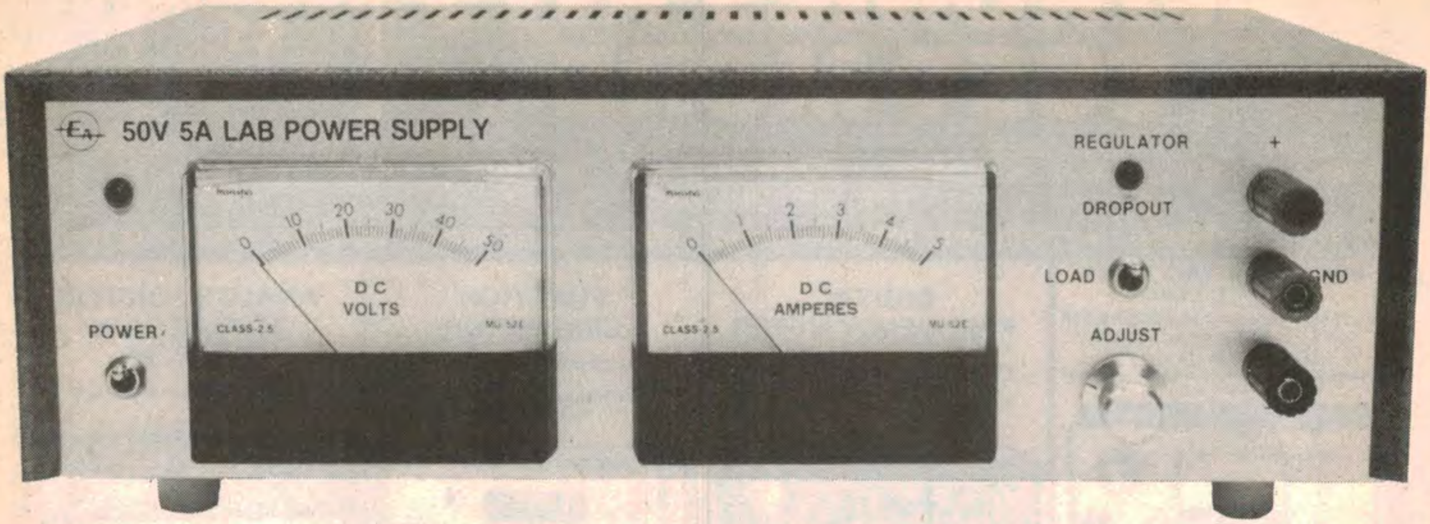


50V/5A laboratory power supply: Pt 2

Last month we introduced our new high power switchmode supply. We discussed the principles of switchmode operation and pulse width modulation, together with the functions of the μA494 switchmode IC. This month we present the complete circuit and constructional details.

design by JEFF SKEEN

The basic "power plant" in this power supply is a 35V 5A transformer, a 10A bridge rectifier, and a pair of 4000μF filter capacitors. In greater detail the transformer is a Ferguson PF4361 with two 35V windings which, connected in parallel, provide a current rating of 5A. The rectifier is a 100V 10A bridge, such as a VJ448, and the filter capacitors are rated at 75VW with a 5A ripple current rating, giving a total ripple current rating of 10A. A 5.6kΩ 1W bleed resistor is connected across this network.

A 10A fuse is used to protect this part of the system, and is followed by a 15V zener diode and 560Ω resistor network. This provides a +15V supply for the μA494, and for the 741 op amp and 555 timer in the regulation indicator circuit. The main positive line goes on to the pass transistor, MJ15004, then via a 0.7mH inductance, an ammeter, and a switch to the positive output terminal.

The regulator IC

The heart of the regulator system is, of course, the μA494 regulator IC. Readers may find it beneficial to refer to last month's explanatory article and diagram of this IC as an aid to the following discussion.

The oscillator, which provides the basic switching function, requires only two timing components: a .001μF capacitor and a 56kΩ resistor from pins 5 and 6 respectively to the negative rail. This gives a frequency of approximately 20kHz, although the exact value is not critical.

Pins 1 and 2 are the inputs for the error amplifier inside IC1. If a reference voltage is applied to pin 2 and a sample of the output voltage to pin 1, the regulator will adjust the output until the two voltages match.

The reference voltage is obtained from pin 14 of the μA494 in the form of a regulated 5V supply with a 20mA capacity. (It can also be used as an external 5V reference if desired.) This is fed to a voltage divider, consisting of a 1kΩ and a 1.5kΩ resistor, the junction of which provides a 3V reference. This, in turn is fed to pin 2 via a 4.7kΩ resistor. (The network between pins 2 and 3 will be discussed later.)

The sample voltage from the output is taken from a point as close to the output terminal as possible in order to compensate for such losses as ammeter resistance, wire resistance, etc, particularly under maximum current conditions. However, it is taken from the supply side of the load switch, so that it functions at all times.

This is fed to a voltage divider consisting of a 2kΩ multi-turn potentiometer and a 120Ω fixed resistor. The divider tap is fed to pin 1 via a 4.7kΩ resistor, which serves to limit the input current to the error amplifier in the event that the output voltage should rise above the μA494 supply voltage. The 0.1μF capacitor across the resistor network helps to reduce the output ripple.

