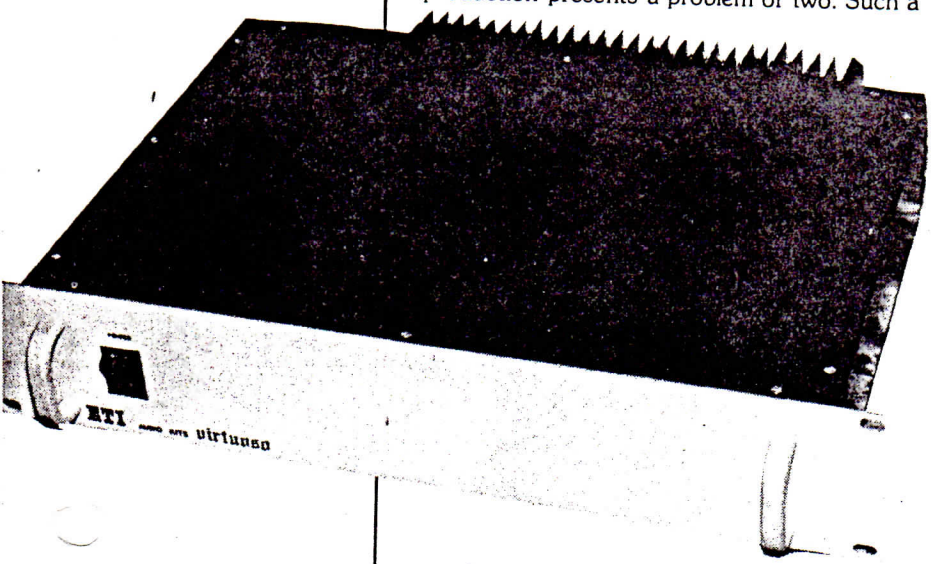
VIRTUOSO POWER AMPLIFIER

Graham Nalty launches his super-fi project with a look at the design features and power circuits of the Virtuoso Power Amplifier



High fidelity amplifiers should drive loudspeakers to produce the same sounds that create the effect and enjoyment at a live performance.

For a top performance amplifier it is vital to use top quality components. I was pleasantly surprised at the number of readers who opted to build the upgraded Virtuoso pre-amp rather than the standard version (ETI June-November 1986). In preparing this matching power amplifier I have taken the upgrading a stage further, using even higher quality components.

The requirement that an amplifier should be designed for accurate (and pleasurable) sound reproduction presents a problem or two. Such a requirement cannot be measured during development, only auditioned when complete. Fortunately as a result of extensive research, development and testing of audio amplifiers, I can identify those design areas which are most crucial to sound quality.

Those features I have listed below as crucial or important should be pursued to the limit of your budget. Every improvement in these areas should give an improvement in sound quality. The other features of design may not give an improvement in sound quality but inadequate design may result in degraded sound quality or other problems.

Crucial Factors

A power amplifier needs a good strong power supply with low impedance through the whole audio frequency range (and beyond). A mains transformer with a VA rating several times the total power rating is the very first requirement for a good sound.

Passive components (resistors, capacitors) are extremely important and the price difference between the standard and upgraded versions of this amplifier is mostly due to higher grade passive components.

Every cable carrying the signal or power supply will degrade the overall sound as a result of conductor impurities and dielectric losses in the insulation.

Important Factors

Temperature generated distortion can occur when the gain of an audio amplifying transistor varies with changes in the temperature at its junction. The changes in gain cause a blurring of the sound — possibly the reason why some people prefer valve amps which only suffer from temperature generated distortion due to ripple on the heater supplies.

The solution is to use power transistors attached to the heatsink wherever large current or voltage swings from the input signal are found.

This type of distortion also occurs in resistors and can be solved by using resistors with lower temperature coefficients and better heat dissipation properties.

Even with a good power supply, the amplifier circuit itself needs good power supply ripple rejection. Without it, crescendos become blurred and ambience is degraded. Cascade circuiting and ultra-high dynamic impedance improve ripple rejection considerably and using separate rectifiers and smoothing capacitors for separate stages of the amplifier helps prevent ripple from one stage affecting another.

Each switch contact and connector degrades the quality of a passing audio signal. If oxidised the contact acts more like a diode and sound quality is seriously degraded. Hence it is very important to use high quality switches (even gold-plated contacts for low level signal connections).

Slew Rate

Figure 1 shows how slew rate limiting can distort a sine wave signal.

It is essential that the amplifier can accurately process the fastest signal that it is likely to encounter. Also it is important that the amplifier can handle a slew rate considerably larger than the fastest input since distortion rises sharply as signal speed approaches slew rate.

It has been established that there is a strong correlation between slew rate and sound quality — the lower the slew rate the worse the sound. However this may not be because of the slew rate itself, but because the measures taken to increase the slew rate also improve the sound (very fast output transistors sound better because their gain is more linear at high frequencies for example).

DC Offsets

The DC offset is the DC voltage at the loudspeaker

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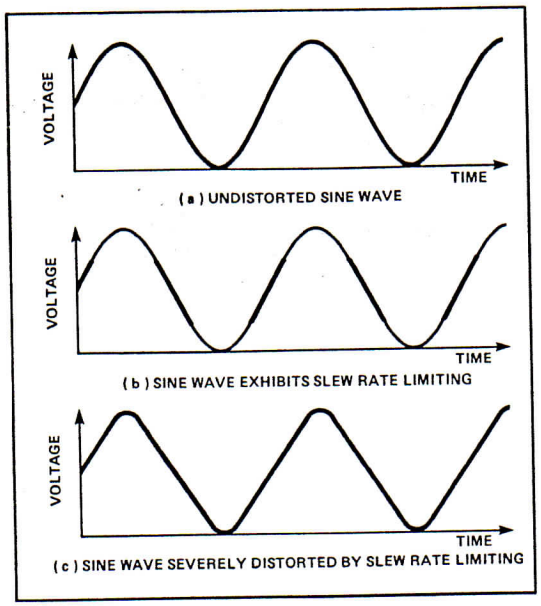


Fig. 1(a) Slew rate limiting.

terminals when no input signal is applied and which is constantly supplied to the terminals. I work within limits of +200mV — the level at which a noise becomes noticeable when a loudspeaker is connected. The Virtuoso Power Amplifier is specially designed for much lower offset.

The one way not to reduce DC offset is via a supply derived from the power supply lines as shown in Fig. 2.

Harmonic Distortion

Harmonic Distortion measurements have no direct relevance at all to sound quality. Measures such as cascode circuitry (Fig. 3) improve distortion figures (by improving linearity) but actually improve the sound quality because of improved power supply rejection (Fig. 4a).

Multiple feedback loops may reduce distortion (lower V_{be}/I_c variation) but in my experience are audibly inferior. This is possibly due to Transient Intermodulation distortion.

This distortion occurs when the signal input rises so fast that the feedback signal from the output of the amplifier cannot catch up. In an amplifier with large negative feedback the open loop gain that results is very large and overloads the internal stages of the amplifier. This does not sound pleasant!

An easy way to reduce TID is to lower the negative feedback (Fig. 4b) by lowering the open loop gain. Unfortunately this increases the harmonic distortion.

Current Delivery

Many designers are now claiming excessively large output current capability for their amplifiers, to some extent as an over-reaction to the situation where some high-powered amps were shown to have inadequate current delivery.

An amplifier can be overloaded either by voltage limiting (clipping) at a voltage just short of supply or by current limiting (by protection circuitry, power supply or breakdown current of the output devices).

An ideal amplifier has current and voltage capability designed so that the maximum voltage and current delivered under normal use are very close to (but do not exceed) the maximums. The ideal low-powered amplifier should in normal use overload on 50% of occasions due to voltage limiting and on 50% due to current limiting.

In the case of high-powered amplifiers the ability to supply a larger current or voltage can add considerably to the cost. At the same time it can be expected to have a large margin of reserve capability over the requirements for its use.

The Virtuoso Power Amp should be more than adequate for most users with a peak voltage capability of 40V and peak short term current limit of 40A (from protection circuitry). Also important is high frequency stability (oscillation at supersonic frequencies or ringing when driving square waves into reactive loads).

Those purists who can detect audible differences from phase inversion (reversed connections to each loudspeaker) would also include correct polarity (positive gain) as an important design feature.

These are the major features which are of concern in the design of audio amplifiers. Now we are able to move on to the details of the Power Amplifier.

As the power supply is the number one feature in a high fidelity power amplifier, I shall start with that (see Fig. 5).

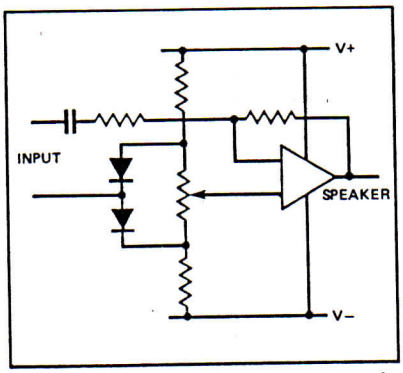


Fig. 2 DC offset adjustment not suitable for hi-fi applications

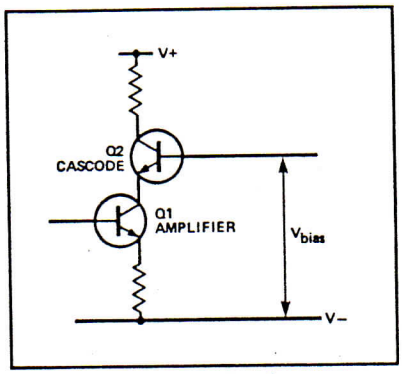


Fig. 3 Cascode circuitry improves linearity of gain for Q1 and power supply rejection from power supply

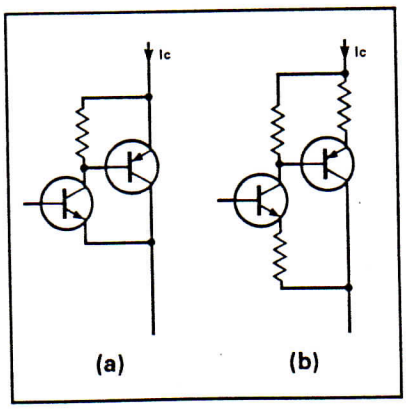


Fig. 4(a) Low variation of $\frac{V_{be}}{I_c}$

(b) Reduced negative feedback

Mains Supply

The great British mains supply is not exactly high quality but it is the only one we have, so let's make the most of it.

The effect of load interference from fridges, cookers and other assorted appliances can be considerably reduced by connecting a separate mains supply from the fusebox. A second separate supply can be used to good effect to power tuners, pre-amps, CD-players, turntables and cassette decks.

Further, a copper bar in the ground connected to the earth of these supplies will make an

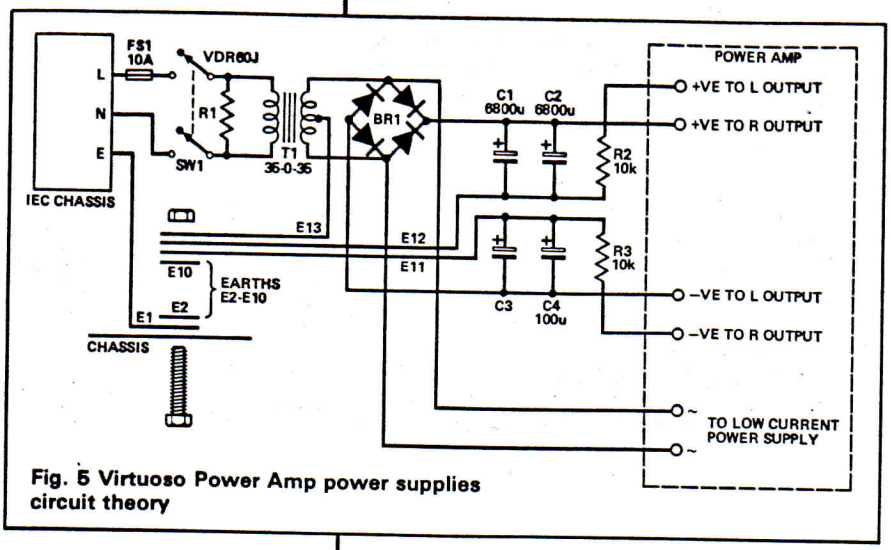


Fig. 5 Virtuoso Power Amp power supplies circuit theory

audible difference by removing currents induced in the earth by household appliances.

