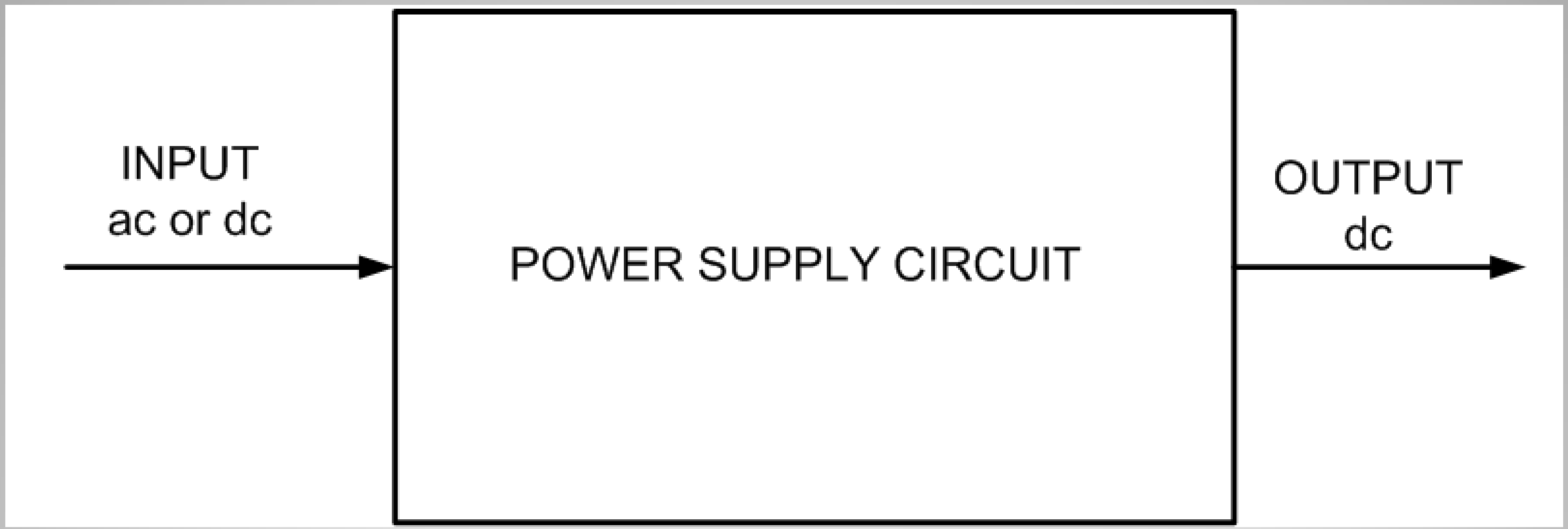
INTRODUCTION TO BASIC POWER SUPPLIES

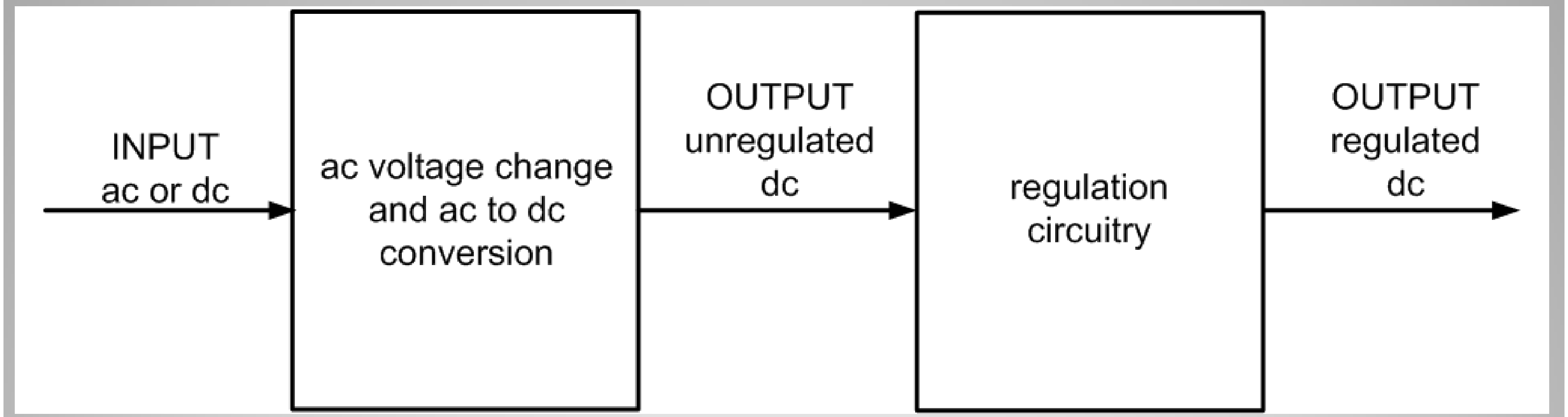
POWER SUPPLY SYSTEM



The power supply system has an input which is either ac or dc and, for our discussions, a dc output. This dc output is used to power some form of electronic circuitry.

The input could be the 240V 50Hz mains supply or a dc supply from a car battery or even a power rail within an existing circuit.

POWER SUPPLY SYSTEM



Breaking this system down , we will first look at the ac voltage change and ac to dc conversion.

Then, we will look at some simple dc regulation circuitry

