Universal dc-dc inverter

This inverter can be configured to suit a wide variety of applications — powering our audio amplifier modules from a 12 V battery, powering 12 V equipment from a 24 V or 32 V battery, deriving a high voltage supply from a low voltage dc source etc, etc.

David Tilbrook
Roger Harrison

WE'VE CALLED this a 'universal' dc-dc inverter as it has been designed so that, simply by winding the appropriate secondary, or secondaries, on the output transformer you can derive almost any dc output voltage(s) you want. Thus, this project can be used to power any of our audio power amplifier modules (ETI-470, ETI-477, ETI-480, ETI-499), with perhaps the exception of the ETI-466 300 W amp. You can power the ETI-565 HeNe laser and the ETI-452 Guitar Practice Amp, or any other project or device you desire, providing it falls within the power rating of the inverter.

We described a dc-dc inverter power supply to power a PA/guitar amp employing one of our 100 W '480 modules way back in May 1977. This was the ETI-481PS which provided ±40 V rails from a 12 V battery. It ran at 20 kHz and required special rectifier diodes, a potcore and a ferrite transformer assembly — all of which are now very difficult, if not impossible, to obtain. Since we described the Series 5000 stereo power amplifier in the January-February-March '81 issues, many readers have sought to adapt it for use in their vehicles (car/truck/sin bin . . .). Some managed to chase up the parts for the ETI-481PS, but they have now virtually 'dried up' and we have been pressed to do a 'replacement'. Well, this is it, albeit with some refinements.

We decided to make this inverter a 'universal' project as it struck us there are wider applications than was first envisaged. Besides, we've had a number of requests for a 12 V inverter to power the ETI-565 HeNe laser, both to provide portability and to free it from mains operation for improved safety. It seems that many schools have built the laser for use in their science labs.

Design considerations

A number of factors were considered of prime importance when we tackled the design of this inverter. First came the frequency of oscillation. Would we have a low frequency design, which eases component selection and ensures their availability, or set the oscillation frequency above the audio band? A third option was to do something between those two extremes. Cost, size and component availability were also important.

The problem with a low frequency inverter, operating at — say — 2 kHz or less, is suppressing the switching 'spikes' that appear on the power supply rails. This can be difficult and these spikes almost inevitably create interference in low-level input stages. As the spikes contain predominantly odd harmonics the result is a cacophony of buzzes that is constantly present. Rectifier filter capacitors at the lower frequencies are, by necessity, large and we didn't want a bulky project.

Setting the inverter oscillation frequency above the audio band, at 20 kHz for example, gets rid of the above problem but introduces several others. Circuit techniques that work at low frequencies require specialised components at 20 kHz. Hence, a different inverter technique is necessary, and this inevitably increases costs and specialised components often prove hard to get — which became the major problem with the ETI-481PS which ran at about 25 kHz.

We chose the median course. Setting the oscillation frequency at around 6-7 kHz puts the odd harmonics where they (mostly) won't be heard. Filtering is easy and suitable capacitors are compact.

We wanted a design that used a minimum number of components, so that the project would be compact, but consistent with the other restraints. There are three common techniques employed in transistor dc-dc inverters these days — the self-excited single transformer circuit, the self-excited dual transformer circuit and the driver inverter.

The self-excited single transformer inverter is by far the simplest. The general form of this inverter is shown in Figure 1. The transistors operate in push-pull and feedback is taken from a winding on the output transformer. It

