Highly efficient design uses switchmode technique

50V/5A laboratory power supply: Pt.1

This is the first of two articles describing a new and very efficient variable power supply using the switchmode principle. The new power supply can deliver voltages anywhere in the range from three to 50 volts DC and at voltage settings of 35V or less, it can deliver currents up to five amps. It is easily the most powerful DC supply we have ever described, with a maximum power output of 175 watts!

by JEFF SKEEN

Not only is this new power supply the most powerful we have ever produced, it is also the most efficient, and for its rating, the most compact. In fact, if we had not had the benefits of the switchmode principle, the supply would be a great deal more bulky and expensive. At the lower voltage settings the supply would have had to dissipate powers in excess of 150 watts. To do that, you need very large heatsinks which would probably have to be fan-cooled.

Most computers these days use switchmode power supplies as these are a practical and efficient method of providing a highly regulated supply with high current output.

This month's article will be devoted to the principles of switchmode power supplies while next month's will contain the full constructional details of the new supply.

Basic principles

To gain an understanding of the operating principles involved in a switchmode power supply we will start our circuit explanation with the simplified diagram shown in Fig. 1.

In this circuit transistor Q1 is an ideal switch with "on" and "off" (or open and closed) times controlled by a pulse width modulator (PWM) circuit attached to the base. By ideal we mean that Q1 has no voltage drop between emitter and collector when conducting.

When Q1 is on (base voltage is low) current I1 is drawn from Vcc, passes through Q1 and L1 and supplies both the load, RL, and charges the output capacitor, CO. The voltage at the cathode of the diode, D1, is the same as Vcc so the diode is reverse biased and non-conducting.

While Q1 is on, energy from the current I1 passing through L1 is stored in the magnetic field developed by the coil. When the signal on the base of Q1 goes high, Q1 turns off and ceases to pass current. The energy stored in the magnetic field must now be dissipated and this energy is delivered to the circuit as current, I2, which is driven by the voltage induced across L1 by the collapsing field.

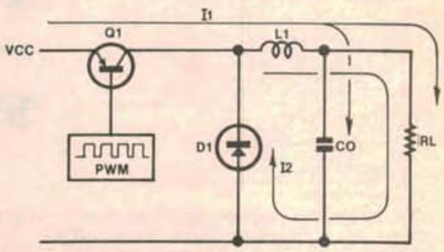
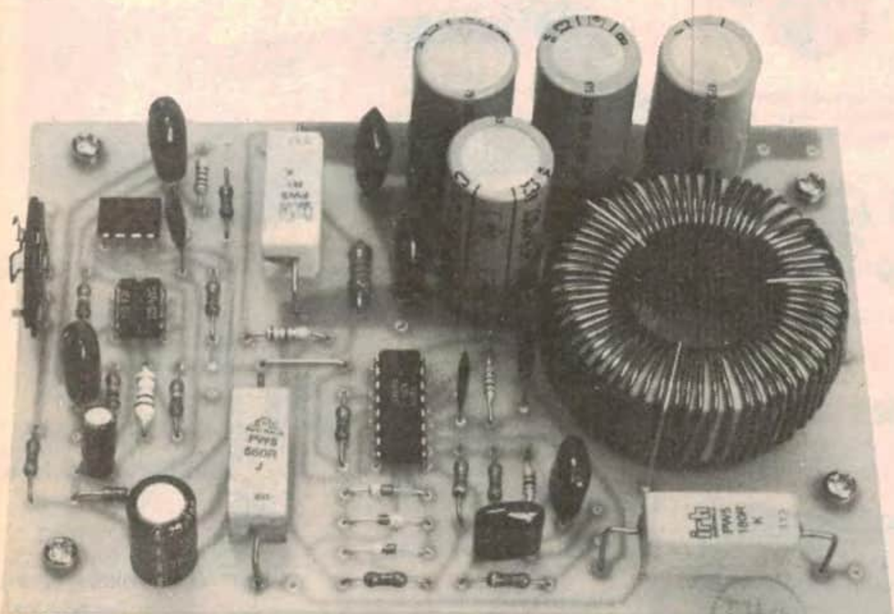


Fig. 1

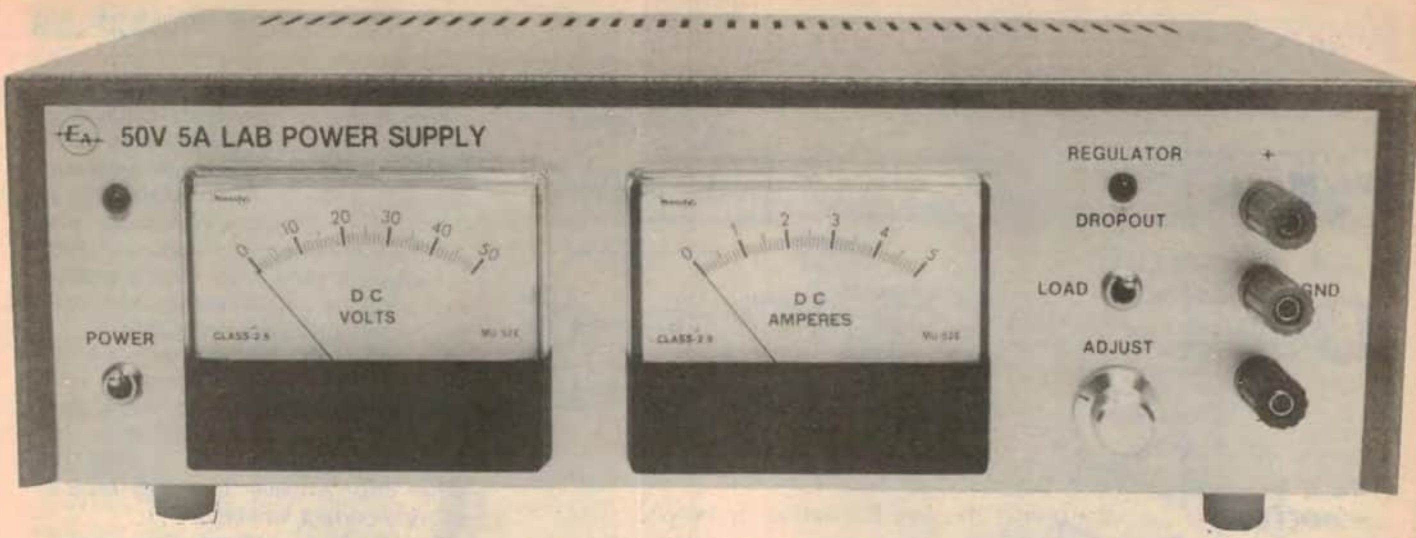
The induced current I2 flows from the coil, through the load, through D1 (which is now forward-biased) and back to the coil. In addition, CO begins to discharge, also supplying current to the load.

