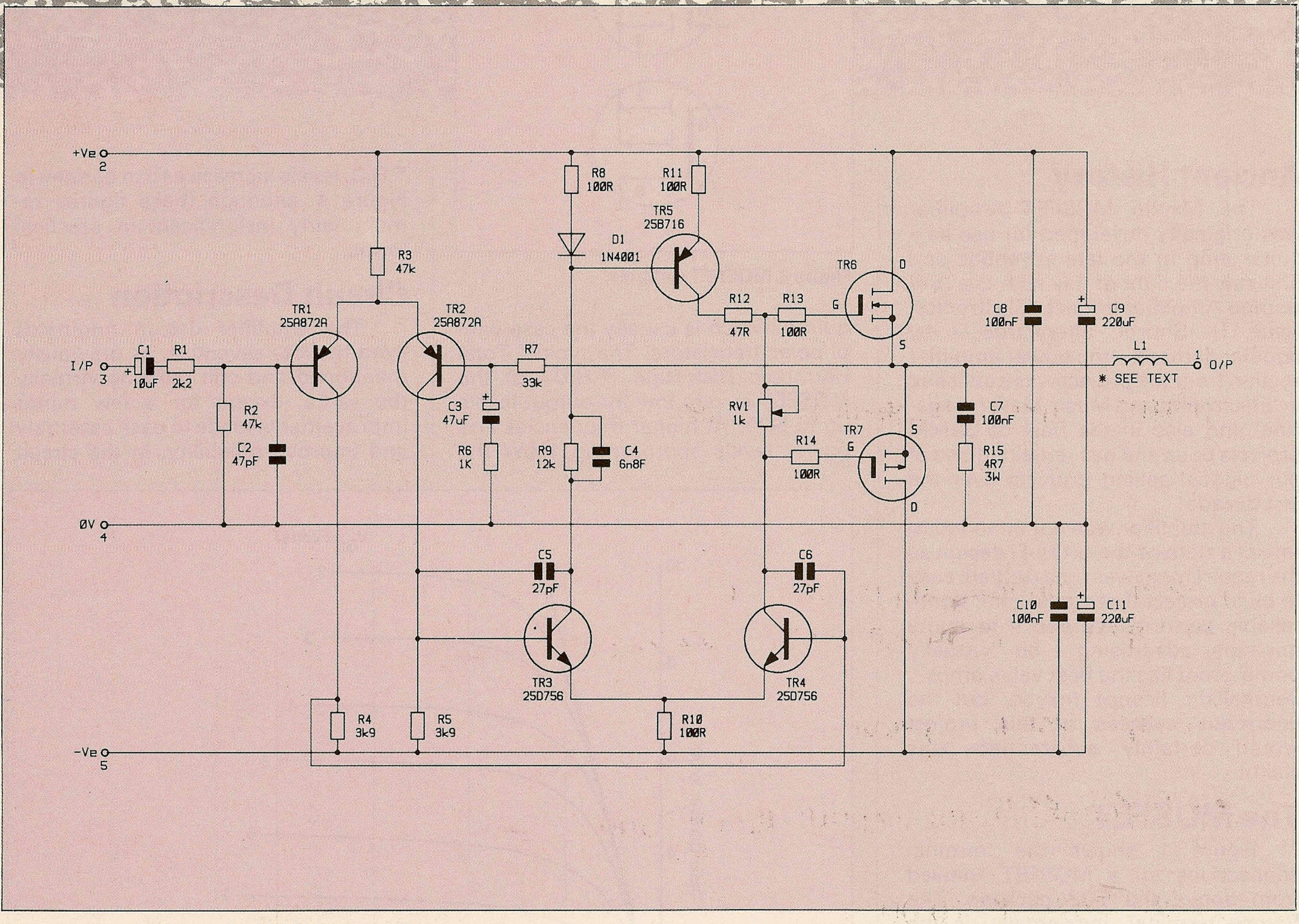


Figure 5. Circuit diagram for MOSFET Amplifier.

