Stabilised Hi-Fi PSU

The power supply can make the difference between an adequate amplifier and a great one. In this article, J. Linsley Hood explains the advantages of a stabilised PSU, and concludes with a simple and novel circuit to upgrade your hi-fi.

IF YOU LOOK inside the boxes of some of the top name hi-fi power amplifiers — the ones that get the rave reviews from the 'golden-eared' fraternity — you will find, more often than not, that the power supply units are stabilised, rather than being of the simple transformer, rectifier, reservoir capacitor variety. The reason for this is twofold. First, the presence of a stabilised PSU is an indication of the rather greater care that has gone into the building of these amplifiers, and if you aim at the top, as a hi-fi manufacturer, this is a necessary part of your philosophy; and second, because the stabilised PSU really does confer some valuable advantages in the operation of the equipment. Let us look at some of these.

The amount of power one can get from a power amplifier, for any given load impedance, increases rapidly as the DC power line voltage is increased. However, so does the cost of the output power transistors (in fact, all the transistors), as well as the capacitors used in the design. As an aside, the fact that 50 V capacitors cost a lot less than half that of the equivalent 100 V ones is the main reason for the popularity among the high power amplifier manufacturers of direct coupled (two power supply lines of half the voltage) output stages. If Joe Public thinks that they also sound better, so be it!

Unfortunately, the realities of life are not on our side. From the point of view of the power output, what is important is the actual supply line voltage at maximum load, but what the transistors have to support is the worst case condition of line voltage off-load, and the on-load voltage will always be a good bit less than this. If, on the other hand, one has a constant DC supply, one only needs to make sure that the transistors and capacitors will stand this, and this will also be the voltage available when one is driving to full power.

Just doing a cost assessment of stabilised versus cheap-and-cheerful gives a small overall cost advantage in favour of the simple system, which is why it is more commonly used. However, the stabilised PSU has other more subtle advantages which are of value to the discriminating user. These are those which follow from the low ripple level on the supply line of any properly designed stabiliser circuit, and its low supply line impedance. The first of these ensures that hum breakthrough is eliminated, not just at low power levels, which is easy, but also at high powers, when the voltage ripple on the reservoir capacitor is becoming significant. The second feature, that of the low line impedance, not only gives a lower degree of LF breakthrough from one channel to another (at frequencies where the impedance of the reservoir capacitors is significant) but also gives a more firm and solid bass response. In fact, in my view, this is a more important contribution to the firmness of bass response than the absence of an output coupling capacitor in a 'direct coupled' system.

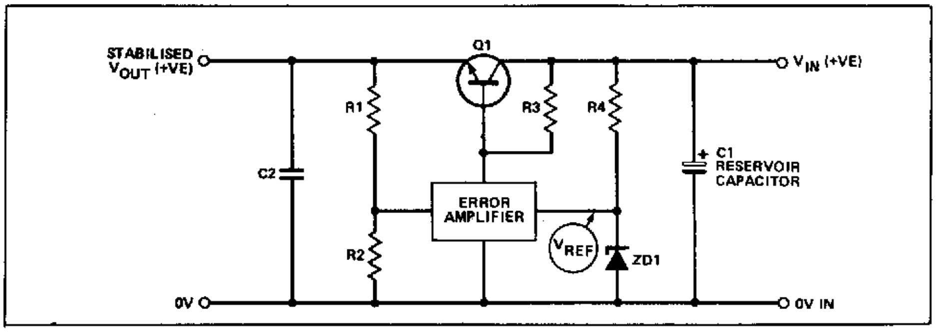


Fig. 1. Simple stabilised power supply.