When the PWM signal at the base of Q1 goes low again, Q1 will turn on and pass current (I1) once more. D1 will again be reverse-biased and non-conducting, and current from Q1 will pass through L1, recharging CO and powering the load. This current will also rebuild the magnetic field around L1, preparing it for the next Q1 off-cycle.

The inductor L1 together with the capacitor CO forms a filter which



Close-up view of the control PCB assembly for the new power supply. Note that the final version differs slightly from this early prototype.



Our new switchmode supply has adjustable voltage output from 3 to 50V and a maximum 5A output at voltages below 35V.

averages out the waveform from the collector of Q1 to give a DC voltage across RL. The magnitude of this voltage is given by the equation,

$$V_{out} = Vcc \times t_{on}/T$$

where t_{on} is the period when Q1 is conducting and T is the total period of the waveform applied to the base of Q1.

For an ideal power supply, this output voltage is independent of the output current. This is another way of saying that the power supply has zero output impedance.

From the above formula we can see that any factors which would tend to cause changes in the output voltage can be compensated for by adjusting the on-time (or duty cycle) of Q1. To do this we need a control circuit which can modulate the pulse width of the signal applied to the base of Q1 while monitoring the output voltage for any changes. This is then referred to as "pulse width modulation".

The reason for the high efficiency of the switchmode regulator is that the pass transistor, which is the principal source of losses, is operated at its two most efficient points. At cutoff, there is a large voltage across the transistor but little current through it. Conversely, at saturation there is little voltage across the transistor but a large current through it.

Either way, very little power is dissipated in the switching transistor so efficiency is high. And heatsinks can either be small or, in some cases, dispensed with entirely.

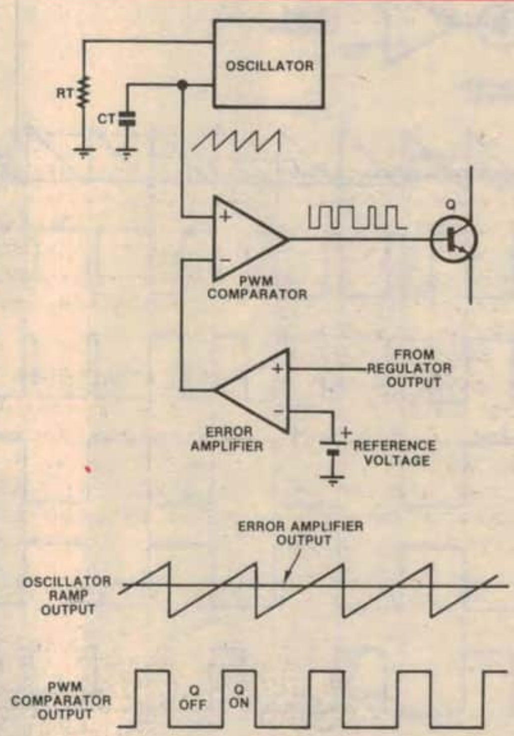


Fig. 2

Basic PWM circuit

Now refer to Fig. 2 which illustrates the basic components of a PWM circuit and how they function together. There is an RC oscillator which produces a sawtooth output, an error amplifier which monitors the output voltage and a comparator which actually produces the square wave pulse train which is fed to the base of switching transistor Q.

OK. Now the RC oscillator produces a sawtooth waveform with its period defined by RT and CT. Not that surprising really, is it? In our power supply, the operating frequency is just beyond the limit of audibility, at around 20kHz. But the actual frequency is not important.

The error amplifier performs the same function as the error amplifier in any linear regulator circuit. It compares a proportion of the power supply output voltage against a very stable reference voltage. The output of the error amplifier is then essentially a constant voltage on which is superimposed an amplified version of the small fluctuations in the power supply output. In other words, as far as we are concerned, the output of the error amplifier is essentially a constant DC voltage.

This voltage from the error amplifier is compared to the sawtooth voltage from the oscillator by the PWM comparator. When the sawtooth voltage is the higher, the PWM comparator will have a high output and Q will be turned on. When the error amplifier voltage is the higher the PWM comparator output is low and Q is turned off.

