12-230V inverter with overload protection

This article describes the operation and construction of a 300VA inverter capable of supplying 230 volts at 50Hz from a 12 volt DC source. The output is voltage regulated, and has current limiting with ultimate thermal shutdown.

by I. M. WOODHEAD*

It is often necessary to operate 230V AC equipment in an area where the mains supply is unavailable. This may include, for example, electric hand tools, measurements in the field with laboratory equipment, or perhaps domestic appliances.

There are two alternatives: either an engine-driven alternator, or an inverter operating from a storage battery. If a large power output is required, or if it is necessary to operate the supply for an extended period of time, an engine-driven alternator is the obvious choice.

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But if energy requirements are relatively low, an inverter has the advantages of quietness, efficiency, and the possibility of exact frequency control.

A transistor inverter can be either self-oscillating or driven. However, the low-cost and relative compactness of a self-excited inverter are outweighed by two disadvantages: frequency and output voltage are notoriously variable with changes in supply voltage and load. In addition, the transformer used in a self-excited inverter has to meet tight specifications on leakage inductance, mutual inductance, and winding resistance if the operating frequency is to stay within the design limits.

In a driven inverter on the other hand, these problems are eliminated. The output voltage can be controlled by pulse width modulation and if it is necessary to control the frequency precisely (to drive chart recorders, turntables, or tape recorders for example), then this can be done using a crystal oscillator. It is the drive circuitry which determines the characteristics of the driven inverter; the transformer is merely used for voltage conversion so its specifications are not critical.

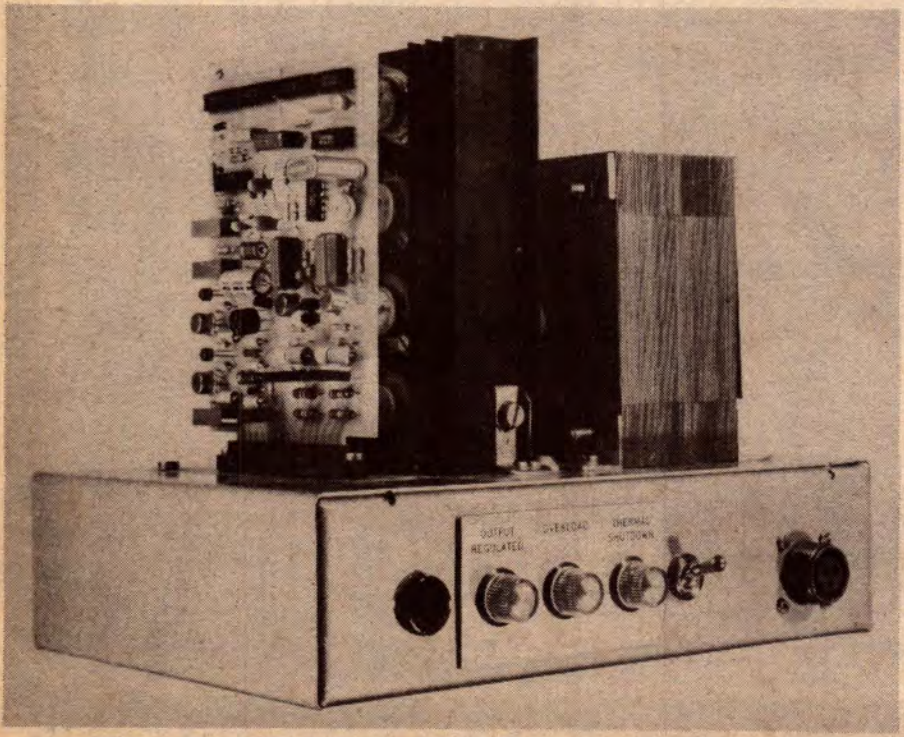
For all these reasons, a driven inverter is considered the most versatile and so forms the basis of the design described here.

Referring now to the circuit diagram, a conventional crystal oscillator using a CMOS NAND gate drives four series-connected CD4017 decade dividers. The crystal frequency is 1MHz so the resultant frequency is 100Hz. This is then fed to a CD4018 presettable counter wired in the divide-by-two mode to give two antiphase outputs.

These outputs are fed via NAND gates to drivers consisting of two series-connected Darlington pairs, and thence to the primary windings of the transformer. The NAND gates are capacitively coupled to the drivers to prevent one driver conducting should the oscillator fail.

