

POWER SUPPLIES

Some pointers on the use of monolithic three-terminal voltage regulators from Tim Orr.

THE PRODUCTION OF stable regulated supply voltages has been simplified by the introduction of three terminal voltage regulators. These devices make power supply design relatively simple, but the designer must be aware of other important details that can cause poor results. Consider a simple unregulated supply, fig. 1.

A mains transformer isolates a piece of equipment from the

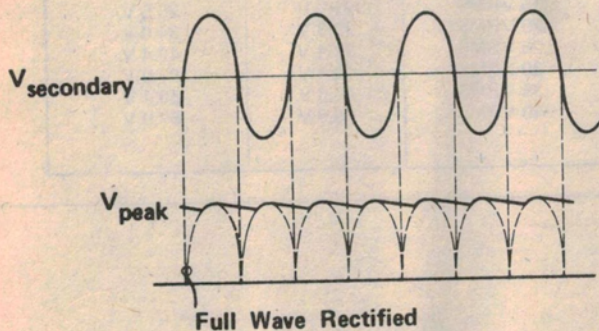
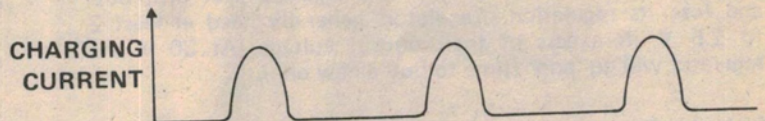
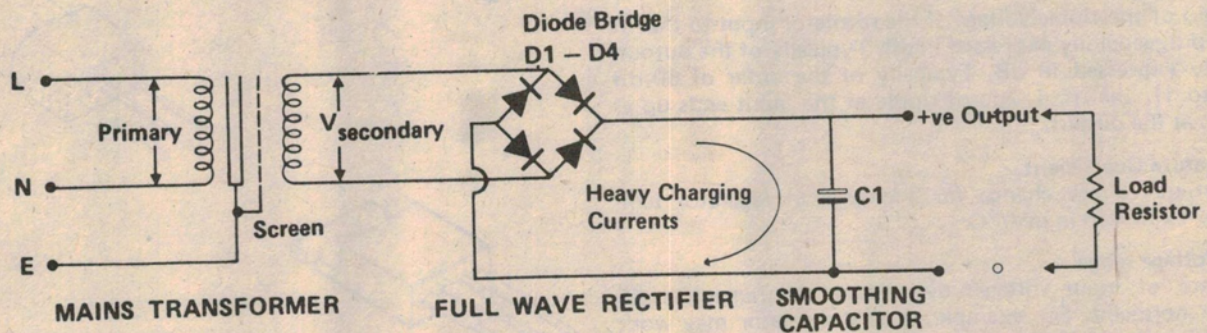


Fig. 1 (above) A simple unregulated power supply, (top) the output (with a load resistor).



There are three sections, a step down, isolating transformer, a diode bridge and a smoothing capacitor. The transformer is driven from the mains. Some transformers have a copper screen to isolate the primary winding from the secondary windings. For safety, and noise reduction, this should be connected to earth.

Another type of mains transformer uses what is known as a split bobbin; the primary is wound on one bobbin, the secondary on another. Thus the two windings are inherently physically isolated. These two transformer types are generally constructed on what is known as an 'E' core; take one to bits and you will find that it is constructed out of lots of 'E' shaped laminations. These 'E' laminations are butted into 'I' laminations, and clamped together. This butting together of the laminations can cause magnetic field problems. The wider the gap between the 'E' and 'I' laminations, the larger the magnetic field around the transformer.

potentially lethal mains voltage and provides a suitable voltage to be rectified, smoothed and applied to a voltage regulator. The secondary voltage of the transformer is measured in volts RMS at a particular loading.

If the transformer is rated at 15 V at 10 volt-amperes (VA), the output voltage will be 15 V when the load upon the transformer secondary is 10 VA (10 watts).

