New design uses power MOSFETs:

Improved 300W 12/230V inverter

Here's an improved design for a 300 watt inverter, suitable for powering 230V appliances away from the power mains. It features automatic self starting, voltage regulation, a low battery voltage indicator and simplified construction.

by PETER HARRIS

Power inverters are very popular devices, no doubt because they allow many standard electrical appliances like TV sets, lights and electric drills to be used away from the power mains. In effect, they convert the appliances so that they run from a 12V battery — or looking at it the other way around, they turn the 12V battery into a convenient source of 230V DC.

This new design for a 300 watt inverter has been developed as a replacement for an earlier design of similar power rating described in the September 1985 issue of *Electronics Australia*.

It is also a development from the 600W inverter design described in the December 1987 issue, and is in many ways a "little brother" to that design. Like its big brother, it has been developed by the R&D department of Altronics Distributors, in Perth. This company has retained copyright for the PC boards used in the project.

Complete kits for the new inverter are available from Altronics, under the catalog number K 6750. Please see the company's advertising for further details.

Compared with the previous 300W design, this new inverter uses a simpler circuit with fewer parts. It also uses a pair of power MOSFET devices for the input DC switching, instead of the paralleled pairs of bipolar power transistors used in the earlier design. This gives better thermal stability, because of the intrinsic stability of MOSFETs compared with bipolars. It also makes assembly easier.

Features of the new design include voltage regulation, a LED indicator which shows when the battery is getting low, and a choice of either manual or autostarting, at the flick of a switch. In auto-start mode, the inverter draws virtually no current from the battery until the 230V appliance in the load circuit is plugged in and turned on.