Two output transistors are used for each phase. These ensure adequate gain, the typical gain of a 2N3771 being 20 at 15A, and 10 at 30A. The use of a transistor pair also reduces the saturation voltage since the current in each transistor is halved. In the prototype, with a 250W load, the saturation voltage when using one transistor was 2.0V. When the second was connected, the saturation voltage dropped to 1.1V.

The ideal way of ensuring that two paralleled transistors take on equal current is to use emitter resistors chosen so that the voltage across each resistor is of the order of 0.5V. This applies negative current feedback



Above is the prototype. A PC board accommodates most of the components, and is mounted on top of the chassis with the heatsink and power transformer.

which reduces gain and saturation voltage variations between the two transistors. However, this is rather wasteful of energy when large currents are involved. To avoid this, base resistors R14 and R15 along with R16 and R17 were used to equalise transistor collector currents. Current sharing using this method has proved to be quite satisfactory.

Diodes D1 and D2 conduct the reactive current after their opposite transistor pairs have ceased conduction. The current pulse they have to pass is of the order of 30A when the power factor is 0.2. However the conduction period is short and diode specifications indicate that a 2.5A rating is sufficient.

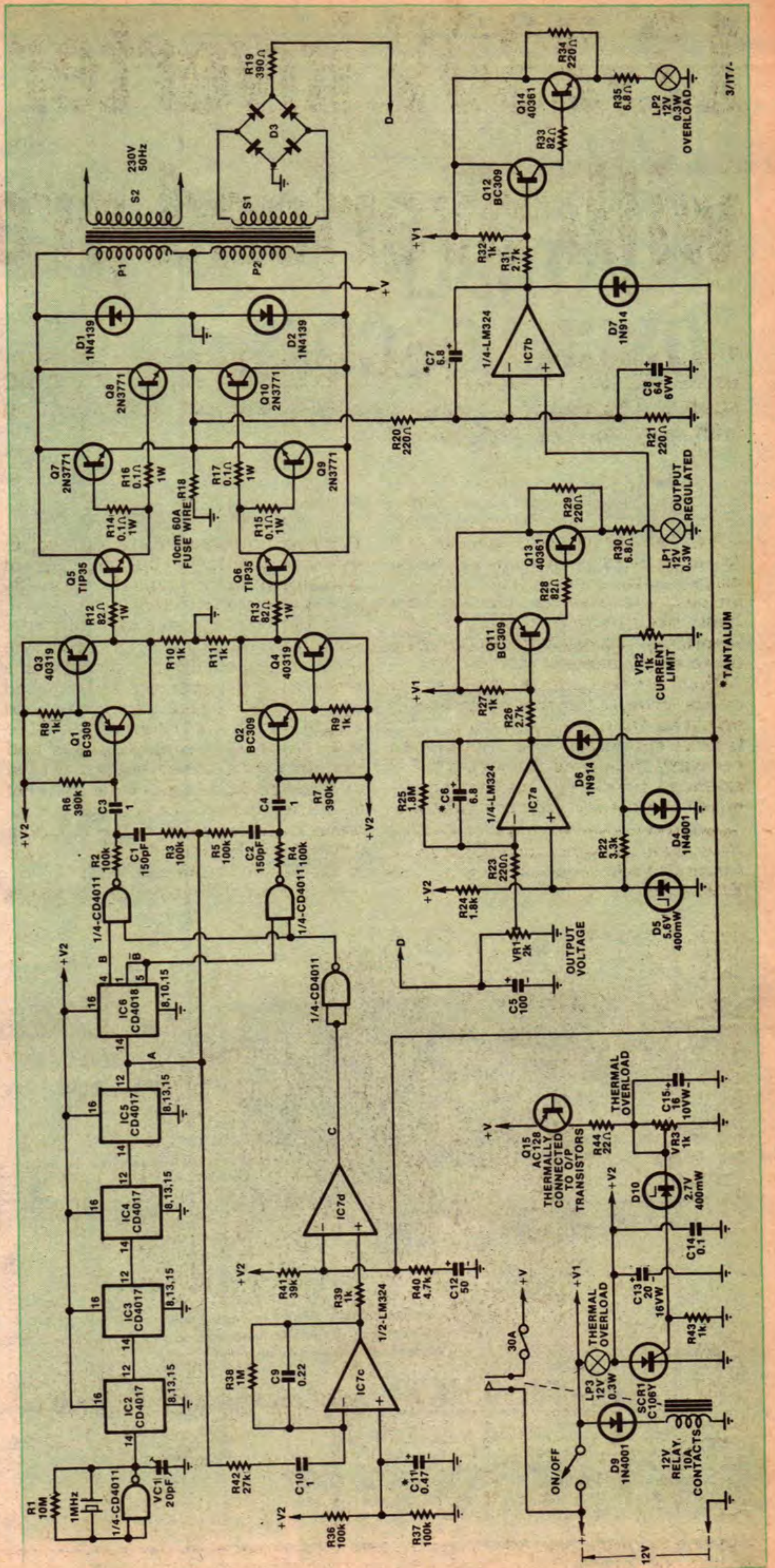
The 100Hz square wave is picked off the input of the CD4018 and differentiated by C1 and C2 with R3 and R5 before being fed to the inputs of each phase driver. This slows the switching times of the drivers and therefore reduces the maximum possible pulse width of each phase to slightly less than 180°, ensuring that under conditions of maximum power transfer, the current in one transistor pair has decayed to zero before the other pair begin to conduct. It also slows the switching time from 10us to 60us. At full power this results in a switching loss at only 0.6W which is negligible.