Mains input aspects

Usually, the ac input is 240V rms, 50Hz mains supply.

CAUTION this voltage is LETHAL

Take extra care when handling mains powered equipment, make sure of your safety when constructing and testing.

PLUS make sure that adequate insulation and construction techniques are employed in the unit.

Mains input aspects

Mains powered equipment must be properly protected by a fuse and double pole power switch.

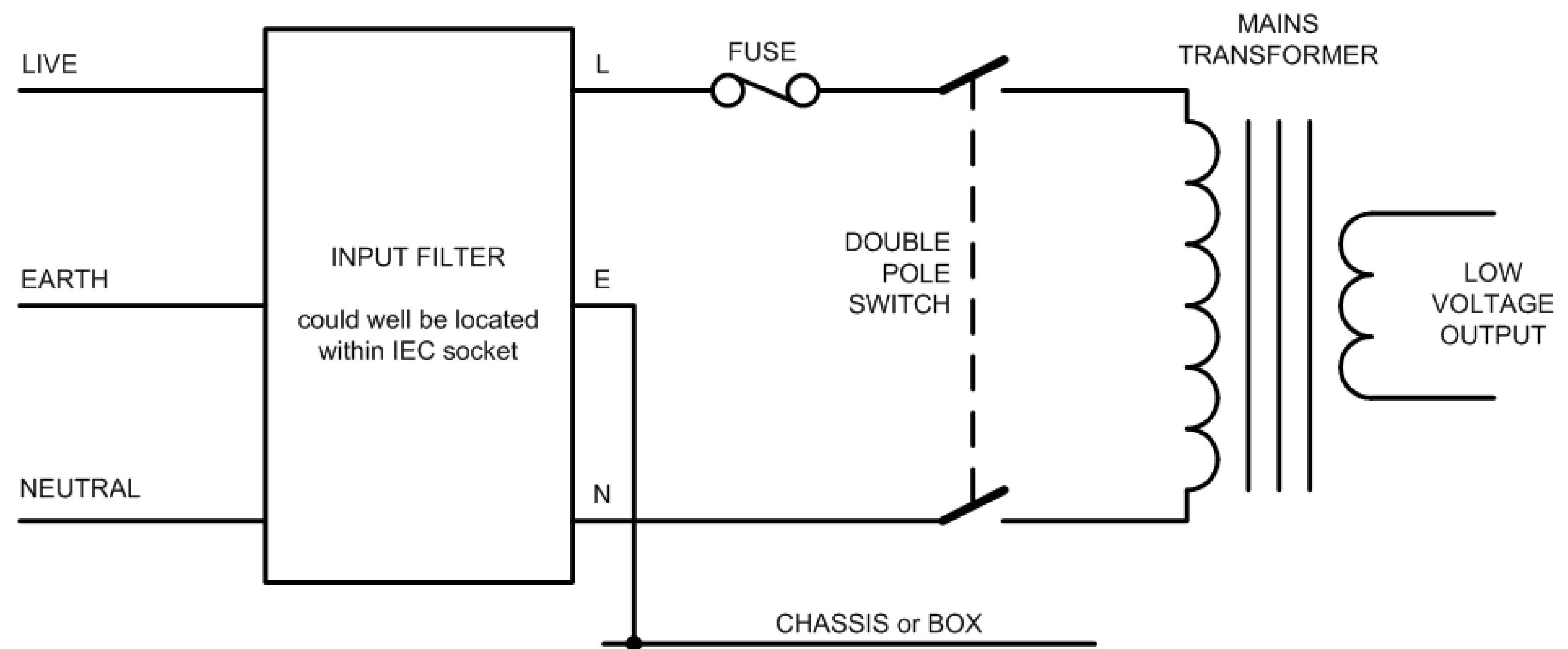
The mains powered equipment container (box) must be earthed if metallic or double insulation techniques employed to provide input to output isolation.