diagram of Figure 5, TR1 and TR2 are configured as the well known differential pair front end and for the specified power supply, each transistor is biased at 500μA. 2SA872A devices are used here because of their very low noise and high voltage specifications. The circuit around TR5 and D1 form the constant current load for voltage amplifier TR4. Potentiometer RV1, positioned between TR5 and TR4 collector, is required for setting the quiescent current in the MOSFET output stage. At the fully clockwise position RV1 becomes a short circuit and the Gates of MOSFETs TR6 and TR7 are effectively at 0V. By turning RV1 anti-clockwise a voltage potential is developed between each MOSFET Gate and both devices will start to conduct. This type of output stage is commonly known as class B as the MOSFETs will not generate any output current until AC signals are present. The AC open-loop gain of the amplifier is very high, therefore it becomes necessary to introduce a feedback loop in the form of R6, R7 and C3. These two resistors set the AC gain at 33 (times) and C3 provides DC blocking to prevent symmetry and biasing problems at the output. The amplifier gain naturally determines the input signal level requirements and, for example, with an RMS input signal of 0·86V the output signal will be 0·86 x 33 = 28·38V (80·2V Pk-Pk). When the amplifier output is driving into an 8Ω load the power available will be (28·38 x 28·38) ÷ 8 = 100·7 Watts (RMS). The amplifier frequency response is determined, at the LF end, by capacitors C1 and C3 and rolls off at 20Hz. At the HF end C2, C5 and C6 begin to roll off at 40kHz but due to the simple circuit design, waveform distortion becomes more apparent here. Resistors R13 and R14 introduce gate resistance to the MOSFET to help prevent HF oscillation – which MOSFETs are very prone to! C7 and R15 form a Zobel network which, together with L1, ensures good stability when driving into reactive loads at higher frequencies.

Construction

Referring to Figure 6 and the parts list assemble the PCB.

Module assembly is quite straightforward and reference can be made to the constructors' guide for general building techniques. Attention must be paid to MOSFET and bracket mounting and also to inductor L1. Figure 7 shows the MOSFET assembly details; first position the aluminium mounting bracket (Note: this is *not* a heatsink!) onto the PCB and insert one of the five 6BA bolts through the centre locating hole. Fit a 6BA washer and nut to the bolt, but before tightening the nut, ensure the bracket is positioned centrally over both MOSFET positions shown on the PCB legend. This is important – if the MOSFET terminals are to be prevented from shorting out onto the bracket. Place one silicon insulator pad onto each MOSFET and, after straightening any bent Gate or Drain terminals, fit the MOSFETs into their respective positions as shown. Finally, lock each device in place with two 6BA nuts, washers and bolts inserted from the PCB track side. Solder all four bolt heads onto the copper track to ensure good electrical connection. To make the inductor L1, first straighten out the 0·9mm enamelled copper wire, smoothing out the kinks and bends, and close-wind 15 complete turns using a pencil or plastic tube (ball-point pen) as a former. The former must be strong and between 8mm and 10mm in diameter and if wound neatly the coil produced should be not more than 15mm in length. Cut off excess wire and bend both end wires at right angles as shown in Figure 8; to fit into the PCB correctly, bend the two wires allowing for 23mm centre spacing. Scrape away the enamel from both wire ends then fit and solder L1 into the PCB. Note that R16 is printed on the legend but is not supplied or required. Resistor R9 may be a little large for the existing board holes, but will just fit okay. Thicken the track running from the Source (case) mounting bolt of TR6 to inductor L1, with plenty of molten solder. The track running between the remaining two Source bolt heads can also be treated in this way.

