240V AC from 12V or 24V DC:

The Powerhouse

This husky new DC-AC inverter design picks up where most of the others drop off. It will deliver up to 600VA of smooth mains power from either a 12V or 24V DC source, and is therefore ideal for campers, farmers, boating enthusiasts and building site workers.

by PETER HARRIS

Power inverters are very handy devices, providing the ability to use mains-powered equipment, tools and appliances in places far removed from a normal mains power point. Fully electronic inverters also offer the advantage of quiet, pollution-free operation, plus the convenience of automatic no-hassle operation.

The last inverter to be described in *Electronics Australia* was the 300VA unit of September 1985. This has been extremely popular, but almost inevitably there were those who wrote in asking "Haven't you got a design for one delivering higher power?". Until now we didn't, but now we do. If you're one of those who've been waiting, I think you'll find your wait has been worthwhile.

The new Powerhouse inverter delivers a full 600VA — twice that of the previous design. It also features the ability to run from 24V DC as well as the 12V accepted by the earlier design. Other features include voltage regulation, a LED indicator which shows when the battery voltage is getting low and a choice of either manual or auto starting, 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 turned on.

Both the DC input and AC output of the Powerhouse are fused, using readily available 3AG cartridge fuses. Replacement fuses should therefore be available wherever the inverter is taken — even back o'Bourke.

By the way, the Powerhouse design has been developed by the R&D department of Altronics Distributors, in Perth WA. This company has retained copyright for the PC boards used in the project. Needless to say complete kits for the Powerhouse are available from Altronics, under the catalog number K 6770 — please see the company's ads.

Circuit description

The circuit 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 (IC1).

The oscillator works as follows: Initially the input to pin 6 of IC1 is low and the output is high. Capacitor C1 will start to charge up via R1 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 at 100Hz — twice the ultimate output frequency.

The output of IC1 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 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 (see later) to a pair of paralleled Schmitt inverters. The inverter outputs then fed to the power of the PCB.

2. DRIVER CIRCUIT This section is on the K 6770B PCB. 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 are (ZD2, ZD3, ZD8 and ZD9) are to protect them from over voltage. This can be caused by inductive loads connected