A lot of consumer electronic units (TV, DVD players and the like) utilise double insulation techniques, so their mains input power lead only contains Live and Neutral wires, rather than also including an earth wire as well.

Double insulation techniques present at least two ‘high voltage’ insulation barriers between the mains input circuitry and the system being powered. For example, the mains transformer has its primary (high voltage) winding on one bobbin and its secondary winding an a separate bobbin. Thus, if the primary winding burns up, the mains voltage cannot reach the ‘secondary side’.

If in any doubt, connect the box to mains earth.

Mains input aspects

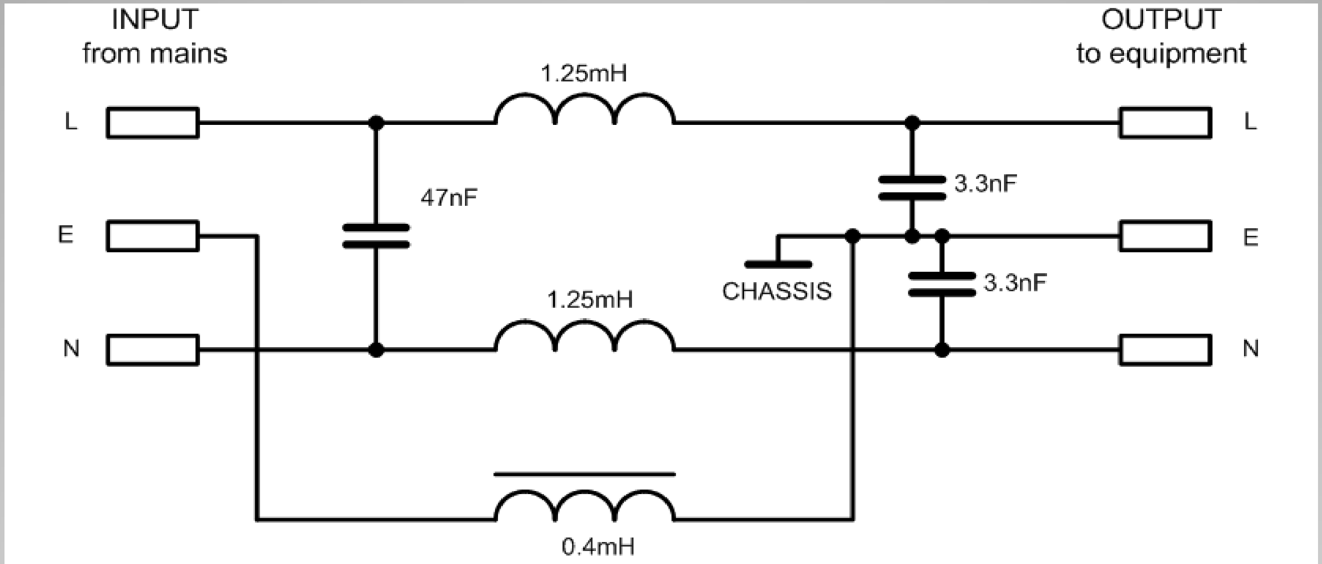


TYPICAL INPUT CIRCUIT

Only use one fuse and locate this in LIVE line (a blown fuse in the NEUTRAL line would leave most of the circuit, including the transformer, at LIVE potential. Make sure this fuse is correctly rated (and also the one in the mains plug!)