The actual value of this potentiometer is not critical, provided its associated resistor is maintained in proportion. In fact, we started out with a 100kΩ unit in conjunction with a 5.6kΩ fixed resistor, and this worked perfectly satisfactorily. Our only reason for changing to 2kΩ is because a survey of our advertisers showed that the 2kΩ unit, having been used in other popular projects, is in much better supply.

At the same time, the multi-turn unit, while providing a very fine control action, is an expensive item (around $10) and some builders may be tempted to use a conventional linear pot. There is no objection to this, and it could conveniently be a 100kΩ/5.6kΩ combination.

Pins 8 and 11 of the μA494 are the collector connections of the two internal switching transistors (see Fig. 3 last month), while pins 9 and 10 are the emitter connections. These two transistors are connected in parallel and control an external BD139 transistor (Q1), thus forming what is effectively a Darlington pair. Q1, in turn, controls the MJ15004 pass transistor (Q2), and is necessary to isolate the internal transistors from excessive voltages on the base of Q2.

In greater detail, when the pass transistor (Q2) is turned off, the transistor driving its base will also be off. Thus, the collector of the driving transistor will have the full +50V output from the bridge rectifier applied to it via the 47Ω and 390Ω resistors. This voltage exceeds the +40V collector/emitter rating of the internal transistors, while the BD139 is rated to withstand this voltage.

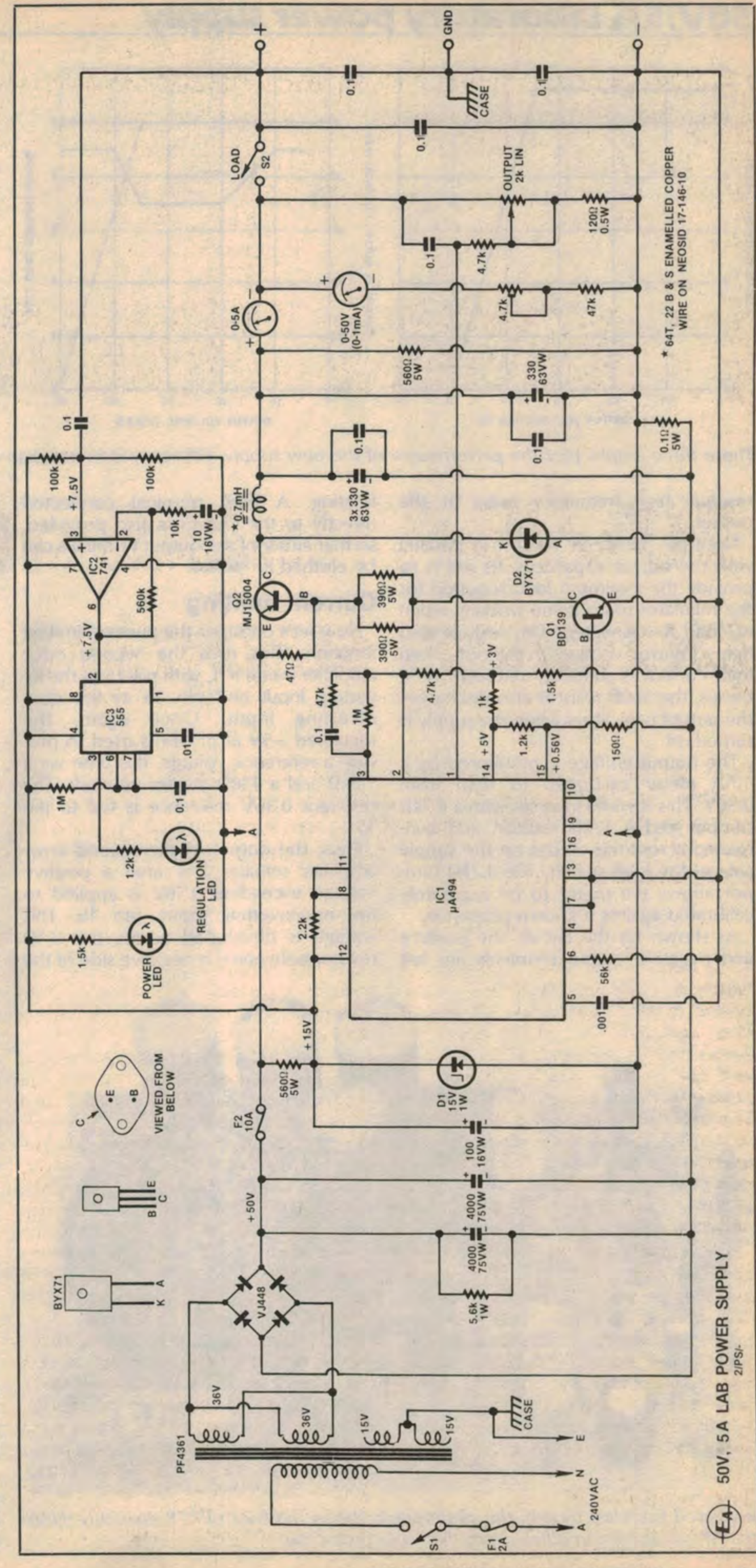
So the basic scheme is this: Q1 and Q2 are turned on and off by the two parallel connected transistors inside IC1. These in turn are controlled by the internal error amplifier, as described last month (see Fig. 2). When the oscillator ramp output is higher than the error output voltage, Q2 turns on; when the ramp output voltage is lower than the error voltage, Q2 turns off.