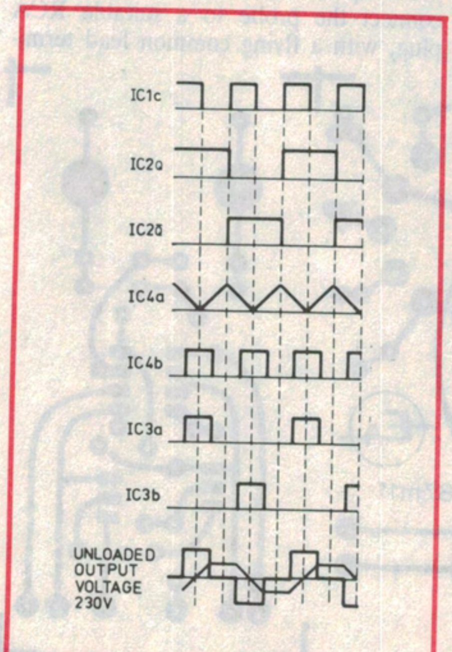
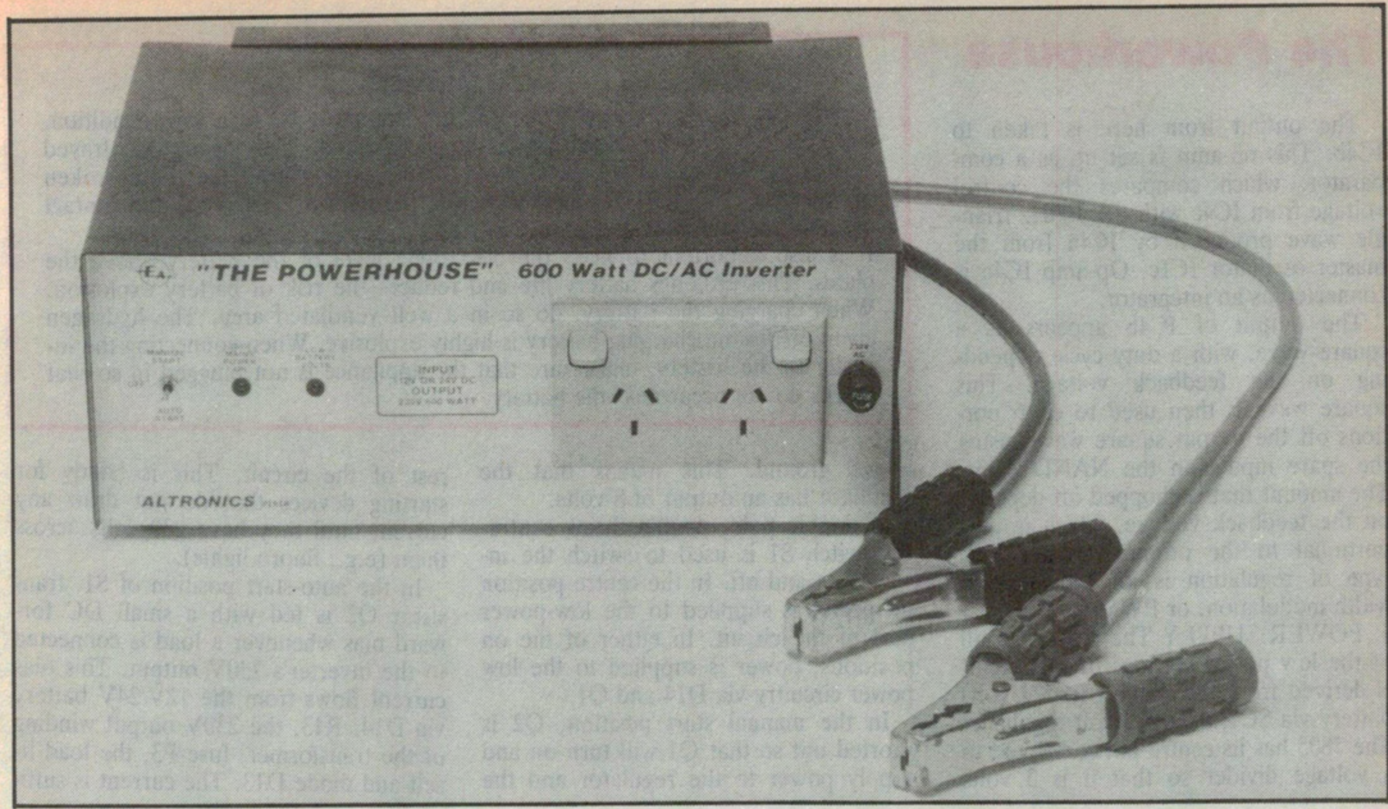


Fig.1: The main waveforms present in the Powerhouse when it's working.



As the battery clips suggest, the Powerhouse inverter is meant for those BIGGER jobs . . .

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, ZD5, ZD6 and ZD7) that are connected to the gates of the FETs are used to ensure that no input voltage to the gate can destroy the FETs. The 4.7k 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 fuses.

The power transformer of the inverter has two pairs of primary windings, and these are connected according to the battery voltage to be used. For use with a 12V battery the second pair of windings is connected in parallel with the first, while for use with a 24V battery they are connected in series.

3. VOLTAGE REGULATION This utilises the 12 volt AUX winding on the transformer. The voltage generated in this winding is rectified and smoothed by D1-D4, R8, RV2 and C9. 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 inverting 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 ZD1, 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.

SPECIFICATIONS

Nominal supply voltage	12V or 24V DC
Output voltage	see table below
Frequency	see table below
Regulation	see table below
Maximum load	600VA
Standby current	16mA

LOAD POWER (W)	INPUT CURRENT (A)	INPUT VOLTAGE*	OUTPUT VOLTAGE ** V RMS (AVG)	OUTPUT FREQUENCY (Hz)
0	0	13.2	250 (225)	50.8
40	2.9	13.0	242 (223)	50.6
100	7.9	12.7	237 (220)	50.6
150	13.6	12.5	233 (221)	50.6
300	29.5	12.2	225 (225)	50.7
450	45.7	12.0	219 (230)	51.6
600	66.9	11.8	204 (223)	51.0

Notes

* During tests, prototype unit was powered from two 40 amp-hour batteries connected in parallel. 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 shown. Apart from lighting or heating loads, the average value is likely to be more relevant in many applications.

WARNING!