The old 15A plugs and sockets make a much better contact than the new 13A types, and it is possible to obtain gold-plated mains plugs and sockets (13A and 15A) to reduce the problems of mains tarnishing.

For mains cable there is a version of the Kimber 4 TC loudspeaker cable suitable for mains, its only drawback being that it cannot easily be fitted into a 13A mains plug.

The Virtuoso Power Amplifier has been fitted with a standard IEC socket which cannot really be justified in hi-fi terms. Anyone who wishes could bypass it by taking the mains lead directly from the fuse and switch (see power supply circuit in Fig 5).

Kimber Cable

Kimber cable is a multistrand cable of 7 different sized strands of oxygen-free copper, specially treated to increase surface conductivity. The insulation is of Teflon tested at 1500V to ensure its integrity.

I have found it the best cable for internal wiring of amplifiers to date. Firstly the sound quality is good — better sonically than the single strand cable I used in the Virtuoso Pre-amp. The second advantage of Kimber is that it is easy to use — flexible but it stays where it is put.

Kimber cable has two disadvantages. Firstly it sounds different if the direction is changed so it is usually supplied with arrows pointing in the preferred direction from cartridge to speakers (or from mains socket to rectifiers or from mains transformer to rectifiers to amplifier circuits). Secondly it is ten times the price of the single core cable used in the pre-amp!

Fuse Views

The mains fuse FS1 will of course slightly degrade the sound quality of the amplifier but is included for safety reasons (and because most constructors will want it). The 1¼in fuseholder used has a higher current rating than 20mm holders but is not ideal for hi-fi because of its lightly sprung contacts.

It is time to look seriously at fuses in audio amplifiers. We should have fuses firmly attached (screwed down) to the fuseholder. We should test many fuses for audio quality to find those with the lowest sonic degradation. (I would be interested in hearing from any readers who have encountered silver fuses for audio applications).

PARTS LIST

	Standard	Upgraded Version	3U Case
RESISTORS			
R1	VDR 60J 275V	VDR 110J 275V	VDR 110J 275V
R2, 3	10K ½W metal film	—	—
CAPACITORS			
C1, 2	6800µ 63V	6800µ 63V* BHC ALS 20A	15000µ 63V BHC ALS 20A 2200µ 63V LCR FAC114/ ULL
C3, 4	100µ 63V	100µ 63V Mullard 108	100µ 63V Mullard 108
SEMICONDUCTORS			
BR1	25A 200V bridge	Motorola BYW62	IR 25CPF20 + 25JPF20 or 26MBF20502
MISCELLANEOUS			
FS1	Mains fuse holder 1¼in × ¼in chassis mounting with 10A fuse		
SW1	Mains switch rocker type		
T1	Mains transformer (low mechanical noise)		
	35-0-35 300VA	35-0-35 500VA	

IEC chassis plug and insulating cover. ¼in blade push-on connectors and insulating covers. insulating fuse-holder cover. 2BA soldertags. 2BA crimp connectors (red sleeve*). heavy duty cables*. M16 cable gland and cord grip bush (3U version in place of IEC plug).
*see Buylines.

It has been observed that by increasing the fuse rating, the sound quality is improved. Unfortunately this reduces the protection given and may even result in legal problems if the house burns down as a result!

Similarly the best mains switch in sonic terms would be no switch at all, but for safety reasons I cannot recommend its omission.

Even with a separate supply for your amplifier and a copper bar going through your floor the mains voltage is still far from a perfect 50Hz sine wave. There are three ways to reduce the problem.

Mains filters have series inductors in the current path and this resistance to the transformer current demands make the amplifier sound sluggish, degrading the portrayal of rhythm and tempo in music.

Capacitors can be used for interference suppression although class X capacitors should not be used in positions where failure might expose anyone to electric shock. Class Y capacitors do not have that restriction.

Voltage dependant resistors exhibit a high resistance at voltages below the mains peak (350V for 250V RMS mains). When this peak is exceeded by a certain margin the resistance rapidly decreases and the VDR absorbs all the energy of the excess voltage.

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The rating of VDRs is normally specified in joules. The VDR in the Virtuoso (R1) is rated at 110J. If the voltage surge reaches 600V the VDR will pass a clamping current of 40A — obviously for a very short period of time.

Transform Your Mains

The mains transformer is the heart of a good amplifier. It is simply not good enough to say that your amplifier gives 100W per channel so needs a 200VA transformer. Having a bigger transformer will significantly improve the all-round quality of the amplifier.

In the standard version of this Virtuoso Power Amplifier the transformer is rated at 300VA. The upgraded amplifier uses one rated at 500VA — the largest that will fit in a 2U case. If you were prepared to use a 3U case you could fit a 625VA transformer.

The problem of mechanical noise from the transformer is addressed by using an audio-grade transformer wound specially for low mechanical noise.

Many constructors prefer to house the transformer outside the case containing the circuitry to avoid either transformer vibration or electromagnetic/electrostatic fields affecting other components. Certainly I would reduce vibrations by situating the amplifier on a non-resonant surface. The disadvantage with a remote transformer is the finite resistance of additional cable, plugs and sockets.

Rectify Yourself

I have used a standard (low cost) 25A bridge rectifier in the standard version and the Motorola BYW62 35A bridge in the upgraded version.

In both cases the bridge is bolted to the heatsink to minimise any effects of temperature generated distortion.

Recently I was most impressed by the improvement achieved by fitting fast recovery rectifier diodes in place of standard power diodes in an amplifier. I will be recommending them in the low current power supplies of upgraded Virtuoso Power Amplifiers.

The main reservoir capacitors (C1, 2) of an amplifier are extremely important. These have a great influence on the sound quality and you *must* use capacitors of the highest quality (long life, high ripple current, low ESR).

Such capacitors are very expensive but are justified by their sonic performance.

Large electrolytic capacitors have excessive inductance so you can improve their impedance characteristics by bypassing them with smaller values which have less inductance and react faster to high frequency transient loads.

The upgraded amplifier shown pictured has a main reservoir capacitor of 6800µ (C1,2) bypassed directly by a 100µ Mullard 108 long life electrolytic (C3, 4) with a further top quality 1µ0 polypropylene located on the circuit board very close to the output devices.

Incidentally the value of 6800µ is restricted by the size of the case and constructors seeking extended deep response are recommended to use larger values.

The output stage of the amplifier draws high currents and even with a low impedance power supply the effect of these currents is to generate an additional ripple voltage on the power supply lines.

Despite very careful design the input circuit of the amplifier is very sensitive to such a ripple voltage.

The most effective way to prevent ripple caused by the output stage from reaching the input stage is to feed both parts of the power amplifier from completely separate rectifiers and reservoirs.

Figures 6-8 show different ways of providing power to the lower level stages of a power amplifier.

Fig. 6 is very common in low quality amplifiers. Not only does this kind of circuit give poor sound quality but it is more prone to high frequency instability from unwanted high frequency oscillations fed back along the power supply lines.

The circuit of Fig. 7 gives better performance at high audio frequencies and suffers less from high frequency instability but that of Fig. 8 is considerably more superior still in both ways.

It is not essential that the power supply components (rectifier and reservoir) are as high quality (expensive) as those required for the output stage.

Next month I shall be moving on to describe the power supply regulator circuits.

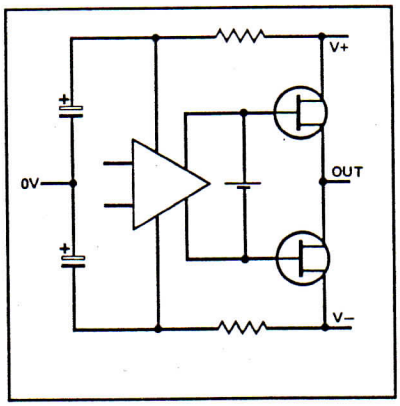


Fig. 6 Power amp power supplies connections

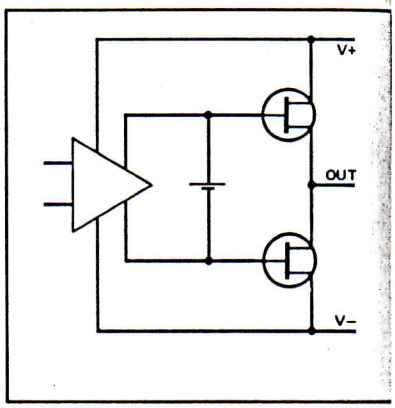


Fig. 7 Improved power supply

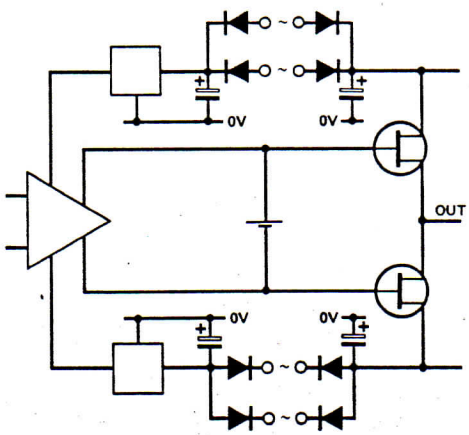


Fig. 8 Top quality power supply

BUYLINES

If a larger case than the suggested 2U case is used, the value of C1, 2 should be increased. Only highest quality capacitors should be used such as ALS 20A, Mullard 114, LCR FAC 114/CW or DIVM slit foil.

The 2BA red-sleeve crimp connectors are suitable for cables of 0.5mm² to 1.25mm² (2 cores of Kimber cable). Cables between 1.5 and 2.5mm² require blue-sleeved connectors, and up to 6.55mm² require yellow.

For the upgraded Power Amplifier 2 cores of Kimber cable in parallel (twisted together) are recommended for all high current connections.

Top hi-fi reviewer Paul Miller gives his verdict on the 2U versions of the Virtuoso.

Although most enthusiasts will derive great pleasure in the construction of their own amplifier, the absolute quality of these units remains a bone of contention. This short piece assesses the basic and upgraded Virtuoso power amplifiers — technically and subjectively — in the light of comparably priced domestic designs.

On test there proved to be significant differences between the two products. Taking the more expensive amp first, the distortion figures were very good at the 1W level, being primarily composed of second and third order harmonics. The higher order and more subjectively disturbing harmonics were suppressed by at least 100dB throughout the power bandwidth. Only the second-order intermodulation results were a little weak at this price level, however 0.11% is acceptable.

A 2.67dB power increase was registered between the 8 and 4 ohm loads but the supply sagged quickly into lower impedances — the 3.4dB loss will restrict the use of more 'awkward' loudspeakers.

Another thing to watch is the input level. With less than half a volt required to reach full output it will be very easy to drive the amp into clipping. This may reduce the useful range of a preamp's volume control but it does allow the Virtuoso to be driven directly from line sources, such as tuners, cassette decks and CD-players.

The cheaper Virtuoso amplifier had similar power characteristics but proved to be marginally unstable under the test conditions. Fortunately, full-blown oscillations did not occur but a parasitic RF resonance (probably around 10MHz) caused intermodulation within the audio band. This was manifested as 'fuzzy' crest on the output sinewaves (as viewed on an oscilloscope) long before clipping was reached.

Furthermore, the spectrum analyser revealed a large increase in 2nd-10th harmonics (typically around −68dB) associated with all fundamental tones above one quarter power. This is reflected in the THD figures. I am sure that this is a layout (capacitive?) problem which should be easily rectified, at which point the technical parameters should be on a par with those of the upgraded amplifier.

Subjectively, the Virtuoso sounded quite 'fast' and dynamic, reaching some form of sonic equilibrium very soon after switch-on (some amps take several hours).

The bass was suitably tight and well controlled but the upper octaves appeared rather more forward and 'obvious'.