By looking at the timing diagram which is part of Fig. 2, this operation can be fur-

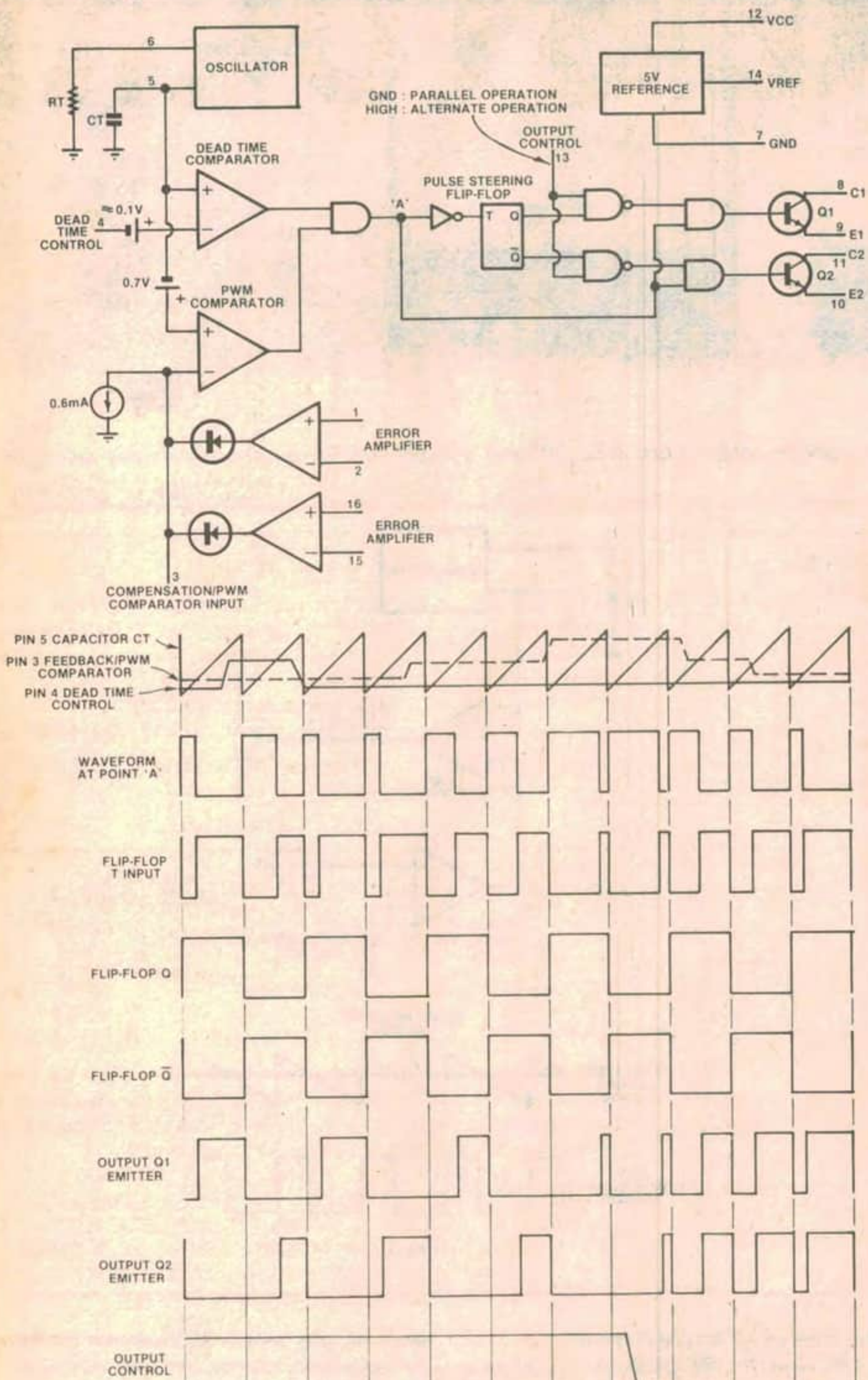


Fig. 3

ther elucidated. Note that if the error amplifier output was higher than shown in the timing diagram, the intersection times of the two waveforms would be shorter and hence the pulses from the comparator output would be correspondingly shorter (although still having the same repetition rate, ie, 20kHz).

By the same process, if the error amplifier output was lower, the intersection times of the two waveforms would be longer and the comparator's output pulses would also be longer.

Well, that essentially describes how a pulse-width modulation circuit works. Such a circuit could employ a number of discrete semiconductors at the simplest level, or in the most refined versions use a specially designed IC. Such an IC is the Fairchild μA494 switchmode regulator which is the heart of our new power supply.

Fig. 3 is a full block and timing diagram for the internal circuit of the μA494. It differs from the simplified diagram in several ways. Firstly, components for an extra mode of operation have been added so that the μA494 may be used in push-pull or bridge type circuits with transformer coupled outputs. These components include an extra transistor, logic circuitry and an extra comparator (called the dead time comparator).

Secondly, instead of one there are two error amplifiers provided. One error amplifier is used for output voltage control in the same manner as in the simplified diagram of Fig. 2 while the other error amplifier is usually used to provide current limiting.

To do this the voltage drop across a small resistor in series with the load is measured. If the voltage drop exceeds a preset value (indicating excessive current) then the output of the error amplifier rises and reduces the output transistor on time so that the output current is kept to a safe level.

Logic circuitry

The logic circuitry is arranged so that the mode of operation of the output transistors can be selected by the appropriate voltage level applied to the output control, pin 13. A high level on the output control and the output transistors turn on and off alternately in sympathy with the flipflop outputs. A low level (or ground) applied to the output control causes both output transistors to operate in parallel and ignore the flipflop outputs.

With the output control grounded, the state of the output transistors at any time is dependent upon the output state of the dead time and PWM comparators. Both comparators high and the output transistors are on, either or both comparators low and the output transistors are off.