Always use a double pole mains switch.

Mains input aspects – filtered IEC connector

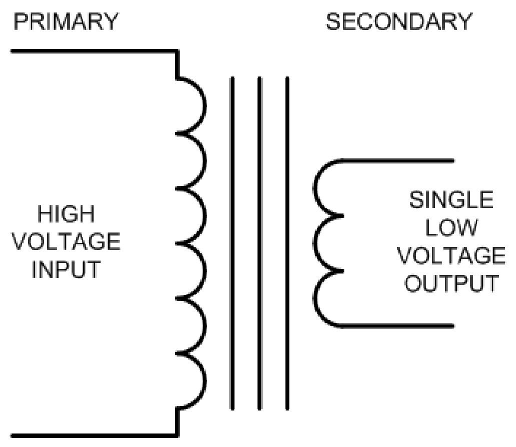


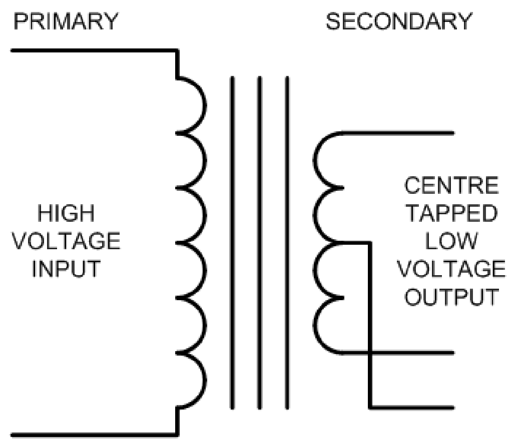
FILTERED IEC CONNECTOR – typical filter components

Filtered mains input sockets are very useful when dealing with transmitters and receivers, but more RF filtering might also be needed.

Beware that some transceivers use large capacitors for RF filtering from input Live and Neutral wires to chassis. A higher current flows in the Live to chassis capacitor than the Neutral to chassis capacitor. This could cause tripping of the mains supply RCD, especially if several transceivers are connected to the mains, even though switched OFF

MAINS transformers





PRIMARY SIDE

Usually single 240V winding or two 120V windings

Might have tappings to allow operation from other supplies such as 200V, 220V, 240V, 100V, 110V etc.

These multi tapped transformers are usually fitted to test equipment that could be used all over the world.

Also, in the UK and in Europe the mains frequency is 50Hz, but elsewhere could be 60Hz. You can use a transformer designed for 50Hz on a 60Hz supply, but a transformer designed for 60Hz could well overheat when run from a 50Hz supply – beware imported goods, especially those designed for USA (60Hz) market.

