23 Power Supplies

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Amateur radio equipment normally derives its power from one of four sources:

- The public AC mains which is nominally 230 volts at 50Hz in the EU, though 240 volts still exists in the UK.
- Batteries, which are either primary (non-rechargeable) or secondary (rechargeable)
- Engine driven DC generators or alternators, whether separate or incorporated in a vehicle.
- Renewable sources such as wind, possibly water turbine or pedal driven generators, solar cells or rarely, thermocouples. As these are intermittent in nature, a secondary battery with a regulator must be used in conjunction.

For fixed stations the AC mains is readily available, is relatively cheap and is almost always used. It can be converted by transformers, rectifiers, smoothing circuits or switch mode (high frequency) circuits to a wide range of direct voltages and currents necessary for amateur equipment use.

Batteries, both primary and secondary (accumulators) have always provided a convenient though relatively expensive source of power, especially for low powered or portable rigs, or test equipment.

Discrete engine driven generators can give an output of DC or AC, but the most popular give an output of 240/230 V AC at a nominal 50Hz, matching the domestic mains. Car alternators at present provide charging for a 12V accumulator, though 42V may soon be common.

Renewable sources provide AC or DC according to type, and are discussed in detail later.

SAFETY

The operation of all power supplies (except perhaps low-voltage, low current primary batteries) can be dangerous if proper precautions are not taken. The domestic mains can be lethal. High voltage power supplies for valve equipment can also be lethal and great care must be taken with them. There is a case on record of 12 volts proving fatal, for it is not voltage which kills you but current, and the law of the late German doctor (Georg Siemon Ohm) applies. Having wet hands is asking for trouble; if you must handle high voltages, do so with one hand in your pocket.

Where petrol or liquefied gas is used for your engine's fuel, there is a fire hazard, particularly when re-fuelling. If you persist in re-fuelling while the engine is running, and have a fire, you will not get much sympathy from either your insurance company or relatives.

SUPPLIES FROM THE PUBLIC MAINS

It is assumed that the supply will be a nominal 230 volts at 50Hz in accordance with EU regulations.

A rectifier (or rectifiers) will be needed to convert AC to DC. Rectifiers are nearly always silicon PN junction or Schottky diodes but Silicon Carbide diodes will be met occasionally (see the chapter on semi-conductors for more on rectifier diodes). These are all very efficient in that they have a very low forward voltage drop and a very high reverse resistance, within their rating. Copper oxide, selenium and germanium diodes are obsolete for this purpose. The diode has a conventional symbol (**Fig. 23.1**) in which the arrow points in the direction of current flow, not electron flow - so the arrow head is the anode, and the plate the cathode. By convention it is the cathode, which is marked +, banded or coloured red because it is positive when rectifying AC.

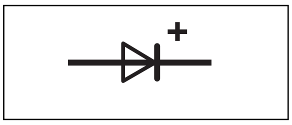


Fig 23.1: Rectifier symbol

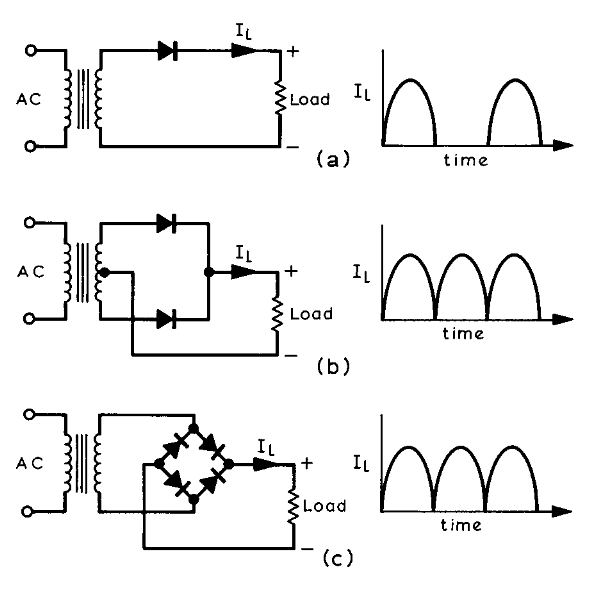
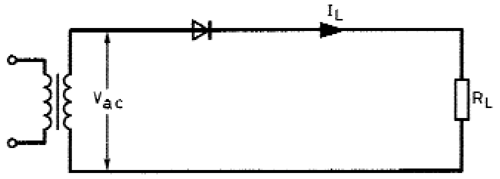
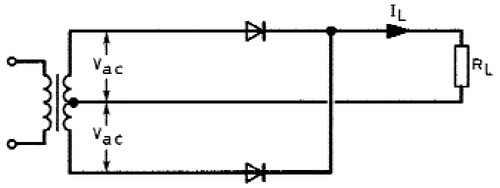
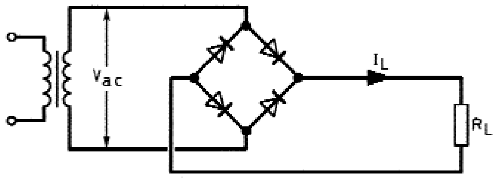
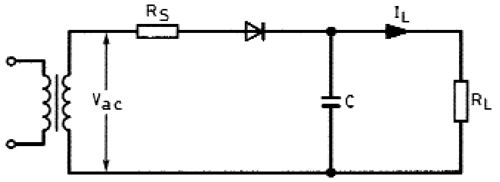
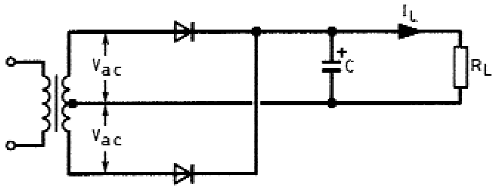
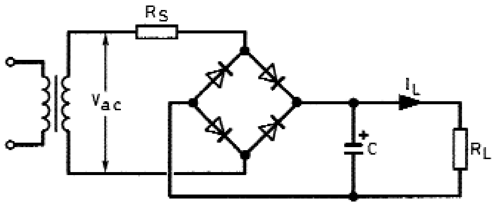
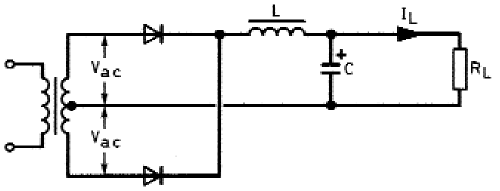
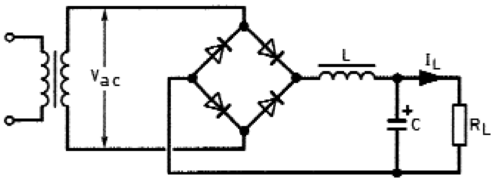


Fig 23.2: Rectifier circuits showing the output current waveforms with resistive loads. (a) half-wave, (b) full-wave or bi-phase half-wave, (c) bridge

Fig. 23.2 shows three types of rectifier circuits which are widely used in amateur Power Supply Units (PSUs), together with waveforms of the current supplied by the rectifier(s). In all cases this can be resolved into a DC and an AC component. The latter is called ripple, and requires removal. It can be seen that the half-wave circuit of **Fig 23.2(a)** has a worse ripple than either of the full wave circuits, and has the lowest frequency component (50Hz). Also notice that DC flows through the transformer, which may cause saturation and over-heating if the transformer is not designed for this purpose. Consequently it is not much used.

The full-wave circuit of **Fig 23.2(b)** needs a centre-tapped transformer while the bridge circuit of **Fig 23.2(c)** does not. The bridge incurs two diode (voltage) drops but uses the transformer winding more efficiently. Microwave oven transformers are not designed to use bridge rectifiers, and the insulation (if any) of the low potential end is inadequate, but the circuit of Fig 23.2(a) may be used if the high leakage reactance of the transformer can be tolerated. The oven power supply cannot be used without modification, as it is neither smooth enough nor of the right polarity to feed a valve amplifier.

In most cases the rectifier diodes feed a large value capacitor (the reservoir capacitor), which stores energy during the part of the cycle when the diodes are conducting and releases it when the diodes are not conducting, so maintaining a relatively constant output voltage. The difference in voltage between the diodes conducting and not conducting causes an

Circuit	Average DC output voltage	PIV across diode	Average diode current	Diode peak current	Secondary RMS current
	$0.45V_{ac}$	$1.4V_{ac}$	I_L	$3.14I_L$	$1.57I_L$
	$0.9V_{ac}$	$2.8V_{ac}$	$0.5I_L$	$1.57I_L$	$0.785I_L$
	$0.9V_{ac}$	$1.4V_{ac}$	$0. 5I_L$	$1.57I_L$	$1.11I_L$
	$1.4V_{ac}$ (no load)	$2.8\ V_{ac}$ maximum	I_L	See Fig 24.6	= Diode RMS current See Fig 24.7
	$1.41V_{ac}$	$2.82V_{ac}$	$0.5I_L$	See Fig 24.6	I_L
	$1.4V_{ac}$ (no load) See Fig 15.6	$1.4V_{ac}$ maximum	$0.5I_L$	See Fig 24.6	= Diode RMS current x 1.4 See Fig 24.7
	$0.9V_{ac}$	$1.41V_{ac}$	$0.5I_L$	$2I_L$ when $L = L_C$	$0.65I_L$
	$0.9V_{ac}$	$1.4V_{ac}$	$0.5I_L$	$2I_L$ when $L = L_C$	$1.22I_L$ when $L = L_C$

CD1665

Table 23.1: Operating conditions of single-phase rectifier circuits

Type	VRRM	Iav	IFRM	IFSM
Diodes				
1N4001*	50	1.0	10	20
1N4007*	1000	1.0	10	20
1N5401†	100	3.0	20	60
1N5408†	1000	3.0	20	60
BY98-300	300	10	50	100
BY98-1200	1200	10	50	100
BY96-300	300	30	100	200
BY96-1200	1200	30	100	200
Bridge rectifiers				
1KAB10E	100	1.2	25	50
1KAB100E	1000	1.2	25	50
MB151	100	15	150	300
MB156	600	15	150	300
GBPC3502	200	35	200	400
GBPC3506	600	35	200	400

*Note: The diodes marked * and † are wire ended - the rest are mounted on screwed studs.* V_{RRM} *is the maximum reverse voltage or peak inverse voltage, Iav is the average output current in amps,* I_{FRM} *is the maximum repetitive peak current in amps,* I_{FSM} *is the maximum non-repetitive peak forward current with a maximum duration of 5ms.*

Table 23.2: Electrical characteristics of some common diodes and bridge rectifiers

AC ripple voltage to be superimposed on the average DC output voltage (see below re smoothing circuits). In a few cases the diodes feed an inductor (choke) which is then followed by a capacitor. The choke is heavy and expensive, but does lower the peak current in both diodes and capacitor.

A rectifier diode for mains frequency has three important parameters:

- Maximum mean forward current
- Maximum peak forward current
- The peak inverse voltage, which is encountered by the diode when it is not conducting. This is made up of the instantaneous voltage of the transformer, ie when it is at its negative peak, added to the voltage appearing on the smoothing capacitor. Placing diodes in series is a means of increasing peak inverse voltage, but shunt (voltage sharing) resistors need to be added across each of the diodes to ensure equal voltage across each diode.