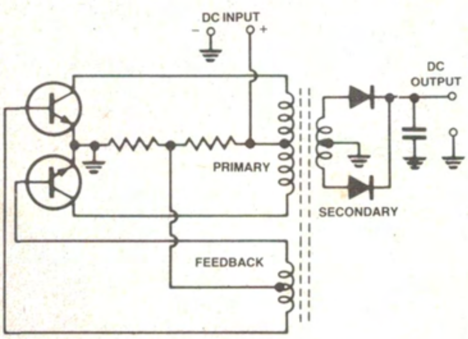


Figure 1. **Typical circuit of a self-excited single transformer dc-dc inverter. Efficiency of this type of circuit often exceeds 90%, with correct choice of transistors.**

has two great advantages — simplicity and high efficiency. With proper choice of transistors, efficiency can be in excess of 90%. However, at the sort of powers we envisaged the inverter would have to deliver — around 200 W or so — switching transistors with suitable current ratings and low saturation voltages (for that's where you lose efficiency) are not cheap, or readily available. Germanium switching transistors are the best. Tried to buy a 20 A germanium switching transistor lately? Some MOS switching devices are also suitable, but still hard to get. You could parallel transistors of lower current rating but the traditional method of using emitter 'ballast' resistors severely affects efficiency. By using a special primary winding on the transformer, as shown in Figure 2, the devices are essentially in parallel but collector-emitter current sharing is done in the transformer primary. Base current sharing is effected by the series base resistors.

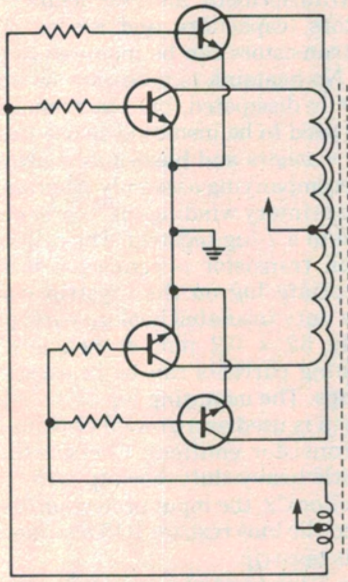


Figure 2. **Obtaining more power output from the simple self-excited inverter by means of 'paralleling' transistors with a special, quadrifilar-wound, primary. For high power use, lower cost transistors can be used.**

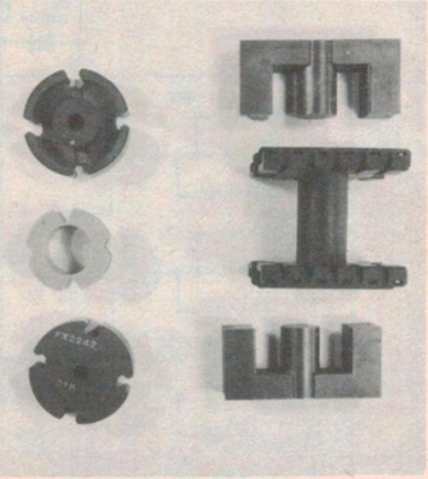
Thus, common-or-garden transistors, like 2N3055s, can be used and little power is lost here. The major drawback is attaining the required oscillation frequency. For this sort of inverter, the oscillation frequency is given by:

$$f \cong \frac{V_{supply}}{4N\delta_m}$$

where: f is frequency of oscillation
V_{supply} is dc input
N is primary turns, collector to centre tap
δ_m is magnetic properties of transformer core

Thus, for a given voltage and core properties, N must be relatively small to achieve the required frequency of oscillation. But here comes a catch. The feedback winding must develop enough voltage to drive the base such that the transistor(s) saturate properly. In practise, this means about 3 V. If the dc input is 12 V, you need a turns ratio of 4:1 between the primary and feedback windings. If you make the feedback winding (centre tap to one set of bases) one turn, then the primary has to be four turns. With available cores, the oscillation frequency did not even approach what we wanted.

A driven inverter is more complex, but it overcomes the problem just outlined. A typical arrangement is shown in Figure 3. This employs a low power, self-excited push-pull oscillator driving a set of push-pull output transistor switches which drive the output transformer. The old ETI-481PS inverter was of this type. Efficiency is the greatest drawback of this type of circuit. The driving oscillator always draws significant power. You can achieve efficiencies



The transformer assemblies we used. At left is the FX2242 potcore assembly; right is the Philips EC52/24/12 assembly. Note the ferrite 'Es' of this assembly have round centre legs. The bobbins are shown in the middle.

of 80%, typically, but at 200 W output, you're losing 40 W and in a battery system, this is not good.