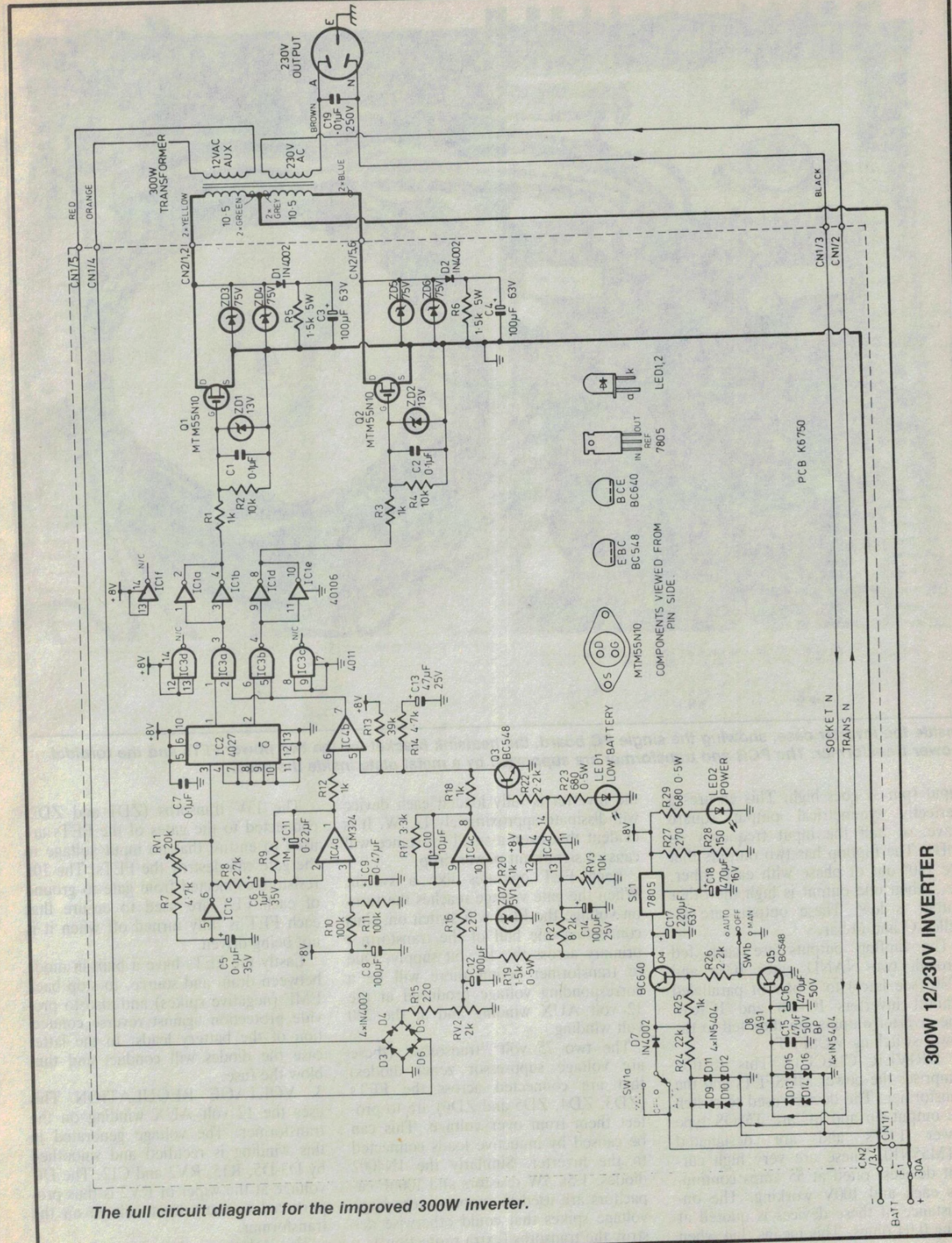
Circuit description

The circuit of the inverter can be broken up into several sections, as this will make it easier to understand. They are 1. the oscillator; 2. the driver circuit; 3. the voltage regulation circuit; 4. the power supply and auto-start circuit; and 5. the low battery voltage shut-off circuit.

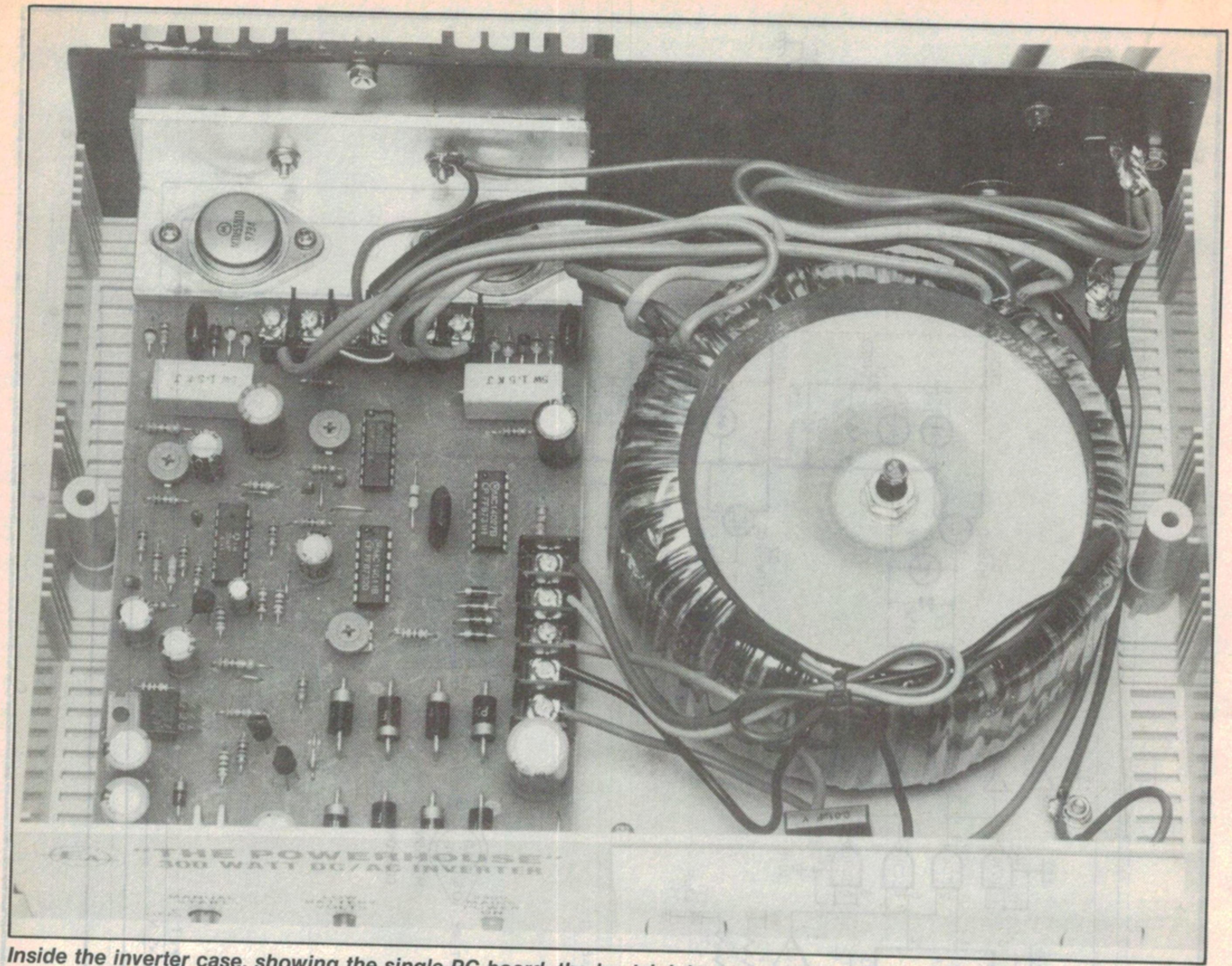
1. OSCILLATOR This uses an RC circuit using one section of a 40106 or 74C14 CMOS Schmitt trigger (IC1c).