Equipment to be operated from this inverter must be in a safe condition, since the voltages 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 battery explosion. When charging the battery, do so in a well ventilated area. The 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.

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 connected as an integrator.

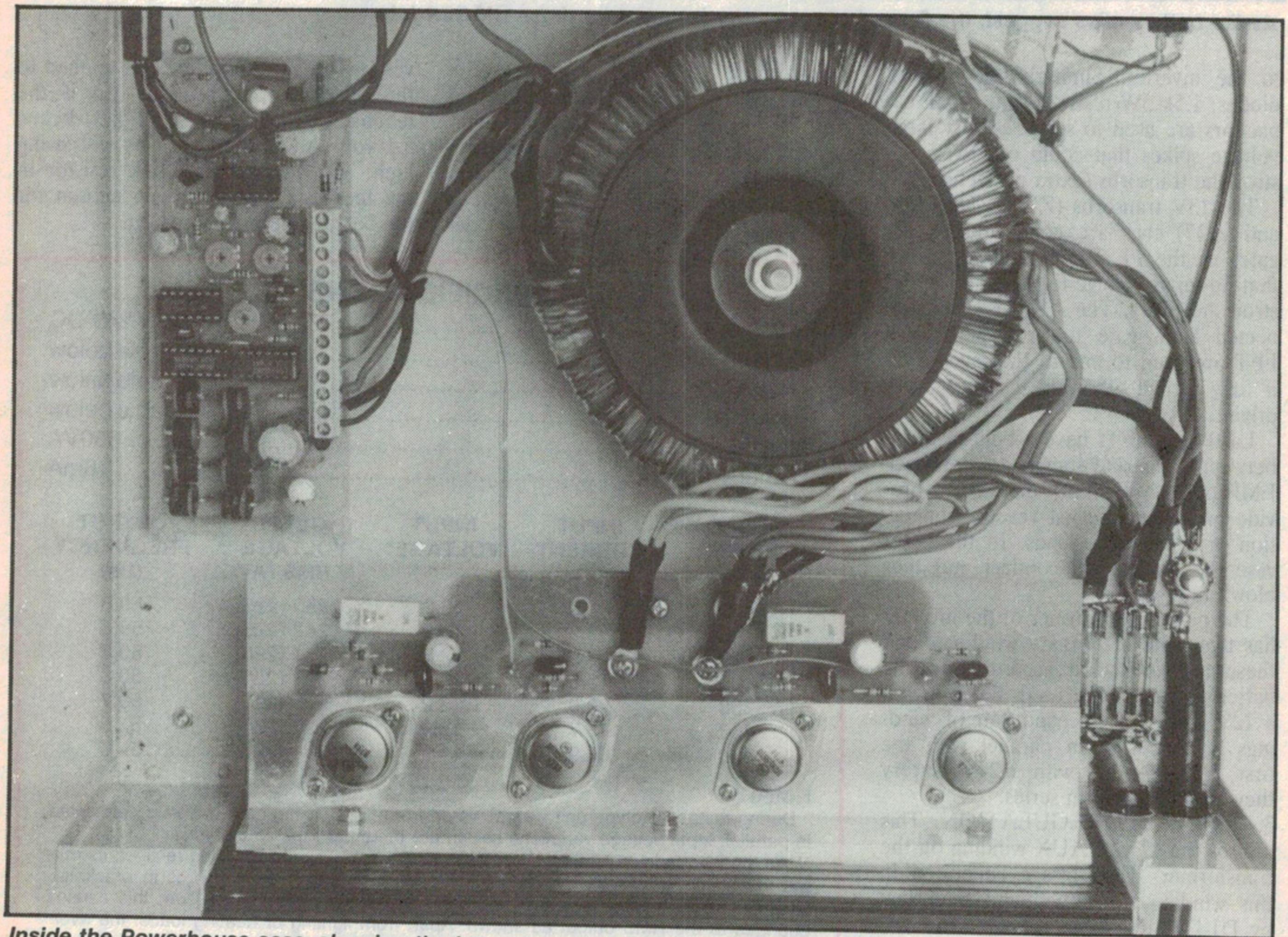
The output of IC4b appears as a square wave, with a duty cycle depending on the feedback voltage. This square wave is then used to chop portions off the output square wave, using the spare inputs on the NAND gates. The amount that is chopped off depends on the feedback voltage, which is proportional 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 (or 24 volt) battery via SC1, a 7805 5 volt regulator. The 7805 has its centre pin connected to a voltage divider so that it is 3 volts above ground. This means that the regulator has an output of 8 volts.