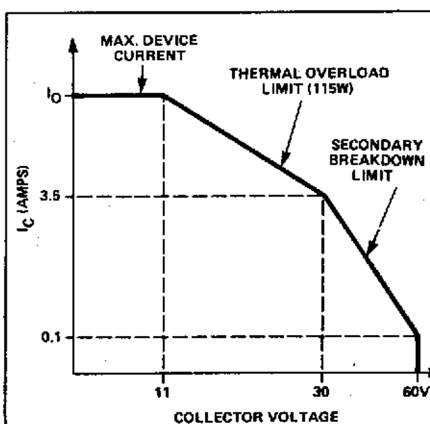


Fig. 2. Power transistor limiting values.

So, having reviewed the propaganda in favour of the use of constant, stabilised power supply lines, two questions remain: can one upgrade an existing amplifier this way, and how simply could one be built? The answer to the first question is almost certainly 'yes' provided that one uses some care. The second I propose to explore. Since this will be done by starting with a basic circuit and adding components, the usual practice of numbering components from left to right and top to bottom will not be followed, so as to achieve continuity from figure to figure.

The Stabilised PSU

These are normally designed along the lines shown in Fig. 1. In this a 'pass' transistor (Q1) is connected as an emitter follower between the unstabilised DC input and the required stabilised DC output. The base drive current to this pass transistor is controlled by some form of error amplifier which compares some proportion of the output DC voltage with a reference voltage derived, perhaps, from a zener diode (ZD1) supplied through R4. Depending on the zener voltage, the controlled DC output can be adjusted, within the limits set by the DC input and the reference voltage, by a suitable choice of R1 and R2. A small capacitor is usually connected across the output to make sure that the output impedance remains low at HF.

This is a very good circuit arrangement, and is used in a very wide range of designs. Indeed, with a little more internal craftiness, very similar systems are employed in the 'three terminal' IC voltage regulators one can now buy for around one dollar. However, there are snags.

In the case of the IC voltage regulators the main snags are that they are usually limited to input voltages less than 50 V, that the maximum output voltages are usually less than 35 V and that at these voltages the available output currents will probably be less than 0.5 amps, which is rather too low to be of much use for audio power amplifiers. Nevertheless, where these can be used, they are the best possible solution in terms of performance in relation to cost.

In the case of do-it-yourself units of this kind built up from discrete components, though higher voltage and current operation can be organised, the most immediate problem is that of the 'safe operating area rating' or SOAR as shown in Fig. 2. This graph, which is that for a typical power transistor of the 2N3055 types, shows that there are limits on the permissible conditions of operation, and that, as a general rule, you cannot allow the transistor to pass much current at voltages above some 30 V without it blowing up, due to what is known as 'secondary breakdown.' (This arises because silicon diodes have a forward voltage which decreases as they get hotter. So, if enough current, at enough voltage, flows through the transistor, the resultant heating will inevitably cause some localised area of the base-emitter 'diode' to get hotter than the remainder, and then all the transistor current will plough through this small area, with expensive and inconvenient results!)

Two ways of safeguarding against this snag are possible. The first (and simpler, if the amount of current needed is less than that permissible at the given input voltage V_{IN}), is simply to include a current limit circuit as shown in Fig. 3.

In this, Q2 is added, with R5. If the output current taken exceeds the amount needed for the voltage drop across R5 to turn on Q2, then this will 'steal' the base current from Q1 and hold the output current to the chosen limiting value.

However, circumstances often arise where this simple answer just isn't good enough, and then it is necessary to organise a rather more cunning scheme, known as 're-entrant' short-circuit protection. In this, the protection circuit is arranged so that the full, but limited, output current is allowable up to some prearranged voltage drop across the pass transistor Q1, which is known to be within safe operating limits. If the voltage across the pass transistor exceeds this value, some supplementary circuit comes into operation to instantaneously limit the current through the transistor to some lesser value appropriate to its new collector-emitter voltage drop.

This type of arrangement is a much better scheme, and allows stabilised PSUs to be built which will give quite large current outputs at the sort of voltages which would be of use in audio amplifier systems. Moreover, the fact that the output voltage and current will both collapse rapidly in the event of an overload can allow a good measure of protection, if the limit levels are set correctly, for both the amplifier itself and also things like loudspeakers used with it.