The network betweens pins 2 and 3 is used to provide a "soft start" when the power supply is first turned on. Pin 3 is the inverting input to the pulse width modulation (PWM) comparator, and is normally held low. While the inverting input is low, the output of the comparator will be high and, ultimately, will turn on the pass transistor.

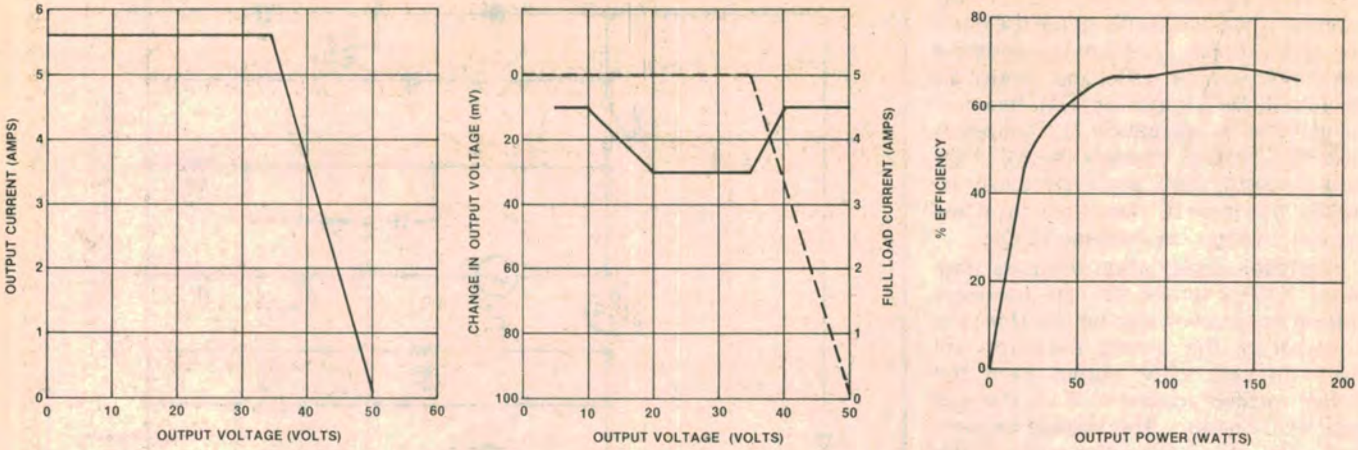
But if pin 3 is driven high the PWM comparator output will go low, turning off the pass transistor. This is the basis of the soft start action. At the instant of switch-on, a voltage will be applied to pin 3 via the 47kΩ resistor and the 0.1μF capacitor, the latter initially offering zero impedance. Then, as the capacitor charges, the voltage on pin 3 falls, providing the soft start. When the power supply is turned off, the capacitor is discharged through the 1MΩ resistor.

From here, the basic circuit functions exactly as described in Fig. 1 last month. The relevant components are the 0.7mH inductor, diode D2, and four 330μF capacitors wired in parallel with the load. Note that the diode specified is a BYX71, a type often used in the line output stage of TV receivers. It was chosen for its fast response times.

The total capacitance across the output is 1320μF. Two 0.1μF polyester capacitors are connected across the main output capacitors as high frequency bypasses. As a further precaution, a network of three 0.1μF ceramic capacitors is connected directly across the output terminals to remove any



50V, 5A LAB POWER SUPPLY



These three graphs plot the performance of the new supply. Efficiency is better than 60% for outputs greater than 50W.

residual high frequency noise at the output.

Note the 560Ω 5W resistor in parallel with the output capacitors. Its job is to provide the minimum load required for the regulator to continue working when no load is connected. This resistor also helps control voltage overshoot when load current is suddenly reduced. As a bonus, the 560Ω resistor also discharges the output capacitors when the supply is turned off.

The output voltage is monitored by a 1mA meter calibrated to read from 0-50V. This is wired in series with a 4.7kΩ trimpot and a 47kΩ resistor, and connected across the output on the supply side of the load switch. The 4.7kΩ trimpot allows the meter to be accurately calibrated against a known reference.

As shown on the circuit, the positive and negative output terminals are left floating. A third terminal connected directly to the chassis is also provided, so that either of the output terminals can be earthed if desired.

Current limiting

Now let's consider the current limiting function. This uses the second error amplifier inside IC1, with pin 15 as the inverting input and pin 16 as the non-inverting input. Once again, the regulated +5V at pin 14 is used to provide a reference voltage, this time via a 1.2kΩ and a 150Ω divider network. The resultant 0.56V reference is fed to pin 15.

Thus, the output of the second error amplifier remains low until a positive voltage exceeding 0.56V is applied to the non-inverting input, pin 16. This voltage is developed across the 0.1Ω resistor between the negative side of the filter capacitors and the negative output terminal. When the current flow through the resistor reaches 5.6A, 0.56V will be developed across it and applied to pin 16.

As soon as the voltage on pin 16 reaches 0.56V, the second error amplifier acts to limit the current by reducing the duty cycle of the pass transistor, Q2.