Testing

First ensure that all components have been correctly soldered onto the board and that all joints are sound. Clean off any excess flux with a suitable PCB solvent and inspect for shorts and 'whiskers'– most problems on this amplifier are caused by a lack of attention here! With a suitable test meter set to read ohms check for continuity between the mounting bracket and each MOSFET case, Drain and Gate terminal. Any connection between the MOSFETs and bracket will cause problems, so if a 'short' is found it will be necessary to strip down the MOSFET assembly to investigate the cause. Check between 0V pin 4 to +V pin 2 and 0V to −V pin 5; except for an initial 'kick' as the decoupling capacitors charge there should not be any

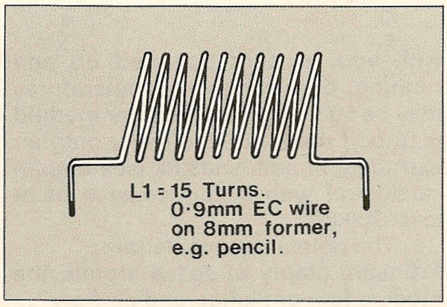


Figure 8. Making the inductor L1.

short circuits here either. Check for continuity between the output pin 1 and the MOSFET cases as well. Finally, with a small screwdriver or trimming tool adjust the wiper (arrow) on RV1 so that it points to the + symbol below R14.

Supply and Demand

A split rail supply is required for powering the amplifier and you will probably find that this item costs more than the amplifier itself! Figure 9 offers a suggested circuit for a PSU suitable for most requirements. You may also like to note that a full specification High Quality Power Supply module will be available as a kit in a future edition of 'Electronics' magazine. Toroidal transformer T1 (YZ23A) is an audio grade