We settled on the self-excited dual transformer technique, illustrated in Figure 4. Here, a separate feedback transformer is used and it is this which controls the frequency of oscillation. This enables the choice of the right sort of core to obtain realistic turns ratios and the desired frequency of oscillation. We managed to use a common potcore for the feedback transformer (a 36 mm diameter FX2242 type) and an EC-core for the output transformer of a type we have used previously (in the ETI-1505 fluorescent light inverter). Supply rail filtering can be done quite effectively with common greencaps. Ordinary 2N3055 transistors — which cost less than a dollar these days — can be employed, thus keeping the cost down. ▶

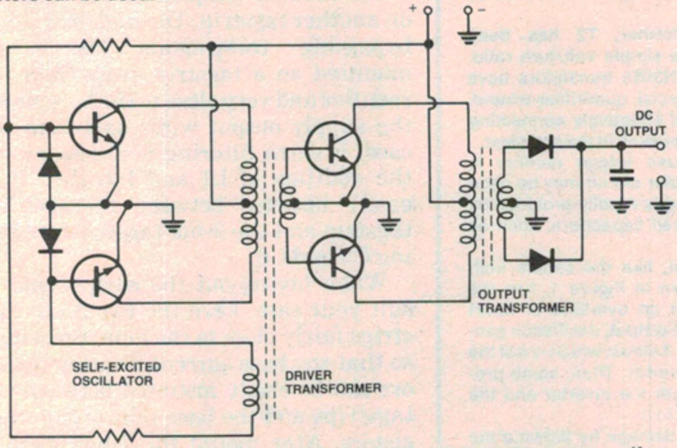


Figure 3. **Typical circuit of a driven dc-dc inverter where a low power self-excited oscillator drives a set of transistor switches which drive the output transformer. Of the three types, this technique has the poorest efficiency.**

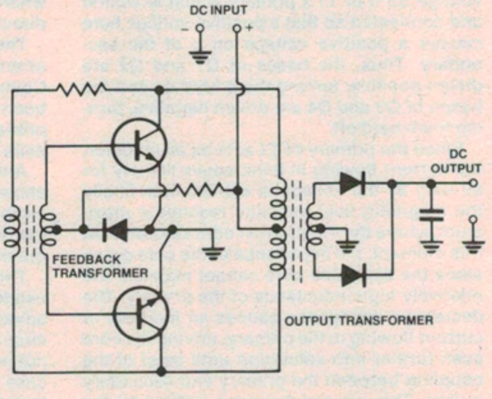


Figure 4. **Circuit of a self-excited dual transformer dc-dc inverter where the feedback is separated from the output transformer. In this circuit, the oscillation frequency is determined by the feedback transformer. Efficiencies similar to the Figure 1 circuit can be achieved.**