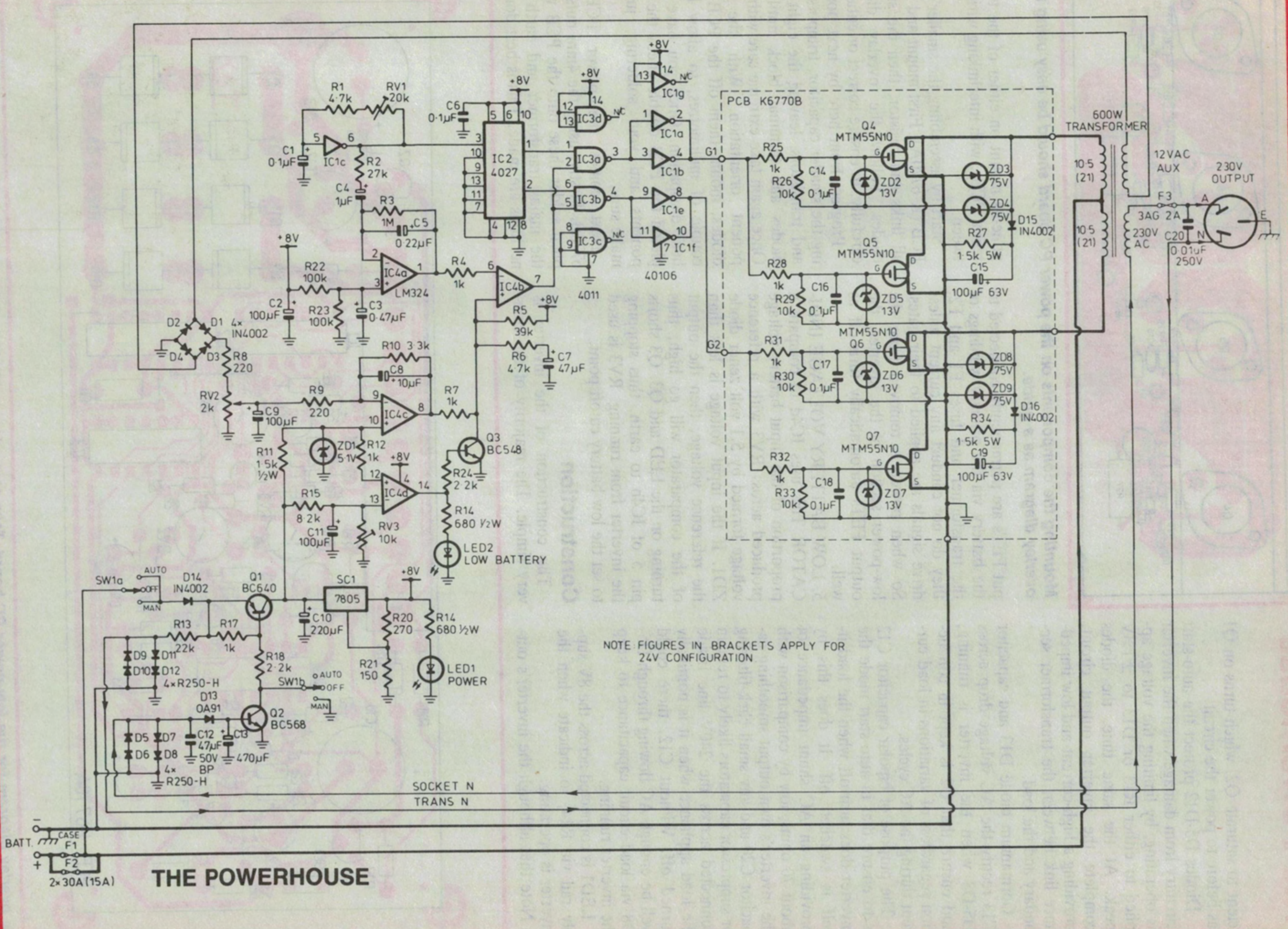
A double pole, double throw centre-off switch S1 is used to switch the inverter on and off. In the centre position no power is supplied to the low-power part of the circuit. In either of the on positions, power is supplied to the low power circuitry via D14 and Q1.