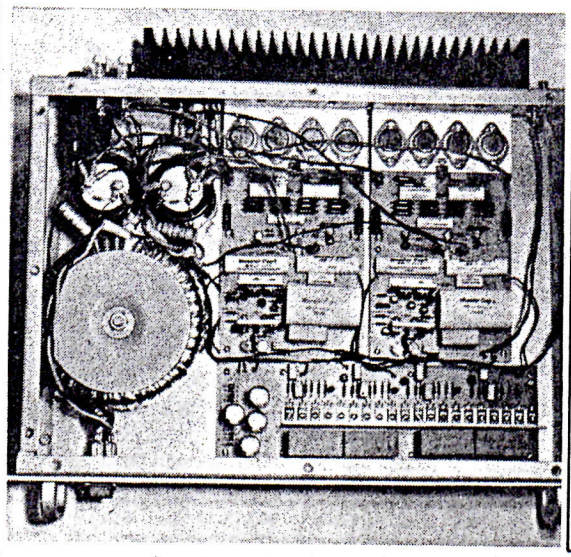
Strong vocal material was articulate and well-defined, the stereo soundstage was not as precisely focused as with some of the better domestic amps but the larger-than-life image certainly had a tanglible quality about it. Percussion was detailed, incisive and full of a sharp, metallic timbre. This is a hard and fast amp that reveals bags of detail.

The standard version was noticeably softer-sounding than the top Virtuoso with a restrained top-end and less of the latter's beguiling fluidity. Of course, much of this may be attributed to the complex distortion structure which is precipitated by the instability. Nevertheless, many enthusiasts may actually prefer the laid-back, less incisive, but ultimately less accurate reproduction of this amplifier.

The Virtuoso power amplifier will stand comparison with some of the better domestic products in most aspects of its performance — slotting comfortably into most good-quality hi-fi systems. It should also be great fun to build!

Test Results	Standard	Upgraded
Max continuous power output, 8 ohms	103W	89W
4 ohms	173W	164.5W
2 ohms	50W	75W
8 ohms + 2μF	Marginally unstable	Output voltage held
Total harmonic distortion (0dBW=1W)		
100Hz	0.011%	0.0021%
1kHz	0.0035%	0.0036%
10kHz	0.0067%	0.0046%
(at ⅔ power) 100Hz	0.093%	0.001%
(at ⅔ power) 1kHz	0.088%	0.001%
(at ⅔ power) 10kHz	0.027%	0.0019%
Anharmonic distortion	−73dB	−84dB
Noise (unwtd)	−99dB	−105dB
Intermodulation distortion (0dBW)		
in-band	−55dB	−58dB
out-of-band	−58dB	−58dB
(at ⅔ power) in-band	−56dB	−70dB
(at ⅔ power) out-of-band	−48dB	−71dB
Input sensitivity (max output)	497mV	402mV
Output impedance/Damping factor	0.054 ohms/148	0.033 ohms/245
DC offset	−7.7mV	+32.6mV
Phase	positive	positive
Kit price	c. £250	c. £450

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AMBIENCE AND CRESCENDO

The ambience of a live musical performance is an easily degradable property. Ambience can be lost by delayed electrical disturbances such as dielectric absorption in capacitors, by temperature generated distortion in resistors and semiconductors, by low level 50Hz and 100Hz ripple in power supplies and by poor power supply ripple ejection in the amplifier circuit.

There are several 'audiophile' amplifiers that sound pleasant for a single instrument or voice but which sound blurred when several instruments play together or crescendo. The main cause of this is poor power supply ripple rejection, and also power supplies being shared between different stages of amplification.

Needless to say, the Virtuoso Power Amplifier tackles all these problems head on.

VIRTUOSO POWER AMPLIFIER

Graham Nalty follows the regulation of his super-fi amplifier

I am sure it is not necessary to explain to ETI readers the sonic benefits of regulated power supplies in an high quality amplifier like the Virtuoso. The low current regulator here uses a very simple circuit modified to improve the sonic performance.

The basic circuit, probably familiar to many readers, is shown in Fig. 1. The output voltage is set by ZD1, Q2, R2 and R3.

It works like this.

If the voltage across the zener diode is 12V then the voltage at the base of Q2 is about 12.6V. Assuming the current through R2 and R3 is large compared with the base current of Q2, then R2 and R3 act as a voltage divider and the output voltage will be:

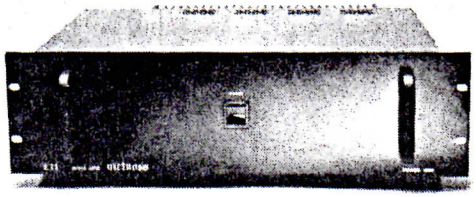
$$12.6 \times \frac{(R2 + R3)}{R3}$$

If the voltage falls, Q2 base current and collector current fall accordingly. This reduces the current through R1, thereby raising the voltage at the base of Q1 and hence restoring the output voltage.

If the output voltage rises, the current through Q2 increases and lowers the base voltage of Q1.

Better By Design

The power supply circuit is shown in Fig. 2. The design of the Virtuoso regulator is required first and foremost to achieve a good sonic performance.



For this reason, power transistors are used for all those transistors in which the dissipation varies with the voltage or current of the audio signal, even in the smallest way. They are also attached to a heatsink to ensure that temperature generated distortion is kept to an absolute minimum.

Another feature of the design is that apart from the reservoir capacitors, which are bypassed with plastic film capacitors for fast high frequency response, capacitors in the regulator circuit are kept to a minimum, and those that are used are of the highest quality (lowest loss factor).

In my experience low power zener diodes add distortion to the audio signal, so in the actual circuit the zener diode ZD1 of Fig. 1 is replaced by a transistor (Q11, Q12) and two resistors. Capacitors C11 and C12 are fitted to lower the

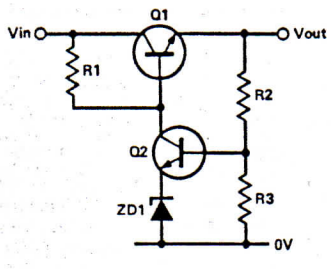


Fig. 1 The basic circuit of the regulated power supply

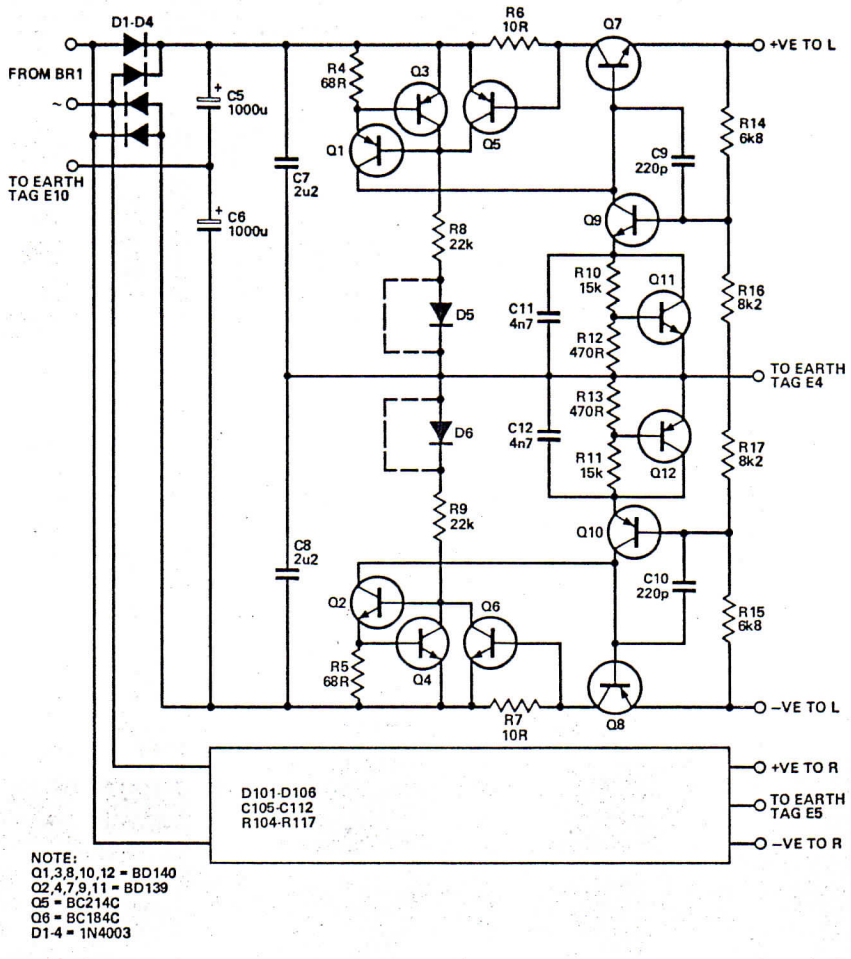


Fig. 2 Circuit diagram of the regulator board. The left channel is shown.

PROJECT

impedance of this circuit at high frequencies.

Another requirement for good sonic performance is low power supply ripple at the output. In the circuit of Fig 1, ripple voltages (due both to rectification and to variations in load current) at the input can be fed to the base of Q1 and the output ripple performance will not be too good. This can be improved considerably by replacing R1 with a constant current source.

In Fig 2, the constant current is provided by R4(R5), R8(R9), Q9(Q10) and Q11(Q12). This is a standard two transistor constant current source.

By adding constant current diodes D5 and D6 in series with R8 and R9 the impedance considerably increases, which raises the dynamic impedance of the current source feeding the regulator.

Current limiting is provided by Q5(Q6) and R6(R7). When the current limit of 60mA is reached, a voltage of 0.6V is reached across the base emitter junction of the transistor. This causes the transistor to conduct and to starve the base of Q11 of current.

In this way the current from the current source is reduced and the output voltage drops.

As the power dissipation of the series transistors is much greater than the power dissipated when the output is short circuited no further limiting is required.

C9 and C10 are fitted to maintain high frequency stability.

A Case Of Power

Two PCBs have been designed for the regulated power supply. For installation in the 2U case version a horizontal PCB is used, whilst a vertical PCB is used for the 3U case.

There are two major reasons for choosing to use a 3U case. Firstly it enables larger power supply components to be used in a mono bridged amplifier of around 200W to 400W rating into 8Ω.

Secondly the 3U version has been developed using much larger reservoir capacitors for the power supply to compensate for the effect that upgraded cables and passive components can have on the perceived balance between bass and treble instruments (better quality components allow more high frequency energy through while reducing lower resonances).

Other modifications on the 3U version include three bypass capacitors for each of the main reservoirs and the facility to use fast-recovery diodes on a heatsink for rectification.

The Ameliorated Amp

Before describing how to build the regulator, I want to say a few words about some of the special components used in the upgraded versions.

The Holco resistors listed are more expensive than standard metal film resistors, but when you consider how much you pay for metalwork and transformers in a big amplifier, the quality is well worth the cost. I have not suggested using bulk foil resistors, but that option is certainly open to constructors who want to get the absolute best performance.

Bypassing is used to speed up the response to all signals at all frequencies. The larger the capacitor the greater the inductance, and the more important it is to bypass it. That is why a high quality long life electrolytic capacitor is used as a bypass. The LCR EXFS/RP extended foil polystyrene capacitors were first used for the RIAA equalisation in the Virtuoso pre amplifier and have proved to be of the highest sonic quality.

The solder you use can affect your sound quality, and strong claims are made for an American solder called Wonder Solder. (Many manufacturers of very expensive interconnecting leads use it).

Construction

There is only one way to build the main power supply shown last month — slowly and carefully.

At the input side you are dealing with mains voltage, while the transformer secondaries have extremely high current capability and the reservoir capacitors will go bang very loudly if shorted.

The circuitry is easy but ensure you have checked and rechecked each connection, in particular the main input socket, the bridge rectifier connections, the earth connections and the reservoir capacitor polarity (a wrongly connected reservoir capacitor will give a low DC reading and gradually get warm, so can be detected before damage is done).

PROJECT

BUYLINES

All components that are not readily available from normal suppliers can be obtained from Audiokits, 6 Mill Close, Borrowash, Derby DE7 3GU. Tel: (0332) 674929.

PARTS LIST

Components X1, X2, X3 are used in the left channel of the board, components X101, X102, X103 in the right. Capacitors C7a, C7b refers to pairs of components used in the 3U version only.