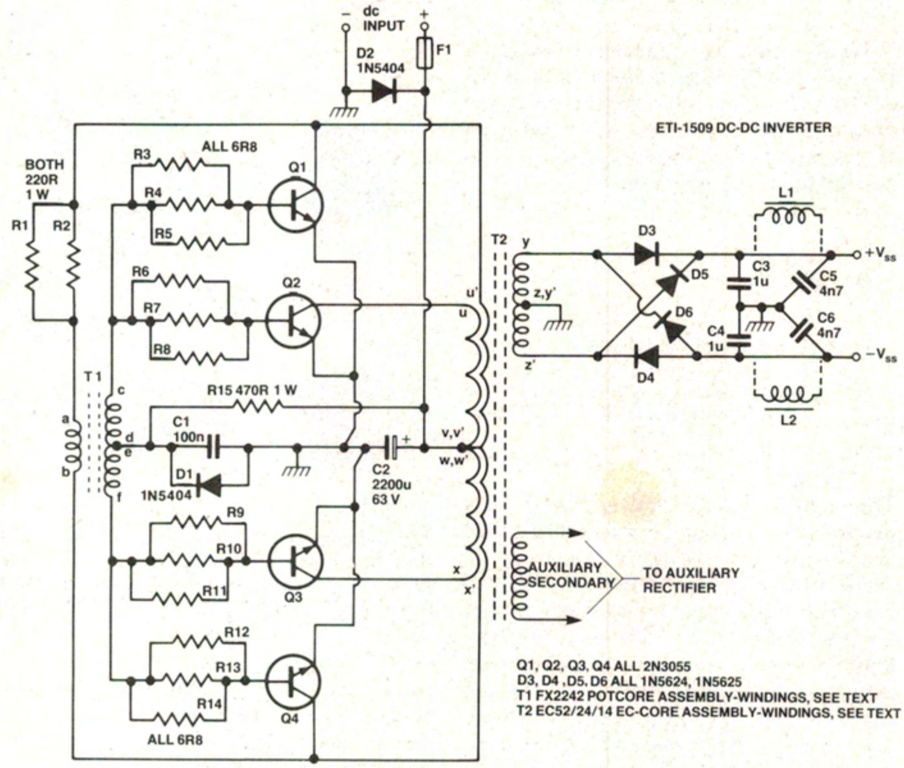


Figure 5. **Circuit of the universal dc-dc inverter. The two inductors shown at the rectifier output, L1 and L2, are only necessary if extra filtering of the dc output is necessary. These can be any value between about 1 mH and 10 mH. Speaker crossover inductors are ideal for this application. Choose inductors rated to carry the dc output current. At low currents (200 mA or less, say) RF chokes will suffice.**

HOW IT WORKS — ETI-1509

The circuit is a push-pull self-oscillating inverter with feedback provided by transformer T1, output being taken from T2. The moment the supply voltage is connected, current flows through the 470 ohm resistor R15, through the secondary of T1 (c-d-e-f) and the base current limiting resistors of the transistors Q1 to Q4. One of these transistors will turn on as circuit balance is not perfect and device characteristics are not matched. If, for example, Q1 commences to turn on, current will flow through the u'-y' primary of T2. This causes a magnetic field to build up in the transformer core creating a positive voltage on x' (x goes positive too). This puts a positive voltage on b of T1's primary which is wound and connected so that a positive voltage here causes a positive voltage on c of the secondary. Thus, the bases of Q1 and Q2 are driven positive, turning them hard on and the bases of Q3 and Q4 are driven negative, turning them hard off.

Since the primary of T1 acts as an inductor, the current flowing in it increases linearly for as long as the voltage is applied until finally the magnetic field intensity reaches a maximum, where the transformer core saturates. At this moment, the impedance of the core drops since the saturated core cannot maintain the relatively high inductance of the primary. The decreased impedance causes an increase in current flowing in the primary, driving the core even further into saturation until most of the coupling between the primary and secondary is lost. This causes the drive voltage to the bases to disappear. Current stops flowing in the transformer and the magnetic field starts to collapse. This causes the voltage sense of each winding to reverse. Thus, u and u' on T2 go positive and x-x' go negative. This causes b on T1 to go negative and thus c goes negative, removing charge from the bases of Q1 and Q2 which turn off. At the same time, f goes positive, turning Q3 and Q4 on. The whole sequence of events then repeats for the opposite 'side' of the oscillator, until once again, Q1 and Q2 are driven on and oscillation results.

The frequency of oscillation depends primarily on the core material of T1, the turns on its primary winding (a-b) and the applied voltage. In this case the frequency is around 6 - 7 kHz. Resistors R1 and R2 provide control of the feedback and diode D1 provides a return path for the base emitter current to the transistors when the secondary voltage of T1 reverses direction.

The output transformer, T2 has been arranged to provide a simple volt/turn ratio. Common, low cost 2N3055 transistors have been used and the special, quadrifilar-wound, primary is a means of effectively connecting pairs in parallel, as discussed in the main text.

Although a full wave bridge rectifier is shown here, any rectifier circuit may be used on the output. Filtering is readily provided by low value non-polarised capacitors, such as greencaps.