The inputs to the comparators differ from the simplified diagram in that there are DC offset voltages applied. To gain an understanding of the operation of the comparators assume firstly that the dead time control (pin 4) is connected to ground. The 0.1V offset which is now applied to the inverting (–) terminal of the dead time comparator means that for the comparator output to go high, the voltage (ramp) across CT must be greater than 0.1V.

Since CT is discharged below this voltage at the beginning of each ramp, there will always be a short interval at the beginning of each cycle when the output of the comparator is low and hence the output transistors are off. This is called "dead time" and is required to preclude the possibility of both output transistors being on together when connected in the push-pull mode.

Due to storage effects in the bases of the switching transistors, it will take a short while for them to respond to the controlling signal applied to their bases and turn off. If sufficient time is not allowed between their on cycles, the transistors may form a short circuit across the power supply with potentially disastrous results.

The PWM comparator is designed to compare the ramp voltage across CT plus a 0.7V offset, against the voltage present on pin 3, the compensation/PWM comparator input. Most of the time the voltage present at pin 3 will be held low by the 0.6mA current sink and so the non-inverting input will have the higher voltage on it. This will cause the PWM comparator to have a high output most of the time.

If either error amplifier detects an error then the voltage at the inverting (–) input of the PWM comparator will rise since the error amplifiers can supply enough current to swamp the 0.6mA current sink. The PWM comparator output will remain low, and hence the output transistors will remain off, until the voltage at the non-inverting (+) input of the PWM comparator rises above the voltage at the inverting input.

This is shown by the dotted voltage level in the first line of the timing diagram.

The outputs of the error amplifiers are connected to pin 3 via diodes which form an OR gate and isolate one error

Fairchild μA494: basic data

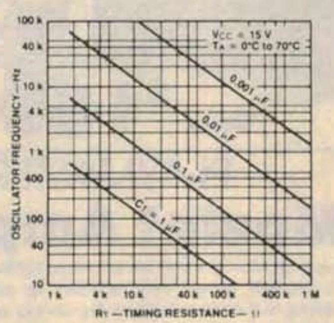


Fig. 4: oscillator frequency vs timing resistance.

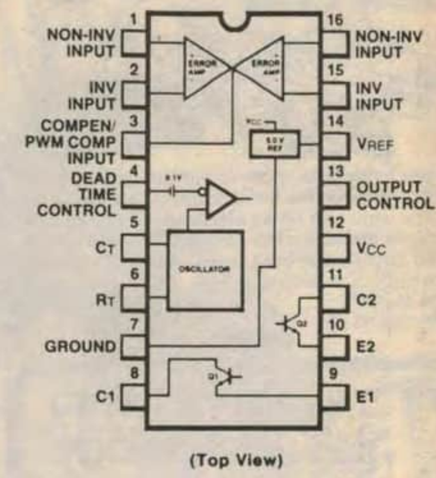
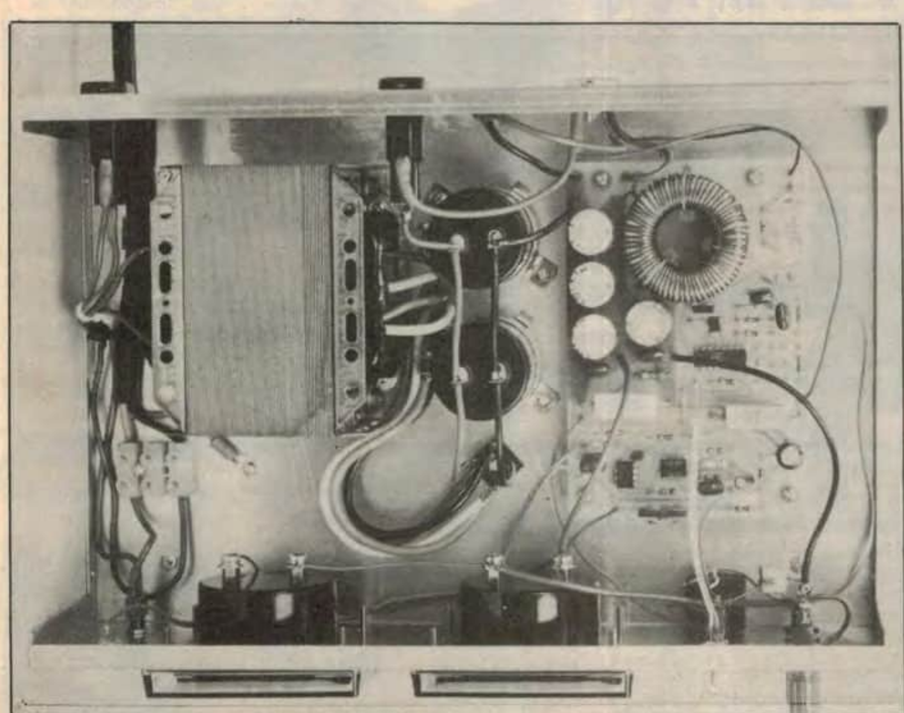


Fig. 5: connection diagram for the μA494 PWM control circuit.

NOTE: Figs. 4 & 5 and the accompanying table reproduced from the Fairchild linear data book, courtesy Fairchild Australia.