The oscillator works as follows: Initially the input to pin 5 of IC1c is low and the output is high. Capacitor C5 will start to charge up via R7 and RV1 until the upper hysteresis level of the Schmitt trigger is reached, at which point the output will switch low. This then starts to discharge the capacitor, until the lower hysteresis level is reached, when the output switches high again. The frequency at which this is set to operate is at 100Hz — twice the ultimate output frequency.

The output of IC1e pin 6 is fed into pin 3 of IC2, a dual flipflop connected in toggle mode. In this mode the outputs only change state when the clock



The full circuit diagram for the improved 300W inverter.



Inside the inverter case, showing the single PC board, the heatsink bracket for the two power FETs and the toroidal power transformer. The PCB and transformer are supported by a metal plate inside the case.

input (pin 3) goes high. This ensures a perfectly symmetrical output square wave, at half the input frequency — 50Hz. The flipflop has two outputs that are 180° out of phase with each other, i.e., when one output is high the other output is low. These outputs are labelled Q and Q-bar.

The flipflop outputs are each fed through two NAND gates IC3a and IC3b (see later) to a pair of paralleled Schmitt inverters IC1a/b and IC1c/d. The inverter outputs are then fed to the power switching MOSFETs.

2. DRIVER CIRCUIT This section comprises the power MOSFETs and the transformer. The devices used to switch the output on and off are TMOS type power FETs and are designated MTM55N10. These are very high current devices, rated at 55 amps continuous each and 100V working. The on-resistance of these devices is quoted at being 0.04 ohms. This means that when the inverter is fully loaded each device will dissipate approximately 12.5W. It is evident that even a small resistance will cause a significant power drop.

Each FET operates like a switch. When the gate voltage reaches the turn-on voltage the FET will switch on, thus connecting one half of the transformer primary across the 12 volt supply. Due to transformer action there will be a corresponding voltage produced at the 12 volt AUX winding and at the 230 volt winding.