Of course, the usefulness of a stabilised power supply is not limited to improving audio amps. This was just one of the possible uses which might appeal to the hi-fi enthusiast in pursuit of an economical and sensible route to a rather higher-fi.

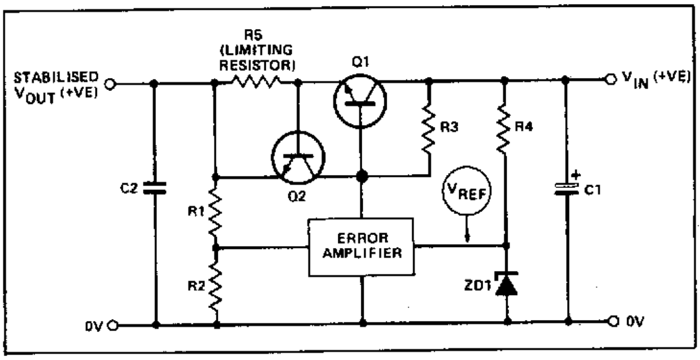


Fig. 3. A stabilised power supply with current limiter.

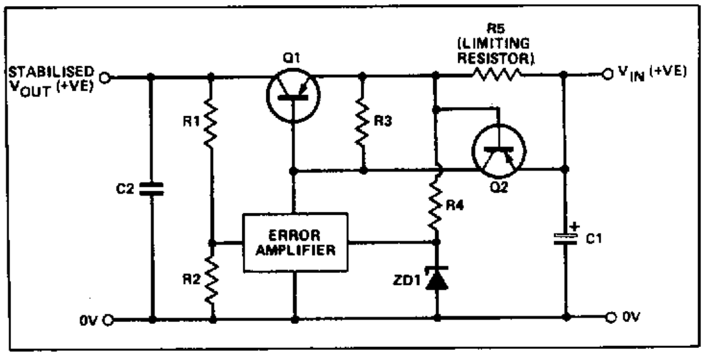


Fig. 4. An alternative arrangement to Fig. 3.

An Improved PSU

So — we want a simple PSU system, with an adequate degree of voltage stabilisation, and a re-entrant overload limit characteristic. How best can this be done?

The general scheme shown in Figs. 1 and 3 has several inherent snags, in spite of its popularity in the PSU circuit league. Of these snags, the first is that there must be a sufficient difference in voltage between V_{IN} and V_{OUT} for Q1 to be functional, and for an adequate current to flow through R3 to give the necessary output maximum current, with the lowest likely current gain in Q1. This would lead, say, in a 3 amp PSU to a value of R3 being chosen which would pass 100 mA at a 10 V input/output voltage drop. If we now have an input voltage of, say, 60 V, then when Q1 isn't asking for the full base bias current — as, for example, when the PSU was off load — the error amplifier will have to dissipate 60 - 10 V x 100 mA = 5 W, with a further 1 W being dissipated in R3.

If, however, we turn Q1 the other way round, as in Fig. 4, then the base bias current can be supplied from the '0 V' line, which will mean that the minimum necessary voltage drop between V_{IN} and V_{OUT} can be reduced to, say, 3 V which will reduce Q1's dissipation. Also, only as much current is fed into Q1's base as the output current calls for. This greatly reduces the quiescent dissipation in the error amp circuitry as well. Of course, we would then have to put the current limit transistor on the input side, if we were going to use the same kind of limiting system. We can, however, do a bit better than this — using the final circuitry in Fig. 5.

In this circuit, I have shown a two-transistor error amplifier (Q3 and Q4) which uses the 0 V line as its voltage reference, allowing us to delete the reference voltage circuit R4 and ZD1. In this circuit, Q4 is turned on by current flowing into its base through R8, Q2 and R10. This causes an amplified current to flow in Q4's collector circuit and turn on Q1. However, when the output voltage rises to a high enough level, the zener diodes ZD2 and ZD3 conduct and start feeding base current into Q3. This promptly gobbles up the current that was previously flowing into the base of Q4 and prevents the voltage from rising further.