This inverter circuit, like the simple self-excited inverter shown in Figure 1, has the advantage that, when an overload or short circuit is applied to the output, oscillation cannot be maintained and it stops, which is not the case with a driven inverter. Thus, some protection is afforded both the inverter and the equipment connected to it.

Diode D2 prevents damage by blowing the fuse should the dc supply input be connected in reverse.

The circuit of the inverter is shown in Figure 5.

As it was to be a 'universal' inverter, the output transformer was designed to provide a simple volts/turn ratio for the secondary, making it easy to calculate and wind the secondary for the required output. The ratio is two volts per turn. A 'Table of Suggested Outputs' has been drawn up for a variety of applications. Note that more than one secondary can be wound on the output transformer if required.

Construction

The inverter can be housed in any convenient enclosure and we have shown only general construction as layout is not particularly critical. A suggested layout is shown in the wiring diagram. A metal case is assumed. Four tagstrips are used as tiepoints to terminate the two transformers and to mount the resistors, capacitors and diodes. The four transistors can be mounted to the case. No heatsink is necessary as little power is dissipated, but the transistor cases need to be insulated so use insulating washers and bushes as shown in the accompanying assembly diagram.

The primary windings of T1 are terminated to a 7-lug tagstrip. The collector of each transistor is connected to the appropriate lug on the tagstrip using heavy duty insulated hookup wire, preferably 32 x 0.2 mm or heavier, as switching currents can be in excess of 20 amps. The mounting lug of the 7-lug tagstrip is used as a ground tiepoint for the transistor emitters. Connect them up with heavy duty hookup wire too. Capacitor C2, the input protection diode D2 and the bias resistor R15 also mount on this tagstrip.

Two 5-lug tagstrips are used to terminate the feedback transformer, T1, and to support the base current limiting resistors and several other components.

The rectifier components are mounted on another tagstrip. The high frequency bypassing components should be mounted on a tagstrip away from the rectifier and very close to the hole where the supply output wires exit from the case. If extra filtering is necessary (by the addition of L1 and L2) then it is easily inserted between the rectifier tagstrip and the 3-lug tagstrip containing C5 and C6.

When laying out the components to suit your case, keep the two 5-lug tagstrips fairly close to the four transistors so that the base current limiting resistors can be easily mounted between the tagstrips and the base pins of the transistors. Also, mount the 7-lug tagstrip that terminates the primaries of T1, close to the transistors so that high

PARTS LIST — ETI-1509

Resistors		all ½ W, 5% unless noted
	R1, R2	220R, 1 W
	R3 — R14	6R8
	R15	470R
Capacitors		
	C1	100n greencap
	C2	2200u/63 V axial electro. (or 2500u/50 V)
	C3, C4	1u greencap
	C5, C6	4n7 ceramic
Semiconductors		
	D1, D2	1N5404
	D3, 4, 5, 6	1N5624, 1N5625
	Q1, 2, 3, 4	2N3055
Miscellaneous		
	T1	FX2242 potcore assembly (windings, see text).
	T2	Philips EC-core assembly (windings, see text). 2 x EC52/24/14 cores (4322-020-52520) 1 x former, no tags (4322-021-33020) clamp assembly: 1 x 52PLATE 1 x 55UBOLT 2 x 632NC2A

Two 7-lug tagstrips; two 5-lug tagstrips; one 3-lug tagstrip; chassis or box as required; winding wire — 1 mm and 0.4 mm enamelled copper wire; 32 x 0.2 mm hookup wire; 10 x 0.2 mm hookup wire; nuts, bolts etc.

Price estimate $30 — $35

current carrying leads are kept short.

Make sure you have enough room to mount both T1 and T2. A single bolt through the centre hole of the T1 potcores will secure it but use a fibre washer under either the head of the bolt or under the nut to prevent cracking one of the potcore halves.