Recommended Operating Conditions

Symbol	Characteristic	μA494C Min	μA494C Max	Unit
V_{CC}	Power Supply Voltage	7.0	40	V
V_{IN}	Voltage on Any Pin Except Pins 8 and 11 (Referenced to Ground)	−0.3	V_{CC} +0.3	V
V_{C1}, V_{C2}	Output Voltage	−0.3	40	V
I_{C1}, I_{C2}	Output Collector Current		200	mA
C_T	Timing Capacitor	470	10	pF μF
R_T	Timing Resistor	1.8	500	kΩ
f_{osc}	Oscillator Frequency	1.0	300	kHz
T_A	Operating Ambient Temperature Range	0	+70	°C



LEFT: here is a sneak preview inside the prototype. Full constructional details will be published next month.

amplifier output from the other. In this way error amplifier outputs may swing high or low independently of each other.

If required, the voltage of pin 3 may be raised with an offset to reduce the duty cycle of the output pulses in the same manner as the 0.1V offset on the dead time control. This feature may be used to provide a "soft start" facility on a power supply to minimise current transients upon turn on.

The last section of circuit to be covered is the 5V voltage reference. This generally forms the reference against which the power supply output voltage is compared. It can also be used as a supply voltage for external circuits and will provide up to 20mA of current in this mode.

Next month we shall present the full constructional details of the new power supply together with performance specifications.

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.

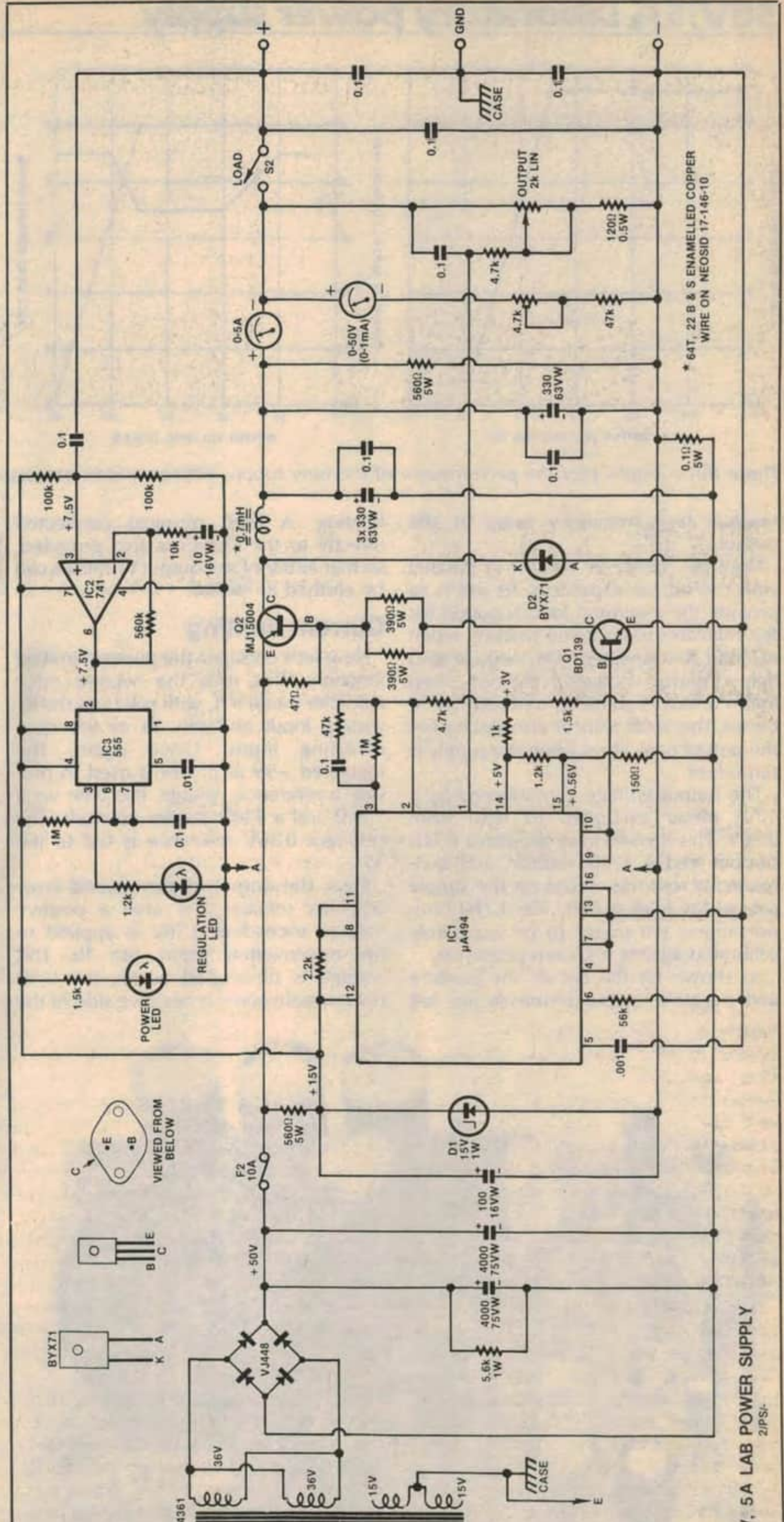
So the basic scheme is this: Q1 and Q2 are turned on and off by the two parallel connected transistors inside IC1. These in turn are controlled by the internal error amplifier, as described last month (see Fig. 2). When the oscillator ramp output is higher than the error output voltage, Q2 turns on;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