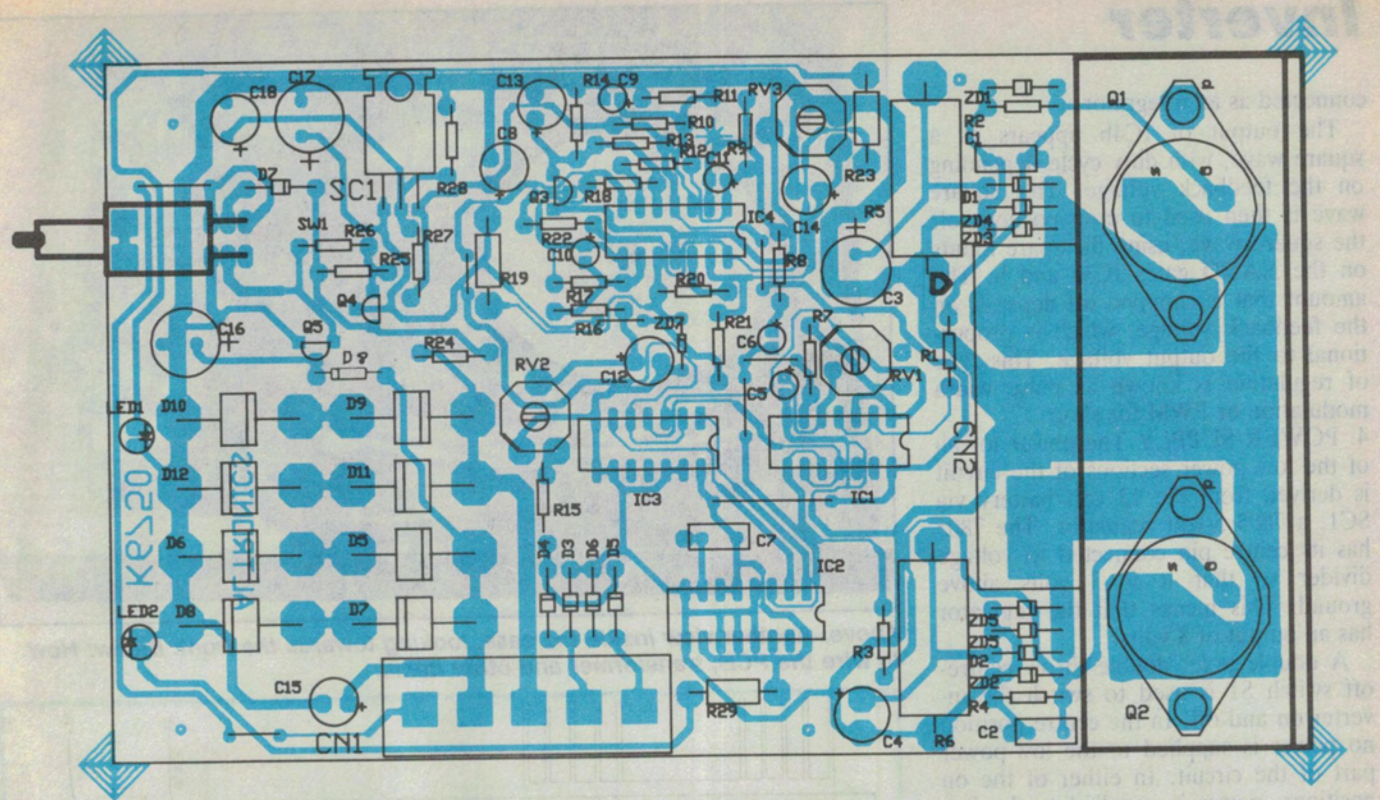
The two 75 volt "transorbs" (these are voltage suppressor zener diodes) that are connected across the FETs (ZD3, ZD4, ZD5 and ZD6) are to protect them from over voltage. This can be caused by inductive loads connected to the inverter. Similarly the 1N4002 diodes, 1.5k 5W resistors and 100uF capacitors are used to suppress very large voltage spikes that could otherwise destroy the transorbs (extra protection!).

The 13V transorbs (ZD1 and ZD2) connected to the gates of the FETs are used to ensure that no input voltage to the gate can destroy the FETs. The 10k resistors connected from gate to ground of each FET are used to ensure that each FET is fully turned off when it is not being driven.

Lastly the FETs have a built-in diode between drain and source, to stop back EMF (negative spikes) and also to provide protection against reverse connection of the battery leads. In the latter case the diodes will conduct and thus blow the fuse.

3. VOLTAGE REGULATION This uses the 12 volt AUX winding on the transformer. The voltage generated in this winding is rectified and smoothed by D3-D5, R15, RV2 and C12. The DC voltage at the wiper of RV2 is thus proportional to the output voltage on the transformer.

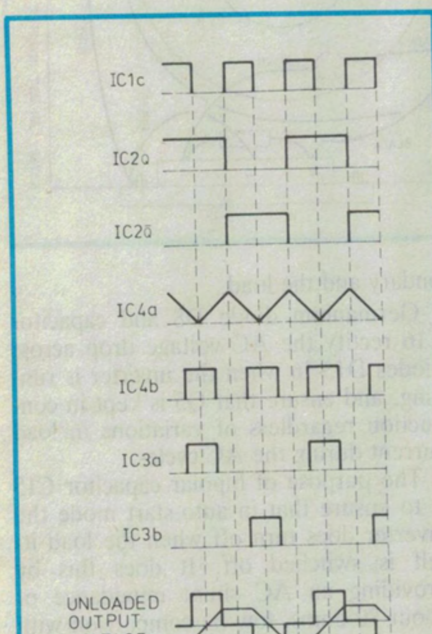
This voltage is then fed into an in-



Use this overlay diagram as a guide in wiring the components to the inverter's PC board.

verting op-amp formed by IC4c, connected as an inverting comparator with a gain set at 3300/220 = 15. This compares the voltage from RV2 with a nominal 5.1V reference voltage developed by zener diode ZD7, applied to the positive op-amp input. So if the feedback voltage from RV1 falls below 5.1 volts, the output of IC4c will swing high. The value of the 3.3k resistor in the feedback path has been chosen for the best regulation characteristic.