While in this part of the circuit note particularly the method of connecting the IC negative supply pin, pin 7, to the negative output terminal. This is via its own heavy duty lead from the printed circuit board (PCB) directly to the terminal, rather than to some point on the board which is, nominally, at the same potential. This is essential to preserve good regulation which can otherwise be upset, at the heavy currents involved, by small voltages developed along copper pattern conductors or in cables.

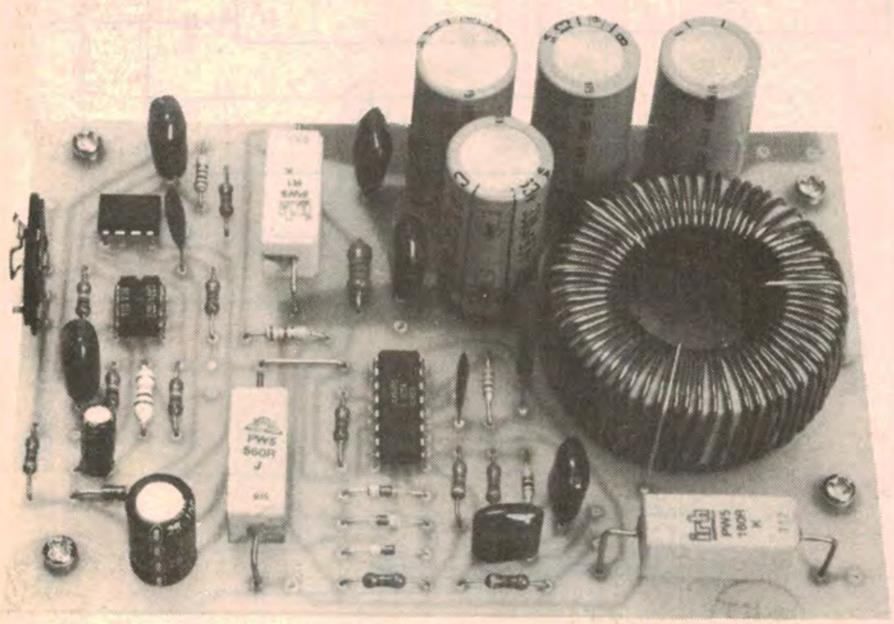
Pins 16, 13 (output control) and 4 (dead time control) also share this lead, but more as a matter of convenience than necessity.

In practice, the exact value of the 0.1Ω resistor can present a problem. If it is slightly high, current limiting may begin too soon. If so, the simple solution is to increase the 150Ω resistor in the pin 15 divider network to, say, 180Ω, or whatever value is required.