If the load is removed the output voltage will rise. The percentage change from load to no load is known as the transformer regulation and is typically 10 – 20%.

If the rectifier is followed by a capacitor-input smoothing circuit, the dc voltage is 1.414 (the square root of 2) times the transformer RMS voltage. Thus a 15 VRMS (loaded) transformer will generate about 20 Vdc when full wave rectified and smoothed, which will rise to about 25 Vdc when the load is removed (assuming 20% regulation, see fig. 1).

When calculating these voltages, remember that each forward biased diode in the current path will drop 0.6 V, so a full wave rectifier will cause a 1.2 V drop.

The smoothing capacitor should be selected to withstand the peak no load voltage from the transformer. Also, make certain that the polarity of an electrolytic capacitor is correct; they can literally explode if wired up backwards!

The magnetic field can generate a significant amount of induced hum in nearby electronics, this can be overcome by using a low leakage toroidal transformer which is constructed from circular laminations. The primary and secondary windings are wound through the centre of the toroid. The toroidal transformer, by virtue of its 'continuous' laminations results in a low stray field and a low profile design, making it ideally suited for audio amplifier applications.

When a load is placed upon the power supply shown above, the output voltage appears as a DC voltage on top of which is a ripple voltage. This can be thought of as two separate periods, a charge period where the capacitor is charged up by the power supply and a discharge period where the load discharges the capacitor.

This charging and discharging generates a ripple voltage which has a period of 10 ms (100 Hz). A load current of 100 mA, and a 100 μ

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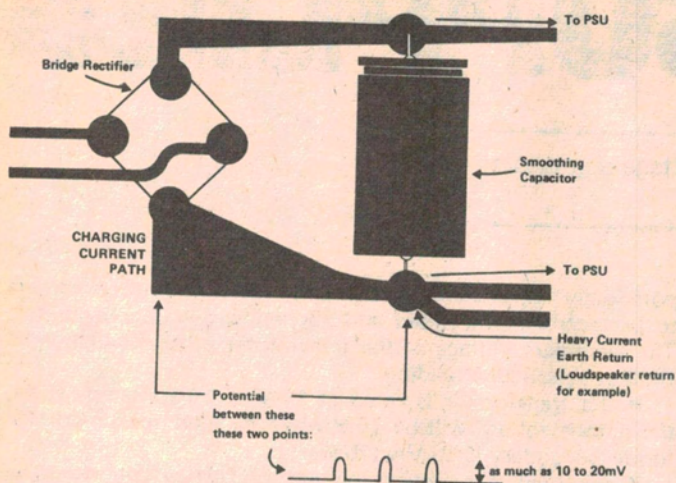


Fig. 2. Correct pcb layout for power supply design. Note the thick short tracks from the bridge rectifier to the filter capacitor.

capacitor will result in a ripple voltage of about 0.7 V p-p.

As a rule of thumb allow 1 to 1.5 V p-p maximum ripple if a voltage regulator is being used. This will generally result in an output ripple of less than 1 mV.

Generally the discharge period is much longer than the charge period.

This means that the transformer is only supplying power to the capacitor for short periods. During these periods the smoothing capacitor is rapidly charged, and it is quite common for these current surges to exceed several amps. This can cause mains BUZZ problems when laying out printed circuit board designs for power supplies.

The correct layout is shown in Fig. 2. If the current surge is 1 A and the track resistance is 20 milliohms then the voltage developed between the rectifier and the filter capacitor will be 20 mVpp.

| V secondary at rated load | V peak at rated load | V peak off load transformer regulation 20% |
|---------------------------|----------------------|--|
| 5 VRMS | 7.1 V | 8.5 V |
| 6 VRMS | 8.5 V | 10.2 V |
| 9 VRMS | 12.7 V | 15.3 V |
| 10 VRMS | 14.1 V | 17.0 V |
| 12 VRMS | 17.0 V | 20.4 V |
| 15 VRMS | 21.2 V | 25.5 V |
| 20 VRMS | 28.3 V | 34.0 V |
| 25 VRMS | 35.4 V | 42.4 V |
| 30 VRMS | 42.4 V | 51.0 V |
| 35 VRMS | 49.5 V | 59.4 V |
| 40 VRMS | 56.6 V | 67.9 V |