In the manual start position, Q2 is shorted out so that Q1 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 Q2 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/24V battery via D14, R13, the 230V output winding of the transformer, fuse F3, the load itself and diode D13. The current is suffi-



Inside the Powerhouse case, showing the large wound-core transformer. Note that the power PCB in this prototype unit was a mirror image of the final design. The full circuit schematic is shown opposite.



THE POWERHOUSE

cient to saturate Q2, which turns on Q1 as before to power the circuit.

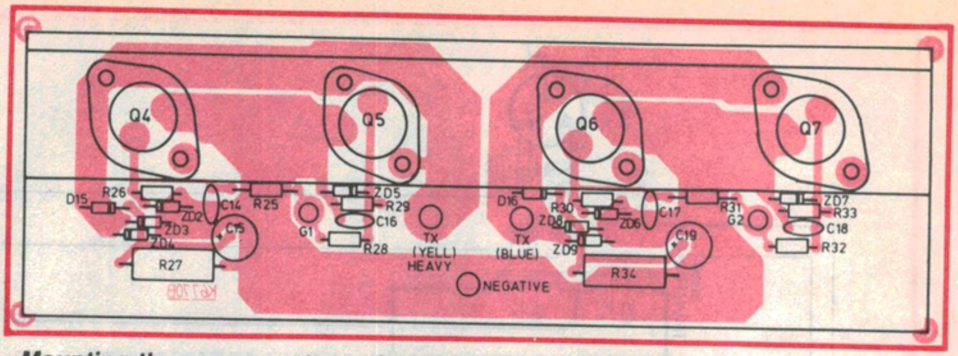
Diodes D5-D12 protect the auto-start circuitry from damage when the inverter is operating, by limiting the voltage applied to either R13 or D13 to ±1.3V peak. At the same time, the diodes complete the inverter output circuit, providing a high-current and low impedance link between the transformer secondary and the load.

Germanium diode D13 and capacitor C13 rectify the AC voltage drop across D5-D8 when the inverter is running, and ensure that Q2 is kept in conduction regardless of variations in load current during the AC cycles.

The purpose of bipolar capacitor C12 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 C20 and any small click-filtering or suppressor capacitors likely to remain connected across the 240V line inside the load appliance when it is nominally turned off. Without C12, there could well be enough AC flowing through D5-D8 via load circuit capacitance to keep the inverter running.

LED1 is connected across the 8V supply rail via R14, 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 fuses F1 and F2, 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.



Mounting the components on the power PC board should be easy using this overlay diagram as a guide.

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 ZD1. If the input voltage is less than the reference voltage, then the output of the comparator will go high, thus turning on the LED 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.