The power output of the inverter is determined by the pulse width of the signal fed to the driver stages. This is controlled by error voltages derived from both the output voltage and current. A sample of the output voltage is obtained from secondary winding S1. This voltage is rectified by the full wave bridge D3, filtered, and applied to the inverting input of operational amplifier IC7(a) via the output voltage control potentiometer VR1. The resulting DC voltage is compared in the amplifier with a 5.6V reference from D5 to yield a voltage error signal.

To obtain a current error signal, the supply current to the output transistors is passed through R18 to develop a voltage proportional to current. This is averaged and compared with a reference derived from diode D4, which is pre-regulated by D5.

Operational amplifier IC7(b), which amplifies the current error signal, has a large feedback capacitor to ensure stability when the inverter is in the current limited mode. The amplifier has, in this configuration, a large DC gain equal to the open loop gain of the amplifier — about 100dB — and an AC gain of almost unity.

The outputs of IC7(a) and IC7(b) are fed via a diode OR gate to the inverting



At right is the complete circuit diagram of the 12-230V inverter. Main features of the circuit include crystal-controlled output frequency, voltage regulation, and overload protection.

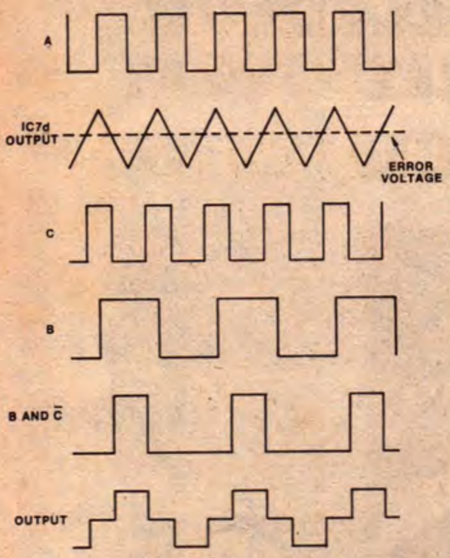
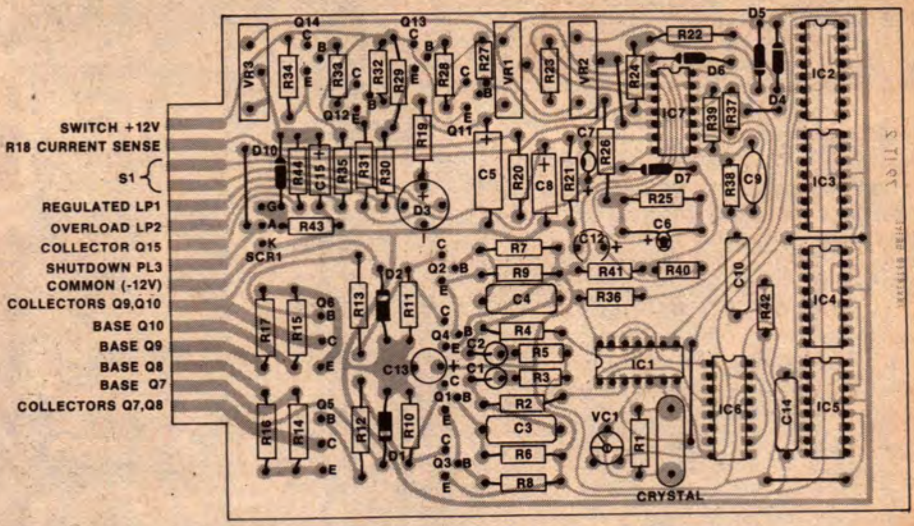