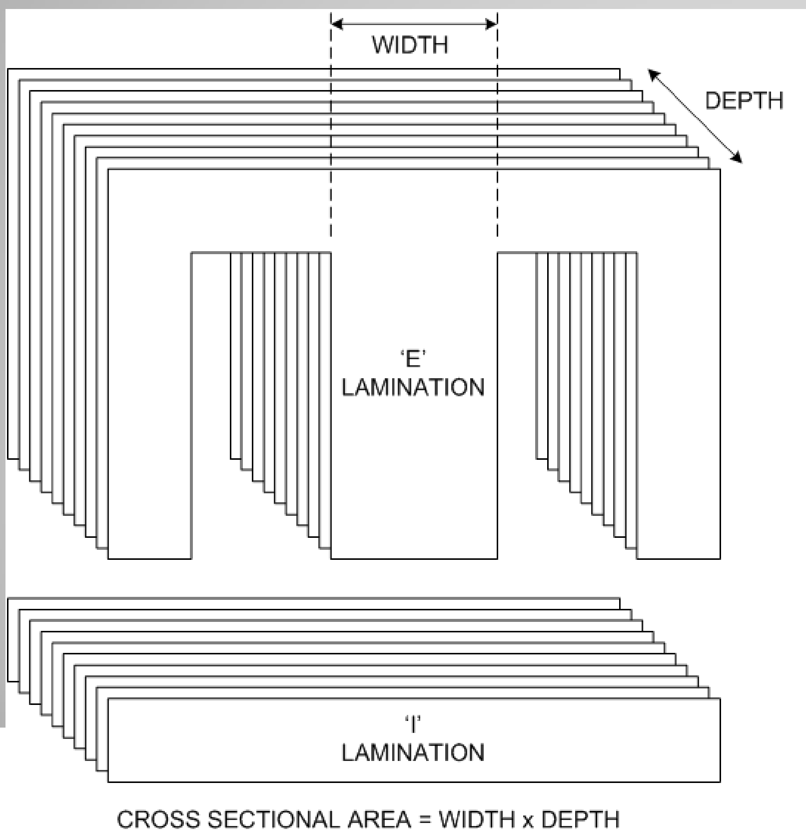
SECONDARY SIDE

Can be many different arrangements, or just simple.

Efficiency usually ~90% for small (<20VA) units, rising to 95% for larger (~100 to 200VA) units.

MAINS transformers - ratings

Transformers are rated in VA – Volt Amps - with respect to their outputs
A 20VA transformer with a 10V secondary will provide 2A (10V x 2A = 20VA)
A 45VA transformer with a 15V secondary will provide 3A (15V x 3A = 45VA)
A 60VA transformer with two 20V secondary windings will provide 1.5A from each secondary winding (20V x 1.5A x 2 = 60VA)