If you use a chassis that comes in two halves (like we did on our prototype) mount all the tagstrips and components on the one half so that all the ground tie points are connected together whether the case is split in half or not. If you use a box with a lid (like a diecast box, for example) mount all the components and tagstrips either on the lid or in the box, for the same reason.

When you have a layout finalised for the housing you're using, it's best to assemble all the electronics first, leaving the transformers till last. *Then* wind the transformers. Use our Table of Suggested Outputs and the Transformer Winding Details as a guide to assemble the two transformers. When you've done these and checked that all is correct, mount the transformers and wire them up.

For the dc input leads, use heavy duty cable or hookup wire, remembering that 20 A or so may be passing through it. Don't forget the line fuse.

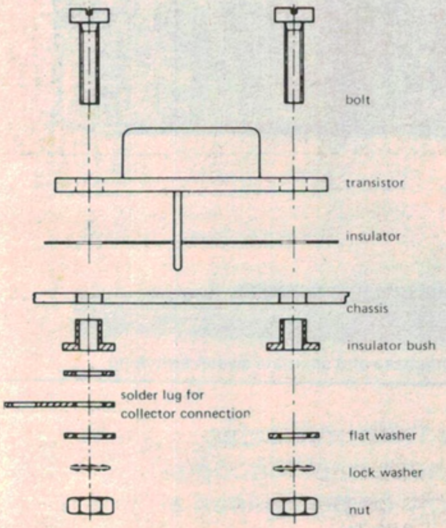
Firing it up

Simple. If you're confident you've wired it up correctly (*and* checked it), hook a multimeter to the dc output and connect power to the dc input. You should hear the transformers 'sing' immediately at quite a high pitch (around 6 kHz if your pitch sense is that good). The output voltage should rise to what you require, also. If you don't hear the transformers sing, then switch off and reverse the primary (a-b) connections of T1. Switch on and the inverter should burst into life. If it doesn't — or worse, bursts into flames! — switch off and take a look at your wiring. Correct any faults before trying again. In particular, make sure you have D1 the right way round.

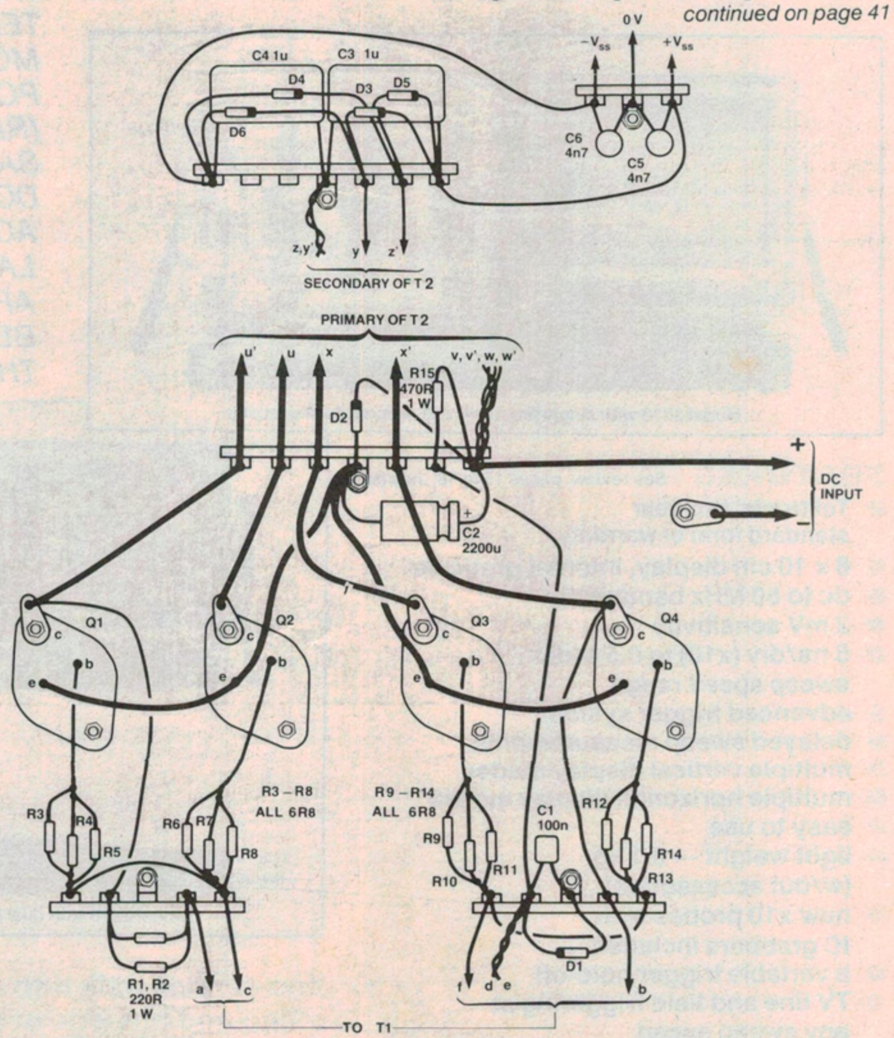
If all is working as it should, you could try and assemble a 'dummy' load for the output. A suitable set of power resistors will do. The exact resistance will depend on the supply and the load current it has to supply. We'll have to leave this to you.