FIG. 1



This component overlay diagram shows the PC board as viewed from the component side. Make sure that polarised components are correctly oriented.

input of IC7(d). A delay circuit, consisting of R41, R40, and C12, controls the rate of change of voltage on this input. This is necessary because the long time constant of the voltage sensing circuit would otherwise cause the output voltage to overshoot when the unit was switched on. R40 is included to allow a small rapid change to be made to the output voltage. IC7(d) is wired as a comparator.

The DC error signal applied to the inverting input is compared with a 100Hz triangular wave fed to the non-inverting input. The triangular wave is generated by IC7(c), which integrates the 100Hz square wave obtained from the 4018 input.

The result of the comparison in IC7(d) is a pulse-width modulated 100Hz square wave. This signal is fed via an inverter to the NAND gates of each phase of the 50Hz drive, the phasing being such that the off-time of each phase is proportional to the error signal. Reference to Fig. 1 will clarify the formation of the various waveforms.

A National LM324 (or RCA CA324) quad op-amp is specified for IC7. This was chosen because, for the current error amplifier, the inputs are almost at zero volts. The 324 can be kept in the linear mode, even when the inputs are at ground potential.

The outputs of the error amplifiers are fed to discrete lamp drivers to indicate the running mode. Lamps were chosen because LEDs are difficult to see outdoors or under strong lights. The lamp driver transistors Q13 and Q14 each have a parallel resistor to keep a small current flowing through the lamp. This keeps the filament just less than red and its resistance somewhat greater than its value when cold. In addition, series resistors, R30 and R35, are used to ease the load on the 40361 drivers, thus enhancing their reliability.

As can be seen from the overlay diagram, the PC board has been designed to plug into a socket. If the socket is not going to be used, holes should be drilled through the contacts in order to properly secure the connecting wires before soldering.

Although the layout is not critical, the wires connecting the output transistors, transformer primary, fuse, relay contacts and battery leads should be capable of handling 30A. Attention should be paid to solder joints and to cleaning the enamel insulation from the transformer primary wires. Poor joints can cause considerable voltage drops at 30A. The supply fuse should have a rating of 30A-35A.

The current sensing resistor consists of about 100mm of 60A fuse wire

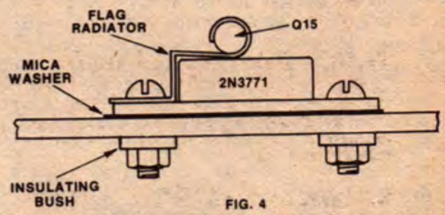


FIG. 4

mounted on either a component board or between two tag-strips. This wire has a diameter of 1.3mm but any copper wire with a diameter between 1mm and 2mm would be satisfactory.

Thermal overload sensing and protection is provided by Q15 and SCR1.

Since the prototype is to be used in arduous conditions, quality Canon sockets were used for the input and output. For general use however, flying leads for the battery supply and a conventional mains socket for the output

Performance of prototype . . .

Nominal supply voltage	**12.6V**
Output voltage	**230V**
Frequency	**50Hz ±0.01%**
Regulation	**5%**
Maximum load	**300VA**
Current limiting	**30A (primary)**
Efficiency (full resistive load)	**85%**

are suitable.