	Standard	2U Upgraded	3U Bridged
RESISTORS			
R4, 5, 104, 105	68R	68R1 Holco H8	68R1 Holco H8
R6, 7, 106, 107	10R	10R Holco H8	10R Holco H8
R8, 9, 108, 109	22K	22k1 Holco H8	22k1 Holco H8
R10, 11, 110, 111	15k	15k Holco H8	15k Holco H8
R12, 13, 112, 113	470R	475R Holco H8	475 Holco H8
R14, 15, 114, 115	5k6	5k62 Holco H8	5k62 Holco H8
R16, 17, 116, 117	6k8	6k81 Holco H8	6k81 Holco H8
CAPACITORS			
C5, 6, 105, 106	1000µ 63V radial	1000µ 63V radial	
C5a, 6a, 105a, 106a			4700µ 63V BHC ALS20A or 6800µ 63V LCR FAC114
C5b, 6b, 105b, 106b			100µ 63V Mullard 108
C7, 8, 107, 108	2µ2 MKC	3µ3 MKP	
C7a, 8a, 107a, 108a			4µ0 IAR Wonder Cap or 4µ7 Audiocap
C7b, 8b, 107b, 108b	10n 63V		LCR EXFS/RP
C9, 10, 109, 110	220p polystyrene	220p EXFS/RP	220p EXFS/RP
C11, 12, 111, 112	4n7 polystyrene	4n7 or 8n0 EXFS/RP	4n7 or 8n0 EXFS/RP
SEMICONDUCTORS			
Q1, 3, 8, 10, 12, 101, 103, 108, 110, 112	BD140	BD140-10	BD140-10 or selected BD244C
Q2, 4, 7, 9, 11, 102, 104, 107, 109, 111	BD139	BD139-10	BD139-10 or selected BD243C
Q5	BC214C	BC214C	BC214C
Q6	BC184C	BC184C	BC184C
D1-4, 101-104	1N4003	UF4003	BYW150 or MUR815
D5, 6, 105, 106	not used	J510	J510

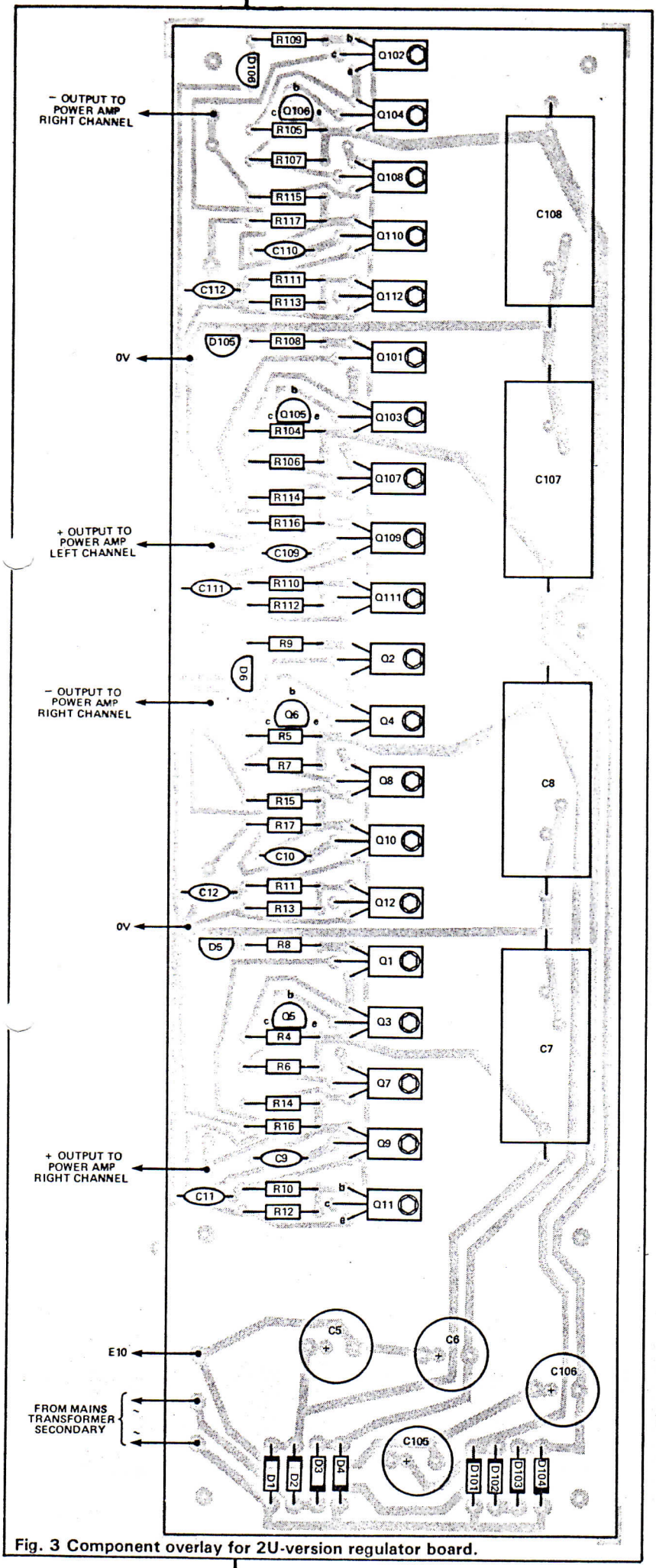


Fig. 3 Component overlay for 2U-version regulator board.

Building Regulation

Building the regulator boards is quite straightforward (the overlay diagrams are shown in Figs 3 and 4).

Components would be best installed in the order: resistors, small capacitors, diodes, small signal transistors, power transistors mounted on the heatsink, and finally the large capacitors.

Mount the resistors so that the colour codes or printed values (in the case of Holco resistors) can be easily read for error spotting.

Before testing the power supply and regulator you will need to make the AC connection from BR1 to the low current power supply as these and the leads from the mains transformer are attached to the same ¼in connector.

It is important to make sure the ends of these leads cannot short, and possibly the best way is to bolt the low current power supply PCB in place with the two relevant pins soldered on. The wires can then be attached to these pins.

It is always a wise precaution when testing new equipment to assume there is a short circuit at the input (just one wrongly connected diode could do precisely that). To this end I advise using a 22R to 100R carbon resistor in series with the supply before switching on.

Next check that the earths E4, 5 and 10 are connected to 0V.

Now switch on.

Each of the outputs should read +45V or -45V (or ±38V if you are using a 30V AC transformer and 4k75 for R16, 17, 116, 117).

Test Voltages

The DC voltage across each reservoir capacitor should read about 1½ times the rated AC voltage of the transformer secondary (±50V for a 35-0-35 transformer).

The voltages across the following components should all read 0.6V: R4, R5, R12, R13, Q7 base-emitter, Q8 emitter-base, Q11 emitter-base, Q12 base-emitter.

You should read 20 to 23V between Q13 and Q14 emitter to 0V. Across R16 and across R17 you should read 20.6 to 23.6V.

If you want to get the full output power from your amplifier, it is essential that the low current power supply is set to the maximum usable value. In practice when the mains is running low (5% below normal) the total voltage drop across the current regulator is not less than 2V. If the rectified DC reads 50V the regulator output should not be less than 45.5V.

The output voltage can be set by varying any of R10 to R17 but for convenience adjust the +ve supplies by varying R14, 114 and the -ve by R15, 115. The values shown in Parts List are carefully chosen but the optimum is affected by V_{be} and H_{fe} characteristics for Q11-14.

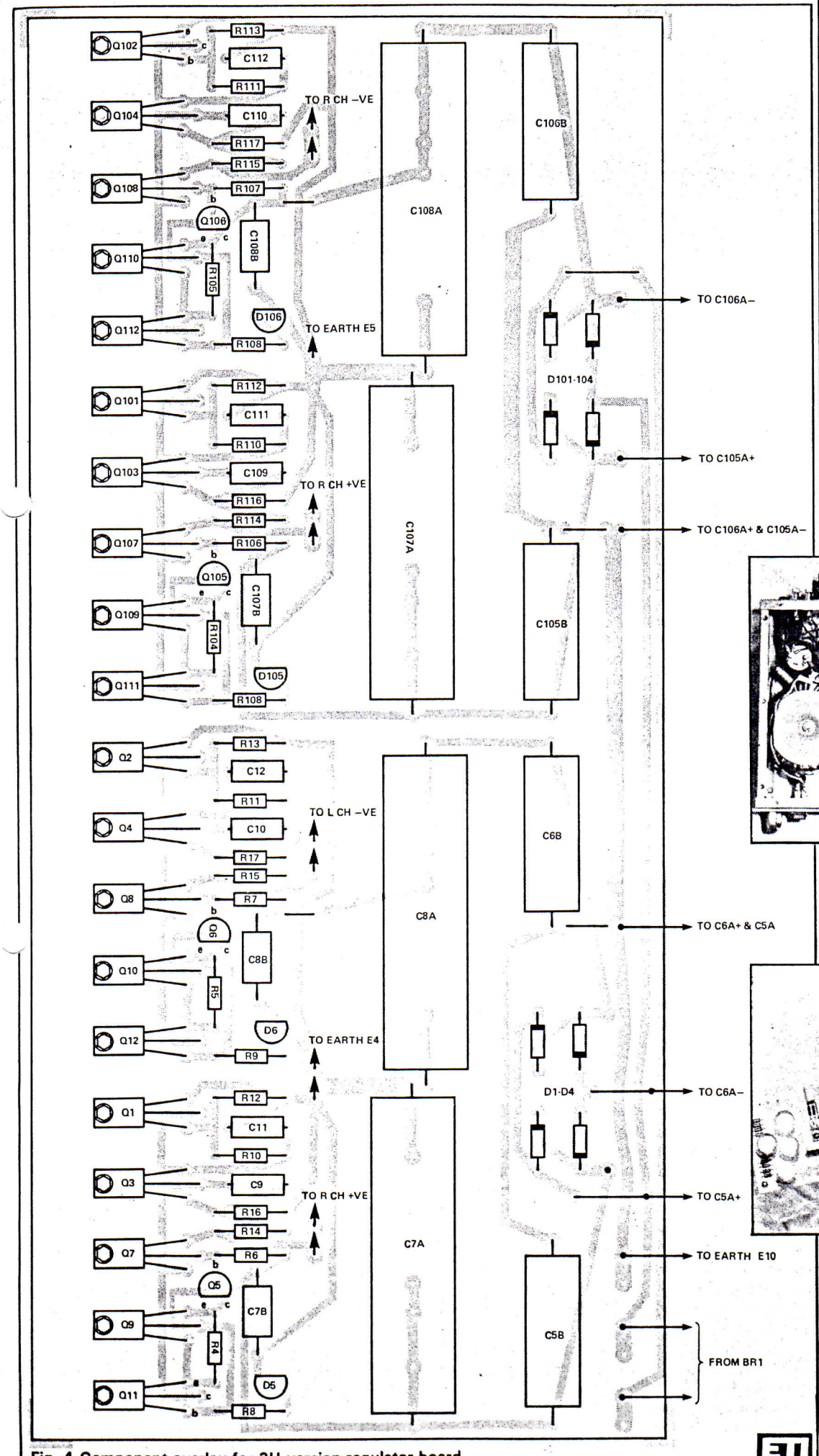
The output voltage can be calculated as:

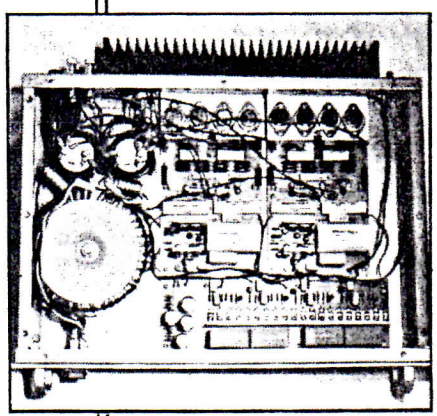
$$V_o = V_{R16} \times \frac{(R14+R16)}{R16} + Q11I_b \times R14$$

where V_{R16} is the voltage across R16 and $Q11I_b$ is the base current of Q11 for a gain of 50.
$Q11I_b \times R14$ is typically about 1V.

I have purposely not used a preset here so that the sound quality will not be degraded. Changing resistor values is inconvenient but a small price to pay for quality.

So with your power ready and regulated, next month we can move on to examine the amplifier board that will complete the Virtuoso Power Amplifier.