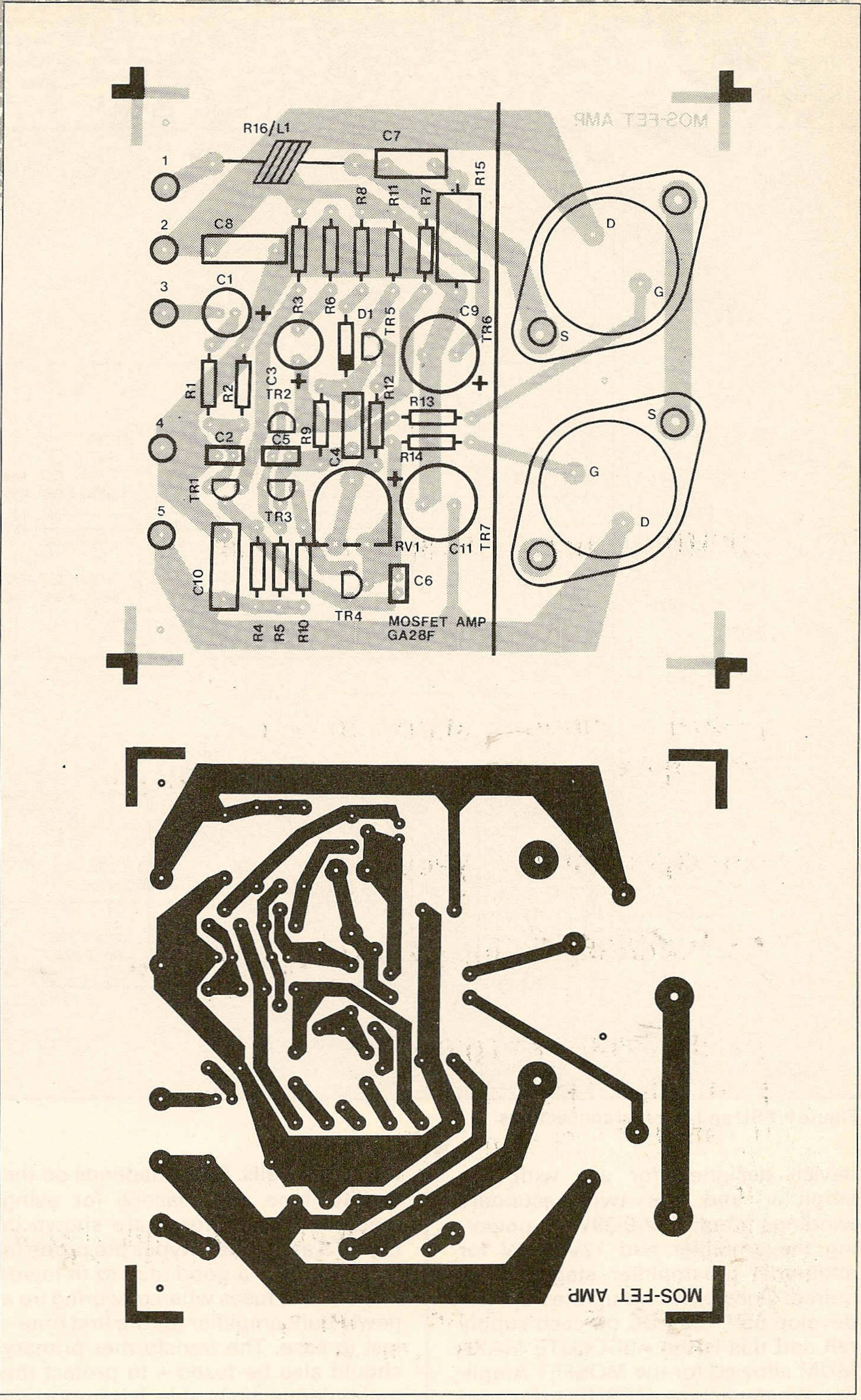


Figure 6. PCB overlay and legend.

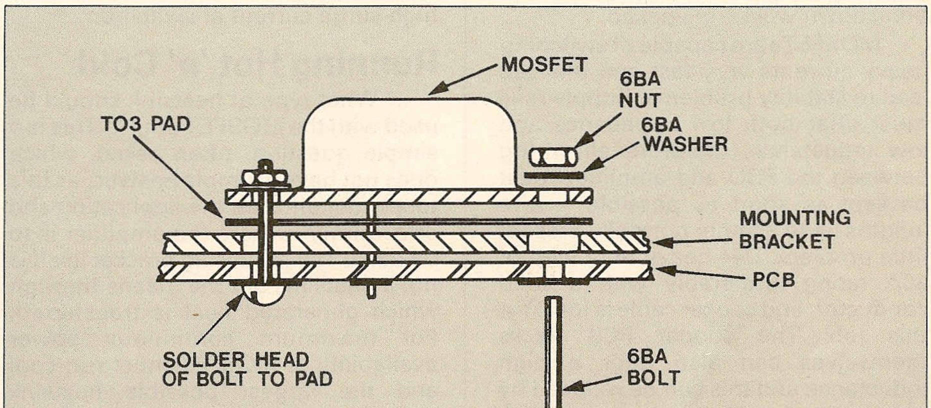


Figure 7. Method of mounting MOSFETs.