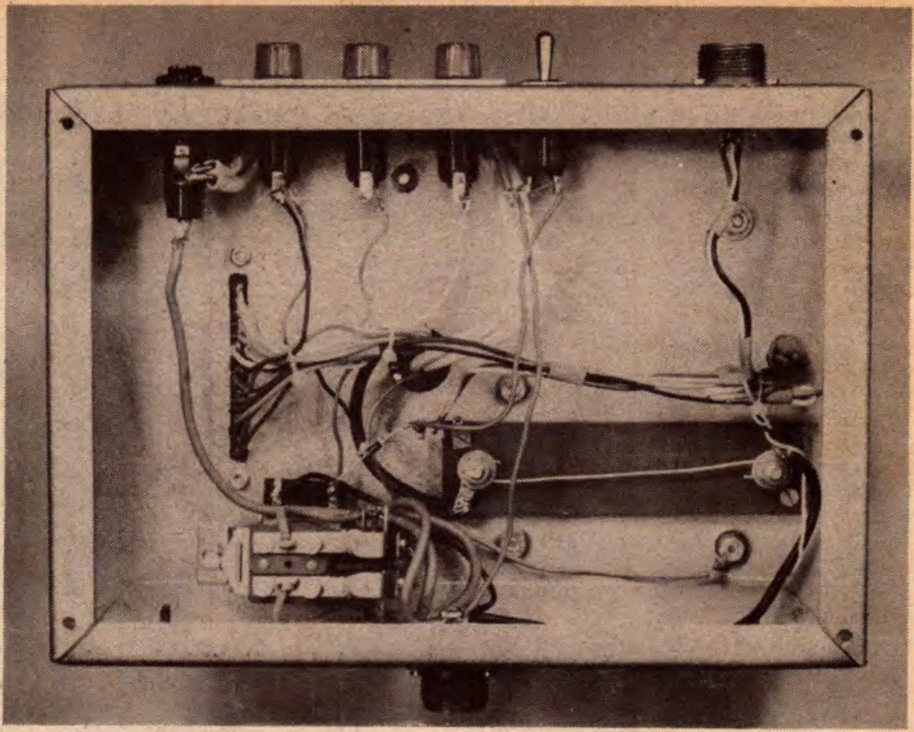
The output transistors are mounted on 20cm of extruded aluminium heatsink. Although the heatsinking requirements are quite small in the normal operating mode, all the power is dissipated in the output transistors when the output is shorted, so an appropriate heatsink is required. Q15 is thermally connected to one of the output transistors with a flag type heatsink. Mounting details are shown in Fig. 4.

The transformer may have a specification similar to a mains transformer and can be specified by the VA rating and the turns ratio. Suggested windings are:

Primary	10.5 — 0 — 10.5V
Secondaries	12V, 0.1A
	230V, 1.5A
Rating	300VA

The reverse polarity protection relay must have contacts which are capable of passing, but not necessarily switching, 30A. A relay with a 12V coil and having a contact rating of 10A will suffice. Ten-turn trimming potentiometers are used as they allow easier setting of the voltage and current limits.

The setting up procedure should be adhered to because, until it is set up, the inverter has no protection and failure of the output transistors could result. Before connecting the power, set the voltage and current potentiometers fully anticlockwise and the thermal overload fully clockwise. Apply the power and, if the unit has been correctly wired, it will operate with either the regulated lamp or the overload lamp illuminated.



An "under-the-chassis" view. R16 (10cm 60A fuse wire) is located on the tagboard at right, while below left is the relay. Leads to heatsink transistors and transformer pass through grommetted holes.

To set the output voltage, either a true RMS voltmeter will be required, or the adjustment will have to be carried out using an approximate comparison method. If an RMS meter is available, lightly load the inverter (using a 100W lamp for example) and advance the voltage control potentiometer until the meter, connected to the output, reads 230V.

To adjust the output using the comparison method, put a 100W lamp on the inverter output beside another 100W lamp connected to the mains. Advance the voltage control until the light output of each lamp appears the same. If during this procedure the overload lamp is illuminated, advance the current control one turn.

Note that because the waveshape of the output is non-sinusoidal, a normal voltmeter will give an erroneous reading.