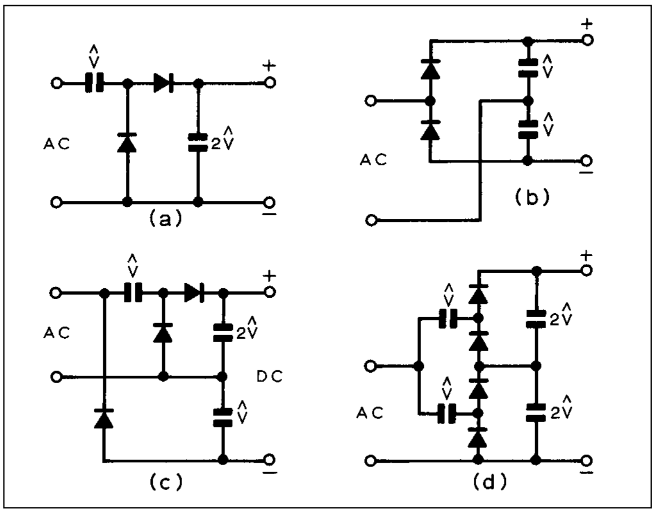


Fig 23.3: Voltage multiplier circuits. (a) Half-wave voltage doubler; (b) full-wave voltage doubler; (c) voltage tripler; (d) voltage quadrupler. $\hat{V}$ = peak value of the AC input voltage. The working voltages of the capacitors should not be less than the values shown. The diodes have to withstand 2V, but to avoid problems with surges it is advisable to double these voltages

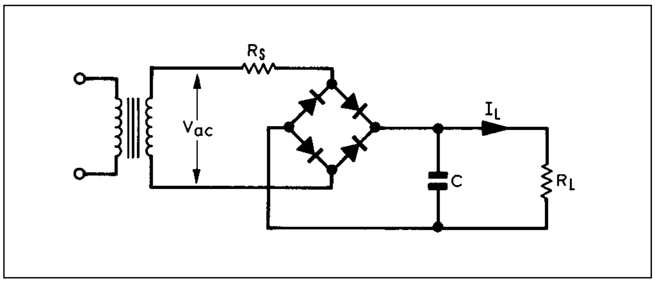


Fig 23.4: Bridge rectifier with capacitor input filter

Table 23.1 shows the voltages and currents associated with various configurations. **Table 23.2** gives the parameters for some of the more common of the many diodes now available.

Other categories are fast and ultra-fast recovery diodes which are used along with Schottky (low forward voltage and fast recovery time) diodes in switch mode power supplies and soft recovery diodes, which because they switch relatively slowly, cause less RF interference. Avalanche diodes break down on over-voltage throughout the silicon chip and not a localised spot.

There are many packages of four diodes as a bridge, ready to mount on a heat-sink. These are relatively cheap, but watch the manufacturer's peak inverse voltage rating; does it apply to the individual diodes or to the bridge? Table 23.2 also lists some common bridge packages.

Voltage Multipliers

When a DC voltage greater than the peak of the available AC is needed, a voltage multiplier circuit can be used. These can give a large voltage multiplication, but with poor regulation (decrease of output voltage with increase of load current). The operation may be visualised roughly by thinking of the diodes as 'ratchets'. The mechanical ratchet passes motion in one direction only, and in the multiplier, each stage 'jacks up' the voltage on the following stage. **Fig 23.3** shows some of the possible circuits.

Smoothing Circuits

These are low pass filters which follow the rectifier diodes, and the behaviour of the circuit depends on the input element of the filter.

This is usually a capacitor in mains frequency circuits and a choke in switch mode PSUs. There may be further components where a greater ripple reduction is needed (see later in this chapter).

Capacitor input

An example is the bridge rectifier of **Fig 23.4** in which R_s is the effective resistance of the transformer (resistance of the secondary, plus the square of the turns ratio times the primary resistance).

Fig 23.5 shows voltage and current waveforms of the capacitor as it charges up during part of the cycle and discharges during the rest. The ratio of output voltage to peak input voltage depends on the value of the capacitor, the load and effective resistance in series with the rectifier. **Fig 23.6** shows the relationship graphically being 2π times the input frequency.

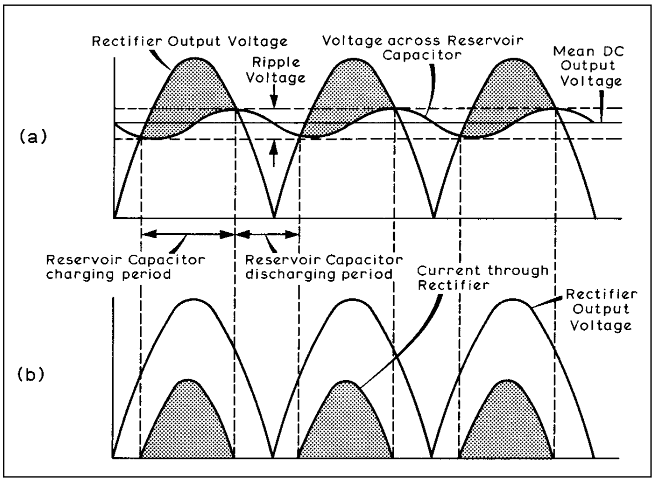


Fig 23.5: The output voltage and current waveforms from a full-wave rectifier with capacitor input filter. The shaded portions in (a) represent periods during which the rectifier input voltage exceeds the voltage across the reservoir capacitor, causing charging current to flow into it from the rectifier

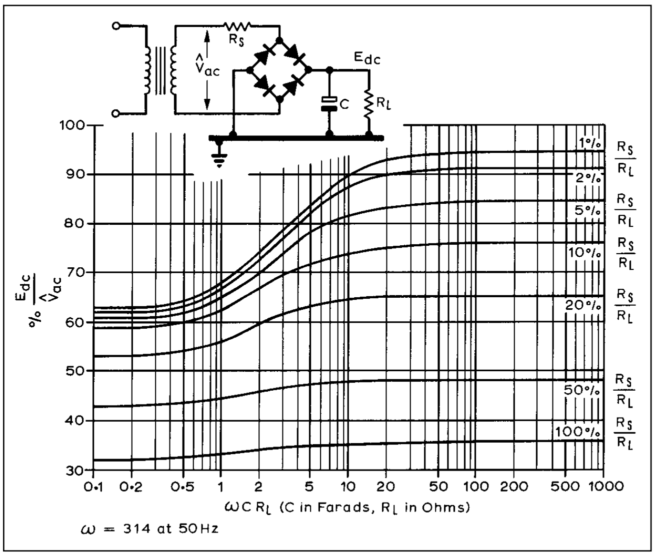


Fig 23.6: Output DC voltage as a percentage of peak AC input voltage for a bridge rectifier with capacitor input filter

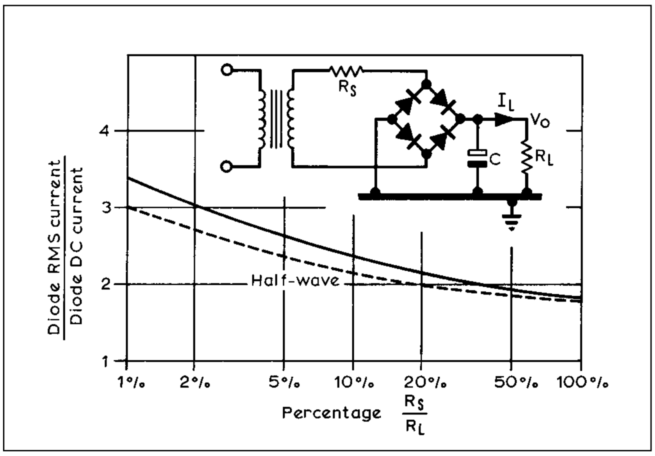


Fig 23.7: Relationship between diode RMS current and percentage R_S/R_L for values of ωCR_L greater than 10. (ω = 314 for 50Hz mains). The dotted line applies to half-wave rectifiers

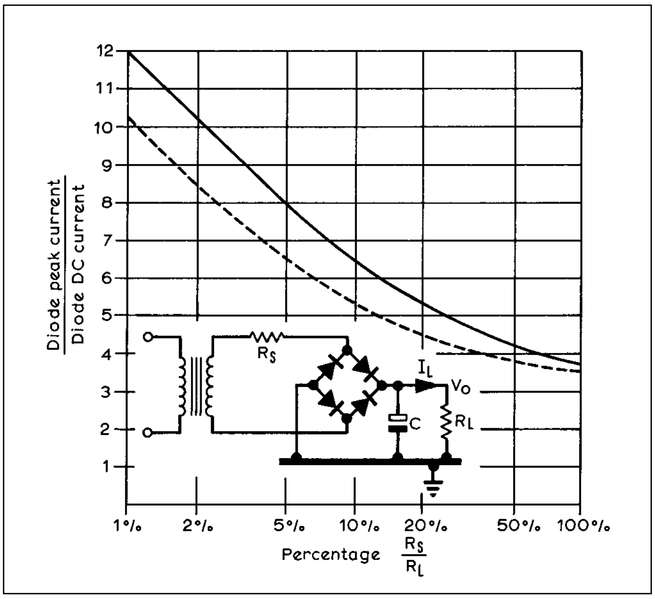


Fig 23.8: Diode peak current as a ratio of diode DC current for values of ωCR_L greater than 10. Note: in a bridge rectifier circuit, diode DC current is half the load current. The dotted line applies to half-wave rectifiers; in this case the diode DC current is equal to the load current

The charging and discharging of the reservoir capacitor constitutes the ripple current and all electrolytic capacitors have a maximum ripple current rating (see the chapter on passive components). Exceeding the maximum will overheat the capacitor and shorten its life. Ripple current is difficult to calculate, but can be measured by using a true RMS ammeter, or estimated at three times the DC rating of the PSU.

As the effective resistance of the transformer becomes a smaller and smaller fraction of the load resistance, R_L, the peak rectifier current increases (see **Figs 23.7 and 23.8**). With increasing C (Fig 23.4) the peak rectifier current increases and the capacitor ripple current increases, although the capacitor (output) ripple voltage decreases (**Fig 23.9**). The efficiency also decreases, meaning more transformer and diode heating. A

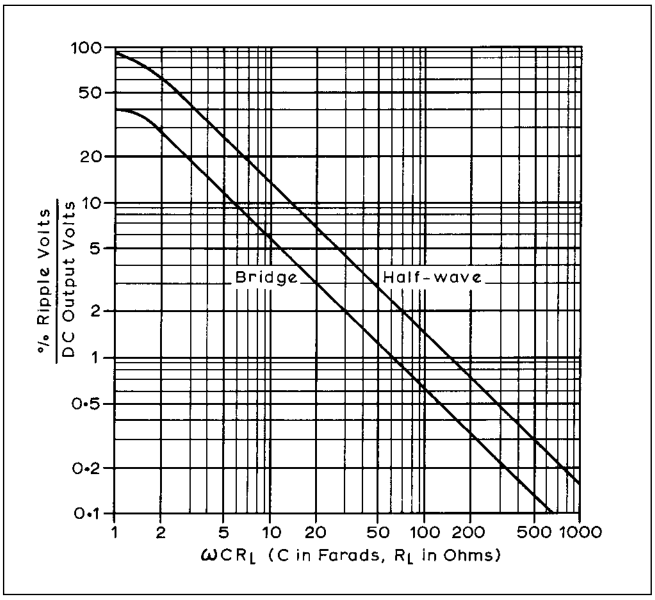
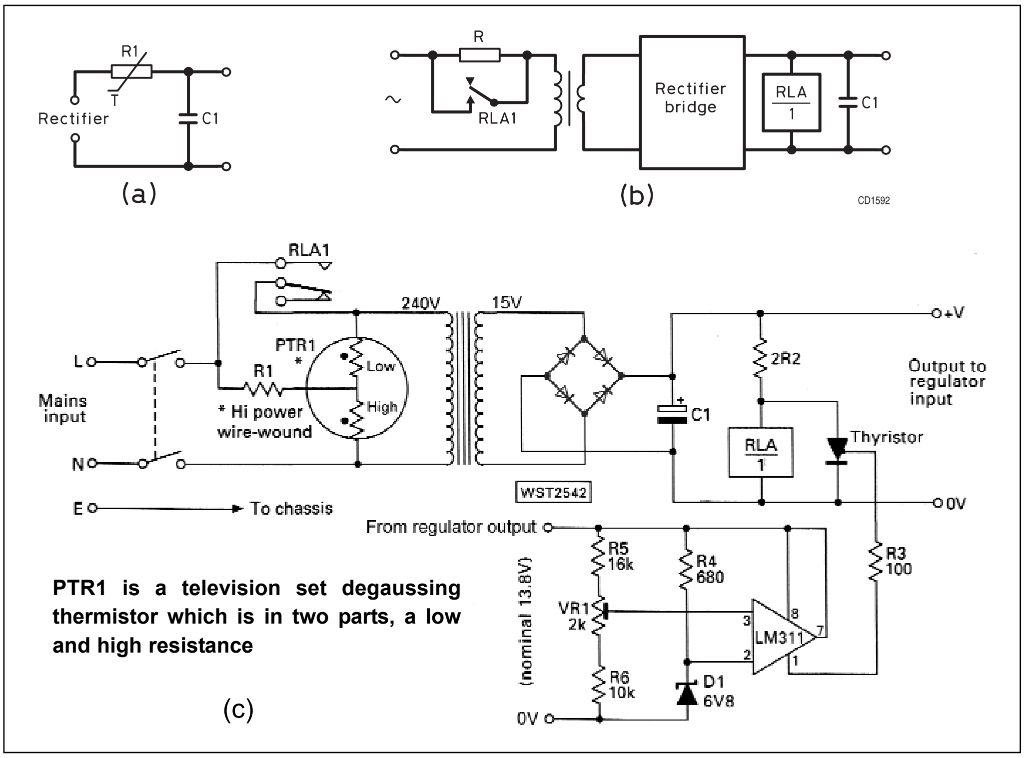