Voltage regulators

A voltage regulator takes a varying (unregulated) input voltage and produces a stable (regulated) output voltage. There is a wide range of fixed voltage three terminal regulators to choose from, with a choice of maximum current handling, output voltage and positive or negative operation. The data sheets for these devices contain lots of seemingly complex information and so a glossary of terms is given here.

Ripple Rejection

The ratio of the ripple voltage at the regulator input to that at the output, generally expressed in dB. Typically of the order of 60 dB (1000 to 1). that is, 1 Vpp of ripple at the input ends up as 1 mVpp at the output.

Temperature Coefficient

The output voltage change for a change in regulator temperature, expressed in mV/°C.

Input Voltage range

The range of input voltages over which the regulator will function normally. For example, a 12 V regulator may work from 14.5 V to 30 V. At 14.5 V the regulator will 'drop out' and lose its regulation. Regulators generally need at least 2 to 2.5 V in excess of their output voltage. At 30 V the regulator will go 'pop' (time to buy a new one).

Output voltage

The voltage at the output terminal with respect to ground. Generally within ±5% of stated value.

Line Regulation

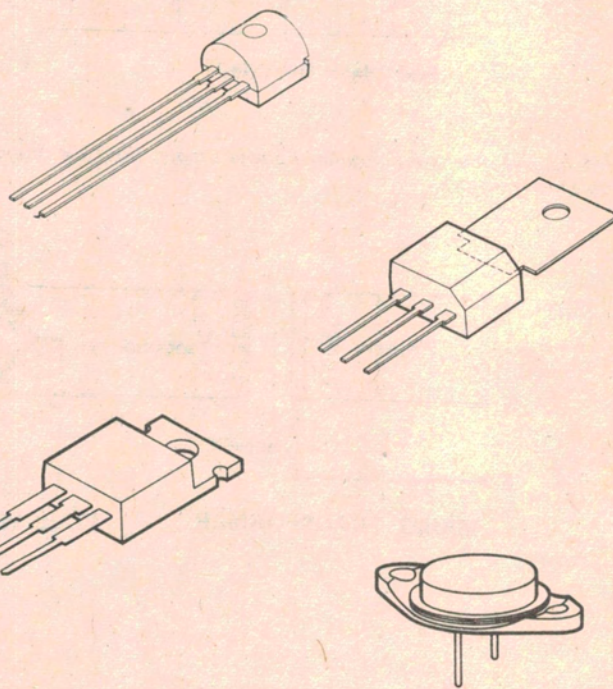
The change in the output voltage caused by a change in the input voltage, typically of the order of 0.2%.

Short Circuit Current

The output current when the output is shorted to ground.

Output Noise Voltage

The RMS noise voltage measured at the regulators output, not including any ripple.



Regulator IC packages. From top: TO-92, TO-202, TO-220, TO-3

Power Dissipation

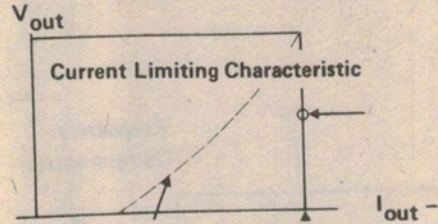
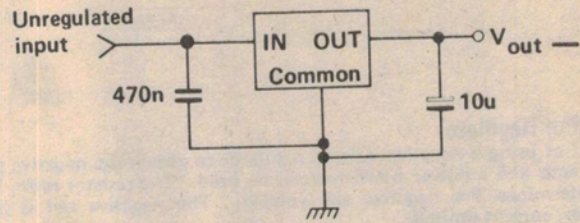
The maximum power that the regulator can safely generate on a particular heatsink.