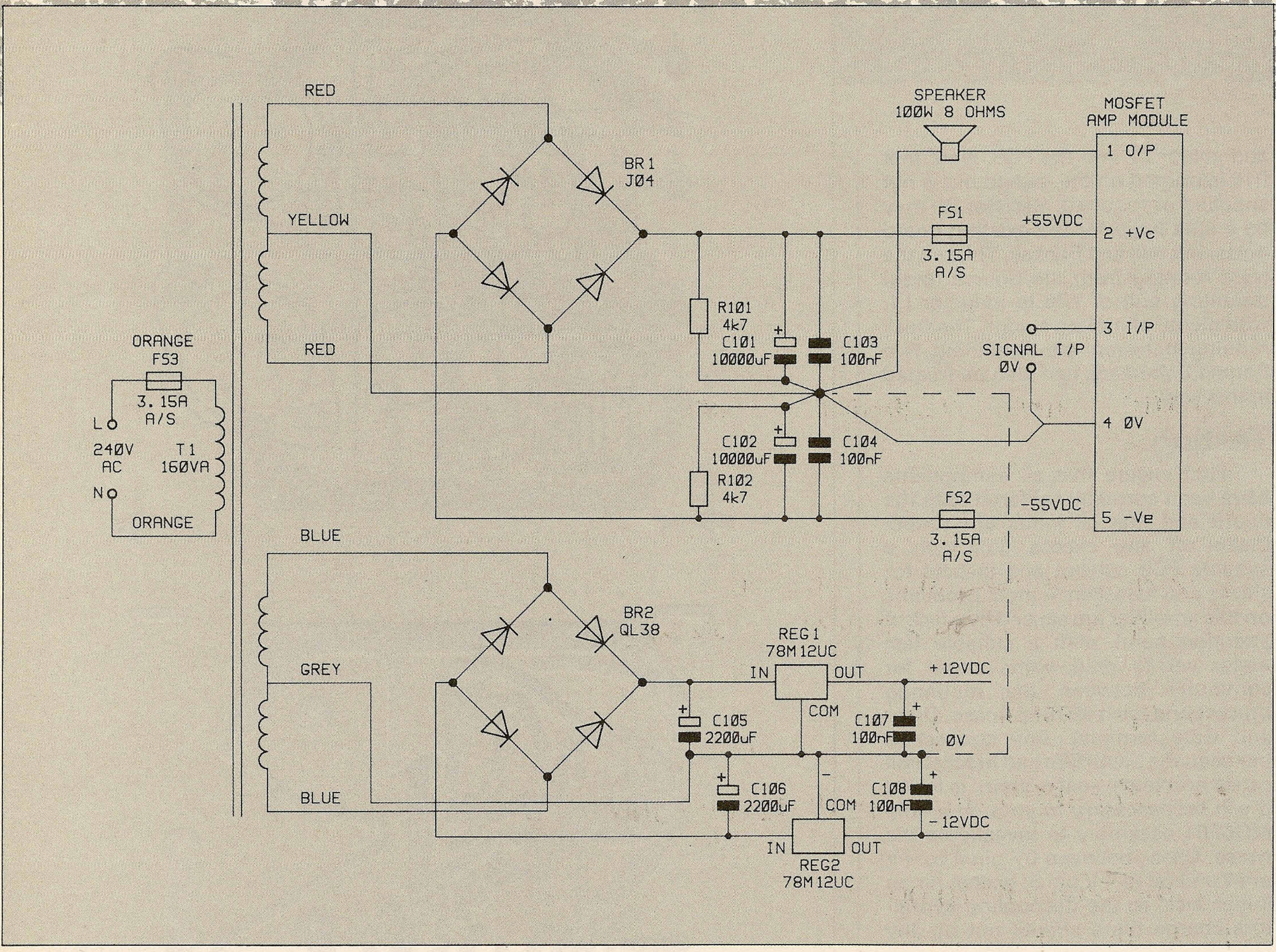


Figure 9. PSU and external connections.

device designed for use with this amplifier and has two secondary windings fitted: 39V-0-39V for powering the amplifier and 12V-0-12V for additional preamplifier stages if required. Once powered up the PSU will develop 55V - 58V DC on each supply rail and this is the ABSOLUTE MAXIMUM allowed for the MOSFET Amplifier. Whatever type of PSU is to be used DO NOT exceed the maximum voltage given as the risk of component breakdown will be increased.

MOSFETs are capable of switching heavy currents very fast and this can lead to stability problems. Supply rails must offer both low impedance and low inductance, therefore all wiring between the PSU and amplifier must be kept as short as possible – wire lengths up to 300mm normally present little problem. Use heavy duty wire of 30A rating, preferably with a solid conductor, and cooker cable is ideal for this job. The copper PCB tracks themselves can also offer a high inductance and this can be reduced by making each ±V supply connection direct onto the MOSFET Drain terminal instead of to pins 2 and 5.