Under load, the output voltage should be within a few per cent of what you require and power dissipation of the

continued on page 41 ▶



Mounting the power transistors.



General wiring diagram of the inverter. Layout is not critical. However, use heavy duty (32 x 0.2 mm) hookup wire for the heavy leads shown here for wiring the collectors and emitters of the four power transistors. Capacitors C5 and C6 provide high frequency bypassing of the output rails. Mount them close to where the supply output leads exit the case.

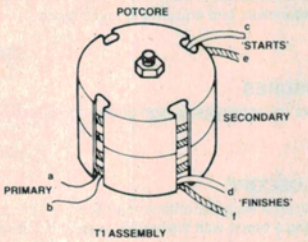
TRANSFORMER WINDING DETAILS

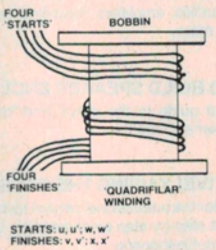
T1

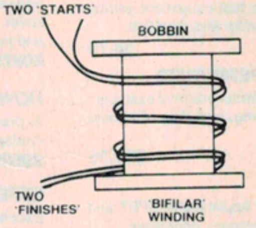
Core	FX2242, 36 mm dia. potcore, two halves with single section bobbin.
Wire	enamelled copper wire, about one metre of 1 mm diameter wire and about 1.5 metres of 0.4 mm.
Primary (a b)	20 turns of 0.4 mm wire wound evenly on the bobbin. Cover with a layer of insulation tape. Note that b is the start.
Secondary (c-d, e-f)	4 turns, bifilar wound (see diagram), of 1 mm wire spread over bobbin. Cover with a layer of insulation tape. Bring out the starts at one end of the bobbin, finishes at the other. Starts are c and e.
Notes	The above refers to T1 wound for a **12 V (nominal) supply.** On a **24 V (nominal) supply,** the primary (a-b) and secondary (c-d, e-f) should be doubled (i.e: 40 turns and 8 turns, bifilar, respectively). On a **32 V (nominal) supply,** the primary turns (a-b) should be increased to 50, the secondary (c-d, e-f) to 10 turns, bifilar.
Winding order	Wind the primary (a-b) **first.**

T2

Core	Philips EC-core assembly, as per the parts list.
Wire	enamelled copper wire, 0.4 mm dia. — length to suit application, and about two metres of 1 mm dia.
Primaries (u-v, u'-v', w-x, w'-x')	use 1 mm wire wound **quadrifilar** (see diagram), two volts per turn. i.e: for 12 V (nominal) supply — six turns; for **24 V (nominal) supply** — 12 turns; for **32 V (nominal) supply** — 16 turns.
Secondary (y-z, y'-z')	0.4 mm or 1 mm wire (to suit current) bifilar wound, two volts per turn. i.e: for ±40 V **supply rails** — 20 turns; for ±**50 V rails** — 25 turns, etc. See table of suggested outputs.
Winding order	Wind the quadrifilar primaries (u-v, u'-v', w-x, w'-x') **first.** Cover with two layers of insulation tape.