The output from here is taken to IC4b. This op-amp is set up as a comparator, which compares the control voltage from IC4c with the 100Hz triangle wave produced by IC4a from the master oscillator IC1c. Op-amp IC4a is



The basic waveforms found inside the inverter. They show how the circuit works.

SPECIFICATIONS

Nominal supply voltage .... 12V DC
Output voltage .... 230V nominal
Frequency .... 50 Hz ± 5%
Regulation .... see table below
Maximum load 300VA
Standby current 16mA

LOAD POWER (W)	INPUT CURRENT (A)	INPUT VOLTAGE*	OUTPUT VOLTAGE** V RMS (AVG)
0	0.03	12.62	249 (246)
40	3.2	12.47	242 (240)
100	7.7	12.39	239 (239)
150	13.1	12.2	228 (242)
300	28.5	11.95	178 (193)

Notes

* During tests, prototype unit was powered from a 50 amp-hour battery. Input voltage variations shown are therefore likely to be typical.

** As the inverter's regulation circuit uses an average value measuring rectifier, its output voltage is substantially constant in terms of average value (figures in brackets). Due to changing form factor in the PWM rectangular output waveform, this causes changes to the RMS output as sown. Apart from lighting or heating loads, the average value is likely to be more relevant in many applications.

Inverter

connected as an integrator.

The output of IC4b appears as a square wave, with duty cycle depending on the feedback voltage. This square wave is then used to crop portions off the square wave, using the spare inputs on the NAND gates IC3a and b. The amount that is chopped off depends on the feedback voltage, which is proportional to the output voltage. This type of regulation is known as pulse width modulation or PWM for short.

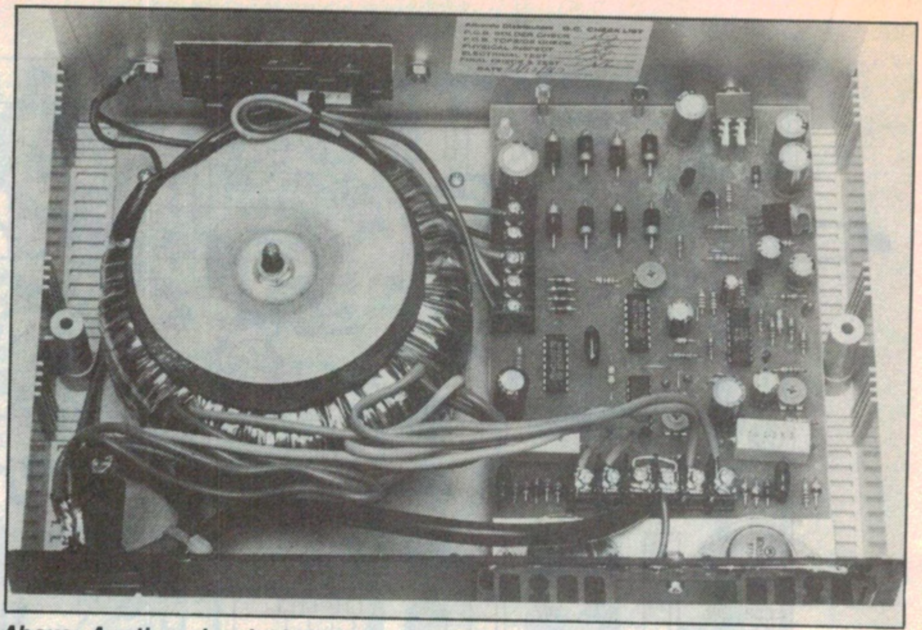
4. POWER SUPPLY The power for all of the low power sections of the circuit is derived from the 12 volt battery via SC1, a 7805 5-volt regulator. The 7805 has its centre pin connected to voltage divider so that it is 3 volts above ground. This means that the regulator has an output of 8 volts.