Fig 23.9: Percentage ripple voltage (RMS) against values of ωCR_L ($\omega = 2\pi f$ where f is the mains supply frequency)



PTR1 is a television set degaussing thermistor which is in two parts, a low and high resistance

Fig 23.10: Soft starting circuits. C1 is the smoothing capacitor. (a) Using R1, an NTC thermistor. (b) Using a relay to short out a series resistor. (c) A more sophisticated circuit. for a 12V supply. When power is applied, C1 charges up slowly because R1 and the low thermistor limit the inrush current. When C1 is sufficiently charged to operate RLA, the relay closes and RLA1 puts full mains voltage across the transformer primary. The high resistance part of the thermistor remains hot and keeps the 'low' part high. The circuit also provides over-voltage protection by 'crow-barring' C1 through the 2R2 resistor. An enhancement is to place a neon lamp in series with a 150kΩ resistor across the relay contact; this flashes briefly at switch-on and stays on if overvoltage occurs or an attempt is made to switch on with a load connected. [The use of the circuit in (c) is by permission of *Practical Wireless*]

simple idea to avoid destroying the diodes by excessive current, is to limit the maximum peak current by adding a series resistor to augment the R_s of Fig 23.4. The minimum value of R_s is given by

$$R_s = V/I_{FRM} \qquad (1)$$

where V is the output voltage of the transformer and I_{FRM} the maximum peak current for the diode.

Then calculate the effective resistance of the transformer as already explained. If it is more than the value calculated above, no augmentation is necessary. If it is less, add a series resistor to make up the difference, bearing in mind the necessary power rating.

Soft starting

When first switched on, the capacitor's inrush current may be excessive and there are means of limiting it.

A simple way is to connect an NTC thermistor (see the chapter on passive components) of correct current rating in series with the primary of the transformer, as in Fig 23.10(a). Another way is to have a resistor in series with the primary, which is shorted by a relay whose coil is in parallel with the reservoir capacitor (Fig 23.10(b)).

This relay must be chosen so that it closes at about 75% of the normal output voltage. By putting the limiter in the primary, the doubling of the magnetising current and possible magnetic saturation when the transformer is switched on at a zero crossing of the mains, is avoided.

A refinement of this circuit is shown in Fig 23.10(c), where over-voltage protection is also provided.

Inductor (choke) input

Here the situation is different (see Fig 23.11) - if the inductor's value is above a certain limit (see below), current flows during the whole time (Fig 23.12), much reducing the peak value The critical value, (L_c) for the inductance in a full wave circuit is:

$$L_c = \frac{R_S + R_L}{6\pi f} \qquad (2)$$

Where L_c is in Henrys, f is the supply frequency in Hertz, and resistances are in ohms. If R_S is much less than R_L and the frequency of the supply is 50Hz, for a full wave rectifier, this reduces to:

$$L_c = \frac{R_L}{940} \qquad (3)$$

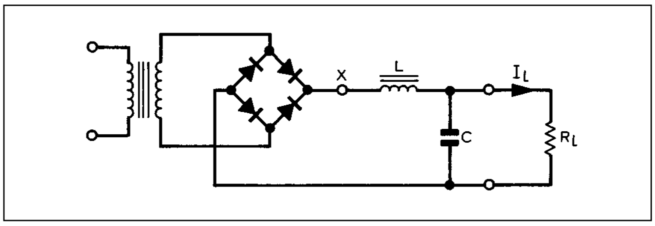


Fig 23.11: Bridge rectifier with choke input filter

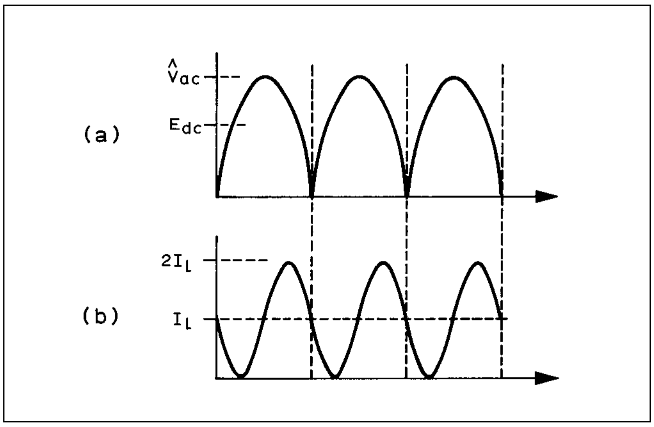


Fig 23.12: Waveforms at rectifier output (point X in Fig 23.11) in a choke input circuit. (a) Voltage waveform. (b) Current waveform ($L = L_C$)

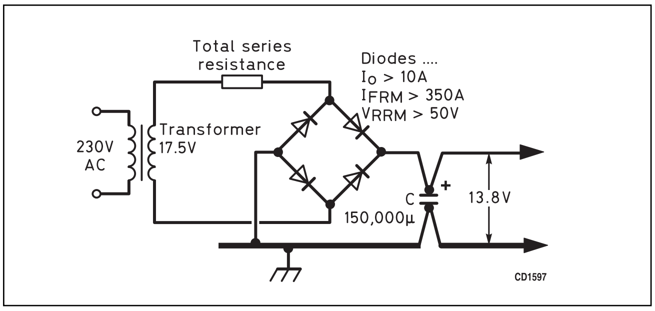


Fig 23.13: Circuit of a power supply for 13.8V at 5A

It will be seen that the inductance required increases as the load current decreases, (the load resistance R_L increases), so it may be necessary to provide a minimum current by means of a bleeder resistor if the inductor input is to remain effective (the output voltage will rise if it is not).

The value of this resistor in ohms is 940 times the maximum value of the inductor in henrys. The inductance of an iron cored 'swinging choke' filter depends on the current through it.

Choice of Components

The ideas given here are for power supplies which will always work but which may not be the most economical in components. The reason for this is that generally components are cheap, but time is important and troubleshooting can be difficult. Components should always be chosen on a 'worst case' basis. That is assuming that:

- The mains voltage can fluctuate from its nominal value by ±10%. This does not allow for drastic load shedding during a very hard winter!
- Electrolytic capacitors generally have a tolerance of +50% to -20%, so that a capacitor marked 100μF can have any value between 150μF and 80μF
- Rectifier diodes should have a peak inverse voltage rating of at least three times the output voltage of the transformer (if one is used), when the mains voltage is 10% higher than nominal. This does not allow for spikes on the mains, and either an even higher rating should be adopted or some means of spike reduction installed.
- Choose a diode or diodes with an average current rating of at least twice the required value.

Capacitor input

1 The secondary resistance of the transformer is assumed to be 0.1Ω and the primary resistance 5Ω. The turns ratio (see below) is 0.0729 to 1 so the effective resistance of the primary transferred to the secondary will be 0.027Ω and the total effective resistance of the transformer is 0.127Ω.

2 The bridge rectifier is a type SKB25/02, which is rated at an average current of 10A, a peak current of 359A and peak inverse voltage of 200V. The RMS transformer output voltage is 17.7V (see below). The minimum value of R_s is 17.7/350 = 0.047Ω, which is well below the effective resistance of the transformer, so no added resistance will be necessary.

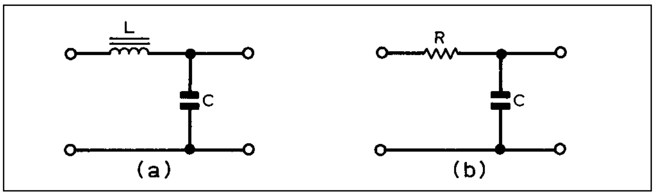


Fig 23.14: Additional smoothing sections to follow the circuits of Fig 23.4 or 2311

3 R_s/R_L = 0.047 /2.76 = 0.017 or 1.7%. The average diode current is 2.5A (two diodes share the 5A).

4 Referring to Fig 23.8, the peak diode current is 12 times this ie 30A and the RMS current from Fig 23.7 is 3.2 times the mean ie 8A.

5 Assume ωCR_L = 100 (this is an arbitrary choice based on the need for low ripple voltage - see later), so E_{DC}/E_{peak} = 0.95 (from Fig 23.6 which also shows that there is not much to be gained by increasing ωCR_L further). Therefore the secondary voltage = 13.8/0.95 = 14.5. However this does not include the voltage drop in each diode of about 1.5V (a total of 3V) so the secondary voltage required is 17.5V.

6 R_L is 2.76 so C is $100/(2\pi 50 \text{ x } 2.76)$ which equals 115,000μF, the mains frequency being 50Hz. Electrolytics have a tolerance of -20 to +50% so this would be scaled up to 150,000μF, an available value if somewhat expensive. Because of this, a higher voltage is often rectified, a smaller capacitor used, and the ripple removed by a voltage regulator circuit - see below.

7 Fig 23.9 gives the ripple as about 0.6%.

The input and output leads to the capacitor should have as little in common as possible to avoid the introduction of ripple. Take them independently to the capacitor terminals as shown in **Fig 23.13**.