There have always been arguments for and against fitting fuses in the supply rails. Much depends on the quality, type and reasons for using them. Anti-surge fuses are shown in Figure 9 as standard types are prone to 'pop out'. It is a good idea to fit lower value (0·6A) fuses when powering up a newly built amplifier for the first time – just in case. The transformer primary should also be fused – to protect the mains connecting cable. It is important to use Anti-Surge fuses (3A) as torroidal transformers draw a very high surge current at switch-on.

Running Hot 'n' Cold

"What type of heatsink should be used with the MOSFET amp?" This is a simple question, often asked, which does not have a simple answer; as this totally depends on the application and environment where the amplifier is to be used. The mounting bracket itself is *not* a heatsink, but the means through which generated heat is transferred. For maximum continuous power availability, a MOSFET must run cool and the largest possible heatsink should be used. One method is to bolt the bracket onto a panel within a metal case used to house your system. Of course, the size of the case is important – a small case may feel cool externally with your system powered up and running, but inside the temperatures may be 50°C or more! Another method is to bolt the module directly onto an extruded, finned heatsink (see Maplin catalogue) with a surface area of at least 200cm^2.

The points to consider are:

1. Ensure plenty of space around the module for ventilation and air flow.
2. Bolt the bracket onto heatsinks or metal panels – not wood or plastic.
3. Flat panels themselves do not radiate heat readily and should have a finned heatsink attached.
4. Use a small mains or 12V fan as well, for extracting/blowing air over the MOSFETs when installed in confined spaces.

Setting Up

Fit low current fuses in each supply rail prior to powering up and do not connect a loudspeaker yet. Connect a multimeter, set to read current, in series with the +V supply rail – ensuring the current range selected is at least that of the fuse fitted – and turn on the supply. Assuming that all is well thus far, select a lower current range on the meter and adjust RV1 for a quiescent current reading of 100mA

DC. The actual value of 100mA is not critical on this amplifier and 80 – 120mA is fine. Turn off the power and after allowing a minute or so for the PSU electrolytics to discharge (CHECK!) remove the meter and reconnect the +V supply rail to the module. Re-connect the meter, set to read 50 volts DC or more, between the speaker output pin 1 and 0V. Power up again and there will probably be a small DC offset voltage of ±20 – 50mV here. If 0·5V or more is present then switch off and look for an assembly fault or check if one of the test fuses have blown. If any component appears to be getting hot or the quiescent current reading cannot be lowered then it is possible that the amplifier is oscillating. This effect usually manifests itself by R15 'cooking' due to the Zobel circuit absorbing generated RF energy. Re-check the PSU wiring and also capacitors C4 to C6 as they are easily broken during installation. Power down and install the 3A fuses for normal use.

In Use

Always take 0V connections from one place on a PSU – including the speaker 0V return. This is often referred to as 'star earthing' and ensures that eddy currents do not flow between different 0V points thus reducing hum and noise. The 0V point at which capacitors C101 and C102 join together, on Figure 9, is the best place to take connections from. When choosing a loudspeaker, ensure that it is capable of handling continuous power levels of 100 Watts RMS or more (8Ω version) and 150 – 200 Watts for 4Ω versions. Multi-banked speaker assemblies should not total less than 4Ω and must be connected together in parallel/serial combinations to achieve this. Remember that many speaker impedance figures are nominal and will vary according to frequency and applied power levels.

Over-driving the amplifier by applying input signals greater than 0·86V will cause the output waveform to 'clip' or square off. Square waveforms are rich in harmonics and can cause excessive excursions of a loudspeaker cone or more commonly, totally destroy a tweeter. Guitarists may like the sound produced, but speakers do not. When using any amplifier at high power levels, due consideration must be given to the application. Bass guitars and 'miked up' drum kits, for example, generate huge transients as strings are plucked or heads are struck. For these applications, devices such as compressors or limiters have to be introduced at the amplifier input – to protect speakers as well as the amplifier!