The use of one or more zener diodes in a chain to provide the necessary output voltage — the actual output controlled voltage will be about 0V5 greater than the sum of the zener voltages — gives a simple system if one specific output voltage is required. However, zener diodes are a bit noisy (especially if their individual breakdown voltages are high, which makes it preferable to use several lower voltage units in a string), so it may be advantageous to use the modified system shown in Fig. 6, if a convenient negative line is available, which would then allow the output voltage to be adjusted between 0V5 and some 3 V less than the available voltage.

Since the total amount of gain in the feedback circuit consisting of Q1, Q3 and Q4 is quite high, it is necessary to incorporate some HF stabilising element. In

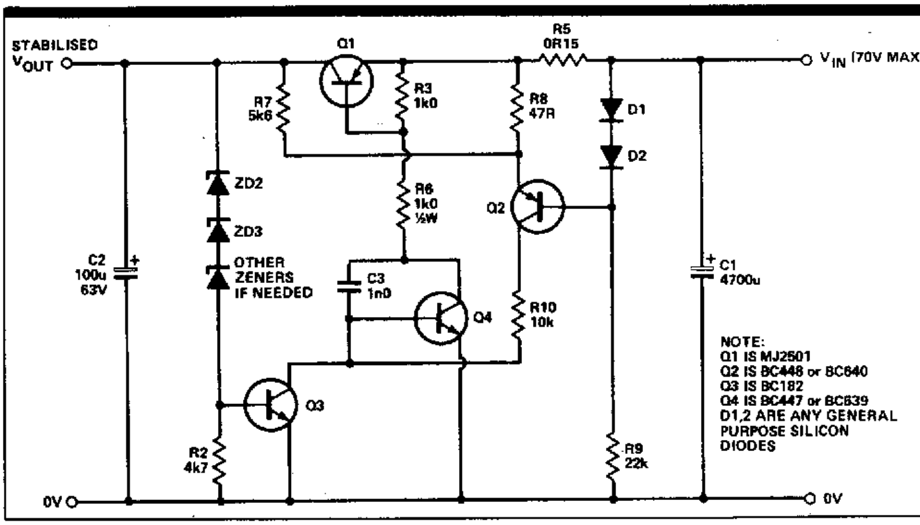


Fig. 5. A stabilised power supply unit with reentrant short-circuit protection.

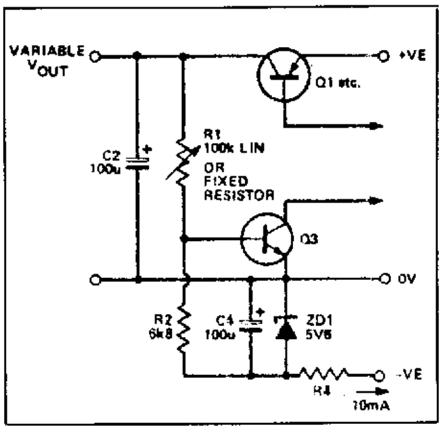


Fig. 6. This modification to the circuit of Fig. 5 allows a variable output voltage.

this case this function is performed by C3 in Fig. 7. The other part of the circuit, that of the 're-entrant' short circuit protection and current limiting action, is performed by Q2 with its associated resistors. The way this works is quite simple.

Assuming that there is no significant voltage drop across R8 and R5, Q2 will be turned on by current fed into its base by R9 & or R4 in Fig. 7), and an amplified current will be fed from the positive line into the base of Q4 via R5, R8, Q2 and R10. (R10 serves to limit the maximum current which can flow, and to reduce the amount of dissipation in Q2). The maximum forward bias potential which can be appplied to Q2 is held to about 1V1 by the two forward biased diodes D1 and D2. So — if we try to take more current from the circuit than would produce a 0V6 drop across R5 then Q2 will lose its operating forward bias and no more current will be fed into Q4 or Q1, which will limit the possible output current to a level just a little less than this value.