The design of all other power supplies working from the mains, no matter what voltage or current, follows the same rules except the following:

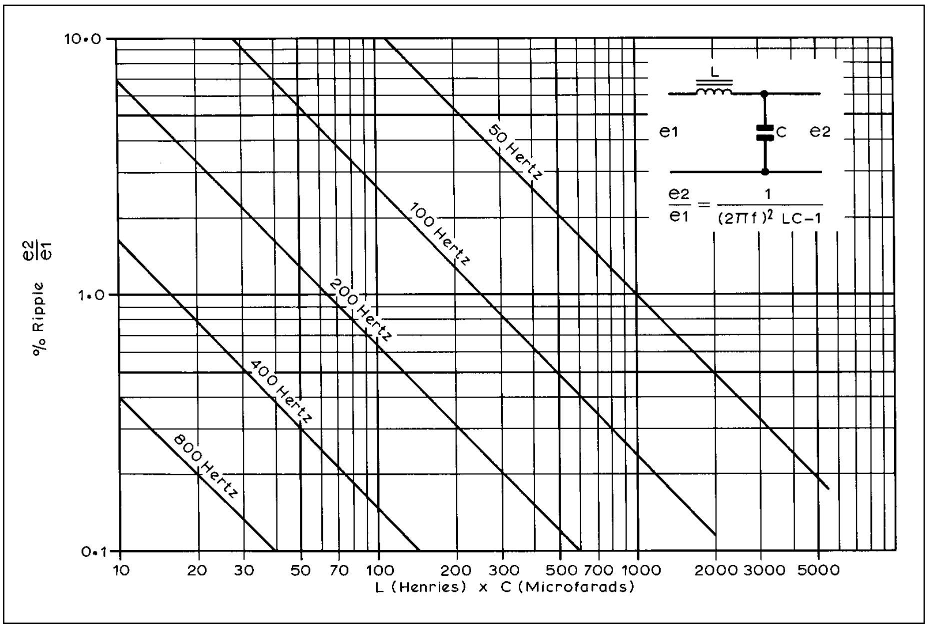


Fig 23.15: Relationship between large ripple and product of LC

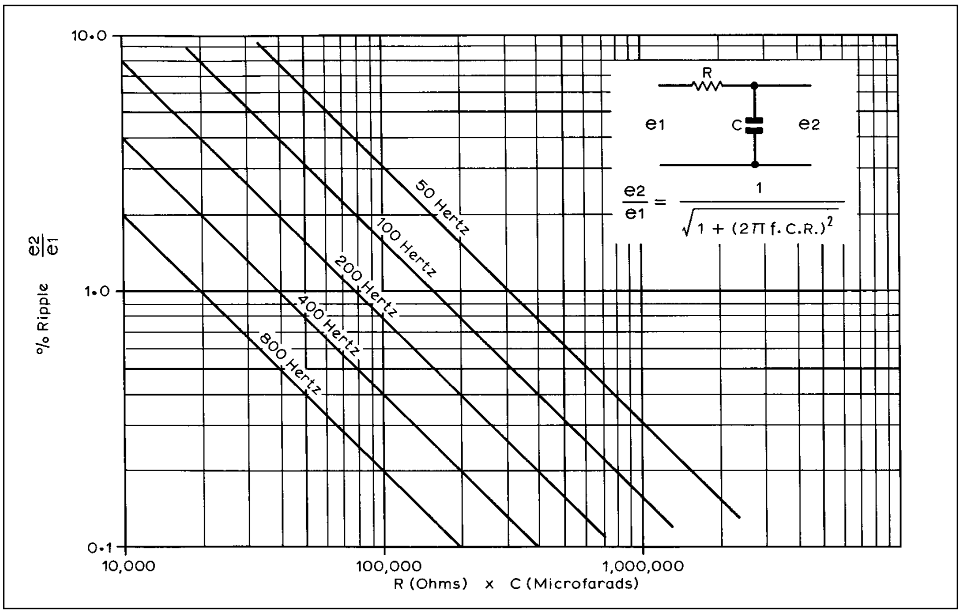


Fig 23.16: Relationship between percentage ripple and product of RC

- When an input inductor (choke) is used (see below).
- Where a 12 or 24V secondary battery (usually a vehicle battery) is 'floated' across a DC supply and takes the place of the reservoir capacitor.

Inductor (Choke) input

Here the inductor is connected directly to the rectifier diodes (Fig 23.11) and is followed by a smoothing capacitor. Note that it is equally possible to use a centre-tapped transformer and just two diodes to make a full wave rectifier.

As mentioned above in equations (2) and (3), the inductor must have a certain minimum value for a given load. This must be calculated for the smallest current expected, which may only be that of a bleeder, if fitted.

The voltage and current values and waveforms for a circuit using at least this value of inductance are shown in Fig 23.12. It is clear that the peak rectifier current is only double the mean current. Under these conditions the transformer RMS current is 1.22 times the load current and the average current per diode is half the load current.

The output voltage is 0.9 of the transformer RMS output minus voltage drops in winding resistance of both transformer and choke less the diode(s) drop. The diode drop can be neglected for power supplies above say 100V and estimated from manufacturer's data where significant. (Power diodes do not just drop 0.6V!)

The value of the filter capacitor (the first if more than one) is arranged to give the wanted ripple voltage ER from the equation:

$$ER = \frac{\text{output voltage}}{0.8LC} \qquad (4)$$

where L is in henrys, C in microfarads and the supply frequency 50Hz (full wave rectification).

Further smoothing can be added to either capacitor or inductor input by means of LC or RC circuits as in **Figs 23.14, 23.15 and 23.16**. The RC circuit is unsuitable for high currents because it drops the voltage.

Care must be taken that L and C do not resonate at the ripple frequency or any harmonics thereof. For a full wave circuit on 50Hz, the lowest ripple component is at 100Hz and the LC product is 2.53 for resonance. Normally LC is very much higher than this (see Figs 23.15 and 23.16). Note that the choke should be designed so that it does not become magnetically saturated at full DC output. An air gap in the core will help in this respect. The 'swinging choke' is so designed that it does approach saturation at full output and has a higher inductance at low currents where it is needed to satisfy equation (3).

Dual Power Supply

The circuit of **Fig 23.17** shows a dual voltage supply from a centre-tapped transformer. On analysis, although it uses a bridge rectifier, the two halves of the bridge feed the two supplies separately. The earth point may be chosen to give V and V/2 or +V and -V as required. In the example shown, output V2 is half of V1.

Voltage Regulators or Stabilisers

These are circuits that give a virtually constant voltage output regardless of load or input, within certain limits. They are necessary for supplying variable frequency oscillators (VFOs), DC amplifiers and some logic circuits. At higher voltages they are necessary for supplying screen and/or grid bias for valve amplifiers.

Shunt regulators - zener diodes

These are diodes with a sharp breakdown voltage, (see the chapter on semi-conductors). If fed from an un-regulated source through a resistor (**Fig 23.18**) it forms a simple regulator for more or less constant loads, with the advantage of being able to source or sink current.

There are reference diodes whose breakdown voltage is nearly independent of temperature, usually available in the 8-10 volt region, at a specified current. Below 5 to 6 volts the zener diode has a negative temperature coefficient and above, a positive

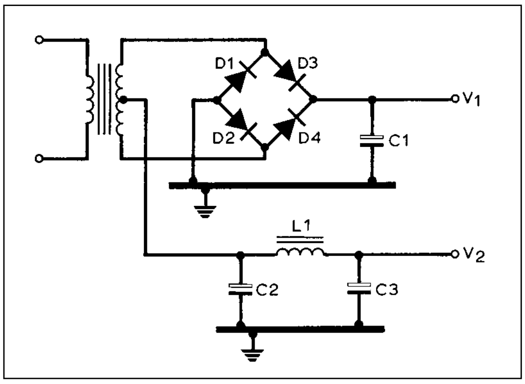


Fig 23.17: Circuit of a dual-voltage power supply

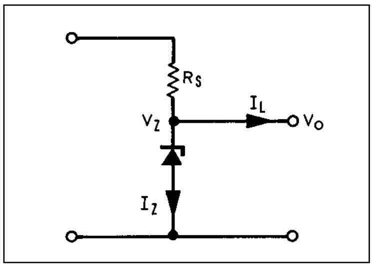


Fig 23.18: A simple zener diode voltage regulator

Type	Zener voltage (V)	Normal operating current (A)	Zener slope resistance (Ω)	Maximum dissipation (W)	Temp coeff (mV/°C)
BZX79C2V4	2.4	0.005	100	0.4	3.5
BZX79C6V2	6.2	0.005	10	0.4	+2.0
BZX79C75	75	0.002	255	0.4	+80
BZT03C7V5	7.5	0.1	2	3.25	+2.2
BZT03C270	270	0.002	1000	3.25	+300
BZY91C10	10	5.0	NA	75*	NA
BZY91C75	75	0.5	NA	75*	NA

** On a heatsink.*
'NA' means 'not available'.
While these are all Philips devices, all semiconductor manufacturers make zener diodes in one or more sizes. The data on Philips devices were used for this table because they were to hand and not because they are recommended above other makes. This table represents the extremes of size, power dissipation and voltage.

Table 23.3: Electrical / thermal characteristics of some zener diodes

one. **Table 23.3** gives some figures for typical zener diodes made by Philips.

The series resistor value (R_s) is calculated so that the diode provides regulation when the input voltage (V_s) is at its minimum when the load current (I_L) is a maximum. It is important to check that the diode's maximum dissipation is not exceeded when these conditions are reversed, ie when V_s is at its maximum and I_L a minimum. The expression for the series resistor is:

$$R_s = \frac{V_{s(min)} - V_{zener}}{I_{L(max)} + I_{zener(min)}}$$

The resistor must be rated for

$$\frac{(V_{s(max)}) - V_{zener})^2}{R_s} \text{ watts.}$$

Shunt regulators - integrated circuits

There are many voltage reference devices made for shunt regulator purposes, ranging from 1.22 up to about 36V. Some have three terminals to allow fine adjustment. They are used in the same way as the zener diodes previously described

Shunt regulators - high voltage

Beam tetrodes used for linear power amplifiers need a screen supply, and the 4CX250 series in particular can sink or source screen current. A series string of zener diodes could be used to cope with this, but would use expensive high wattage diodes. The circuit of **Fig 23.19** transfers the problem to a cheaper power transistor, but does not remove the need for a series string of diodes. These can now be of low wattage and so cheaper. The higher the h_{FE} of the transistor or Darlington pair, the cheaper will be the diodes. Formerly gas filled voltage regulators were used, and are still available. As long as you allow for the difference between the striking and running voltages, the procedure is the same as that for zener diodes.

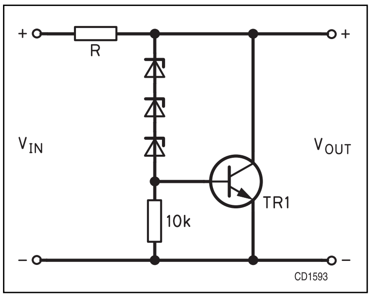


Fig 23.19: Stabiliser for screen of beam tetrode

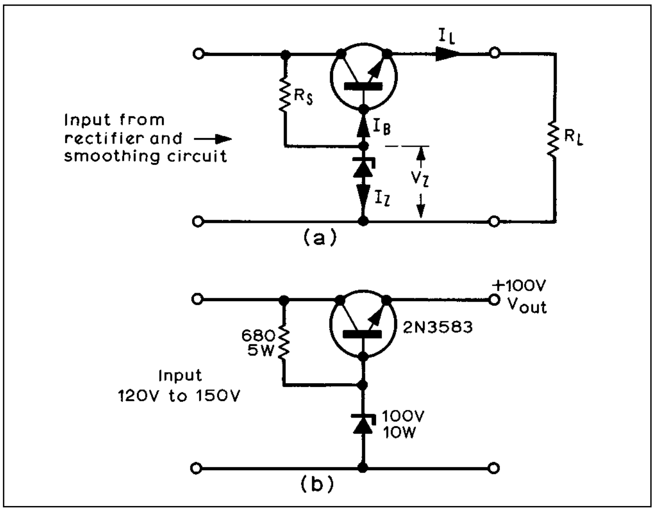


Fig 23.20: A series transistor regulator

Series regulators

In these an active device is placed in series with the supply, and negative feedback applied in such a way that the output voltage remains constant in spite of varying load and input voltage. The output voltage, or a definite fraction of it, is compared with a reference voltage and the difference amplified to control the series pass element in such a way as to minimise the difference. The greater the gain of the amplifier, the better will be the final result, provided the circuit is stable. A single transistor may be good enough in less demanding situations. The pass element can be either a bipolar or field effect transistor. Protection from failure of the pass transistor is advised to avoid damage from over-voltage.