As a rule of thumb the regulator case should not exceed about 80°C (which is hot to touch). However, always run the device at as low a temperature as possible. It is thermal ageing that eventually kills electronic devices and for higher temperatures the ageing process is disproportionately faster.

Tricks of the Voltage Regulator Trade

Fig. 1. The conventional arrangement of a three terminal regulator. It is advisable to use a decoupling capacitor connected close to the input terminals. This prevents high frequency instability. If this capacitor is left out then regulation can sometimes be greatly reduced. The decoupling capacitor on the output helps reduce the impedance at high frequencies, where the regulator loses its performance. For best results use a tantalum capacitor.

The internal current limiting of the regulator is shown. When the load current exceeds the current limit, the output voltage drops to almost 0V. This makes the regulator short circuit protected. Another type of current protection is known as 'FOLD BACK' current limiting (shown dotted). This serves to reduce the short circuit current. These devices protect the power supply from abuse. Another type of protection device is the overvoltage clamp, which protects the circuit being supplied from an increase in the power supply voltage. When the supply voltage exceeds a certain level an SCR is triggered on and clamps the rail to ground. This is intended to pop a fuse and so disconnect the faulty power supply (which is better than replacing a \$1000 worth of ICs). With foldback the short circuit power dissipated in the regulator is less than that with current limiting.



Foldback Current Limiting Max Current

Fig. 2. The output voltage of a regulator can be increased by applying a voltage to the common terminal. This can be done by a zener diode.

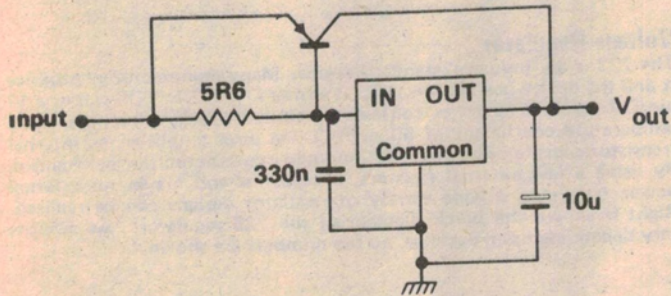


Fig. 4. Sometimes it may be necessary to use a supply which exceeds the maximum voltage rating of the regulator. A simple voltage regulator 2D, and Q1 can be used to overcome this problem. 2D should be chosen so that it is about 6V higher than the regulator output voltage. This technique has the added advantage that the power dissipated in the regulator is less (the rest being dissipated in Q1), and the regulator is presented with a semiregulated voltage, so the output will have better regulation.

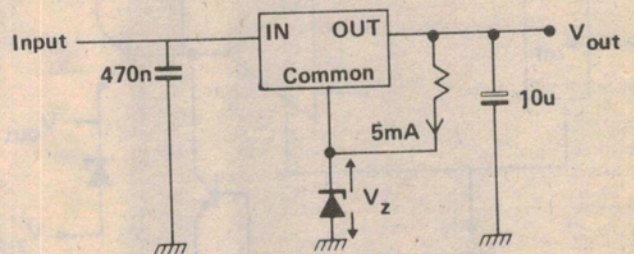
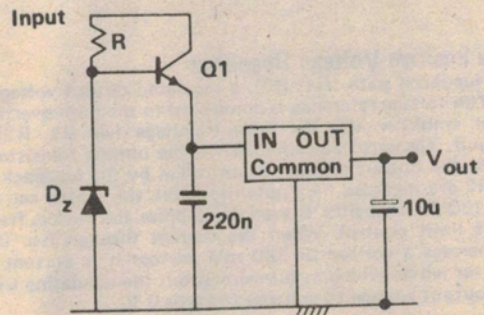