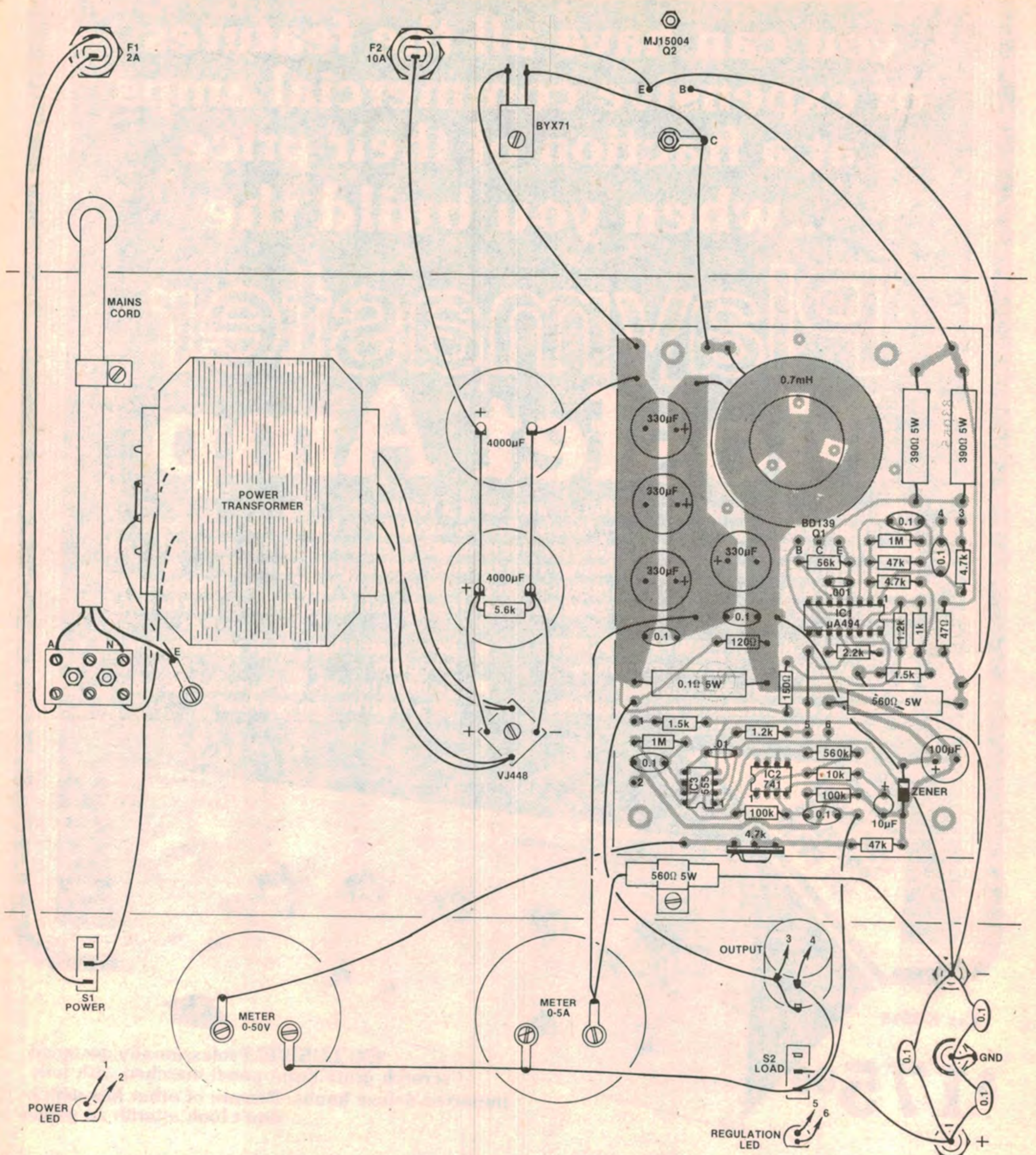
Loss of regulation

Another useful feature of this power supply is a "loss-of-regulation" indicator. Loss of regulation normally occurs as the supply is approaching the limit of its current capacity, but before actual limiting occurs. It is not possible to tell, by meter readings alone, that this condition is being approached.

The indicator operates by sensing the ripple content of the output voltage. When fully regulating, the ripple content is in the region of 20mV peak-to-peak at



Repeated from last month, this photograph shows the control PCB assembly. Note that the final version differs from this early prototype.

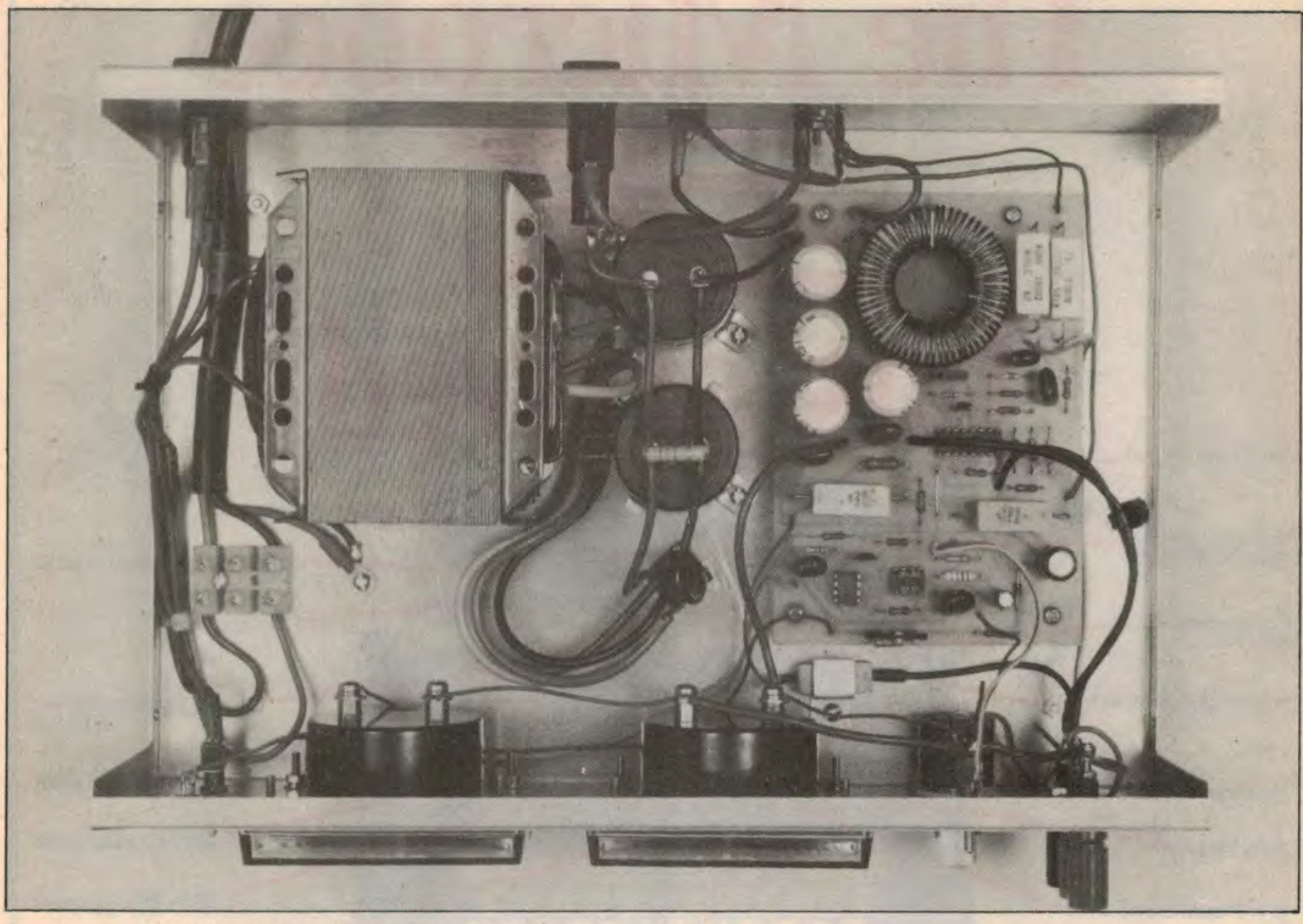


Parts overlay and wiring diagram for the 50V/5A supply. Most of the wiring should use heavy-duty 10A cable (see text).