Figs 23.20 and 24.21 show the simplest type of regulator using only two semiconductors. As previously said, they are only suitable in less demanding situations. There is not much excuse for building voltage regulators out of discrete components, as integrated circuits are cheap and often better.

IC voltage regulators

There are many IC voltage regulators, of which only linear types will be considered here. They all have the elements so far described incorporated into a single chip, and often include

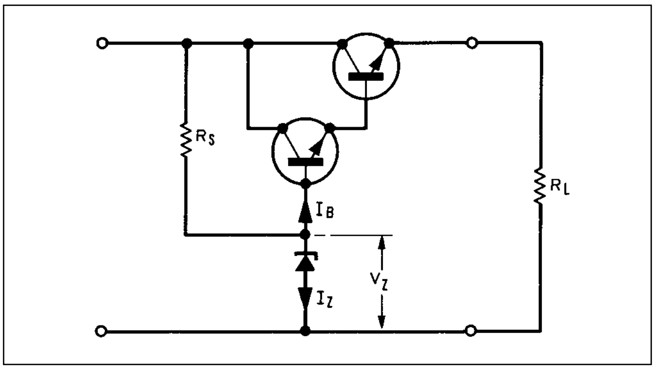


Fig 23.21: A series regulator using two compounded transistors as the series element

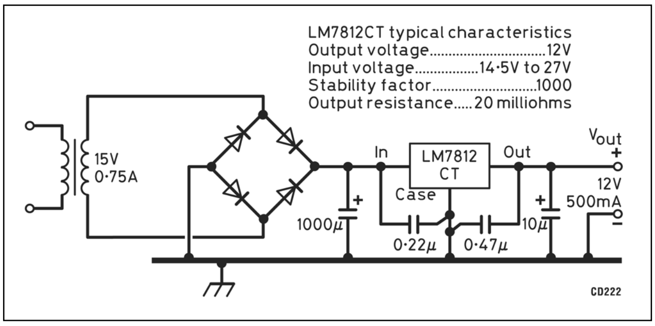


Fig 23.22: A 12V 500mA power unit using a regulator type LM7812CT

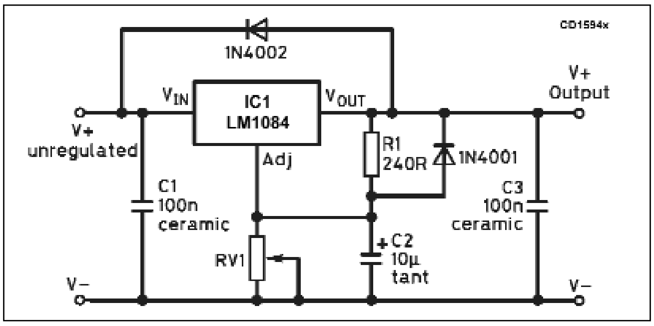


Fig 23.23: Adjustable voltage regulator using an IC. The value of RV1 is (V$_{out}$ - 1.25)R1/1.25 ohms

various over-load and over-temperature protection. There are four main types:

1. Positive fixed voltage eg 5, 12, 15 and 24 V
2. Positive adjustable voltage, adjustable by external resistors
3. Negative fixed voltage
4. Negative adjustable voltage, adjustable by external resistors

All need capacitors connected close to their input and output pins to prevent oscillation, see **Fig 23.22**, and it is advisable to fit diodes to prevent capacitors in the load from discharging back through the IC.

This is particularly important for LM317 and LM1084 type adjustable types (**Fig 23.23**) - take the maker's advice! There is no excuse for attempting to add components to a fixed regulator to get an increased voltage; the adjustable ones cost little more.

Fig 23.4 gives some typical examples. The circuits for adjustable types do vary from manufacturer to manufacturer (Table 23.4 again).

Most IC voltage regulators have internal current limiting and some have 'fold back' current limiting in which the voltage falls sharply if you attempt to exceed the current limit, see Fig 23.24.

The input voltage must exceed the output voltage by a stated amount; this is called the drop-out voltage.

An external pass transistor, connected as shown in **Fig 23.25** for a positive regulator, may be used to increase the output current. The resistor is chosen so that the transistor is turned on (by 0.6V on its base) just before the IC's current maximum is reached.

This applies particularly to the 723 type of IC where its ability can be extended almost indefinitely (note that the correct compensation capacitor must be connected according to the data sheet) [1]

Type	Voltage	Current	Polarity	Vin(min)	Vin(max)
Fixed voltage					
MC78L05APC	5.0	0.1	+	6.9	30
MC79L05APC	5.0	0.1		6.9	30
LM78 12CT	12.0	1.0	+	14.6	35
LM79 12CT	12.0	1.0		14.5	35
LT1086CT12	12.0	1.5	+	13.5	25
MC78T 15CT	15.0	3.0	+	17.8	40
78P 05SC	5.0	10.0	+	8.25	40
LM2931A	5.0	0.4	+	5.65	25*
Adjustable voltage					
LM317LZ	1.2-37	0.1	+	NA	40
TL783C	1.25-120	0.7	+	NA	125
LM317T	1.2-37	1.5	+	Vo + 3	Vo + 40
LT1086CT	1.2-29	1.5	+	Vo + 1.5	Vo + 30
79HGSC	2.1-24	5.0		NA	3 5
MAX 667	5-12	0.25	+	NA	18*

** Low 'drop-out' type, ie it has a low voltage drop across the series transistor. More of these are now available.*

Notes. There are many other different voltage and current rated stabilisers and they are made by many different manufacturers. All the high-powered devices must be fixed to a suitable heatsink. All 'fixed voltage' devices can have their voltage adjusted upwards by adding a resistor, a diode or a zener diode in series with their 'common' lead. The value of resistor varies with the device and the manufacturer, and the latter's literature should be consulted.

Table 23.4: IC voltage regulators

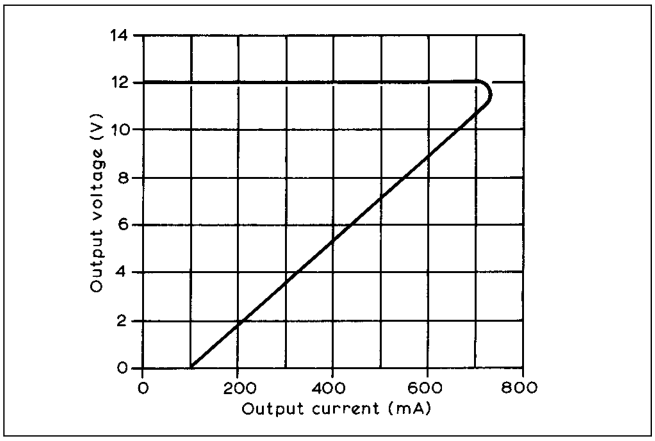


Fig 23.24: Voltage current characteristic showing 'fold-back'

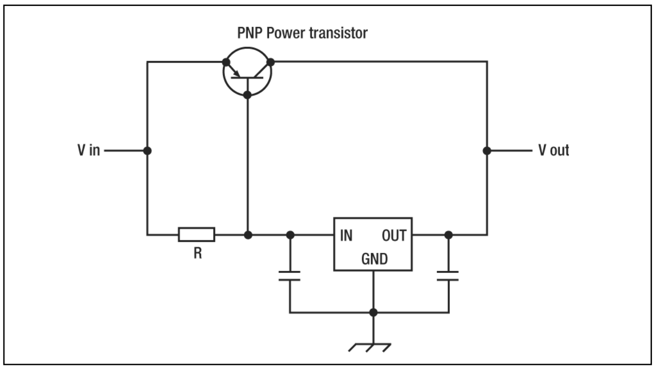


Fig 23.25: Connecting an external pass transistor to increase the output current

Field effect transistors (FETs)

Instead of using bipolar transistors for the pass element, a MOSFET (see the chapter on semiconductors) can be used with advantage. They are now cheap, and have the advantages that they are not subject to thermal run-away, have a reasonably constant gain with drain current, and a very low on-resistance. A disadvantage is that as they are only made in enhancement versions, the gate requires a voltage somewhere between 2 and 8V (according to type) above the source. For efficiency this should be derived from a low power auxiliary rectifier and transformer or winding.

As MOSFETs have an integral reverse diode, protection from damage due to charge stored in capacitors after the regulator is not required.

Over-voltage Protection

If the pass transistor fails to a short circuit condition, the whole input voltage (perhaps 18-20V for a 13.8V supply) will reach the output. Many rigs do not like this very much, and to avoid expense, some form of over-voltage protection ought to be included. The most common is called a crow-bar, so called because it short circuits the supply and either blows a fuse or operates a relay to open circuit the rectifier (see Fig 23.10(c)). A type of thermistor which can be used here comes from the degaussing circuit of a TV set, and is shown in **Fig 23.26**. Varistors and diodes can be specially made for this purpose.

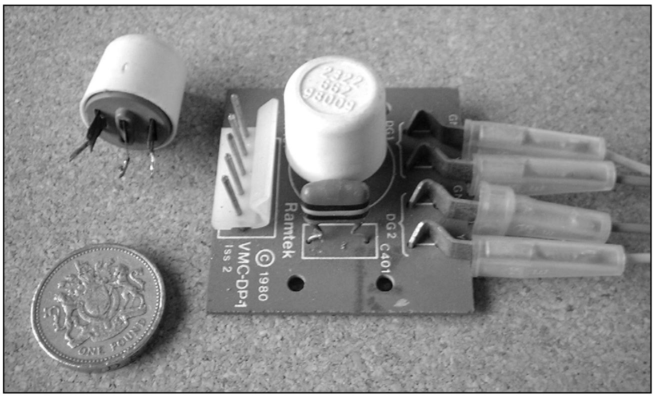


Fig 23.26: The TV de-gaussing thermistor used in Fig 23.10(c)

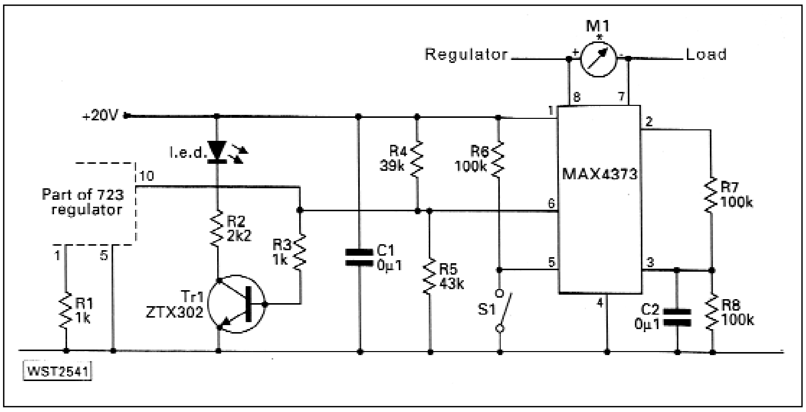


Fig 23.27: Current limiting and protection [*Practical Wireless*]

Over-current Protection

Most ICs have internal current limiting, but where augmentation of the ICs current is used, often with the 723, the internal limit may not work or may need too many millivolts in a current sensing resistor. The Maxim MAX 4373 is a very useful IC that needs very few millivolts from the current sensing resistor, and provides a latched over- current flag. **Fig 23.27** shows it being used to sense the voltage across an ammeter, and shut down a 723 IC by crowbarring an internal amplifier transistor. If you use this circuit, you must put a 1k resistor between pin 1 (Current Sense) of the 723 IC and ground, to prevent destruction of the transistor by excess current. You restore the latch by grounding pin 5 of the MAX 4373. Full details of the Max 4373 series are available from Maxim.