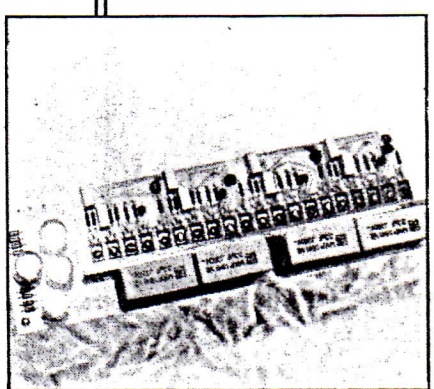
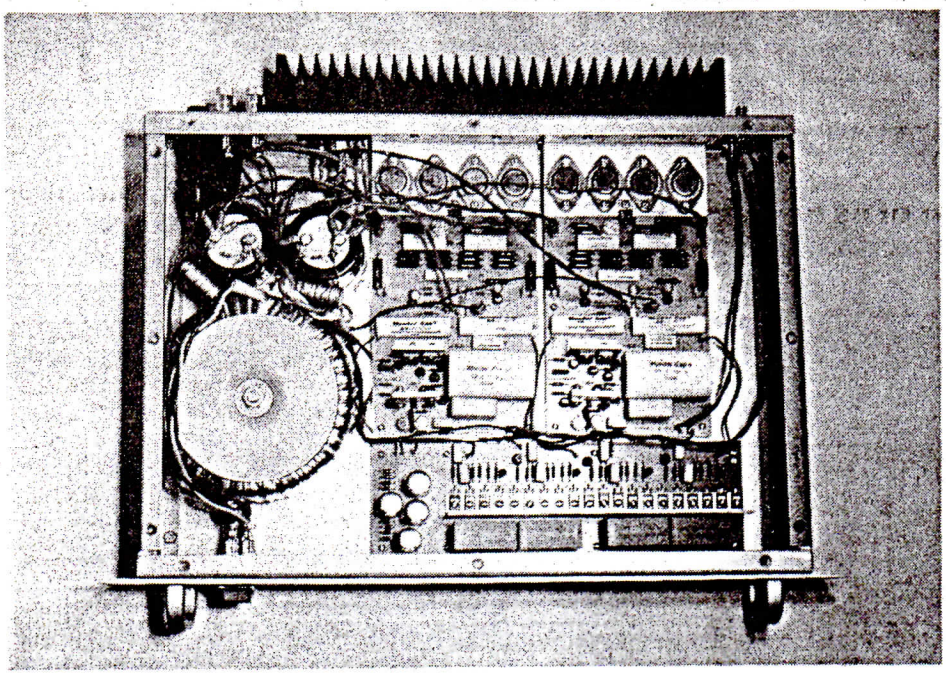


Fig. 4 Component overlay for 3U-version regulator board.

VIRTUOSO POWER AMPLIFIER

PROJECT



Graham Nalty describes the amplifier board that completes his super-fi project

In the third and final article on the Virtuoso Power Amplifier I will look at the power amplifier board itself and at the decisions that were taken concerning its design. First comes the choice whether to operate in class A, sliding class A or class AB.

The class A output stage (Fig. 1) is always ideal but even the larger version of the Virtuoso case would have barely enough heatsink for much more than 10W per channel into 8R (very high levels of heat are dissipated for small output powers).

The Virtuoso has been designed to operate as a fairly low current class AB.

In a true class B amplifier (Fig. 2) each output transistor drives the load speaker for half the current cycle and no current flows through the transistors under quiescent conditions. In practice a fixed current adjusted by the bias voltage is usually set.

The disadvantage is that switching delays (as each transistor current reaches zero at the end of each half-cycle) cause audible distortion, especially at high frequencies.

Sliding bias can prevent the non-driving output transistor switching off but require a voltage feed from the main supply and can cause ripple rejection problems.

On The Way Out

The output devices of this amplifier are bipolar darlington power transistors. These have a lower output-stage non-linearity than MOSFETs (and so greater signal headroom) and much greater peak output current capability. Also MOSFETs have a high input capacity and require high current from the driver stage for good high frequency performance — hence some MOSFET power amps having an emitter follower or source follower prior to the output.

The next question to be answered is how to arrange the input and output coupling.

Fig. 3 shows the basic circuit chosen, with C1 blocking DC to the input and C2 blocking DC in the feedback so that any DC offset at the input is not amplified at the output. This C2 capacitor is large and expensive (more than £10 in the upgraded amp — C45 in Parts List).

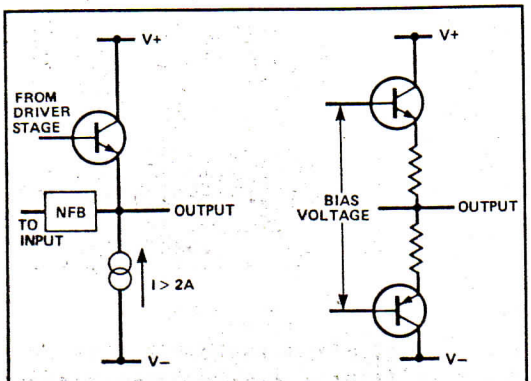


Fig. 1 Class A output stage

Fig. 2 Class B output stage

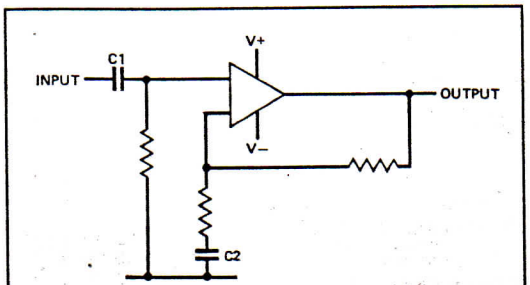


Fig. 3 AC input DC output amplifier

On The Way In

The input stage of the Virtuoso is essentially a differential input long tail pair (see Fig. 4), perhaps the most popular power amplifier input circuit.

Some designers (particularly in the USA) prefer fully symmetrical differential inputs, but using cascode circuitry and increasing the dynamic impedance of constant current sources would make such a design extremely elaborate. Attempting to keep the numbers of transistors practical would affect sonic performance.

The full circuit for the amplifier board is shown in Fig. 6. Its operation is exactly as described in *How It Works* for the simplified circuit (Fig. 5). The individual parts have been expanded to perform their function to a higher standard.

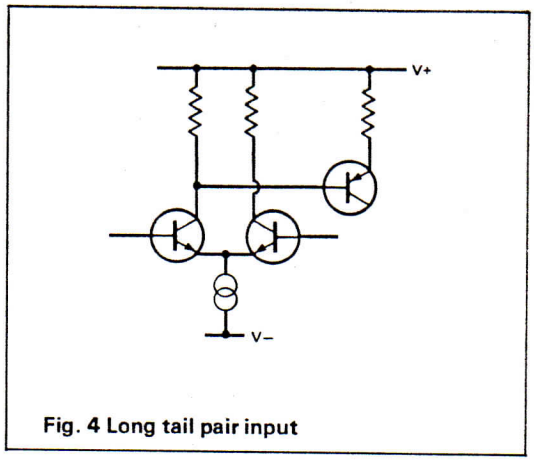


Fig. 4 Long tail pair input

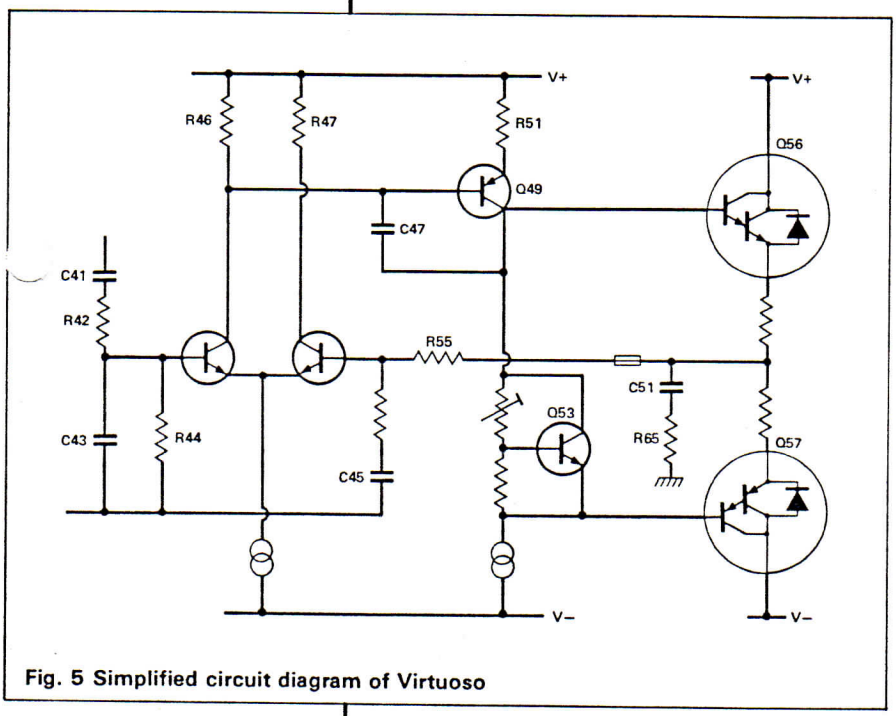


Fig. 5 Simplified circuit diagram of Virtuoso

HOW IT WORKS

The basic circuit of the Virtuoso Power Amplifier is shown in Fig. 5 (component numbering is the same as in the complete circuit Fig. 6).

DC blocking at the input stage is carried out by C41.

A lowpass filter is formed by R42, C43 to prevent very fast high frequency signals reaching the amplifier.

R44 biases the base of the input transistor.

The input stage is a long tail pair fed by a high dynamic impedance constant current source. The output to the next stage is taken from R46 to an amplifier comprising Q49 and Q50. A constant current source provides its load.

The output stage comprises darlington transistors with series emitter resistors. These are biased by a constant voltage network made of RV1, R60 and Q53. High frequency stability is maintained by C51 and R65.

Loudspeakers are protected by a fuse which is within the feedback for minimum sonic distortion.

R41 holds the input of C41 at 0V so that no thump is heard from the speakers when the input is connected. C41 is bypassed by C42 to improve its high frequency performance and together with R44 provides low frequency input filtering. Q41 to Q44 form the input long tail pair.

The darlington arrangement keeps the input base current much lower than with single transistors so that the output DC offset is low even at high values of R44 and R55.

C56 (across Q41,42) is required for high frequency stability (dual matched transistors are used in the upgrade).

The cascode transistors Q45,46 remove ripple from the power supply before they reach Q41-44, improve the high frequency performance and lower the transistor generated distortion in the input transistors.

The second stage amplifier is Q49. Its collector voltage is held constant by cascode transistor Q50 (mounting on a heatsink will reduce temperature generated distortion). A constant current source is provided by Q51, 52 and R58, 59. C54 and C55 provide low high-frequency impedance at the power supply for the output transistors (which are duplicated in parallel for higher output current capability). This prevents high frequency instability of the amplifier.

The quality and value of the emitter resistors (in series with the output transistors) are critical. A fair amount of power is dissipated in these resistors.

When a transistor heats up, its base-emitter voltage decreases. The series resistor provides an increase in voltage with increased collector current. If the resistor value is high enough, thermal runaway is prevented. The use of darlington transistors with two V_{be} junctions requires almost twice the resistance that might be required in a more common circuit with separate driver transistors.

Output Stage Protection

The cost of the output transistors (and in the upgraded version the emitter resistors) mean that it is well worth incurring the additional expense of output stage protection circuitry to safeguard against short circuits or overloading into very low impedances. The circuit used would not usually protect against thermal runaway or high-level high-frequency oscillation.

The circuit is shown in Fig. 7. Diodes D1, D2 protect the collectors of Q1,2 from going to the wrong polarity in relation to their emitters.

The characteristics of the protection circuit for the standard Virtuoso amplifier are shown in Fig. 8. These show a margin of safety up to 40V at 8A. For more current at higher voltages you can add a network made up of a zener diode (15-30V) in series with a resistor, placed in parallel with each of R70 and R71.