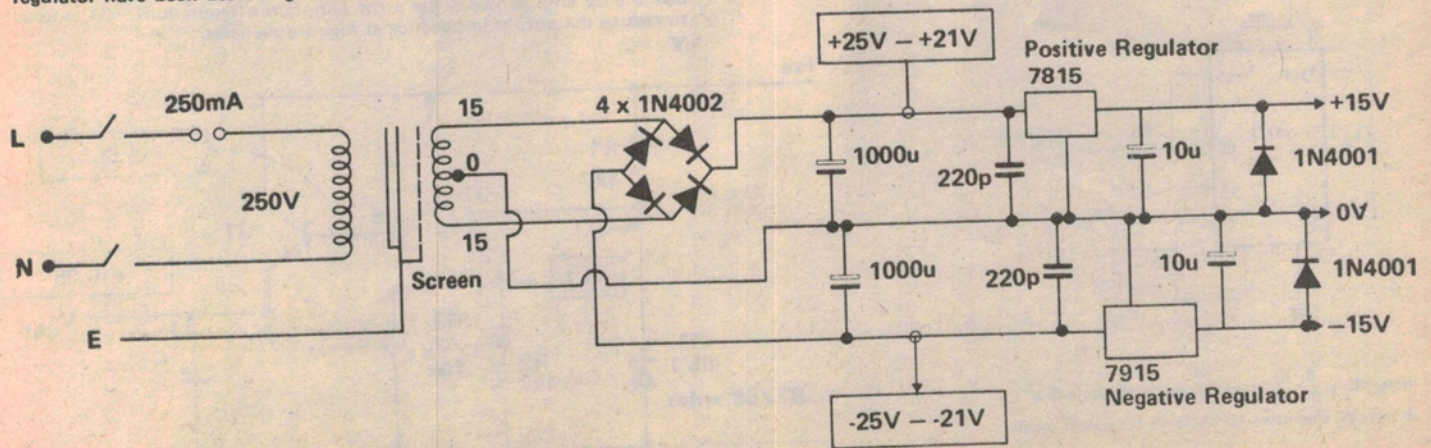
Fig. 3. The output current can be increased by using a bypass transistor. When the current flowing through the voltage regulator exceeds 100 mA (the voltage across the 5R6 being 560 mV), the bypass transistor begins to turn on. This transistor takes all currents in excess of 100 mA and yet the output still remains regulated.



Dual Power Supply

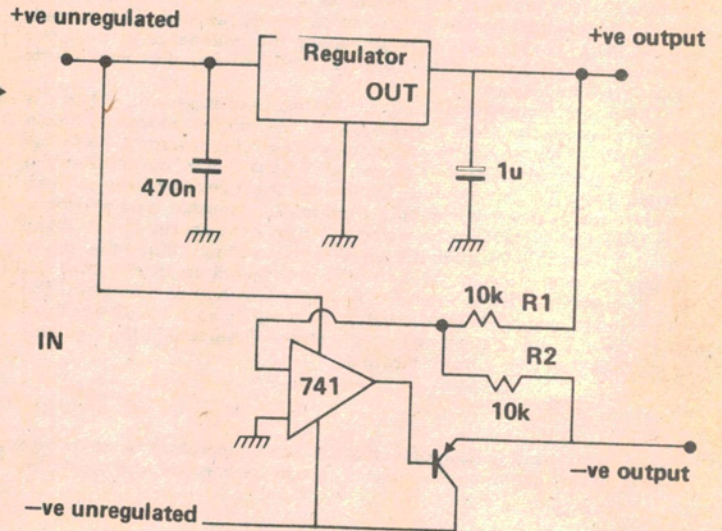
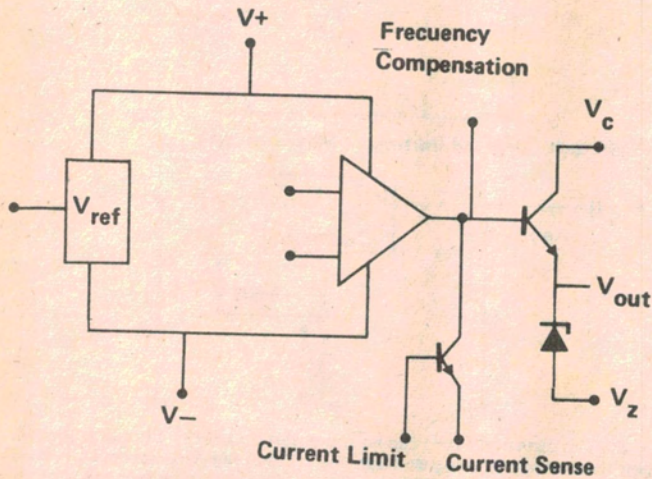
This circuit shows a complete regulated dual power supply. The unregulated rails are obtained from a split secondary transformer, a bridge rectifier and two smoothing capacitors. A positive and a negative regulator have been used to generate the + and - rails. These regulators