100Hz, plus a certain (varying) amount of higher frequency "rubbish" from the switchmode function. As far as this indicator is concerned, it is the 100Hz content that it is important.

The regulation indicator consists of a 741 op amp (IC2) and 555 timer (IC3). IC2 functions as a simple amplifier while IC3 is wired as a monostable and drives a LED indicator. The ripple is picked up close to the positive output terminal, on the supply side of the load switch, and fed to the non-inverting input of the op amp via a 0.1µF blocking capacitor. This input terminal is biased at half the 15V supply voltage by two 100kΩ resistors.

As a result, the output of the op amp will also be at half the supply voltage (7.5V) with the amplified ripple voltage superimposed on it. The gain of the op amp is set at 56 by the feedback network into the inverting terminal, while the 10µF capacitor rolls off the frequency response below 10Hz.



Use this photo and the wiring diagram to position the major components in the chassis.

The output of the op amp is connected to the pin 2 trigger terminal of IC3. When the voltage on pin 2 drops to one third the supply voltage (ie, to 5V), IC3 triggers and activates the LED.

If the ripple level is 20mV p-p, the op output will be held at +7.5V DC with ±0.56V superimposed on it – ie, the output will swing between +6.94V and +8.06V. Thus, for this ripple level, the output of IC2 does not go low enough to trigger the monostable and the LED remains off.

If, however, the ripple increases to about 90mV p-p, the output of the op amp swings ±2.5V. The monostable now triggers on the first negative peak, thus lighting the LED to indicate loss of regulation. The LED remains on for as long as loss of regulation continues.

A 1MΩ resistor and a 0.1μF capacitor set the monostable period to approximately 0.1s. Thus, the LED will also "flash" briefly if the supply momentarily loses regulation when connected to a heavy load.

Whilst on the subject, it should be pointed out that loss of regulation is not a gradual process. Instead, the supply "drops its bundle" quite suddenly and the ripple content on the output rises dramatically.

Construction

Most of the components are mounted on a printed circuit board (PCB) coded 83ps5 and measuring 132mm × 92mm. This board, together with the various external parts, is mounted in a standard K&W instrument case measuring 305mm × 205mm × 95mm (W × D × H). A Scotchcal adhesive label provides an attractive front panel.

Construction can commence with the PCB assembly. In addition to the minor components, this also carries the toroid inductor and the four 330μF output capacitors. Mount the parts on the PCB according to the overlay diagram, beginning with the resistors and then moving on to the capacitors and semiconductors. Don't forget the wire link adjacent to μA494 IC, and make sure that you install the transistor, ICs and electrolytic capacitors the right way round.

An important point to note here concerns the two 390Ω 5W resistors adjacent to the toroid. These can become quite warm under some operating conditions and, to assist heat radiation, it is a good idea to mount them proud of the PCB. One is mounted about 3mm above the board and the other (nearest to the indicator) about 10mm higher, thus exposing all four sides of each resistor to the air.

The 0.1Ω and 560Ω 5W resistors should also be mounted slightly proud of the PCB.

The inductor is wound on an iron powder ring core (toroid) made by Neosid and designated type 17-146-10. It measures 44mm OD, 24mm ID, and 16.5mm thick. Note that this is NOT a ferrite core, and that ferrite should not be used.

To wind the inductor you will need about four metres of 1mm (22 B&S) enamelled copper wire. Wound as a single layer, this should give about 64

We estimate that the current cost of components for this project is approximately

$140

This includes sales tax.

closely-spaced turns and an inductance of about 0.7mH. Anchor one end of the wire in a vyce, move to the middle of the wire, and wind on the free end. In this way, only half the wire length has to be passed through the toroid for each turn.

This done, the other half of the wire can be wound on to complete the winding. Note that the toroid will probably only accommodate about 3.5m of wire. Terminate the start and finish of the winding by twisting the ends together for half a turn.

The ends can now be trimmed and cleaned of insulation, and the toroid mounted on the PCB. It does not matter which way round you connect the leads, but make sure that the toroid is correctly positioned before soldering.

The toroid is secured using three U-shaped pieces of tinned copper wire to clamp it to the PCB. These are soldered to three pairs of anchor points arranged so that the wire clamps do not become shorted turns. The large, circular area of copper on the reverse side of the PCB provides a small measure of shielding.

With assembly of the PCB completed, attention can be turned to the metalwork. Spray the Scotchcal label with a clear lacquer (eg, "Estapol"), then carefully affix it to the front panel. The chassis can now be drilled to accept the various parts using the wiring diagram and Scotchcal label as a guide.