However, this has ignored the contribution made by R7 and R8. If there is too much voltage across Q1, which, as we have seen above, would reduce its ability to handle large currents safely, part of this voltage will also appear across R8, and this will also tend to turn off Q2, or at least make it current-limit at lower levels of voltage drop across R5. This has the required effect of tying the output current limiting value to the voltage drop across Q1, and means that, under something approaching short-circuit conditions, only a much reduced output current will flow.

Using The Circuit

So, here we have a fairly simple, low quiescent dissipation stabiliser circuit which uses standard discrete components and transistors, and which can be used to stabilise a single positive DC supply line (or if its 'mirror image' circuit is built, as in Fig. 7, a negative supply line too!) up to the maximum input voltages and currents which the components can stand. How, then, can we use this to improve an existing audio amplifier, which just uses a simple transformer-rectifier-reservoir capacitor system, as envisaged at the start of this article?

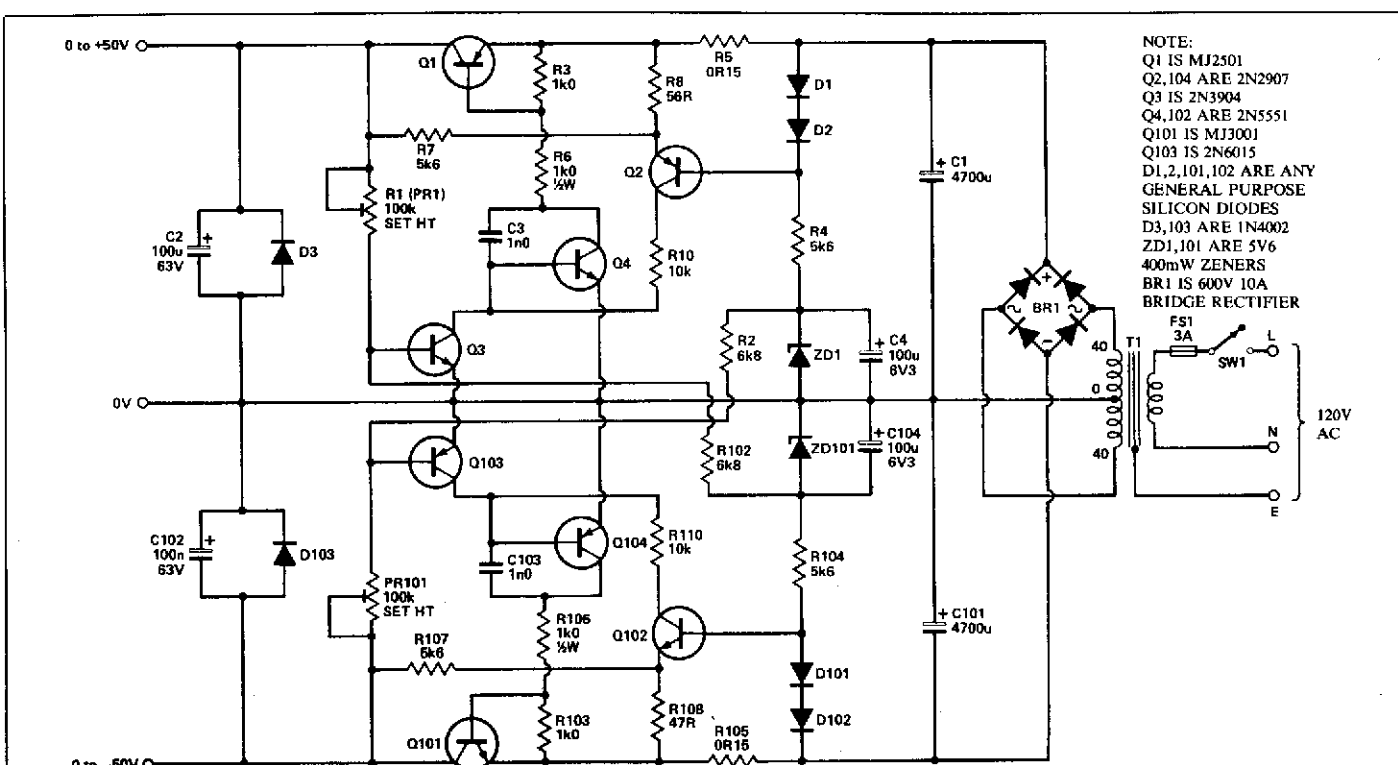
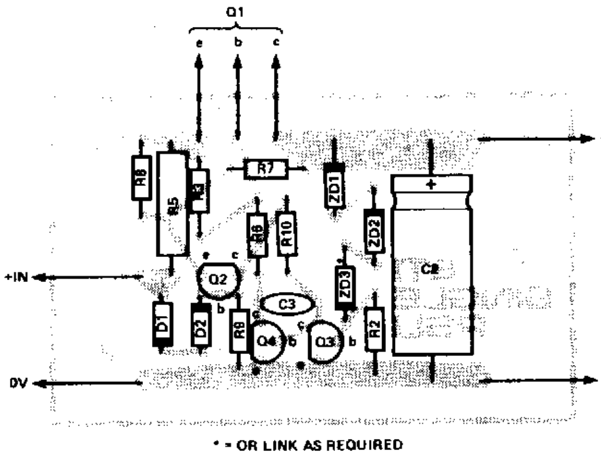