A double pole, double throw centre-off switch S1 is used to switch the inverter on and off. In the centre position no power is supplied to the low-power part of the circuit. In either of the on positions, power is supplied to the low power circuitry via D7 and Q4.

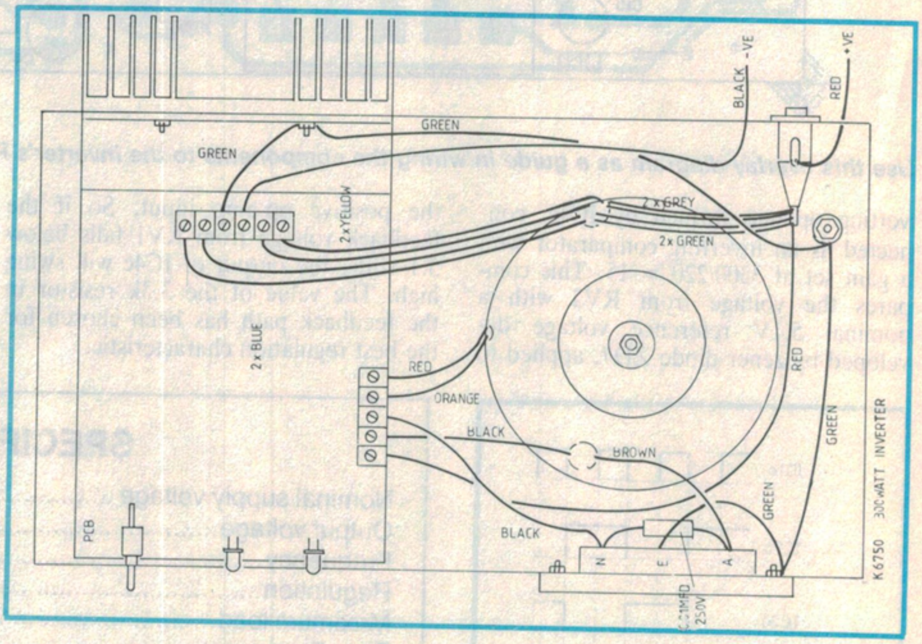
In the manual start position, Q5 is shorted out, so that Q4 will turn on and supply power to the regulator and the rest of the circuit. This is handy for starting devices that do not draw any current until they have 230 volts across them (e.g., fluoro lights).

In the auto-start position of S1, transistor Q5 is fed with a small DC forward bias whenever a load is connected to the inverter's 230V output. This bias current flows from the 12V battery via D7, R24, the 230V output winding of the transformer, the load itself and diode D8. The current is sufficient to saturate Q5 which turns on Q4 as before to power the circuit.

Diodes D9-D16 protect the auto-start circuitry from damage when the inverter is operating, by limiting the voltage applied to either R24 or D8 to ±1.3V peak. At the same time, the diodes complete the inverter output circuit, providing a high-current and low impedance link between the transformer secondary and the load.



Above: Another view inside the case, looking towards the front. Below: How to wire the PCB, transformer and other items.



Germanium diode D8 and capacitor C16 rectify the AC voltage drop across diodes D13-16 when the inverter is running, and ensure that Q5 is kept in conduction regardless of variations in load current during the AC cycles.

The purpose of bipolar capacitor C15 is to ensure that in auto-start mode the inverter does turn off when the load itself is switched off. It does this by providing an AC shunt impedance of about 70 ohms, low by comparison with the inverter's own output smoothing capacitor C19 and any small click-filtering or suppressor capacitors likely to remain connected across the 240V line inside the load appliance when it is nominally

WARNING!

Equipment to be operated from this inverter must be in a safe condition, since the voltage produced are at mains potential. This means that frayed cords, exposed unearthed metal parts (unless double insulated), and broken or wet insulators must be repaired before the item is used. **Note that contact with both output lines could prove fatal!**

It is also important to keep the electrolyte level of the battery above the plates. This prolongs battery life and reduces the risk of the battery explosion. When charging the battery, do so in a well ventilated area. They hydrogen given off from a charging battery is highly explosive. When connecting the inverter to the battery, make sure that the appliance is not plugged in so that sparks do not occur near the battery.

turned off. Without C15, there could well be enough AC flowing through D13-16 via load circuit capacitance to keep the inverter running.

LED2 is connected across the 8V supply rail via R29, to indicate when the inverter is operating.