Quick-acting Positive-Temperature Coefficient (PTC) thermistors are now made with very short time constants for current limiting in series connection.

Constant Current Circuits

From time to time, a constant current source is needed, for example to charge a secondary battery (see below). A depletion mode FET with a source bias resistor will do the trick (see **Fig 23.28**), but the I_{DSS} of a junction transistor is only loosely specified. Corresponding to drop out voltage, the knee voltage of the FET has to be overcome before constant current is achieved. To save trouble, FETs with built in source resistors can be bought.

A similar arrangement with a bipolar transistor, whose base is held at a fixed potential, can provide a constant current up to several amps if required.

The LM317 adjustable regulator can be used in the circuit of **Fig 23.29**. The LM317 passes enough current to maintain 1.25V between the output and Adj pins, so the current in amps will be 1.25/R where R is in Ohms. As the circuit only has two connections, it can be used for either positive or negative supply, having due regard to polarity.

For a really high current supply, put a suitable choke in series with the primary of the transformer of a normal full wave circuit. Achieving the correct choke is easier done by trial and error!

SWITCH MODE POWER SUPPLIES

All the previously mentioned DC supplies transformed the mains, rectified it and perhaps regulated it. At 50Hz, the transformer is bulky and heavy. If a higher frequency could be used, the transformer and smoothing arrangements could be made much smaller.

The switch mode device does just this, and was used in the 1930s as a means of effectively transforming DC. With the advent of transistors, much higher frequencies, up to the MHz region could be used, also making efficient regulation possible, if needed.

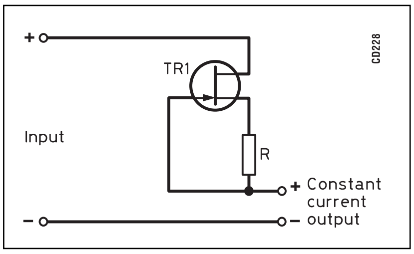


Fig 23.28: Principle of the constant-current circuit. TR1 small JFET; R to set current - depends on G_m of FET

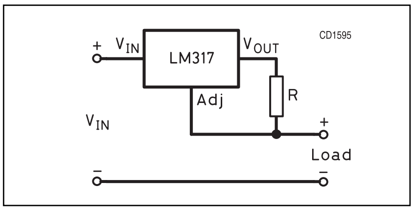


Fig 23.29: LM317 used as a constant-current regulator I_{LOAD} = 1.25/R

The following two sections are extracts from the *Power Supply Handbook* [2].

Introduction to Switch-Mode Supplies

Today almost every item of domestic and other electronics seems to contain some sort of switch-mode supply. Cellular telephone handsets utilise switch-mode supplies to generate the positive and negative supply required by the RF power amplifier stages and positive voltages for the processor ICs, as well as chargers for the battery. Personal computers have for many years used off-line switchers, even ham radio equipment has had them included in some way or another.

Many people who don't know any better think that putting a switch-mode supply inside a sensitive radio is crazy as they generate horrific interference because of the rapidly changing switching currents. However, with care in the design and construction, adequate screening and filtering they can be made surprisingly quiet. Like it or not the 'switcher' is here to stay and when one understands the subtleties of these supplies most of the bad feelings go away. For compact, lightweight supplies switchers are hard to beat, and they often cost far less than a conventional linear supply of the same power rating.

How much better is switch-mode than linear?

An excellent example of the differences between the two types of supplies was presented in the SGS Thomson Micro-Electronics book *Power Switching Regulators - Designer's Booklet 1st Edition* (1993). The company name has since changed to ST-Microelectronics but the data given is timeless:

Switching regulators are more efficient than linear types so the transformer and heatsink can be smaller and cheaper. But how much can you gain?

We can estimate the savings by comparing equivalent linear and switching regulators. For example suppose we want a 4A / 5V supply.

For a good linear regulator the minimum dropout voltage will be at least 5V at 4A. The dropout voltage is given by:

$$Vi_{(min)} = V_o + V_{drop} + 1/2\ V_{ripple}$$

Using a 60Hz supply with a 10,000μF smoothing capacitor and assuming a minimum mains voltage of 80% of nominal we need a minimum of 13.25V DC at the input of the regulator. It is prudent to raise this a bit so we will choose 14V.

Power dissipated in series element is:

$$P_d = (V_{in} - V_o) \times I_o \quad = 36W \qquad \text{Note: This is a 20W supply!}$$

The heatsink will need to have a thermal resistance of 0.8°C/W or better.

The transformer needs to supply a power of 14V x 4A = 56W. It must therefore be dimensioned for about 62VA to take care of the assumed transformer efficiency factor of 90%.

In contrast, a switching regulator IC using the same nominal input voltage of 14V will dissipate a maximum of 7W. This power is divided more or less equally between the IC and the recirculation diode. It follows that the transformer needs to be about 30VA and the heatsink needs to have a thermal resistance of about 11°C/W.

As can be seen from **Table 23.5**, the approximate cost savings are 50% on the transformer and around 80% on the heatsink.

As well as the obvious cost savings one other point should be noted, and that is the lower operating temperatures within the equipment allow a smaller and cheaper box to be used without as many cooling slots.

	Linear	Switching
Transformer	62VA	30VA
Heatsink	0.8°C/W	11°C/W

Table 23.5: Comparison between linear and switch mode supplies

Output Current	Output Power	Dissipation in output transistor	Efficiency
1A	13.8W	16.2W	46%
2A	27.6W	38W	42%
5A	69W	56W	55%
10A	138W	74W	65%
15A	207W	63W	76%

Table 23.6: Dissipation in pass transistors in a 13.8V linear power supply

If you now consider a typical linear regulator for a 12A power supply, we can draw some inference of how much more current we could get if the supply was converted to a switching type.

In a 13.8V nominal 12A supply the typical pass transistor dissipation is shown in **Table 23.6**.

At the maximum output current of 15 amps the total power supplied by the transformer / rectifier / smoothing capacitor bank to the regulator is 207 + 63 Watts. This is a total of 270W.

Assuming an efficiency of 85% we should be able to achieve 16.6A by using the same transformer, rectifier and smoothing capacitor, and changing the regulator from a linear type to a step-down switchmode type.

12V to 24V Boost Converter

For those applications where a simple step-up DC converter is required, the Boost Converter is a good choice when the output current required isn't too high. A Boost Converter can deliver an efficiency of around 90%.

The output is not inherently short circuit proof because of the topology and hence adequate fusing should be fitted to the input. The circuit shown is dimensioned to provide a maximum of 1A of output current.

A basic Boost Converter is shown in **Fig 23.30** using the UC3843B and a low cost mosfet. The UC3843B is an 8-pin DIL IC containing everything except the power switch. The mosfet chosen is the International Rectifier IRFZ-24N that has a suitably low on-resistance and can safely handle up to 17A of RMS current and 68A of peak current.

At 24W output it requires little heatsinking. The circuit will operate from approximately 9V to 16V and provide an efficiency of about 90% at 1A output current.

The UC3843B features an under-voltage lockout threshold of 8.4V so if the input supply voltage falls to less than this level the circuit will be shut down and restart when the supply voltage rises above the threshold. In automotive applications this provides protection should the battery voltage fall below 8.4V whilst the engine is being cranked. Another device in the series is the UC3842B and this has an under-voltage lockout threshold of about 16V so it is unsuitable for 12V automotive applications.

The Boost Converter operates in a flyback mode by alternatively storing energy in the form of magnetic flux in an inductor when the mosfet is turned on and then releasing it to the output

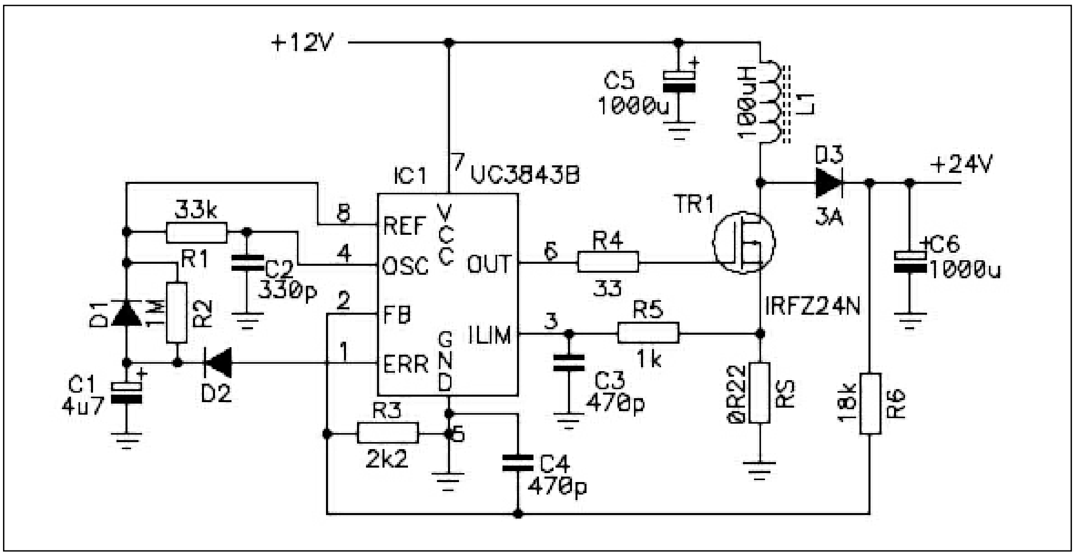


Fig 23.30: 12V to 24V boost converter

when the mosfet is turned off. Because the switching frequency is high, the value of inductor required is quite small and occupies very little volume.

The inductor is wound on a powdered iron core made by Micrometals and able to supply up to 1A of output current. The core material is type 26 and its diameter is 1.06in (27mm) - part number T106-26, colour coded white/yellow. The storage inductor is wound with 22SWG enamelled copper wire with 33 turns (**Fig 23.31**). The boost converter operates at about 100kHz, which is set by R1 and C2 on the oscillator input (pin 4)

Feedback resistors R3 and R6 set the output voltage. The internal reference voltage is 2.5V. The converter features a soft start circuit to reduce the inrush current on switch on. Components D1, C1, D2 and R2 form the soft start circuit. D1 and D2 are 1N4148 or 1N914 types. C1 should be a low leakage tantalum capacitor. The inductor peak current, and hence the maximum power output, is set by the low value resistor Rs in the source of TR1. The voltage developed across Rs is a replica of the triangular waveform drain current, and is filtered by R5 and C3 then fed to the current limit input of IC1. Rs needs to be a high wattage resistor and a 2W wire-wound would be the best choice for this component. The gate drive to TR1 is via R4 to suppress ringing caused by the Miller effect in the mosfet.

The output rectifier diode D3 should be a Schottky for the best efficiency. A type rated at 3A average current is the optimum choice with a PIV rating of at least 30V. A suitable device would be the International Rectifier 31DQ03. Ultra-fast diodes will also work with a slightly lower efficiency. A suitable device would be a BYV28-50 or MUR310. Normal silicon rectifier diodes such as 1N4000 or 1N5400 series are far too slow to work effectively at 100kHz and should not be used.