Fig. 7. Complete circuit for a twin stabilised power supply unit (current output 3 amps at 45 V).



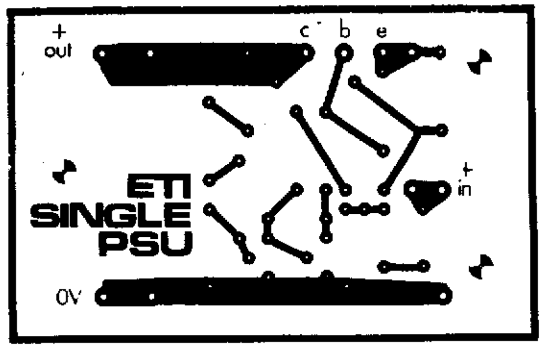


Fig. 8. Overlay for the circuit of Fig. 5.

TABLE 1

Maximum output voltage	Transformer voltage (per winding)	C1 minimum working voltage	R8
30	25	40	56R
40	33	50	56R
50	40	63	47R
60	48	80	43R

TABLE 2

Output current (amps)	Transformer secondary current rating (amps per winding)	R5
0.5	0.7	1R0
1	1.5	0R5
2	3	0R25
3	4.5	0R15
4*	6	0R12

* (not recommended above 40 V)

A single line stabilised supply is shown in Fig. 5 and a twin positive and negative supply is shown in Fig. 7: the DC output voltages and currents can be determined from the values shown in the tables. Now let us envisage a possible application. Measurement shows that on a hypothetical amplifier 'A', all of the internal DC supplies are drawn from a single power supply source which has a quiescent output voltage level of 66 V, dropping to 55 V on full load. If, at half load, which is the worst case condition, the heatsinks don't get alarmingly hot (as we must hope), and the HT line voltage is, shall we say, 60 V, then we could assume that a fixed voltage input supply somewhere between 60 and 65 V would not over-stress the amplifier components, and we could build this output voltage into the circuit of Fig. 5 by the use of an appropriate string of zener diodes.

Such a separate DC supply could then be housed in its own small box, with the DC feed being taken to the amplifier with which it is used. (This is assuming that there isn't room within the exisitng box for the larger, higher voltage transformer which will be needed, or for the other components). What sort of benefits will this bring?