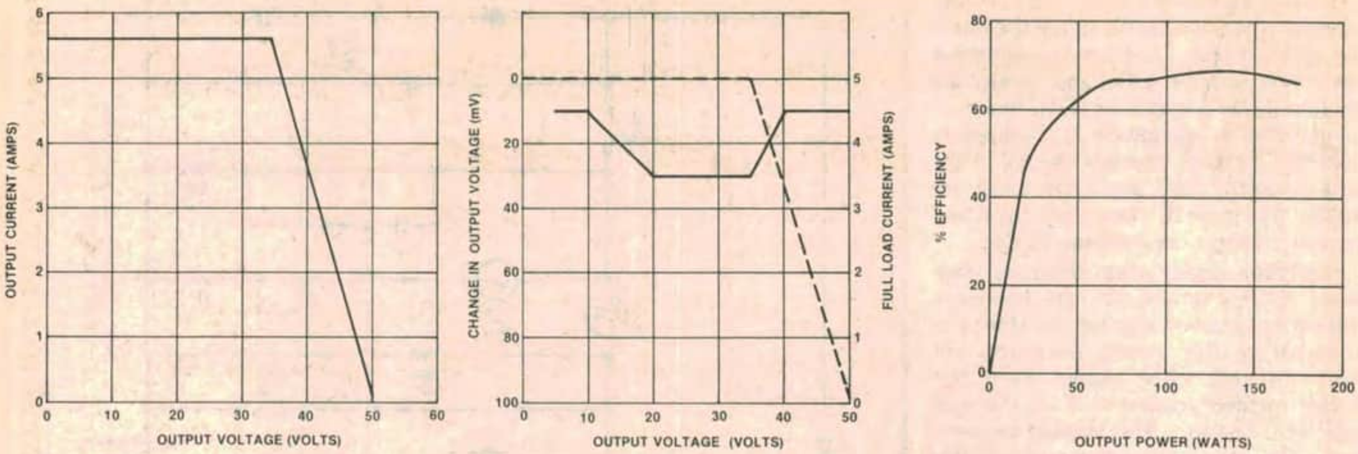
But if pin 3 is driven high the PWM comparator output will go low, turning off the pass transistor. This is the basis of the soft start action. At the instant of switch-on, a voltage will be applied to pin 3 via the 47kΩ resistor and the 0.1μF capacitor, the latter initially offering zero impedance. 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.

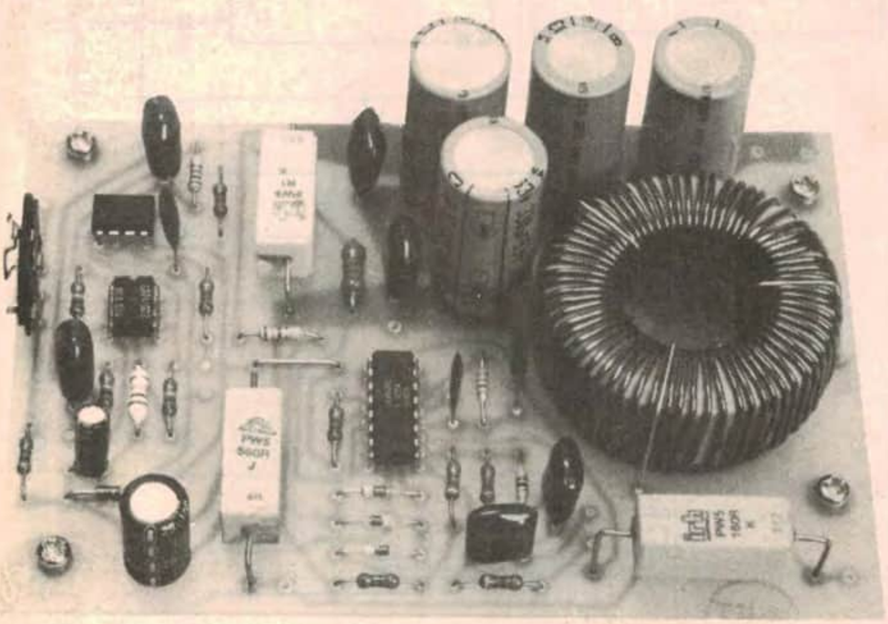
Thus, the output of the second error amplifier remains low until a positive voltage exceeding 0.56V is applied to the non-inverting input, pin 16. This voltage is developed across the 0.1Ω resistor between the negative side of the filter capacitors and the negative output terminal. When the current flow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