should be mounted together with insulating washers on heat sinks. The pin out of the negative regulator is different to that of the positive regulator. The two diodes at the output prevent latching up situations (on load) whereby one side starts up faster than the other and forcibly reverse biases it, preventing it from operating.



Tracking Regulator

Instead of using a negative voltage regulator to obtain the negative rail, an op amp and a power transistor can be used. The resistor ratio, R1, R2 determines the negative rail voltage. The negative rail is not, however, current limited.



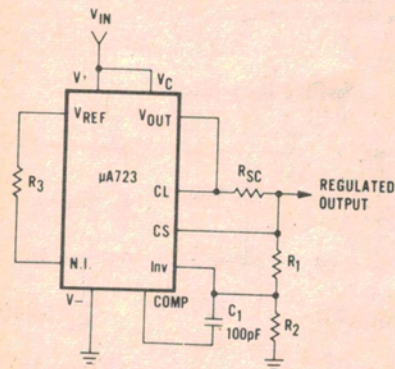
Voltage Regulator

The 723 is an 'industry' standard device. Many manufacturers produce it and the device itself is versatile. It comes in a 10 pin TO5 can or a 14 pin/DIL pack. The device contains a precision voltage reference, with a temperature coefficient of 50 ppm/°C, an error amplifier, an internal transistor capable of handling 100 mA and a current limiting mechanism. By using a few external resistors, a capacitor and maybe an external power transistor, a wide variety of regulator designs can be realised. Right is shown the block diagram of the 723 regulator. As pinouts vary depending upon package, no pin numbers are shown.

Adjustable Positive Voltage Regulator

By using a feedback path (R1, R2), a regulated output voltage can be generated. The voltage reference is connected to the non-inverting input of the error amplifier and the output voltage (via R1, R2) to the inverting input. The error amplifier drives the output transistor on the IC and hence the output voltage is controlled by the feedback voltage. If R1 and R2 are replaced by a potentiometer, the supply can be made variable. A 100 pF capacitor is used to stabilise the device. R_sc is used as a current limit control. When the current through R_sc (the load current) generates a voltage of 560 mV across it, a current limiting transistor is turned on which in turn shorts out the regulating transistor, causing the output voltage to collapse towards 0 V.

$$V_{OUT} = [V_{REF} \times \frac{R_1 + R_2}{R_2}]$$



Note: $R_1 = \frac{R_1 R_2}{R_1 + R_2}$ for minimum temperature drift.
R₁ may be eliminated for minimum component count.

Regulated Power Supply

Sometimes it is necessary to make a simple power supply using discrete components when a non-standard voltage is required. The circuit shown uses all the basic elements of a voltage regulator, that is, a reference voltage ZD1, an error amplifier and a series control transistor Q1. The zener diode, ZD1, sets up a reference voltage of 5V1. This diode has a temperature coefficient of -1.2 mV/°C (a 5V6 zener is best at -0.2 mV/°C). The resistor ratio of R3 and R2 sets the output voltage and the op amp provides the error correction (regulation). C1 is used to reduce the output impedance at high frequencies.