The MOSFET amplifier is robust and fairly 'bomb proof', but not invulnerable. If even greater power outputs are required then two amplifiers can be 'bridged' together in preference to driving one unit to its maximum. Finally, a word about earth loops. A correctly working MOSFET amplifier and PSU will not produce audible 50/100Hz hum by itself, but unscreened low level signal wires can introduce this. If the PSU 0V rail is connected to mains earth and other equipment connected to the mains earth have their inputs and outputs connected via screened wire to the amplifier, then a loop exists between the screen and earth wires. The mains supply generates an electromagnetic field that is very easily induced into the earth loop and hence the 0V rail will be carrying 50Hz signals, which are then amplified and heard at the loudspeaker. One method of reducing this common problem is to terminate the signal wire screen at one end of the wire only. The other end of the screen is then left unterminated. Another way is to connect mains earth to the amplifier case – containing amps and PSU's – but not to connect 0V to the case. On no account should any earth be removed from equipment connected to the mains – unless it has been designed for this purpose or double insulated.

MOSFET AMPLIFIER PARTS LIST

RESISTORS: All 0·6W 1% Metal Film (Unless specified)			
R1	2k2	1	(M2K2)
R2,3	47k	2	(M47K)
R4,5	3k9	2	(M3K9)
R6	1k	1	(M1K)
R7	33k	1	(M33K)
R8,10,11,13,14	100Ω	5	(M100R)
R9	12k 1W Carbon Film	1	(C12K)
R12	47Ω	1	(M47R)
R15	4Ω7 3W Wirewound	1	(W4R7)
RV1	1k Hor Encl. Preset	1	(UH00A)
CAPACITORS			
C1	10μF 35V Minelect	1	(JL05F)
C2	47pF Ceramic	1	(WX52G)
C3	47μF 50V SMPS	1	(JL47B)
C4	6n8F Polylayer	1	(WW27E)
C5,6	27pF Ceramic	2	(WX49D)
C7	100nF Polylayer	1	(WW41U)
C8,10	100nF Polyester	2	(BX76H)
C9,11	220μF 63V PC Electrolytic	2	(FF14Q)
SEMICONDUCTORS			
D1	1N4001	1	(QL73Q)
TR1,2	2SA872A	2	(UF75S)
TR3,4	2SD756	2	(QQ33L)
TR5	2SB716	1	(QQ31J)
TR6	2SK135	1	(QW10L)
TR7	2SJ50	1	(QW09K)
MISCELLANEOUS			
	Insulator TO3 [SIL]	2	(QY44X)
	Mosfet Amp PCB	1	(GA28F)
	Mosfet Amp Mtg.Bracket	1	(GA29G)
	Pin 2141	1pkt	(FL21X)
	Bolt 6BA x ½inch Long	1pkt	(BF06G)
	Nut 6BA	1pkt	(BF18U)
	Washer 6BA (shake proof)	1pkt	(BF26D)
L1	EC Wire 0·9mm *See Text*	1	(BL26D)
	Constructors' Guide	1	(XH79L)
	Instruction Leaflet	1	(XK39N)
OPTIONAL (Not in Kit)			
	Audio Toroidal 160VA	1	(YZ23A)
	J04	1	(BH46A)
	W01	1	(QL38R)
	4k7 1W Carbon Film	2	(C4K7)
	10,000μF 63V Can	2	(FF32K)
	2,200μF 63V Can	2	(FF22Y)
	100nF HV	2	(FA21X)
	100nF 35V Tantalum	2	(WW54J)
	μA78M12UC	1	(QL29G)
	μA79M12UC	1	(WQ89W)
	Fuse A/S 3·15A	3	(RA11M)
	Fuse A/S 630mA	2	(RA08J)
	Heatsink 6W-1	1	(FL77J)