Note that although the inverter's output FETs are permanently connected to the battery via the primary windings of the transformer and fuse F1, they do not conduct any current unless drive signals are applied to their gates. So when power is removed from the low-power section of the inverter, the output FETs automatically turn off as well.

5. LOW BATTERY VOLTAGE INDICATOR This uses IC4d to compare a proportion of the input battery voltage produced across RV3 with a reference voltage formed by 5.1 volt zener diode ZD7. If the input voltage is less than the reference voltage, then the output of the comparator will go high, thus turning on LED1 and Q3. Q3 shorts pin 5 of IC4b to earth, thus stopping the inverter from running, RV3 is used to set the low battery cutoff point.

Construction

The construction of the inverter is very simple. The majority of the components mount on a single PCB measuring 176 x 103mm.

Start by assembling the smaller driver PCB (K 6770A). First mount and solder all links and resistors, then the smaller diodes. Follow the overlay diagram carefully, to ensure correct orientation.

Progress from here by next positioning the smaller capacitors, trimpots, ICs and transistors, leaving the eight large diodes and terminal block until last. Once again take extreme care with component orientation. With the large diodes, mount them off the PCB by a couple of millimetres, to allow better heat dissipation.

Take care in identifying the transorbs (transient suppressor diodes). These are clearly marked on their bodies. Also take note of their orientation. With the 1.5k 5W resistors, mount these also off the board to allow for some heat dissipation.

The indicator LEDs and switch SW1 mount on the front end of the PCB. We used a red LED for the "battery low" position, and a green one for the power indicator.

Finally mount the completed board onto the heatsink bracket, by mounting the power MOSFETs. It is important to note here that the output devices are MOS devices, and can be damaged by careless handling. Make sure you are earthed before you handle them. The MOSFETs have to be insulated from the angle bracket, using the insulating mica washers provided.

Firstly smear the face of each MOSFET with heatsink compound. Align the PCB with the angle and position the MOSFET through and bolt down lightly. Check that the other holes line up correctly and the PCB is square with the back of the angle. When this is done tighten up the screws. Check with a multimeter (on the low ohms range) that no part of the MOSFET is touching the heatsink prior to soldering it in.

Install both devices in the same way. When all are positioned and you have checked for shorts, solder the pins with an earthed soldering iron.

With the PCB complete, now assemble all the bits into the chassis. The toroidal power transformer bolts to a metal baseplate, which is held into the case by nine PK screws to ensure rigidity.

The rear of the PCB is supported by two 3mm bolts, which attach the heatsink bracket to the rear of the case (and the main heatsink). The front of the PCB is supported by two nylon standoffs with the LEDs and switch SW1 protruding through the front panel.

Note that the main heatsink attaches to the outside of the case rear by two 3mm screws, separate from those attaching the PCB bracket.

Use silicone grease under both heatsink brackets where they contact the rear panel, to ensure good thermal contact.

Use 4mm bolts also to mount the double GPO (general-purpose outlet) to the front. Use a 3mm x 12mm bolt to secure the earth lead to the chassis plate, and ensure that this connection is TIGHT. The fuse holder is mounted on the rear panel using 3mm x 9mm bolts. This completed, it is now time to wire the unit.

Wiring the unit is straightforward as the only connections are to the transformer and to the power outlet. If the wiring diagram is followed carefully you should have no problems.

Make sure you use 240V cable for the mains connections, and make sure all high current connections are tight. Now it's time for testing.

Parts List

Semiconductors

7 1N4002 diodes
8 1N5404 diodes
1 0A91 germanium diode
1 5.1V 400mW zener
2 BZT 03 — 13 transient diodes
4 BZT 03 –75 transient diodes
2 MTM55N10 TMOS FET
1 BC 640 transistor
2 BC 548 transistors
1 7805 5V regulator IC
1 5mm green LED
1 40106/74C14 Schmitt trigger
1 4027 dual JK flipflop
1 4011 quad NAND gate
1 LM324 quad op-amp

Capacitors

1 .01uF 250V AC rated
3 0.1uF metallised polyester
1 0.22uF 35V tag
1 0.47uF 35V tag
2 1uF 35V tag
1 10uF 16V RB electro
1 47uF 16V RB electro
1 47uF 50V RB bipolar
3 100uF 25V RB electro
2 100uF 63V RB electro
1 220uF 25V RB electro
2 470uF 16V RB electro