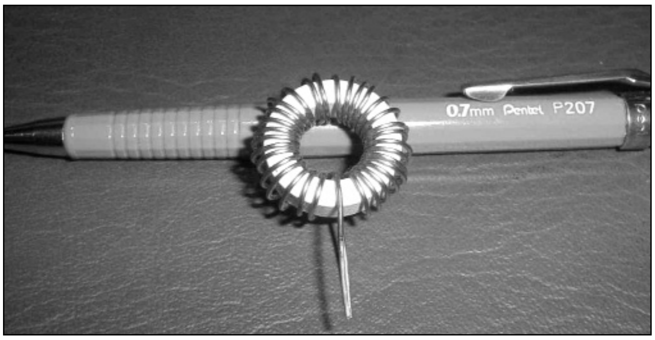


Fig 23.31: Boost converter inductor wound on T106-26 core

The output smoothing capacitor C6 needs to be a type designed for switchmode supply applications and having a low equivalent series resistance (ESR) to reduce the output ripple voltage and able to sustain high peak ripple current. An ESR of less than 0.25Ω is needed if the output ripple voltage is to be less than 100mV p-p. The peak charging current into C6 is approximately the same as the average input current and so a diode and smoothing capacitor capable of handling high peak current is required. A suitable type would be a Nichicon PJ series rated at 35V and having a value of at least 1000µF. The input capacitor C5 can also be a Nichicon PJ type or a normal electrolytic because the ripple current it experiences is not as severe as C6.

All the resistors except Rs can be quarter watt or half watt types. TR1 will require a small heatsink with an insulating washer and mounting bush to prevent the drain shorting to ground. Because of the high circulating currents the grounding of components around IC1 and the mosfet is critical. Although the frequency is only 100kHz the construction should use short leads and low inductance grounding similar to VHF construction techniques.

One or two points about boost converters need to be appreciated. The first is that the power to be converted has to come from the input supply. For a converter with an input voltage range of 9 to 16V the input current will be highest when the input voltage is 9V. With an efficiency of 90% the input power required is 1.1 x 24 = 26.4W and with a 9V supply this is an average current of 3A. When the input voltage is 16V the average input current is about 1.7A. If the input supply cannot deliver the required current the converter will not operate correctly.

Many linear regulated power supplies, although capable of supplying the average current, are not able to supply the high input current pulses that a boost converter draws. Although the average input current is only 3A the peak current can be several times this figure for a short period when the mosfet turns on. If the linear supply runs into current limit the converter will hiccup and behave erratically. When testing a boost converter using a linear regulated bench supply as the input source, it is often necessary to connect a large electrolytic capacitor (10,000µF or more) across the bench supply output to help supply the pulsing peak current.

If the output ripple voltage needs to be less than 100mV, then rather than increasing the value of C6 it is better to insert an additional filter LC network in series with the output (**Fig 23.32**). This can be a small inductor also wound on 26 material (T50-26),

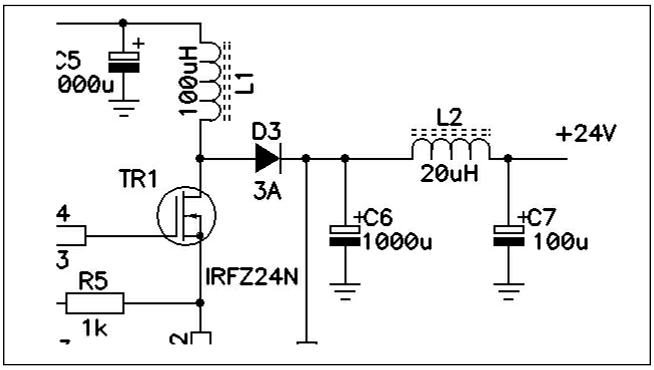


Fig 23.32: Additional output filter

and having a value of about 10 to 20% of the main switching inductor. This with an electrolytic capacitor of about 100µF will reduce the ripple voltage to about 10mV.

For applications requiring more output current the value of Rs can be reduced. If Rs is set to 0.1Ω the converter can supply up to 2A. The rectifier diode will need to be a 5A device and the value of C6 will need to be larger; a value of 2 x 1000µF PJ types in parallel will suffice.

In **Fig 23.33** the Boost Converter is running at approximately 40% duty cycle and supplying about 35W output. The mosfet drain voltage swings between approximately 0.25V above ground up to 25V and the steep transient seen is when the drain current is switched off. This peaks at about +40V. This transient is clamped by the reservoir capacitor to less than 1V peak. The second stage L-C output filter reduces this to approximately 5mV peak.

BATTERIES

The basic types of batteries have been described in the chapter on Principles. There is more on the use of batteries in the chapter on operating out of doors.

There are two types, primary or one shot, and secondary or rechargeable. Strictly speaking, a 'battery' is an assembly of two or more 'cells', but a single cell is commonly also called a battery.

Primary Batteries

At present there are two main varieties, that are suitable for amateur use, based on zinc or lithium. The battery derives its energy from the metal used as the negative electrode. The positive electrode has an effect as well and has to be able to dispose of the hydrogen, which would otherwise be liberated there. A depolariser surrounds the electrode if it is unable to do this. For watches and similar purposes zinc-mercury oxide and zinc-silver oxide cells are available at some cost.

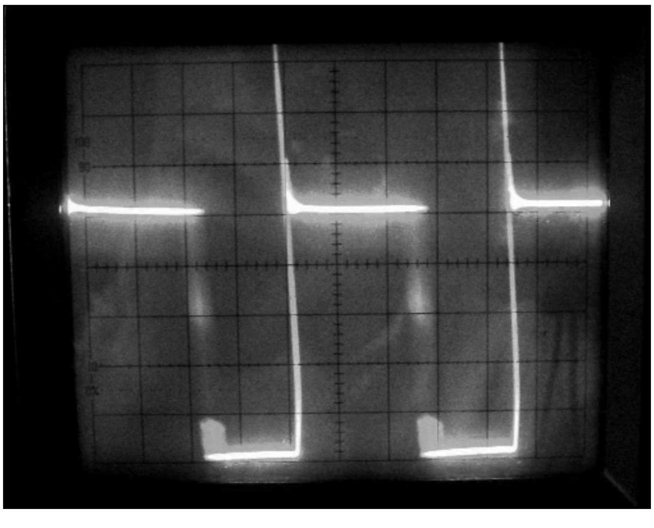


Fig 23.33: Drain waveform of boost converter

Type	Voltage (V)	Weight (g)	Maximum size (mm)	Current range (mA)
AAA	1.5	9	45 10.5	0-25
AA	1.5	18	50.5 14.5	0-40
C	1.5	48	50 26.2	20-60
D	1.5	110	61.5 34.2	25-100
PP3	9	38	48.5 17.5 26.5	1-10
PP9	9	410	81 52 66	5-50
C (HP)	1.5	as 'C' above		0-1000
D (HP)	1.5	as 'D' above		0-2000

Note. Where there are two dimensions, the first is the length and the second the diameter. The current range is that which gives a reasonable life. Manufacturers do not often give capacities in ampere-hours. The shelf life of either type of cell is about a year although it can be improved by keeping it cold. 'HP' is the high-powered type.

Table 23.6: Characteristics of typical zinc-carbon cells & batteries

Zinc-carbon

These form the oldest and cheapest primary cells and are called dry cells as the electrolyte, although not dry, is immobilised so that it cannot spill.

Three different electrolytes are used, an aqueous solution of ammonium chloride (sal ammoniac) in the cheapest, zinc chloride in 'high power' cells, and sodium hydroxide (caustic soda) in manganese-alkaline cells. **Table 23.6** gives some parameters of typical types.

Manganese-alkaline cells are made in the same sizes and **Table 23.7** gives details.

Zinc-air

These are similar to zinc-carbon, but use the oxygen of the air as the depolariser. You buy them sealed and they only 'come to life' when the seal is removed. Potassium hydroxide (caustic potash) is used as the electrolyte, and slowly absorbs carbon dioxide from the air, ending the life of the cell. They must be used in a well-ventilated housing. They have a higher energy density than zinc-carbon cells ie they pack more energy into a given weight or space.

Lithium

The negative electrode is the highly reactive metal lithium, so the electrolyte contains no water. The positive electrode is either iron disulphide (1.5V) or manganese dioxide (3V on load). The electrolyte is either an organic liquid or thionyl chloride (2.9V).

Type	Voltage	Weight (g)	Capacity (Ah)
AAA	1.5	11	1.2
AA	1.5	22	2.7
C	1.5	67	7.8
D	1.5	141	18.4
PP3	9	45	0.55

Note. The dimensions are as above and the capacity is in ampere-hours. They have a shelf life of several years.

Table 23.7: Characteristics of typical manganese-alkaline batteries

Size	Voltage (V)	Capacity (Ah)	Weight (g)
AAA	1.2	0.18	10
AA	1.2	0.5	22
C	1.2	2.2	70
D	1.2	4.0	135
PP3	8.4	0.11	46
PP9	8.4	1.2	377

Note. The dimensions are the same as those for the zinc-carbon cells/batteries above.

Table 23.8: Characteristics of typical nicad (NiCd) cells & batteries

These cells have a long shelf life making them good for battery back up, and have a low internal resistance. They also present a fire hazard if broken or an attempt to charge is made.

Secondary Batteries

Lead-acid, Nickel-Cadmium (Ni-Cad), Nickel-Metal Hydride (Ni-MH) and Lithium are the only types in amateur use which will be described.

Lead-acid

This the earliest cell, with lead plates and dilute sulphuric acid electrolyte. Vehicle batteries nearly always use these, as the alternatives (Ni-Cad or Ni-MH, see below) are too expensive. They are heavy, but have very low resistance. One feature is that if left discharged for some time, the plates sulphate irreversibly and the battery is almost always ruined. The usual charging is at a constant voltage of 13.8V, with some form of current limiting to prevent too large a current flowing initially. Do not try to charge a 12V battery from a 13.8V PSU. If the mains fails or is disconnected, the battery will discharge into the PSU, possibly damaging it. Any charger should therefore contain a diode to prevent reverse current flow. Over-charging a sealed battery will result in explosive gases being generated and may burst the vent.

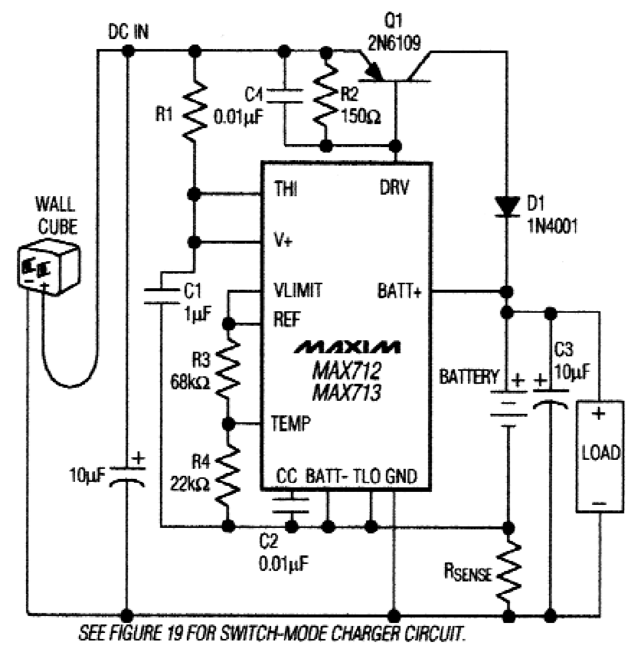


Fig 23.34: The Maxim MAX 712/713 Ni-Cad and Ni-MH fast charger ICs

Nickel-Cadmium

Ni-Cads (1.2V) have an electrolyte of potassium hydroxide in water, which is attacked by carbon dioxide in the air. Today the cells are sealed to prevent this, and as such are much used by amateurs. **Table 23.8** gives data on a selection. Cadmium compounds are toxic and Ni-Cads should be disposed of with care; many local authorities make provision for this and should be consulted.

Charging can be done at a constant current of C/10 amps where C is the capacity in ampere-hours. This will be complete in about 14 hours (allowing for inefficiency) and moderate over-charging at this rate does not result in harm. This long charging time is a nuisance, so fast charge circuits have been developed. When fully charged, the Ni-Cad cell voltage actually decreases with time. Maxim make a charger IC for Ni-Cads, the MAX 713. This detects the decrease and stops fast charge, **Fig 23.34**.