Components C52, 53 and R68, 69 are included to increase power dissipation in momentary periods where the power dissipation

PROJECT

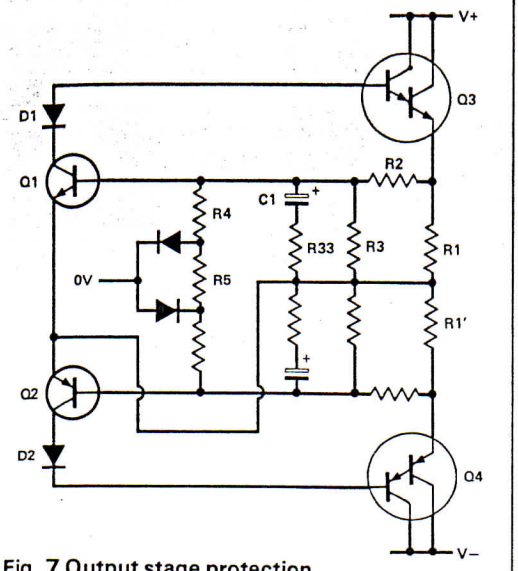
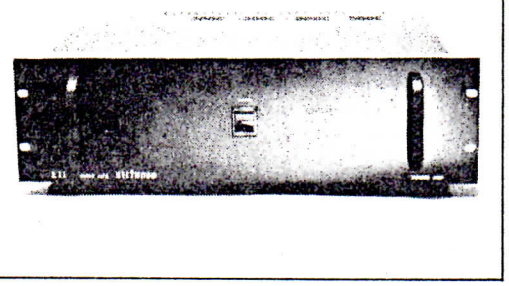


Fig. 7 Output stage protection circuit



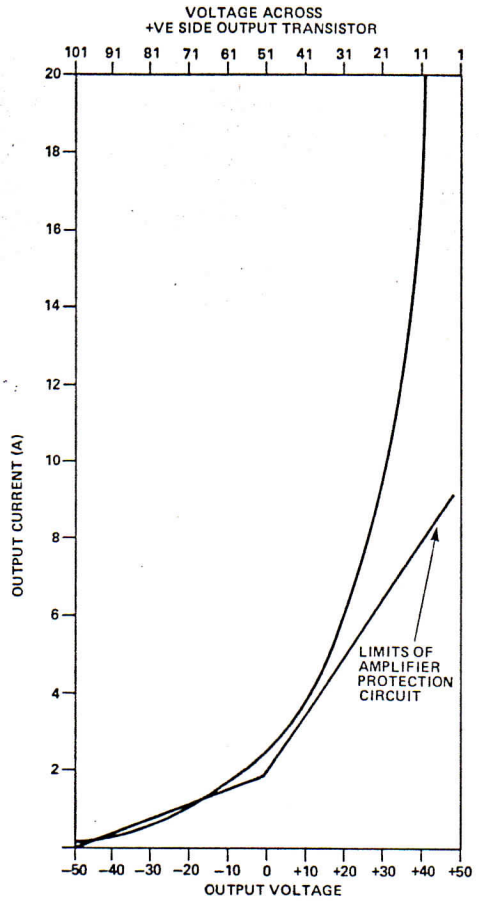


Fig. 8 Characteristics of protection circuit

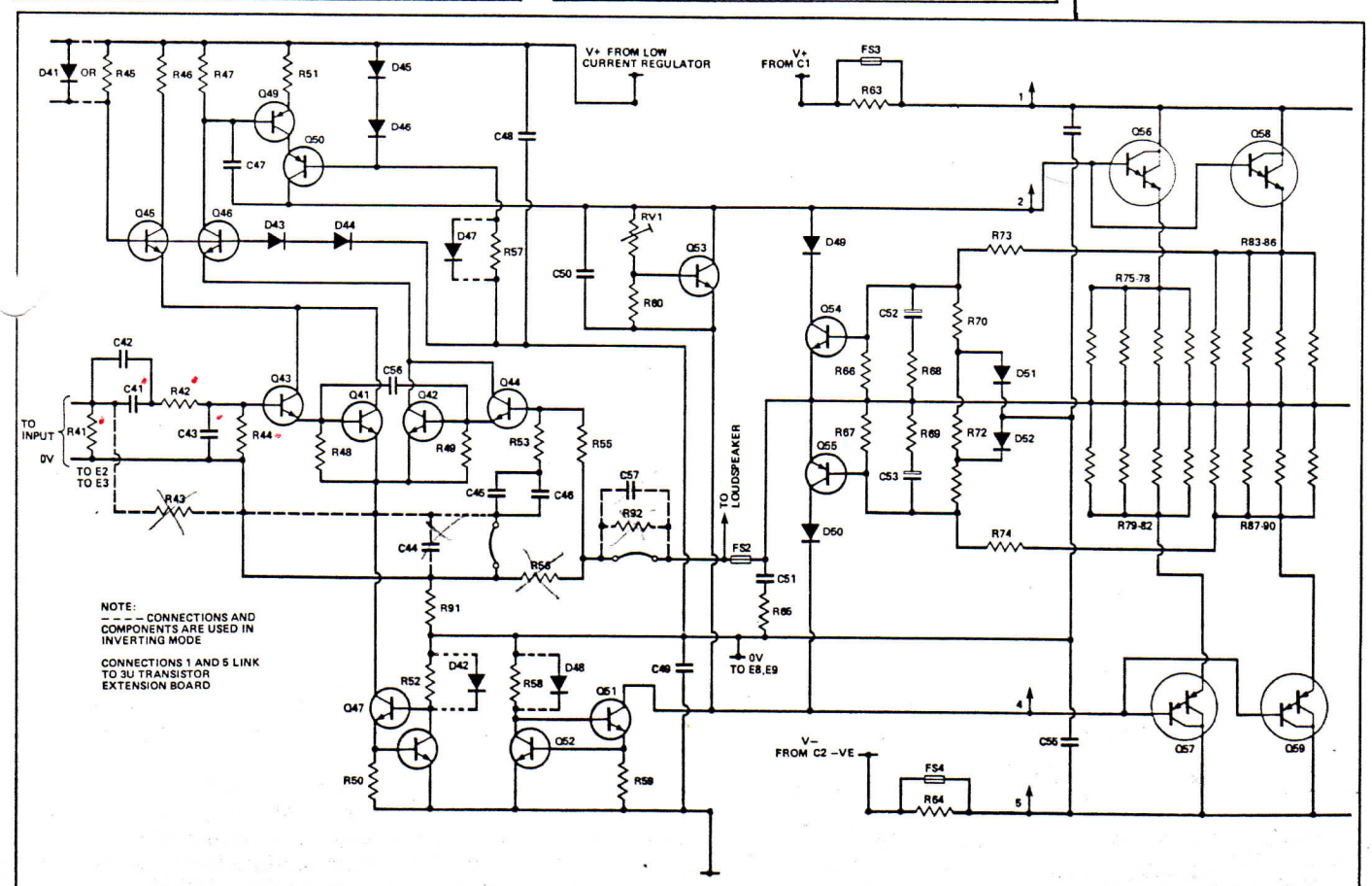


Fig. 6 Complete circuit diagram of amplifier board

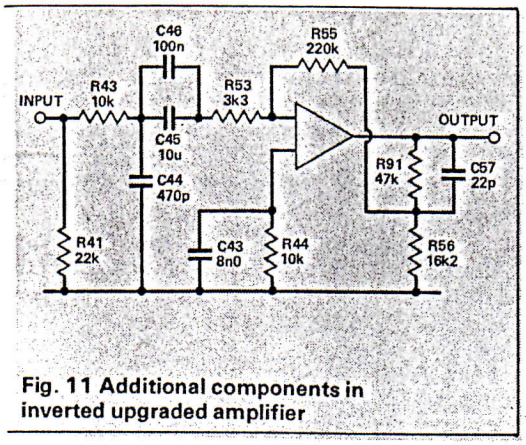


Fig. 11 Additional components in inverted upgraded amplifier

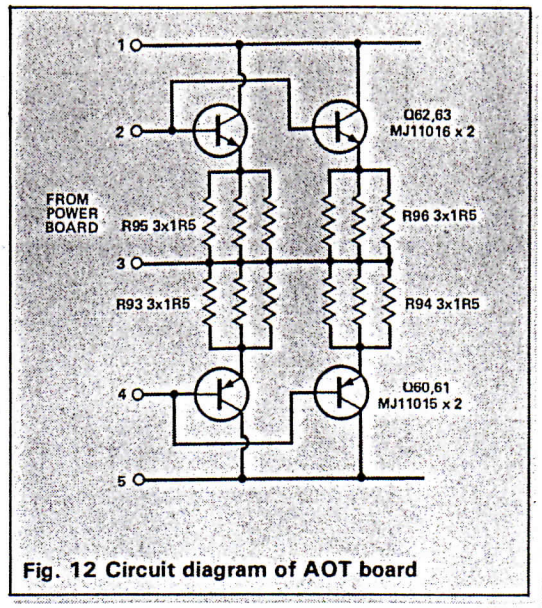


Fig. 12 Circuit diagram of AOT board

If you want to use the bridged Virtuoso into loudspeakers of impedance significantly below 8ohms, you may wish to increase the current capability of the output stage. This can be done using the AOT board (additional output transistors) shown in Fig. 12. The overlay is Fig. 13. Connections are made to the power board as shown in the circuit diagram (Fig. 6) and component overlay (Fig. 14).

Construction

The component overlay for the power amplifier board is shown in Fig. 14.

Unless you are building the inverted version for the bridged amplifier you will not need R43, R54, R56, R91, C44 and C57 (the dotted components from Fig. 6).

Start construction by soldering the PCB pins to the board, including two for the leads from the low current power supply. Next attach the six ¼in blades. The fuses are best installed with the fuse in place, and you may like to solder fuses FS1, FS2 to their cases to improve the contact.

Three wire links are required — one for the earth line near R65, the other two to link across the missing dotted components mentioned above. Then continue mounting diodes D43-46 and D49-52, followed by the lower powered resistors (in the upgrade R45,52,57,58 are replaced by D41,42, 47,48 mounted on transistor pads with flat faces facing the input side of the board). Resistors R75-90 should be mounted so they stand about 2mm off board so that in the unlikely event of a short or transistor blow, the board will not be burned by a roasting resistor.

Next attach the smaller capacitors C43,47, 51,52,53,57 followed by transistors Q41-44,48, 49,52,54,55 (use transistor pads in the upgraded amplifier for all but Q41, 42).

Transistors Q45-47 are TO126 cases attached to a small aluminium heatsink. Q45,46 have their metal side facing the input side of the board, Q47 the other way. Order of assembly from the input side is ⅜in bolt, bracket, Q47, fibre washer, 6BA nut and bolt, fibre washers, Q45, bracket, Q46, 6BA washer, 6BA nut.

Attach the bracket for Q50,51 with fibre washers underneath and mount the transistors — Q50 is insulated from the bracket by a T0220 insulator.

Now fit RV1 and the main heatsink bracket. The four output transistors Q56-59 are mounted via flexible T03 insulators and the base and emitter pins are inserted through the PCB. Don't solder them in yet. Attach the 6BA×¾in bolts via a washer on the topside of the transistor. Insert an insulating bush from the other side into the PCB, into the metal bracket over the bolt. A 6BA solder tag and

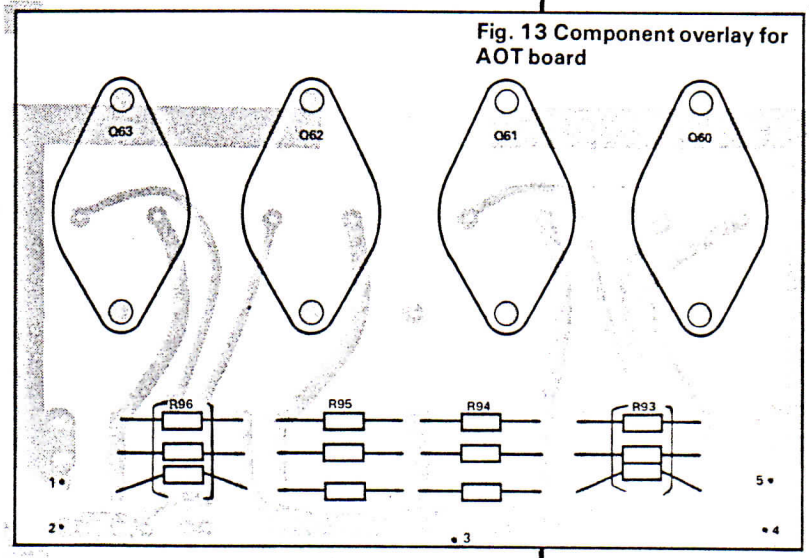


Fig. 13 Component overlay for AOT board

PARTS LIST

	Standard	Upgraded
RESISTORS (¼W 5% unless specified)		
R41	100k metal film	100k Holco H8
R42	3k3 metal film	3k32 Holco H8
R43	used only in inverting amplifier	
R44, 48, 49	220k metal oxide	221k Holco H8
R45	22k metal oxide	see D41
R46, 47	1k0 metal oxide	1k0 Holco H8
R50	330R metal oxide	332R Holco H8
R51	10R metal oxide	10R Holco H8
R52	22K metal oxide	see D42
R53	3k32 Holco H8	3k3 VSRJ bulk foil
R55	221k Holco H8	220k VSRJ bulk foil
R56	used only in inverting amplifier	
R57, 58	10k metal film	see D47, 48
R59	33R metal film	33R2 Holco H8
R60	470R metal film	475R Holco H8
R63, 64	220R 4W w/w	220R 4W w/w
R65	10R 1W metal oxide	10R Holco H2
R66, 67, 68, 69	2k2 metal film	2k2 metal film
R70, 71	2k7 metal film	8k2 metal film
R72	8k2 metal film	22k metal film
R73, 74	150R metal film	470R metal film
R75-78, R79-82, R83-86	0R33 Holco KNA412 3W w/w	each 4 × 1R5 Holco H2