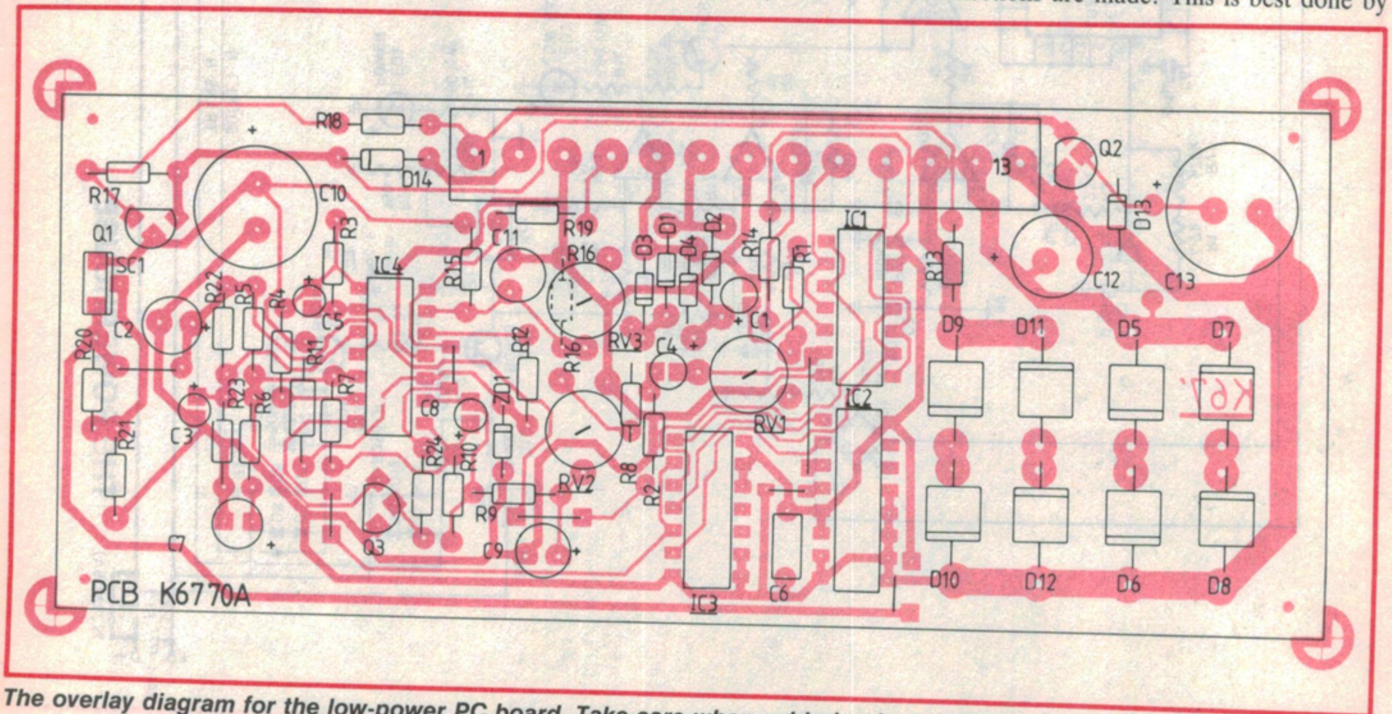
Construction

The construction of the inverter is very simple. The majority of the components mount on either of the two integral PCBs, with interlinking wiring between.

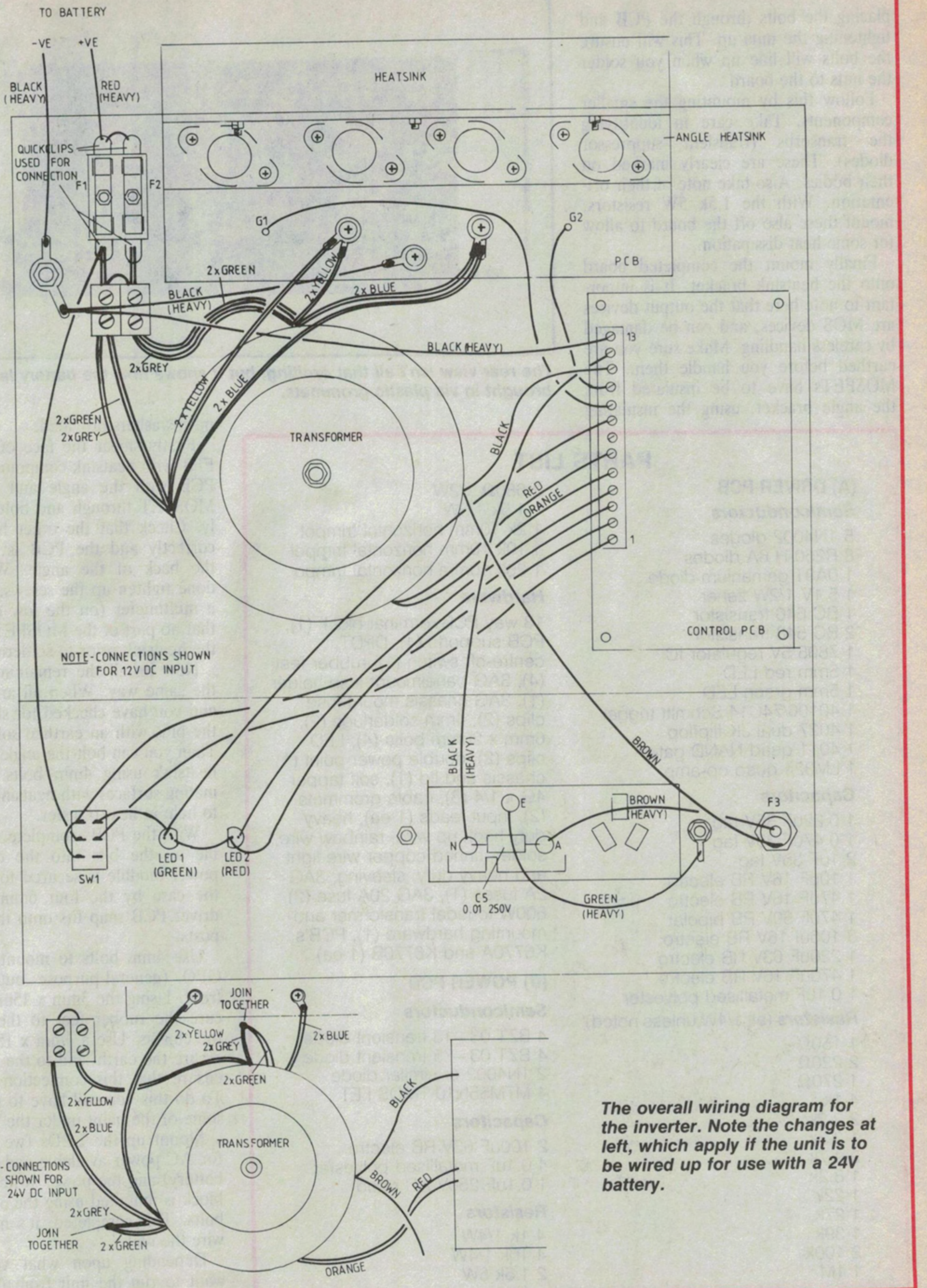
Start by assembling the smaller driver PCB (K 6770A). First mount and solder all links and resistor, then the smaller diodes. Follow the overlay diagram carefully, to ensure correct orientation.