Resistors (all 1/4W unless noted)

1 150Ω
2 220Ω
1 270Ω
6 1k
2 2.2k
1 3.3k
2 4.7k
1 8.2k
1 22k
1 27k
1 39k
2 100k
1 1M
2 1.5k 5W
2 680Ω 1/2W
1 1.5k 1/2W
1 2k 10mm horizontal trimpot
1 10k 10mm horizontal trimpot
1 20k 10mm horizontal trimpot

Hardware

6-way PCB terminal block (1), 5-way PCB terminal block (1), PCB supports (2) DPDT centre-off switch (1), rubber feet (4), 5AG panelmount fuse holder (1), 4mm solderlugs (3), 3mm x 10mm round-head bolts and nuts (8), 3mm x 12mm csk had bolts and nuts (2), 4mm x 12mm bolts and nuts (2), double power point (1), chassis and lid (1), self tapper 4G x 1/4 (9), cable grommets (2), input leads (1 ea), heavy duty hook up wire, rainbow wire, solder, tinned copper wire light and heavy duty, sleeving, 5AG 30A fuse (1), 300W toroidal transformer and mounting hardware (1), PCB K6750.

Inverter

Set up and testing

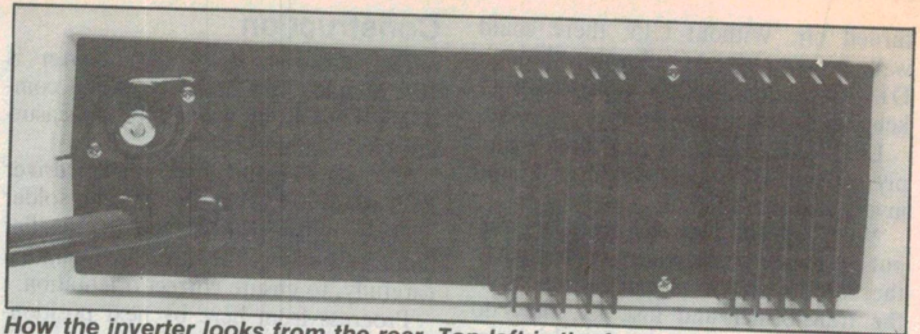
Once the inverter has been constructed and all the components and wiring have been checked, then power can be applied to the circuit.

If it draws large amounts of current (or blows the fuse), then disconnect the two 1k resistors that feed the gate of each FET (R1 and R3), and try again. If it still blows fuses, then there is a problem with the power FETs, so disconnect the battery leads and find the problem.

The most probable cause of blowing fuses would be a short from the case of a FET to ground or the battery leads are the wrong way around! Note that there will be a small spark when it is connected up. This will be the two 100uF capacitors charging up.

If the fuse only blows when R1 and R3 are reconnected, there is a problem on the control PCB. Pull the PCB out of the case and give it a good hard look. 95% of all problems occur though careless construction, bad soldering, components wired in the wrong way around, etc.

Once the unit has passed the "smoke test" you can proceed to set it up properly. If you have access to a frequency counter, then connect it to either R1 or R3. Rotate RV3 fully anti-clockwise and set RV2 and centre position. Connect a 40W (or similar) light globe to the output and switch on (either MANUAL or AUTO).



How the inverter looks from the rear. Top left is the fuse.

Adjust RV1 for a reading of 50Hz on the frequency counter. If no frequency counter is available, then the use of a frequency sensitive device can be used to set the frequency. An example would be a mains clock, a record turntable or a small fan with an induction motor. The speed of these devices will vary with frequency — so adjust RV1 so the speed of the devices matches that of the same device operated of the mains.

Next set the output voltage. This can be done using a true RMS meter, or by using the comparison method. Plug a small load into the inverter (approximately 60W) and switch on. Measure the output voltage and adjust RV2 for a reading of 230 volts. Alternatively, compare the brightness of the globe to the brightness of the same globe running off the mains. Adjust RV2 accordingly.

The last thing to do is to set the low battery voltage cutoff point. For this a variable voltage supply is needed. disconnect R1 and R3 and reconnect and supply. Set the DC supply for 10 volts, then adjust RV3 until the LED just comes on. Finally reconnect R1 and R3 leads and give the inverter a full test. Then put the lid on.

You should now have a fully functional 300 watt inverter. EA