R87-90	1 × OR33 Holco KNA412 3W w/w	4 × 1R5 Holco H2
R91	10R metal film	10R metal film
R92	used only in inverting amplifier	
RV1	2k2 or 2k5 carbon preset	2k2 cermet preset
CAPACITORS		
C41	470n polyester	250n LCR EXFS/RP
C42	4n7 polystyrene	not used
C43	470p polystyrene	470p LCR EXFS/RP
C44	link across	
C45	10u polycarbonate	10u wonder cap
C46	10n polystyrene	10n LCR EXFS/RP
C47	22p polystyrene	22p silver mica
C48, 49	470n polyester	680n wonder cap
C50	10n polycarbonate	8n LCR EXFS/RP
C51	100n polycarbonate	100n wonder cap
C52, 53	0u47 electrolytic	0u47 electrolytic
C54, 55	1u0 polyester	1u0 siderealkap
C56	100p polystyrene	100p silver mica
C57	link across	
SEMICONDUCTORS		
Q41, 42	2 × BC184C	MAT01GH
Q43, 44	2 × BC184C	MAT01GH
Q45, 46, 47	BD139	BD139-10
Q48, 52, 54	BC184C	BC184C
Q49, 55	BC214C	BC214C
Q50	BD244C	BD244C
Q51, 53	BD243C	BD243C
Q56, 58	MJ11016	MJ11016
Q57, 59	MJ11015	MJ11015
D41, 42	see R45, R52	J507
D43, 44	1N4148	Red LED
D45, 46, 49, 50, 51, 52	1N4148	1N4148
D47, D48	see R57, R58	J511

MISCELLANEOUS

FS1, 2, 3, 4 5A 5×20mm

PCB. PCB pins (5). Vertical PCB ¼in blades and connectors (6). Fuse clips (4). Transistor insulator pads (6) — Silpad 4177 (standard), Silpad K10 (upgrade). T03 bushes (8). T0220 bushes (2). Three brackets (power, driver & input transistors). Nuts, bolts, washers. Upgrade only: 7 transistor pads for D41, 42, 47, 48, Q48, 49, 52.

Internal Wiring

Table 1 shows lengths and colour standards for wiring in the 2U case. High current paths should use 5A cable — some constructors use multi-strand, others prefer single-core.

If you use Kimber cable, use two wires twisted together for high current applications, making sure the direction is correct.

If your reservoir capacitors have screw terminals, connect the wires with insulated crimp terminals rather than solder tags (accidental shorting would be rather unhealthy).

The Trial

Remove FS3 and FS4 from each amplifier board and connect the supply. The 470R resistors between supply and the amplifier (normally bypassed by the fuses) will help prevent serious damage if there is a fault when you switch on. The worst that can happen is that the 470R resistors will get warm.

Before you switch on, turn RV1 on both power amps fully anticlockwise. Now switch on.

If all is well the DC voltages on the high current side should read ±51V (±43V for the bridged amplifier). The low current side should be as they were for the regulator circuit (see May issue). The voltage at the speaker terminals should be less than 50mV.

To make further checks, use a digital meter. The base-emitter voltages of Q41-52 should be 0.5-0.7V. The voltage across each of the diode pairs D43, 44 and D45, 46 should be 1.1-1.2V. If you use red LEDs for D43, 44 the voltage will be 3V — this increases the V_{ce} across Q41-44 enabling them to operate on the more linear part of their characteristics.

Now adjust RV1 clockwise until a voltage of about 20mV can be measured across the output emitter resistors (they may vary slightly). The next test is to check that a signal can be amplified — use a signal generator at the input and scope at the output, or if these tools are not to hand use a preamp and loudspeaker. The sound should be clean at low levels but distort badly above 10W.

If everything seems okay, disconnect the test gear and allow the reservoir capacitors about 10 minutes to discharge. Now insert the fuses FS3 and FS4 on each board (bypassing R63,4) and switch on.

INVERTING AMPLIFIER

Delete R41, 42, 44

Delete C41, 43

R41	22k metal film	22k Holco H8
R43	10k Holco H8	10k Holco H8
R44	10k metal film	10k Holco H8
R56	16k2 Holco H8	15k/16k bulk foil
R91	47k5 Holco H8	47k bulk foil
C43	4n7 polystyrene	8n0 LCR EXFS/RP
C44	470p polystrene	470p LCR EXFS/RP
C57	22p polystyrene	22p LCR FSC/P

EXTRA OUTPUT STAGE

R93,94,95,96,	0.47R Holco KNA412	3×1R5 Holco H2
Q60, 61	MJ11015	MJ11015
Q62, 63	MJ11016	MJ11016

T03 transistor pads (4) — Silpad 4177 (standard), Silpad K10 (upgrade). Transistor bushes (8).

PROJECT

nut should be attached to the four bolts nearest the end of the board, a washer and nut to the other four (screw them finger tight). Then attach Q53 with a ¾in bolt, small nylon bush, T0220 insulator, bracket, through the PCB to a washer and nut.

Now screw all nine bolts tight and check with a meter for shorts between the transistors and bracket.

Complete the board with C41,42,45,46,48, 49,54,55 (if you are using Wonder Caps in the upgraded amplifier, you can use the offcuts of wire to parallel all the high current tracks).

Solder all the power transistor leads to the PCB and connect the collectors of the T03 transistors by soldering the solder tags to the PCB tracks.

Your power board is now complete!

With the amplifier boards completed, you can fit everything into the case as shown in Fig. 15.

The heatsink brackets are bolted to the sink by two 4BA ⅜in bolts and washers. The boards are bolted to the case with 6BA ¼in bolts.

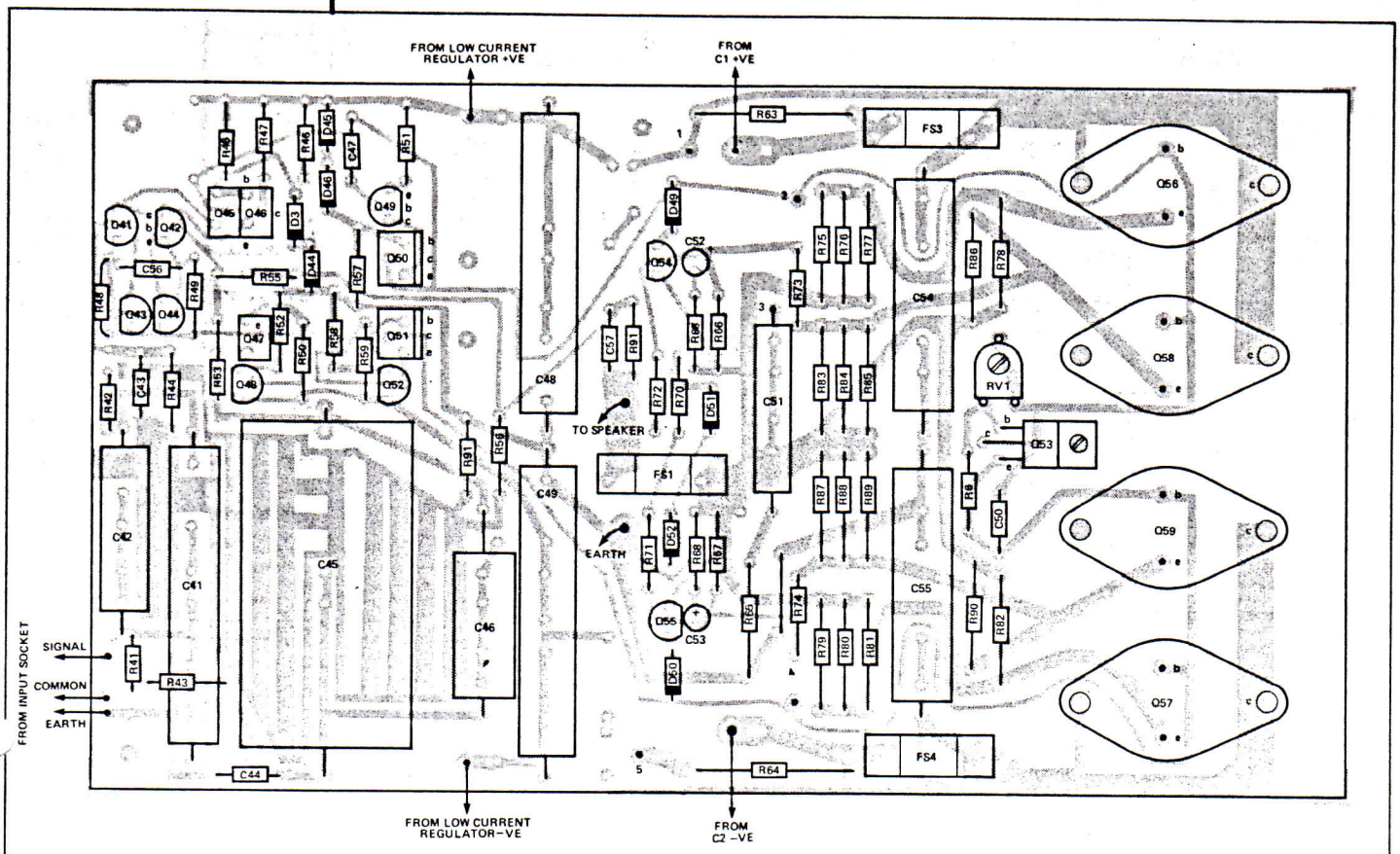


Fig. 14 Component overlay for amplifier board

exceeds the DC safe operating area. Such excursions can *only* be momentary — of the order of milliseconds — and the time constant of R68/C52 and R69/C53 achieves this.

Over The Rickety Bridge

The power output from a bipolar amplifier is limited by its output power transistors. At high collector-emitter voltages, the allowable power dissipation (and current available to drive out of phase loads) is greatly reduced because of secondary breakdown. So even if extra transistors with the necessary voltage rating are connected in parallel, it may not be possible to increase the output power significantly by raising the supply voltage.

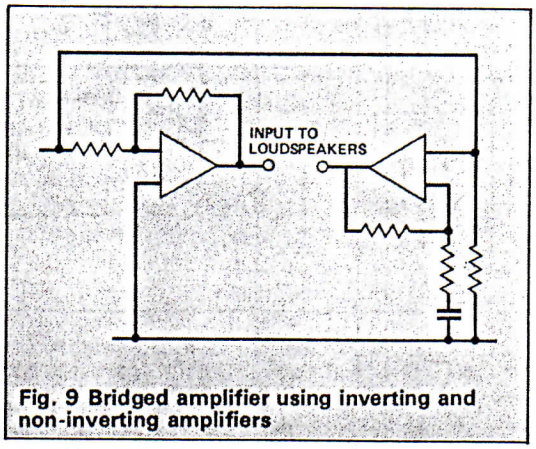


Fig. 9 Bridged amplifier using inverting and non-inverting amplifiers

In such cases it is possible to greatly increase the power driving the loudspeakers by bridging two power amplifiers. This involves simply feeding the audio signal directly to one amplifier and inverted to the second amplifier. The voltage between the two output terminals will be twice that between any one terminal and ground. There are also sonic advantages in that each bridged amplifier has its own power supply so intermodulation effects between channels are eliminated.

Using an inverting amplifier for the audio signal to the second amplifier has sonic drawbacks — this can be avoided by rewiring the second channel in the inverting mode as in Fig. 9.