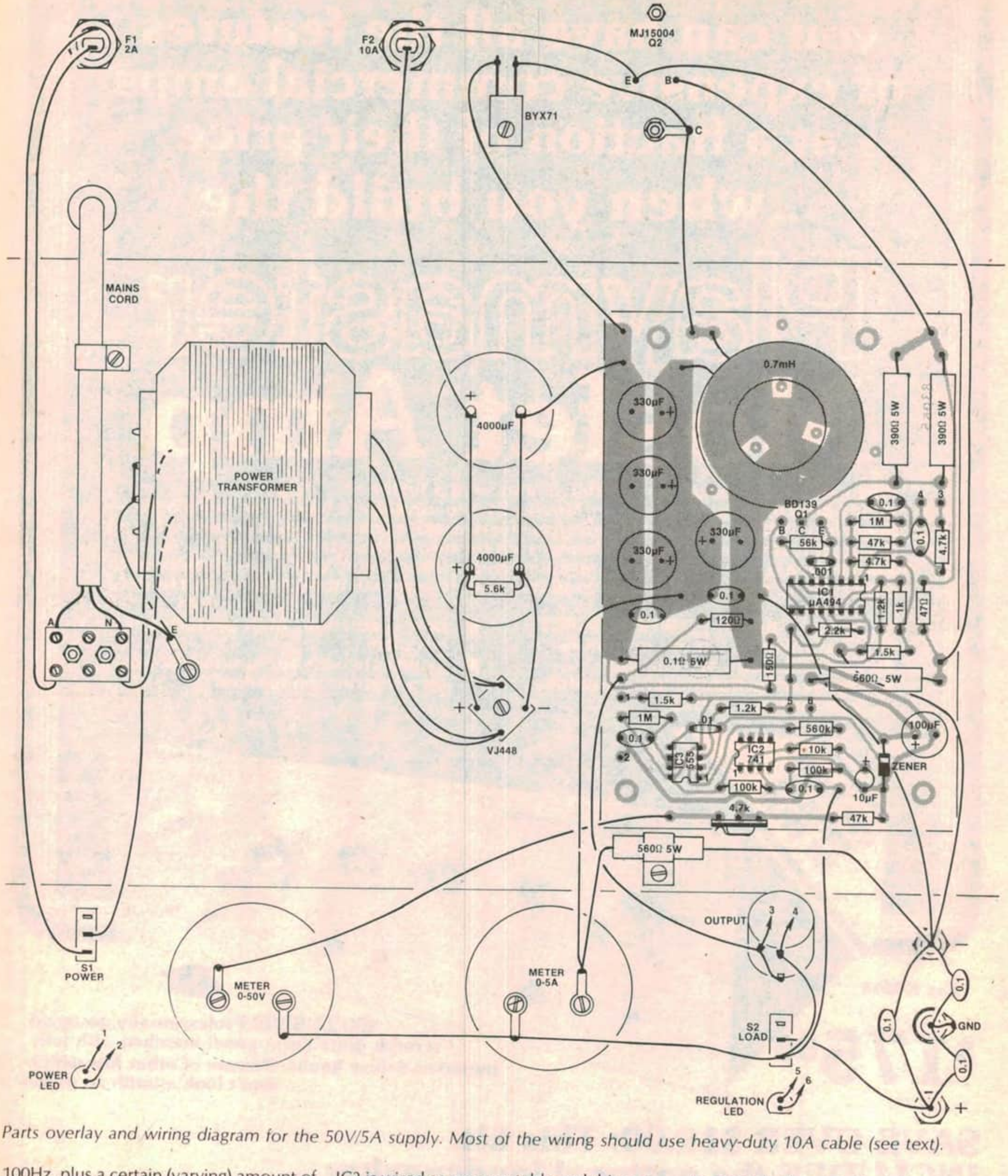


Repeated from last month, this photograph shows the control PCB assembly. Note that the final version differs from this early prototype.