Progress from here by next positioning the smaller capacitor, trimpots, IC's 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. Once you have completed the PCB double check the components and your soldering, just to make sure.

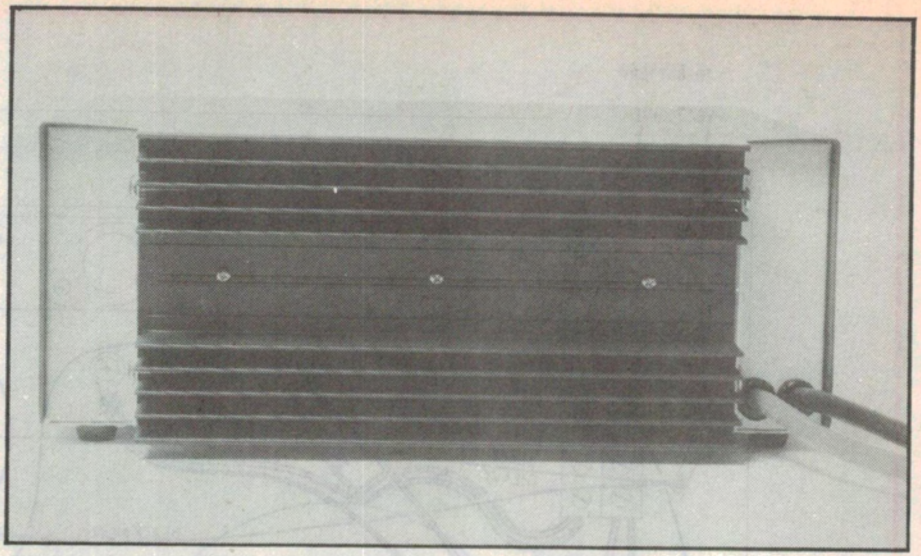
Next comes the power PCB, K 6770B. Firstly, using the 4mm nuts supplied solder these onto the PCB where the mains transformer and earth connections are made. This is best done by



The overlay diagram for the low-power PC board. Take care when soldering in the terminal strip, to avoid solder bridges.



The overall wiring diagram for the inverter. Note the changes at left, which apply if the unit is to be wired up for use with a 24V battery.



The rear view isn't all that exciting, but it shows how the battery leads are brought in via plastic grommets.

placing the bolts through the PCB and tightening the nuts up. This will ensure the bolts will line up when you solder the nuts to the board.

Follow this by mounting the smaller components. 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.

Finally mount the completed board onto the heatsink bracket. 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.