First, one would expect a significant reduction in the existing amplifier 'hum' level, if it is less than perfect in this respect. Second, one could expect an improvement both in the 'solidity' of the bass response, due to the lower LF dynamic impedance of the HT line in

PARTS LIST

Resistors (all ¼W, 5% except where stated)

R1,101 (PR1,101)	suitable fixed resistor or 100k miniature horizontal preset or off-board pot
R2,102	6k8
R3,103	1k0
R4,104 7,107	5k6
R5,105	see Table 2
R6,106	1k0 ½W
R8,108	see Table 1
R10,110	10k

Capacitors

C1,101	4700uF electrolytic (see Table 1 for working voltage)
C2,102	100uF 63 V axial electrolytic
C3,103	1n0 ceramic
C4,104	100uF 6V3 axial electrolytic

Semiconductors

Q1	MJ2501 Darlington 10A, 80 V, T0-3 case
Q2,104	2N2907A
Q3	2N3904
Q4,102	2N5551
Q101	MJ3001 Darlington 10A, 80 V, T0-3 case
Q103	2N6015
D1,2,101, 102	general purpose silicon diodes eg. 1N4148
D3,103	1N4002
ZD1,101	5V6 400 mW zener
BR1	600V, 10 A bridge rectifier

Miscellaneous

PCB heatsink to suit.
centre-tapped transformer (see Tables 1 and 2); power switch; 3 amp fuse and fuseholder.

PARTS LIST

Resistors (all ¼W, 5% except where stated)

R2	4k7
R3	1k0
R5	see Table 2
R6	1k0 ½W
R7	5k6
R8	see Table 1
R9	22k
R10	10k

Capacitors

C1	4700uF electrolytic (see Table 1 for working voltage)
C2	100uF 63 V axial electrolytic
C3	1n0 ceramic

Semiconductors

Q1	MJ2501
Q2	2N2907A
Q3	2N3904
Q4	2N5551
D1,2	general-purpose silicon diodes, eg. 1N4148

Miscellaneous

PCB heatsink to suit.

See text for an explanation of the unusual component numbering.