PARTS LIST FOR 12-230V DC-AC INVERTER

SEMICONDUCTORS
1 CD4011 quad 2-input NAND gate
4 CD4017 decade dividers
1 CD4018 presettable counter
1 LM324 quad op-amp
4 BC309 or BC212 PNP transistors
2 40319 or BC640 PNP transistors
2 TIP35 NPN transistors
4 2N3771 NPN transistors
2 40361 or BC337 NPN transistors
1 AC128 PNP transistor
2 IN4139 silicon diodes
2 IN4001 silicon diodes
2 IN914 silicon diodes
1 2.7V 400mW zener diode
1 5.6V 400mW zener diode
1 B60 C800 bridge rectifier
1 C106Y SCR

RESISTORS (½W unless stated)
4 x 0.1 ohms 1W, 2 x 6.8 ohms, 1 x 22 ohms, 2 x 82 ohms, 2 x 82 ohms 1W, 5 x 220 ohms, 1 x 390 ohms, 8 x 1k, 1 x 1.8k, 2 x 2.7k, 1 x 3.3k, 1 x 4.7k, 1 x 27k, 1 x 39k, 6 x 100k, 2 x 390k, 1 x 1M, 1 x 1.8M, 1 x 10M, 2 x 1k trimpots (Bourns Model 3069), 1 x 2k trimpot (Bourns)

CAPACITORS
2 150pF ceramic or polystyrene
1 0.1uF polyester
1 0.22uF polyester
1 0.47uF 16V tantalum
3 1uF 16V tantalum
2 6.8uF 16V tantalum
1 16uF 10V electrolytic
1 20uF 16V tantalum
1 50uF 16V tantalum
1 64uF 6V electrolytic
1 100uF 16V electrolytic
1 20pF trimmer (optional)

MISCELLANEOUS
1 Transformer (see text)
1 PC board, 100 x 147mm, Code 79it2
3 12V 0.3W lamps and holders
1 1MHz crystal
1 15-way Amphenol PC socket, 0.156in connector spacing
1 12V SPST relay, 10A contacts
1 SPST toggle switch
1 240V ouput socket
20cm extruded aluminium heatsink
1 Flag-type heatsink
1 30A fuse and fuseholder
1 chassis with vented cover
4 rubber feet

NOTE: Resistor wattage ratings and capacitor voltage ratings are those used for the prototype. Components with higher ratings may generally be used, provided they are physically compatible.

After the output voltage has been set, put a 300W load on the inverter (three 100W lamps) and adjust the current control potentiometer until the inverter is just at the point of going into the overload state. Alternatively, if a true RMS ammeter is available, set the current limit to 30A.

The next step is to check and adjust the thermal overload protection. To ensure that it is operative, turn the overload control fully anticlockwise and then put a large load, for example a 1kW heater, on the output and switch on. The protection circuit should shut down the inverter within about 30 seconds, lighting all the lamps. However as a precaution, keep a finger on one of the output transistors. If the thermal overload circuit hasn't shut the unit down by the time the transistor is too hot to touch, switch off and recheck wiring.

Assuming that everything functions correctly, all that remains is to set the shutdown temperature. Allow the unit to cool and set the control fully clockwise. Switch on again and, when the transistors are almost too hot to touch, remove the load and turn the control back until the unit goes into the overload mode. Alternatively if a contact thermometer is available, set the temperature limit when the transistor case reaches 65-70°C.

The design of this inverter incorporates some features which may not be required and could therefore be omitted to reduce the cost.