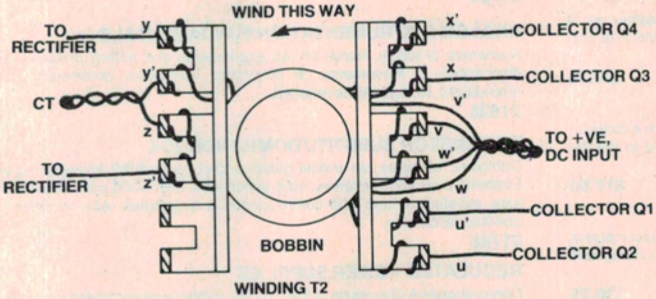


TABLE OF SUGGESTED OUTPUTS

OUTPUT	T2 SECONDARY	RECTIFIER	APPLICATION
±50 V	25 turns bifilar	2 x fullwave	Power 2 x ETI-477 (Series 5000) or 1 x ETI-498 module.
±40 V	20 turns bifilar	2 x fullwave	Power 2 x ETI-480 (50 W or 100 W versions) or 2 x ETI-470 modules.
±15 V	8 turns bifilar (Note 1)	2 x fullwave	Auxiliary secondary to power a preamp. e.g: ETI-481M guitar mixer/preamp or ETI-498 PA preamp.
1400 V	700 turns (Note 2)	voltage doubler (Note 2)	Power ETI-565 laser
12 V (from 24 V or higher dc input)	7 turns (Note 1)	fullwave bridge	Power 12 Vdc equipment from 24 V or higher dc input.

Note 1. This takes rectifier voltage drop into account.
Note 2. The secondary can drive the ETI-565 laser power supply directly, replacing the original power transformer.

▶ *from page 37*

transistors should be quite low. They should only get warm to the touch. (But don't touch them while the inverter's operating — you can get a 'belt'!) You will notice that the operating pitch of the inverter drops when a load is applied.

If all tests out well, hook up the inverter to the unit it is intended to power and try it out. With audio amp modules the 6 kHz oscillation frequency of the inverter should not be audible in the loudspeakers or should be a very, very long way 'down'. Where it is used in conjunction with a sensitive preamp, earthing loops and supply line induction into input leads and earths can cause 'break through' of the 6 kHz oscillation frequency. Take care with the routing of supply leads from the inverter. Keep them away from input leads and make sure the audio equipment is earthed at a single point, either at the power supply chassis or at the dc input common (negative).

Avoid radiation from the inverter inducing 6 kHz breakthrough into any equipment by keeping the inverter physically separate from such equipment. Both transformers have very little external field, but the wiring of the inverter carries considerable switching currents and can induce small, but significant, signals into sensitive audio or RF input leads. If you intend mounting it inside the equipment case, build it in a separate, shielded (i.e: all metal) enclosure and mount that inside the equipment but away from input circuitry.

Performance

This project was hastily built up one Saturday, from a 'lash-up' prototype, to power the ETI-498/499 PA amp for a function the following day! It worked first off. We didn't even have to reverse the primary of T1 to get the feedback phase correct!

Performance was faultless — for both the inverter and the PA.

Occasionally you win some! Breakthrough of the 6 kHz oscillation frequency was only evident with the low level mic gain and the volume pot on the PA amp set full up. Two secondaries were wound on the inverter output transformer (T2), one to provide the power amp with ±50 V and the other to provide the preamp with ±15 V. The breakthrough was subsequently found to be primarily due to a double-earthing problem.

The PA amp ran from a 12 V battery faultlessly for an all-day event. The inverter ran cool — admittedly, it was midwinter and quite cold, but efficiency approaches or exceeds 90% and in this sort of application, average dissipation is very low. ●