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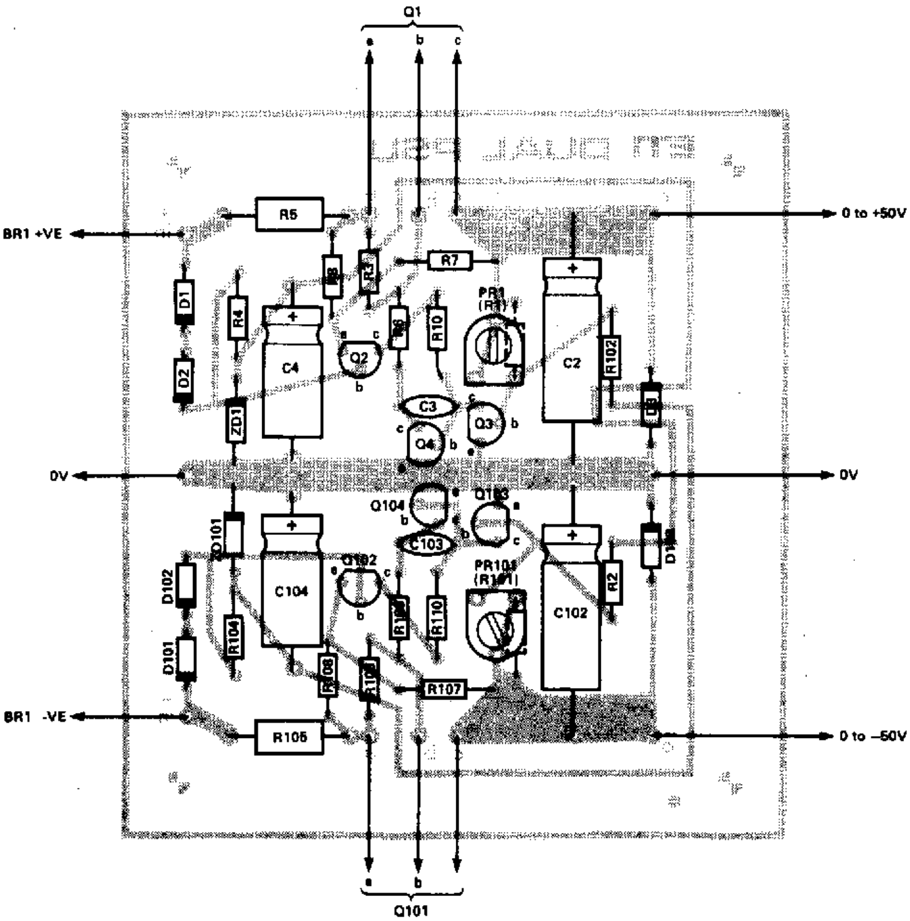
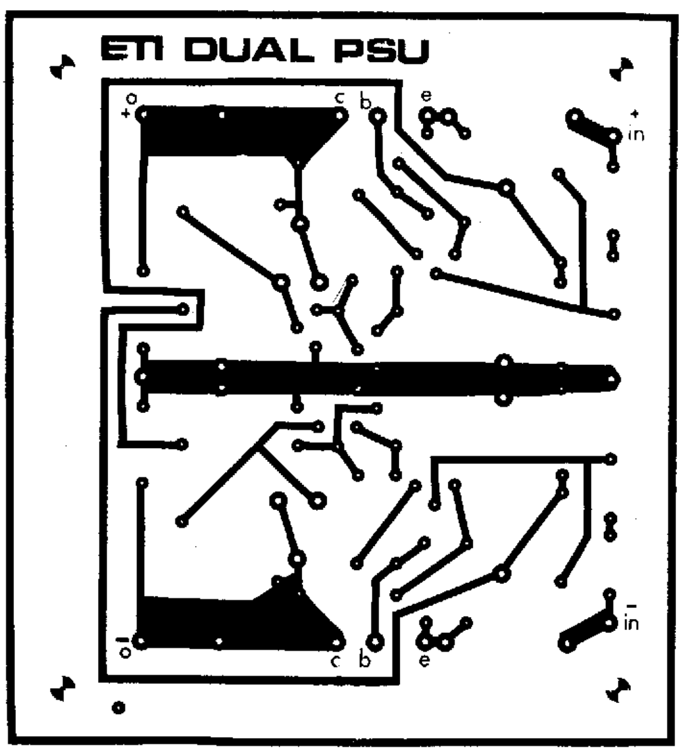


Fig. 9. Overlay for the circuit of Fig. 6.



comparison with even a large value of supply line reservoir capacitor, and this should also give a lower level of LF channel crosstalk. This latter feature is also important because most of the crosstalk signal compenents are heavily distorted in typical transistor output stages. Third, one would obtain a greater immunity from consequential damage, such as loudspeaker units burning out if failure in the amplifier caused it to switch over to some unwanted high current mode; and finally, one would get more power output from it.

This last consequence arises from the fact that output power is determined by the equation $P = V^2/R$, where V^2 is the square of the RMS output signal voltage, and R is the loudspeaker load impedance. For a 30 W amplifier with an 8 ohm load and the HT supply voltage characteristic shown above, a change in full load HT voltage from 55 V to 65 V would give an increase in power from 30 to 45 W without the need for the replacement of any other components.

PCB Layouts

It makes a tidier and more professional looking unit if the necessary small components are mounted on a printed circuit board, so I have shown two such suitable layouts, complete with component overlay, in Figs. 8 and 9. The circumstances in which a PSU of this type might be used to upgrade an existing audio amplifier are rather too varied for anything other than general guidance to be given. However, these circuit layouts also allow the experimentally inclined user to build himself a useful short-circuit protected bench supply, which is literally a unit with dozens of uses.

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