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

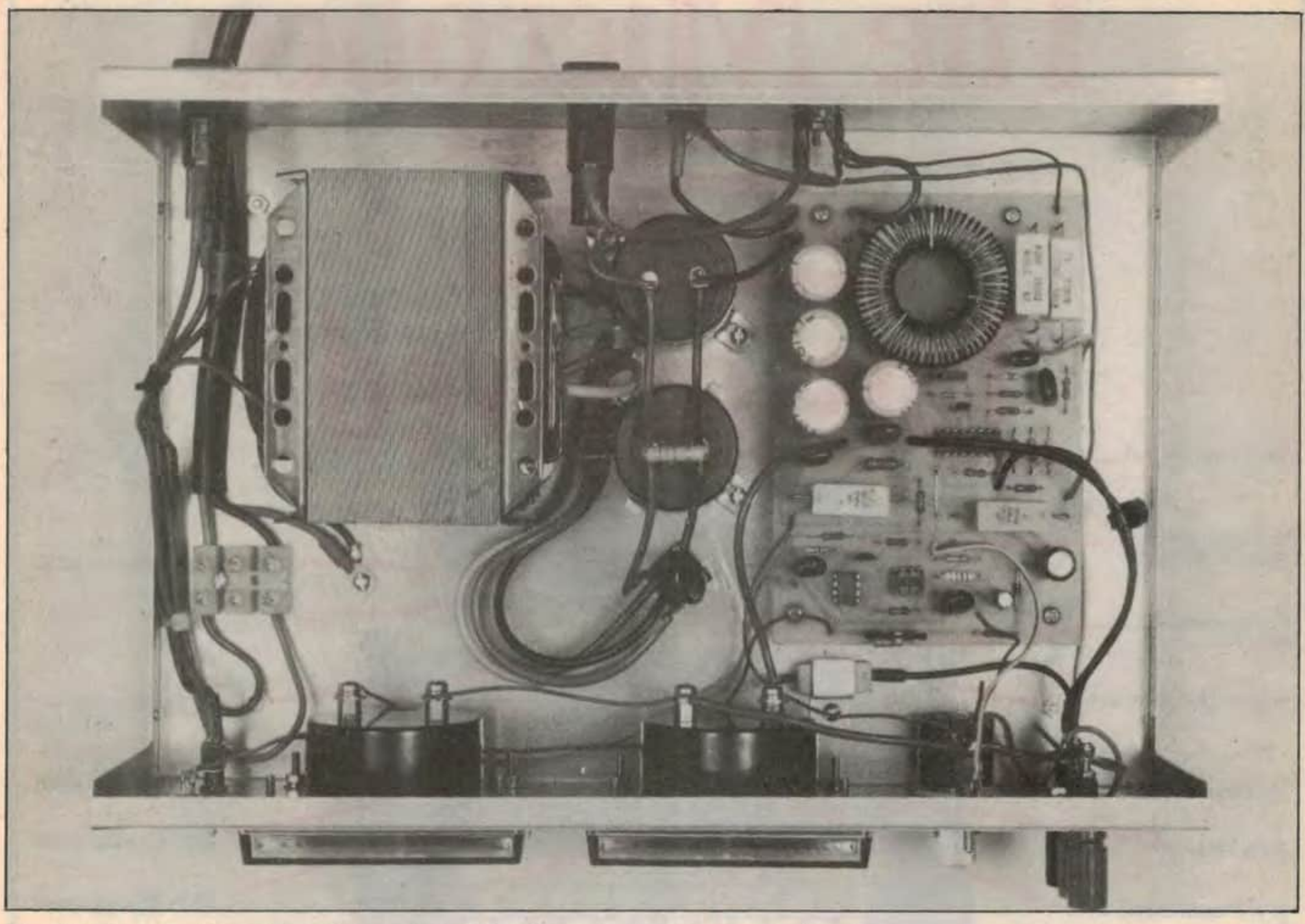


Parts overlay and wiring diagram for the 50V/5A supply. Most of the wiring should use heavy-duty 10A cable (see text).

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.

> We estimate that the current cost of components for this project is approximately
>
> **$140**
>
> This includes sales tax.

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 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

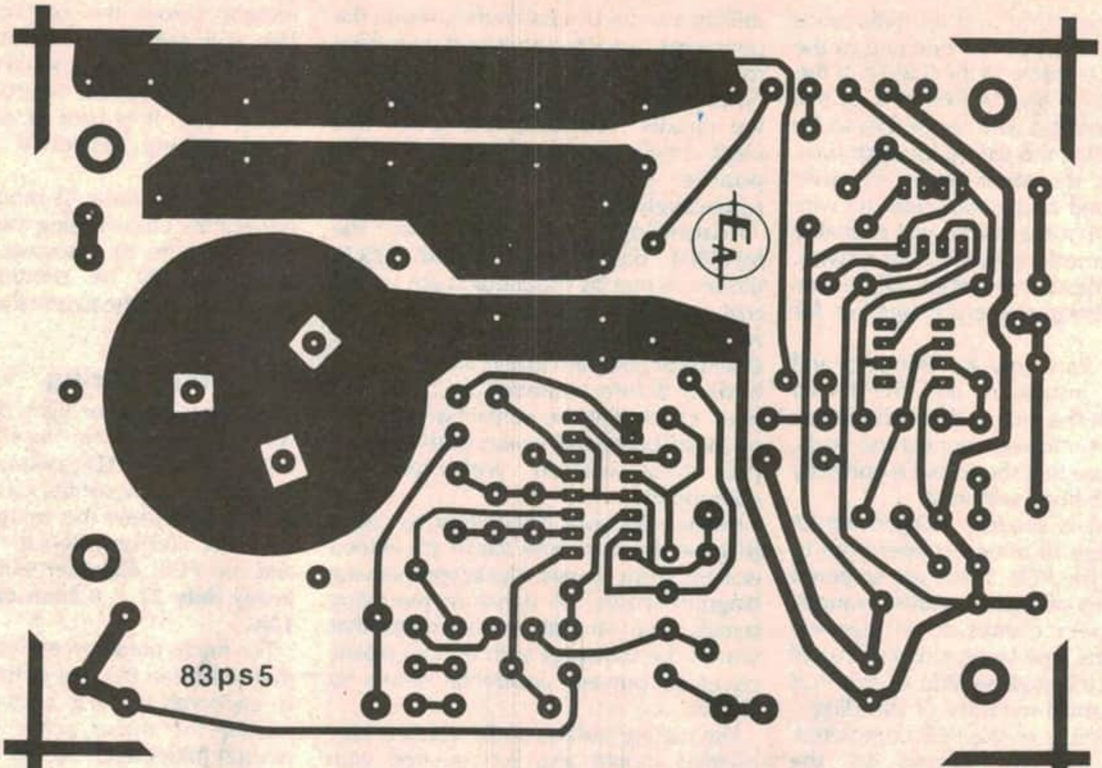
1 K&W instrument case, 305mm × 205mm × 95mm (W × D × H)
1 Scotchcal label, 302mm × 90mm
1 PCB, code 83ps5, 133mm × 92mm
1 power transformer, Ferguson PF4361
2 SPDT toggle switches
3 binding post terminals (1 red, 1 green, 1 black)
1 Minipa MU-52E 5A FSD meter, 75mm × 65mm
1 Minipa MU-52E 1mA FSD meter, 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.



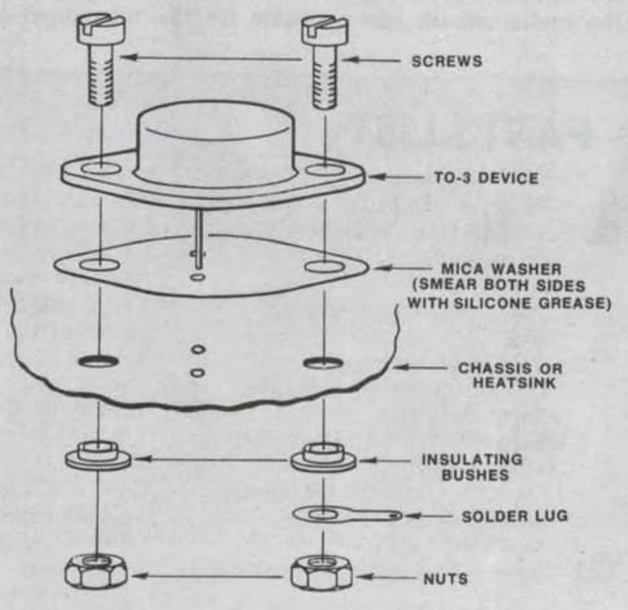
Above is an actual size artwork for the printed circuit board.

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.