There is a memory effect with Ni-Cads if re-charged before being completely discharged; the cell 'remembers' that it was not fully discharged and will not be able to discharge fully after subsequent charge. Some authorities dispute this, believing that it only occurs after repeated discharge to less than complete. If your cell suffers from this, short out the cell only when discharged as much as it will. Beware of reversing the current through the cells of a battery; this damages them. Connecting a resistor across each cell of a battery is recommended, but not usually possible.

Opinion also differs with the procedure for storing cells that are not required. Unlike the lead-acid cell, Ni-Cads may be left discharged, and some have found this better than leaving them fully charged. Maker's advice is not readily available.

Nickel-metal hydride cells

They have advantages over nicads in that they have a higher energy density and they do not contain cadmium. A simple comparison between one of these and the same size in nicad is given in **Table 23.9**. Ni-MH cells are very similar to Ni-Cads, the voltage is the same, but capacity for the same size is higher. There is no memory effect, but the self-discharge rate of earlier cells is higher. Ni-MH cells do not exhibit the decrease of voltage with time at full charge (like Ni-Cads do); the voltage remains constant. The MAX 712 (Fig 24.34) detects this and stops fast charge. Cells such as IMMEDION made by the MAHA company (kindly supplied for review by Nevada Radio), and MaxE made by the Ansmann company, do not have this problem.

Lithium cells

Development of lithium cells is proceeding fast. There are now lithium-ion, lithium-polymer and lithium-iron phosphate. All are relatively costly, but their energy density is about twice that of NiMH cells. As a direct result, life prolonging techniques have become important.

	Metal-hydride	Nicad
Capacity (Ah)	3.5	2.0
Voltage (V)	1.2	1.2
'Memory'*	None	Severe
Toxics	None	Cadmium
Discharge rate (A)	<12-15	<15
Overcharge capability	Cont. at C/5	Cont. at C/5

* *'Memory' is an alleged effect [4] which shows up if a cell is only partially discharged before recharging. It is said to reduce the capacity of the cell. This has been disputed [5].*

Table 23.9: Comparison of metal hydride and nicad 'C' size cells [3]

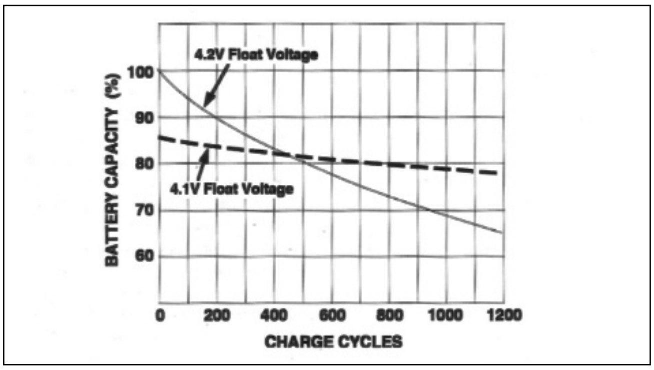


Fig 23.35: Cycle life and capacity vs 4.1V and 4.2V float voltages

To get maximum storage life, the cells should be charged at 3.6 V, to 40% and kept refrigerated at 4.4 degrees Celsius. If you use a lithium battery in your laptop, you could not ask for a worse environment. It will run hot and be kept nearly fully charged.

There is an unavoidable loss of about 5% capacity in the first 24 hours after full charge, and about 3% per month thereafter, assuming that the temperature is at or below 20 degrees C. High rates of charge or discharge also cause loss of life, which is very dependent on charging voltage, as shown in **Fig. 23.35**. The best way to charge is at a voltage limited constant current, and there are many ICs on the market which do just this. Consult IC manufacturer's data sheets for more detail.

Hybrid cells

Various manufacturers now produce hybrid cells which combine the advantages of alkaline primary cells with those of nickel metal hydride. They are designed as cheap replacements for alkaline primary cells, being rechargeable up to 1000 times. The 9v 'PP3' size battery should be very useful for test instruments (and smoke detectors).

Safety

As mentioned above, the electrolyte of lead-acid cells is sulphuric acid, and it should be treated with the greatest respect, and not allowed to touch the skin. If it does, it should be immediately washed off with running water. In particular the eyes should be protected from it. If it gets on clothes, if left, it will slowly make a hole. The explosive nature of the gas evolved by unsealed cells has already been noted. Sparks from the terminals on connection or disconnection can ignite the gas, and the entire cell could explode.

The electrolytes of the other types are undesirable also, and should be washed off if they contact the skin. Lithium is an extremely reactive metal, and if a cell containing it bursts, a fire may start. Do not attempt to destroy such a cell by burning.

A secondary battery, or low voltage high current power supply, will raise a ring or metal watch strap to red heat quickly if it forms a short circuit.

REVERSE BATTERY PROTECTION

Applying power with the wrong polarity can damage equipment. Here are four simple ways to prevent this:

1 Put a power diode in series with the load. This has the disadvantage of wasting a volt or so across the diode, but a Schottky diode would be better (0.31V at 8A for the 95SQ015). **See Fig 23.36(a)**.

2 Put a power diode in parallel with the load and a fuse in series. If the power is incorrectly applied, the diode conducts and the fuse will blow, see **Fig 23.36(b)**.

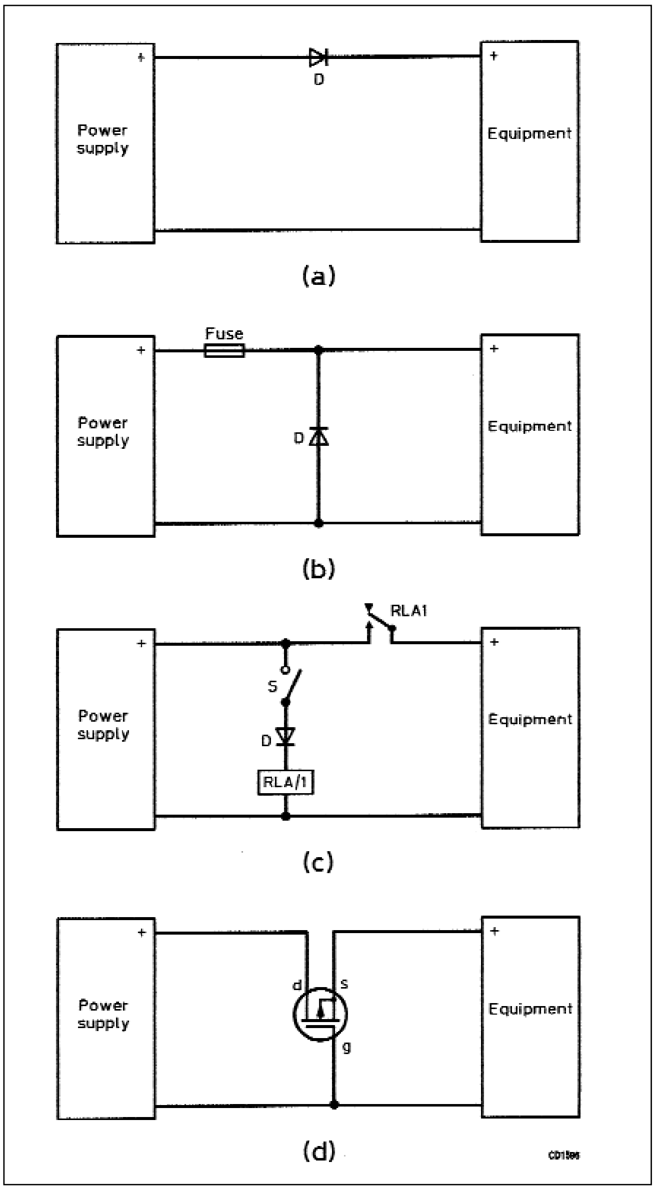


Fig 23.36: Four methods of reverse-polarity protection. D1 is a silicon diode; in (a) it must carry the whole current. In (c), S is the on-off switch, A/1 is the relay operating coil and A1 is the normally open relay contact. (d) Using a p-channel MOSFET

3 Use a relay to switch the power with a diode in series with the relay, which will then only operate if the power is correctly applied, **Fig 23.36(c)**.

4 Use a power MOSFET in the circuit reported by G4CLF. The MOSFET is only turned on by the correct power supply polarity. The 'on' resistance of available MOSFETs is so low that it may be neglected. See **Fig 23.36(d)**.

RENEWABLE ENERGY SOURCES

Wind, Water and Pedal Generators

These may not find much application at home, but could be useful in portable operation. As all of them supply power intermittently, a rechargeable battery will be needed. This implies a regulator, and a simple shunt regulator is all that is necessary, plus a means of preventing reverse current. Commercial practice uses buck-boost switched mode regulators to provide an output voltage even when the solar panel is producing a lower voltage.

Fig 23.37: A wind generator *[Marlec]*

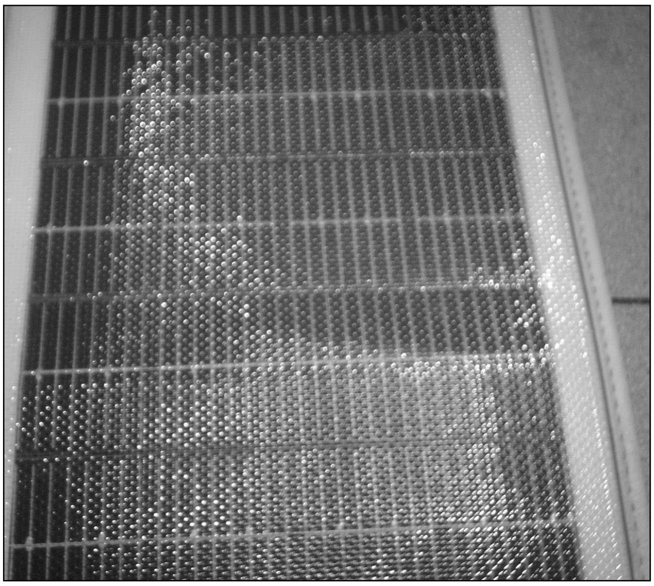


Fig 23.39: One type of solar cell

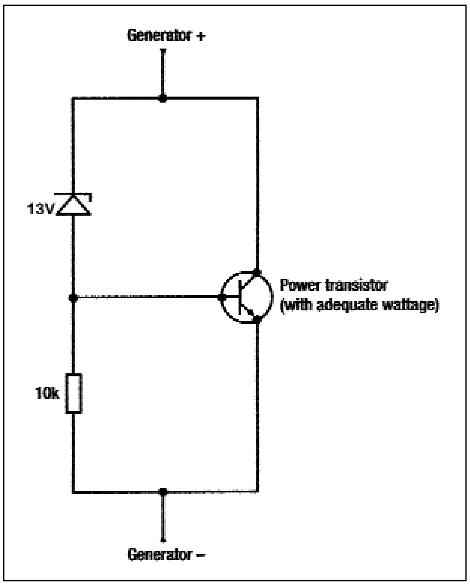


Fig 23.38: A shunt regulator suitable for intermittent generators

A wind generator is shown in **Fig 23.37**, and one type of regulator is shown in **Fig 23.38**.

Solar Cells

A photograph of a solar cell is shown in **Fig 23.39**; they come in various sizes. You cannot estimate the available power by exposing it to bright sunlight, then measuring the no-load voltage and the short circuit current. Thévenin's theorem does not apply, but many makers will provide you with performance curves.

Use of a buck/boost converter (see above and [2]) will extend the effective range of useable solar flux. However, you should beware of possible electromagnetic interference from the converter.

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[5] 'Technical Topics', *Radio Communication* June 1989, p34.

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