The meter cutouts can be made by drilling a series of small holes around the perimeter of each cutout and then filing to a smooth shape. Deburr all mounting holes before mounting the hardware on the chassis. We used red, green and black binding post terminals for the positive, earth and negative outputs respectively.

Heatsinking requirements for the MJ15004 pass transistor and BYX71 diode are met by mounting them on the rear panel. Note that both components must be electrically isolated from the chassis using mica washers and insulating bushes. Before mounting each component, check that the contact area is free of metal burrs and smear both sides of the mica washer with heatsink compound.

Finally, use your multimeter to check that the transistor and diode are indeed isolated from chassis. The accompanying diagram shows the transistor mounting details. We strongly recommend that you fit the transistor with a TO-3 plastic cover to prevent accidental shorts to chassis.

The mating surface of the VJ448 bridge rectifier should also be smeared with heatsink compound. It is then bolted directly to the chassis using a machine screw and nut. Orient the positive and negative terminals of the bridge as shown in the wiring diagram.

One other component which needs to be mentioned is the 560Ω 5W bleed resistor across the output capacitors. This will get quite hot at the higher voltage settings and should be mounted on the bottom of the box to give it some heatsinking. It is held in place using a simple clamp fashioned from scrap aluminium.

The PCB assembly is mounted on the base of the chassis using four 12mm tapped standoffs. At this stage, however, it should simply be positioned in the chassis so that the external wiring can be completed.

Heavy duty wiring

Rainbow cable or light duty hook-up wire can be used for the following connections: to the LEDs, potentiometer and voltmeter; between the base of Q2 and the PCB; between the emitter of Q2 and the PCB; and between the load switch and the PCB. **All other wiring must use heavy duty 32 × 0.2mm cable rated at 10A.**

The mains cord passes through a grommeted hole in the rear of the chassis and is anchored with a cord clamp. Terminate the mains active (brown) and neutral (blue) leads to the insulated terminal block, and solder the earth lead (green/yellow) to a solder lug bolted to chassis near the transformer. Complete the wiring to the mains fuse, power switch and transformer using 250VAC rated hook-up wire. Sleeve the switch terminals to reduce the danger of ac-

PARTS LIST

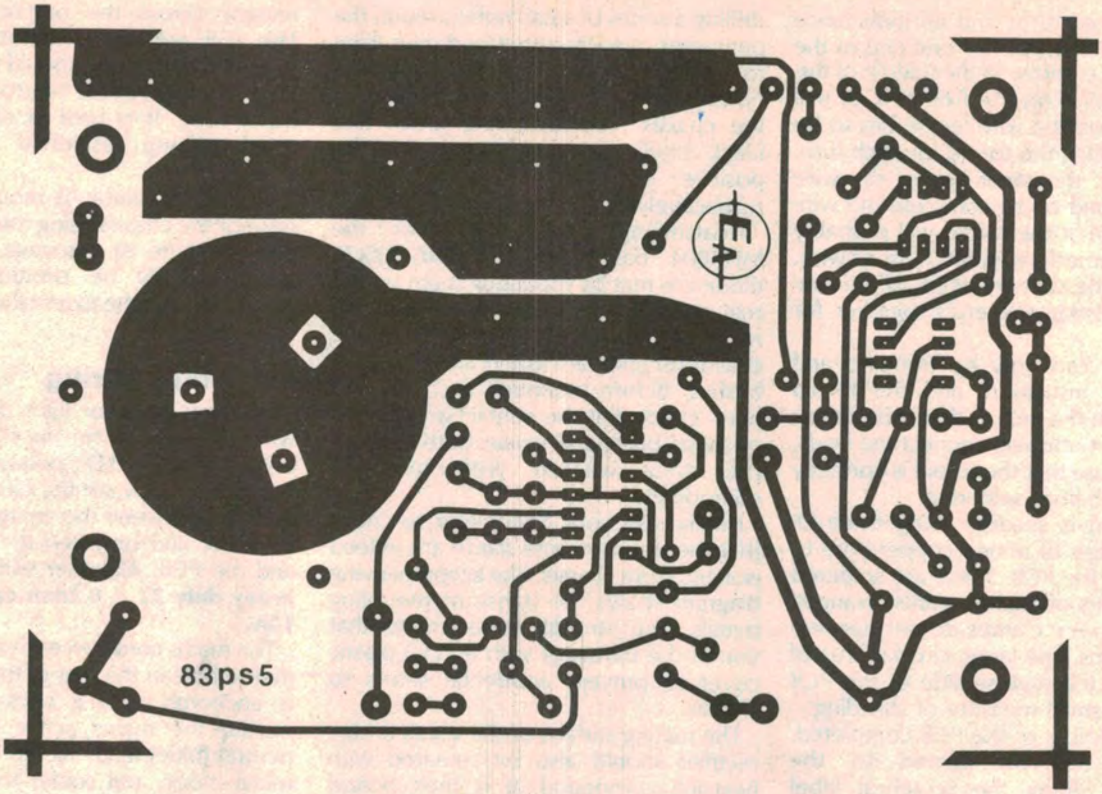
1 K&W instrument case, 305mm × 205mm × 95mm (W × D × H)
1 Scotchcal label, 302mm × 90mm
1 PCB, code 83ps5, 133mm × 92mm
1 power transformer, Ferguson PF4361
2 SPDT toggle switches
3 binding post terminals (1 red, 1 green, 1 black)
1 Minipa MU-52E 5A FSD meter, 75mm × 65mm
1 Minipa MU-52E 1mA FSD meter, 75mm × 65mm
1 0-50V meter scale
1 Neosid 17-146-10 iron powder toroid
4 metres 1mm enamelled copper wire
1 mains cord and plug
1 3-way terminal block
1 cord clamp
1 grommet
2 3AG fuseholders
1 2A fuse
1 10A fuse
4 cable ties
2 heavy duty solder lugs
4 12mm tapped standoffs
1 TO-3 mica washer
1 TO-220 mica washer
3 insulating bushes
1 TO-3 plastic cover
½ metre 32 × 0.2mm 10A cable (red)
½ metre 32 × 0.2mm 10A cable (black)