PARTS LIST

(A) DRIVER PCB

Semiconductors

5 1N4002 diodes
8 R250-H 6A diodes
1 0A91 gemanium diode
1 5.1V 1/2W zener
1 BC 640 transistor
2 BC 548 transistor
1 7805 5V regulator IC
1 5mm red LED
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 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 16V RB electro
1 220uF 63V RB electro
1 470uF 16V RB electro
1 0.1uF metallised polyester

Resistors (all 1/4W unless noted)

1 150Ω
2 220Ω
1 270Ω
4 1k
2 2.2k
1 3.3k
2 4.7k
1 8.2k
1 22k
1 27k
1 39k
2 100k
1 1M
2 680Ω 1/2W
1 1.5k 1/5W
1 2k 10mm horizontal trimpot
1 10k 10mm horizontal trimpot
1 20k 10mm horizontal trimpot

Hardware

13 way PCB terminal block (1), PCB supports (4), DPDT centre-off switch (1), rubber feet (4), 3AG panelmount fuse holder (1), 3AG chassis mount fuse clips (2), 4mm solderlugs (2), 6mm x 20mm bolts (4), LED clips (2), double power point (1), chassis and lid (1), self tapper 4G x 1/4 (8), cable grommets (2), input leads (1 ea), heavy duty hook up wire, rainbow wire, solder, tinned copper wire light and heavy duty, sleeving, 3AG 2A fuses (1), 3AG 20A fuse (2), 600W toriodal transformer and mounting hardware (1), PCB's K6770A and K6770B (1 ea).

(B) POWER PCB

Semiconductors

4 BZT 03 –13 transient diode
4 BZT 03 –75 transient diode
2 1N4002 or similar diode
4 MTM55N10 TMOS FET

Capacitors

2 100uF 63V RB electro
4 0.1uF metallised polyester
1 0.1uF 250V AC rated

Resistors

4 1k 1/4W
4 10k 1/4W
2 1.5k 5W

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.

Now install the remaining devices in the same way. When all are positioned and you have checked for shorts, solder the pins with an earthed soldering iron. Then you can bolt the angle to the main heatsink using 4mm bolts. Smear the mating surfaces with heatsink compound to help in heat transfer.

With the PCBs complete, now assemble all the bits into the chassis. The power module is secured to the rear of the case by the four 6mm bolts. The driver PCB snap fits onto the mounting posts.

Use 4mm bolts to mount the double GPO (general-purpose outlet) to the front. Using the 3mm x 15mm bolts, secure the rubber feet to the bottom of the chassis. Use a 4mm x 15mm bolt to secure the earth lead to the chassis, and ensure that this connection is TIGHT. To do this you will have to scrape away some of the paint under the lug.

Mount up the LEDs (we used green for AC power available and red for low battery) and the power switch. The fuse block is mounted using the 3mm x 6mm bolts. This completed, it's now time to wire the unit.

Depending upon what voltage you want to run the unit from (12 volts or 24 volts) this will determine how the output transformer is wired (see diagram). Note that the wires that connect the transformer primaries to the PCB should be soldered to the crimp lugs, and then bolted down securely.

The fuse block has two fuses that are paralleled together, using the heavy tinned copper wire that is supplied. The incoming positive and the centre tap of the transformer solder directly to the tags on the fuse block. The main earth for the MOSFETs is run to the chassis earth point using the heavy duty black wire, and is attached to the solder lugs by crimping and soldering.

All other wiring is straightforward. Use the rainbow cable for wiring to the switch and the LEDs. The 230 volt side of the transformer is fused via the panel mount fuse holder. Ensure you follow the wiring diagram carefully and double check your work.

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 G1 and G2 wires from the power PCB and try again. If it still blows fuses, then there is a problem with the power FET PCB, 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 100uF capacitors charging up.

If the fuse only blows when G1 and G2 are connected 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 through 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 G1 or G2. Rotate RV3 fully anti-clockwise and set RV2 at centre position. Connect a 100W (or similiar) light globe to the output and switch on (either MANUAL or AUTO).

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 should 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 100W) 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 the G1 and G2 leads from the power FET PCB and reconnect the supply. For the 12 volt version set the DC supply for 10 volts, then adjust RV3 until the LED just comes on. For the 24 volt version, set the DC supply for 20 volts an adjust RV3 for cutoff as before. Finally reconnect the G1 and G2 leads and give the inverter a full test. Then put the lid on.

You should now have a fully functional 600 VA inverter. EA