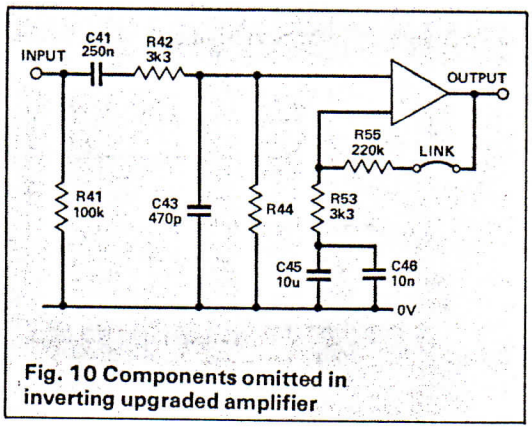


Fig. 10 Components omitted in inverting upgraded amplifier

Bridging the amplifier doubles the output voltage and quadruples the power (the increase is actually slightly less because of the higher current required to drive the loudspeaker).

If you want to double the power output the supply voltage can be decreased to 70% of its original value, with the maximum current output increased to 140%. Thus the output transistors run at lower voltage and secondary breakdown limitations are greatly reduced.

I am not going into great detail regarding building the inverting amplifier as I expect anyone constructing it will have considerable experience of building power amplifiers. Briefly then, the inverting amplifier is built as follows:

- Build exactly as the non-inverting Virtuoso, but leave out all the parts marked in Fig. 10.
- Add the components shown in Fig. 11.

PROJECT

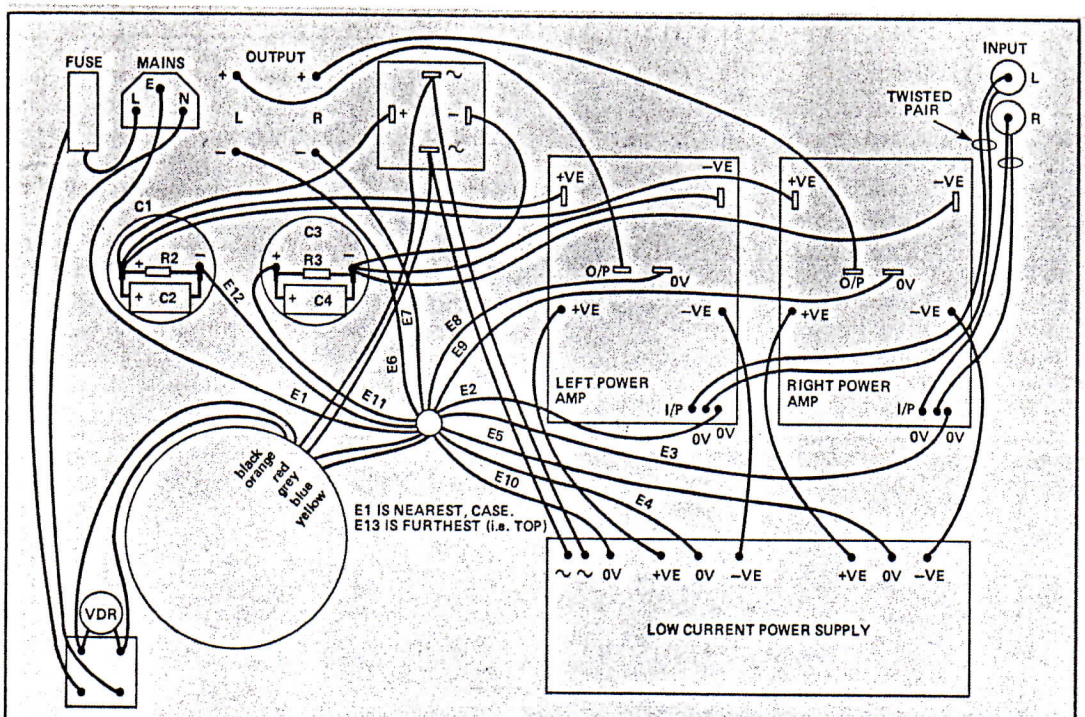
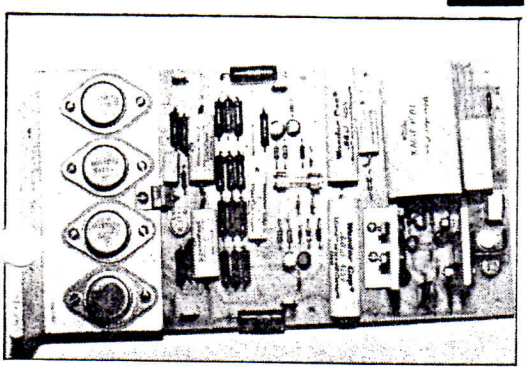
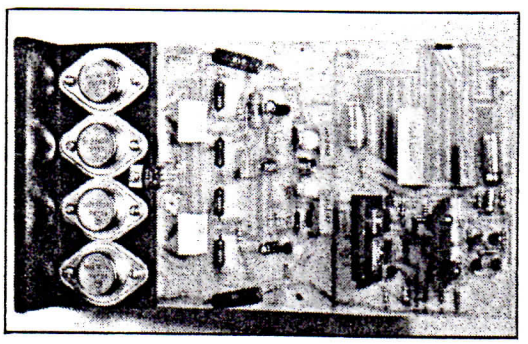


Fig. 15 Wiring diagram for 2U case

If there are no signs of distress you can now couple the amplifier to your other equipment. A precaution I always observe is to connect only the earth side of the speakers to the amplifier before switching on. Then touch the signal lead to the terminal and if the music is coming through then connect it. With the upgraded version make sure the wire or plug doesn't short across the speaker terminals.

Then fetch the port and cheese, sink into your armchair and enjoy the wonderful sound. ETI





Application	Length (cm)	Colour	
		Standard	Upgraded
Earth E1 to Mains Skt	17	Green	Black
L amp signal to earth E2	20	Green	Black
R amp signal to earth E3	32	Green	Black
L reg board to earth E4	29	Green	Black
R reg board earth E5	20	Green	Black
E6 to L speaker	15 + 15	Green	Black
E7 to R speaker	14 + 14	Green	Black
L amp to E8	14	Green	Black
R amp to E9	27	Green	Black
E10 to regulator	13	Green	Black
E11 to C3 +	12 + 12	Green	Black
E12 to C1 -	13 + 13	Green	Black
Mains input L to fuseholder	10	Brown	Red
Fuseholder to mains switch	29	Brown	Red
Mains input N to mains switch	30	Blue	Red
Bridge rect ac to low current reg	23	Brown	Red
Bridge rect ac to low current reg	25	Brown	Red
Low current reg to L amp +	17	Brown	Red
Low Current Reg to L amp -	11	Black	Blue
Low current reg to R amp +	14	Brown	Red
Low current reg to R amp -	9	Black	Blue
Bridge rect + to C1 +	11 + 11	Red	Red
Bridge rect - to C3-	8 + 8	Black	Blue
C1+ to L amp +	15 + 15	Red	Red
C1+ to R amp +	24 + 24	Red	Red
C3- to L amp -	16 + 16	Black	Blue
C3- to R amp -	29 + 29	Black	Blue
L input to L amp 0v	36	Green	Black
L input to L amp signal	36	Red	Blue
R input to R amp 0v	22	Green	Black
R input to R amp signal	22	Red	Red
L amp to L speaker	23 + 23	Red	Blue
R amp to R speaker	32 + 32	Red	Red

TOTAL WIRE LENGTHS

Standard amp	1A	5A	Upgraded amp	Kimber
Green	2.13m	71cm	Black	3.38m
Brown	79cm	39cm	Blue	2.08m
Blue	—	30cm	Red	3.34m
Black	20cm	53cm		
Red	58cm	1.06m		

Table 1 Wirelengths for 2U case

OOPS!

In part one of the Virtuoso in April, capacitors C2 and C3 should be transposed in Fig. 5 (P28). The diagrams for Figs. 6 and 7 should also be exchanged.

BUYLINES

All components for the Virtuoso Power Amplifier are available from Audiokits Precision Components, 6 Mill Close, Borrowash, Derby DE7 3GU. Tel: (0332) 674929.

Audiokits also supply the complete kit for all versions of the amplifier and a full price list of both kits and components can be obtained by sending a large SAE.

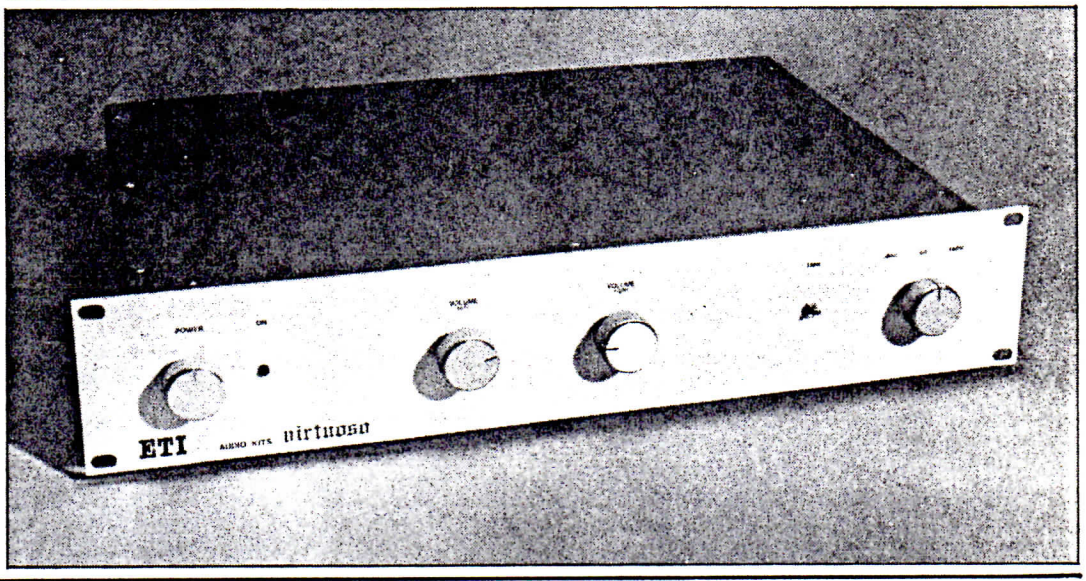
PROJECT

UPGRADING THE PREAMPLIFIER

Since I designed the Virtuoso Pre-amplifier (ETI June-November 1986) new components have become available which enable constructors to further improve the sound quality as follows:

- Upgrade the 1N4002 diodes to UF4002 fast recovery diodes — or (better still) to schottky 11DQ4s.
- Upgrade all polycarbonate capacitors to Audiocap polypropylene capacitors (from Audiokits — see Buylines).
- Replace all resistors to bulk metal foil type — especially cartridge loading, RIAA equalisation and negative feedback resistors.
- Upgrade the volume control to a goldplated switched attenuator with Holco or (better) bulk foil resistors.
- Use Kimber cable for all internal cabling. Where screened cable is required use Van den Hull D502.
- Replace the mains transformer with a higher power version in a remote box.

The summed effect of these improvements is to extend the sonic performance of the pre-amp still further, making it a worthy match for the highest grade Virtuoso Power Amplifier.

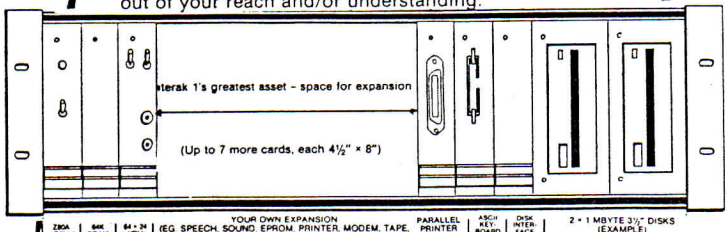


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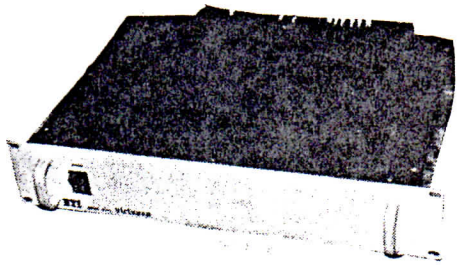
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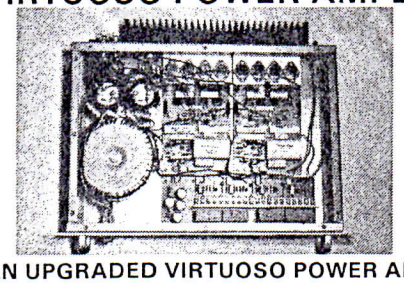
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