SEMICONDUCTORS
1 μA494 PWM control IC
1 741 op amp
1 555 timer
1 BD139 NPN transistor
1 MJ15004 PNP transistor
1 15V 1W zener diode
1 VJ448 bridge rectifier
1 BYX71 fast recover diode
2 red LEDs with mounting bezels

CAPACITORS
2 4000μF/75VW electrolytic, chassis mounting type
4 330μF/63VW PC electrolytic
1 100μF/16VW PC electrolytic
1 10μF/16VW PC electrolytic
6 0.1μF metallised polyester (greencap)
3 0.1μF/60VW ceramic
1 .01μF greencap
1 .001μF greencap

RESISTORS (¼W, 5% unless stated)
2 × 1MΩ, 1 × 560kΩ, 2 × 100kΩ, 1 × 56kΩ, 2 × 47kΩ, 1 × 10kΩ, 1 × 5.6kΩ, 1W, 2 × 4.7kΩ, 1 × 2.2kΩ, 2 × 1.5kΩ, 2 × 1.2kΩ, 1 × 1kΩ, 2 × 560Ω 5W, 2 × 390Ω 5W, 1 × 150Ω, 1 × 120Ω ½W, 1 × 47Ω, 1 × 0.1Ω 5W, 1 × 4.7kΩ large vertical trimpot, 1 × 2kΩ multi-turn potentiometer

MISCELLANEOUS
Rainbow cable, light duty hook-up wire, mains-rated cable, machine screws and nuts, scrap aluminium, plastic sleeving, etc.



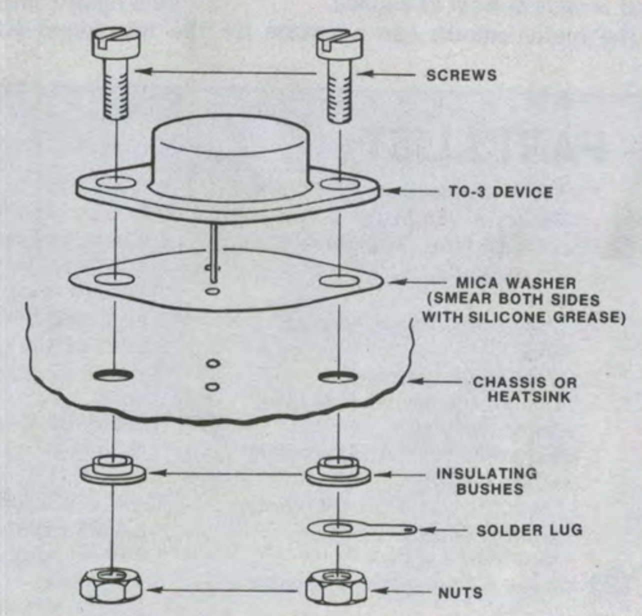
Above is an actual size artwork for the printed circuit board.

cidental contact with the mains.

Do not transpose the connections to the fuseholder F1. By connecting the end terminal of the fuseholder to active as shown, there is less danger of receiving a shock should you remove the fuse with power still applied. We used several cable ties to keep the wiring neat and tidy.

The transformer specified for this project is the Ferguson PF4361 and, in addition to the required 36V windings, also features two 15V windings. Since these windings are between the primary and the 36V secondaries, they are connected in series and the centre tap earthed to provide an electrostatic shield. This should lessen the possibility of power supply "hash" being radiated via the mains wiring. It is also a useful additional safety measure, in the unlikely event of transformer breakdown.

This diagram shows how the MJ15004 power transistor is mounted. The BYX71 diode must also be isolated from chassis.



Testing

When wiring is completed, make a final check that all is correct and apply power. Connect your multimeter across the output and check that the output can be varied between about 3V and 50V DC. Adjust the 4.7kΩ trimpot so that the voltmeter reading matches the multimeter reading.

Finally, the current limiting function can be checked by connecting a 1Ω resistor across the output and slowly advancing the output control. The voltage across the resistor should limit at approximately 5.6V and the regulation LED should light. A 5W resistor should suffice for this short-term test, although it may become rather "red in the face".

Next month, we will describe how the 15V windings are used to produce balanced +12V and −12V rails. This project will involve the addition of a small add-on PCB using 3-terminal regulators, with the additional ±12V output terminals mounted to the right of the present terminals. The centre tap will remain earthed, so the 15V windings will still function as an electrostatic shield.