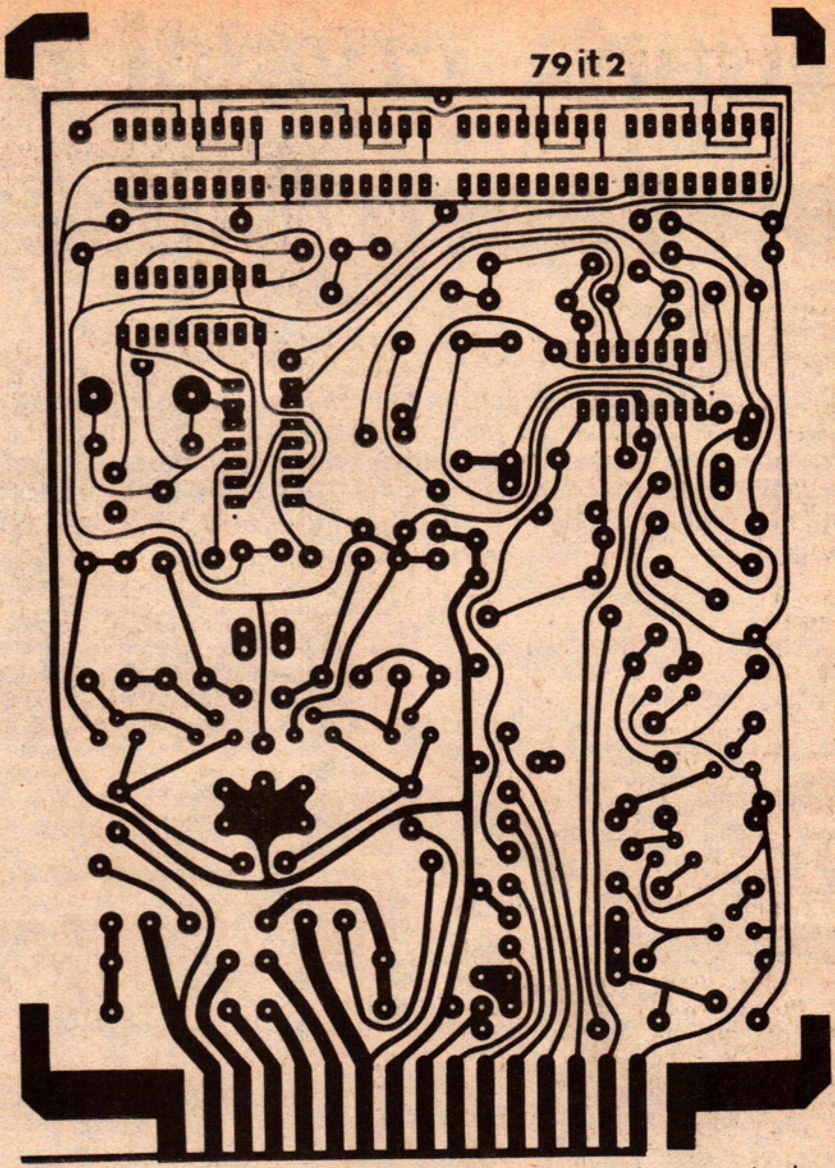
Crystal frequency control is only required when the load is particularly frequency sensitive. If this is not the case, the 4011 may be replaced with a 4093 quad two-input NAND Schmitt trigger. Then by replacing VC1 with a fixed capacitor and removing the crystal, a free running oscillator is formed (see Fig. 2). All the 4017 dividers are thereby eliminated and a wire link is taken from pin 4 of the 4093 to pin 14 of the 4018.

With this oscillator, the frequency depends somewhat on supply voltage but will suffice for most applications; it will still remain independent of load.

The reverse polarity protection relay may be eliminated. Reverse supply polarity will then blow the fuse. However diodes D1 and D2 may be destroyed by the heavy current surge so they should be replaced with diodes rated at more than 10A. Also, a diode should be wired across C14 with its anode to the negative rail so that the control circuits won't "see" the reverse voltage.

The lamp drivers can also be eliminated if desired. R26 and R31 should then both be changed to 1k and the rest of each driver circuit replaced by a LED, the anode of which is connected to the positive supply (see Fig. 3).

The prototype has an idling current of 1.2A with an efficiency of 85% at 250W. The inverter can handle power factors from zero to unity, lagging or leading. The output voltage is within 5% of 230V except for zero load and power factors deviating too far from unity. This is due to the voltage sensing circuit which reads the average output voltage rather than the RMS value.



Here is an actual size reproduction of the PC board. The shorting strip along the bottom is to allow the edge connectors to be gold plated.

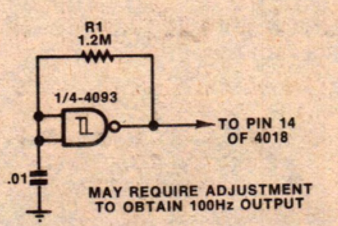


FIG. 2

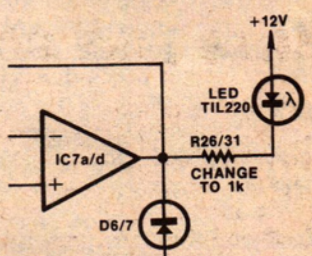


FIG. 3

Notes on components . . .

The transformer specified for this project is not a normal stock item. We understand that if there is sufficient interest, the transformer will be manufactured by Transcap Pty Ltd (Brookvale, Sydney) and distributed through Watkin Wynne Pty Ltd, 32 Falcon St, Crows Nest, NSW 2065. Alternatively, readers may be able to take advantage of the specifications given in the text by modifying an existing mains transformer. 2N3771 NPN power transistors are available from Radio Despatch Service, 869 George St, Sydney, NSW 2000.