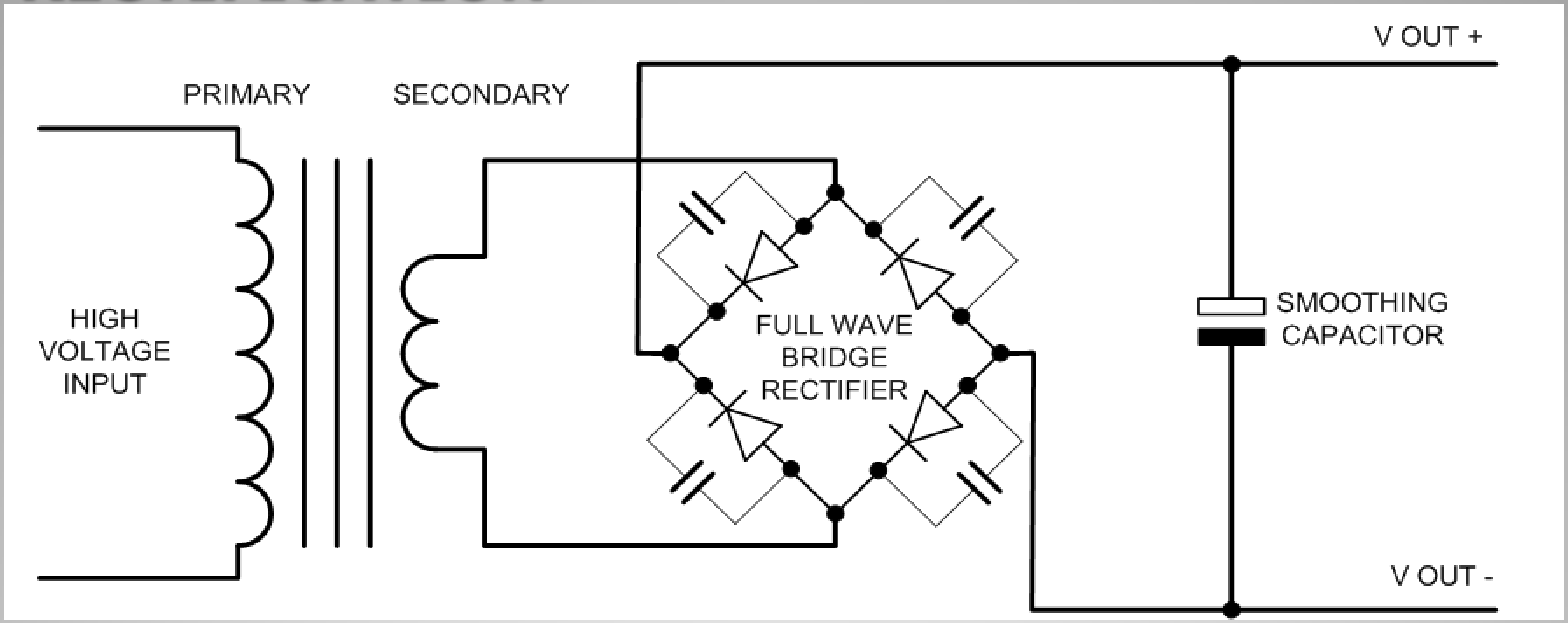


The power rating of a transformer is directly related to the cross sectional area of its magnetic circuit – for a conventional E I transformer this is the cross sectional area of its central limb (or twice the CSA of one side limb)

Rule of Thumb, VA rating = $(CSA \times 5.6)^2$ where CSA is measured in square inches

So transformer with centre limb 1" wide and laminations 1.2" deep is rated to $(1'' \times 1.2'' \times 5.6)^2 = 6.72^2 = 45$VA

ac RECTIFICATION



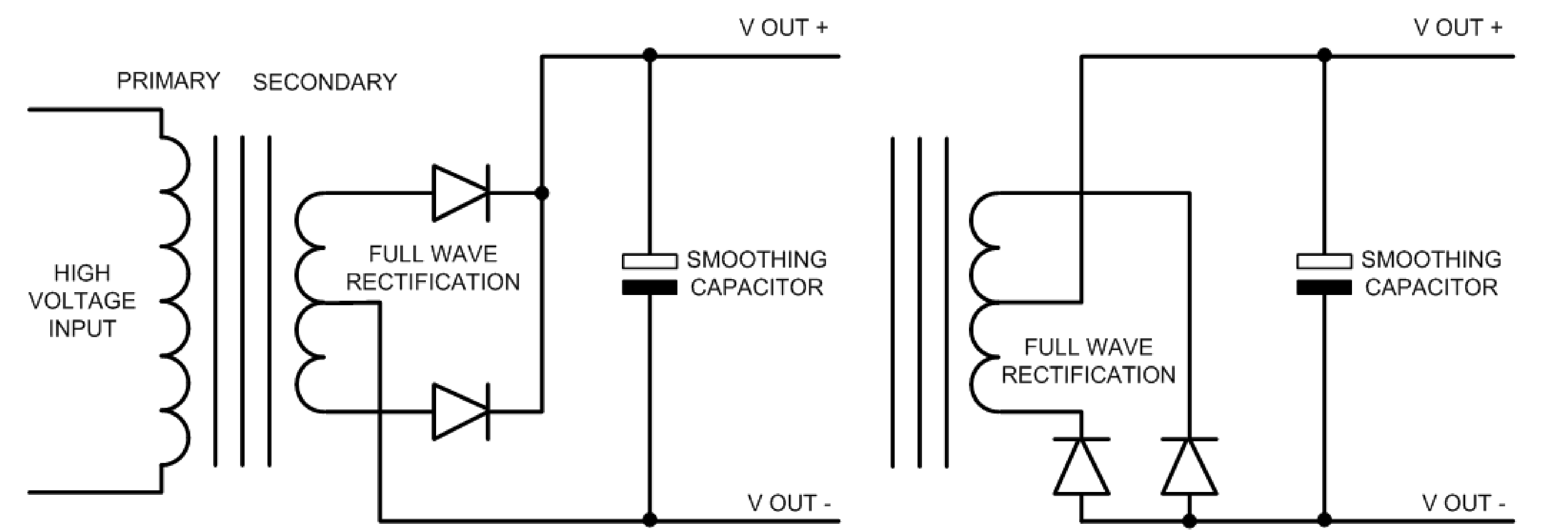
Recommend using full wave rectification – less ripple (1/2 wave rectification is inefficient and also causes dc magnetisation of transformer.

Full wave bridge rectifier shown only needs one transformer winding, but there are 2 diode 'drops' in the dc path.

Ensure that the bridge is rated to at least 2 x the load current and to at least 4 x the secondary rms voltage.

Capacitors (~1nF each) across the bridge diodes reduce high frequency noise.

ac RECTIFICATION



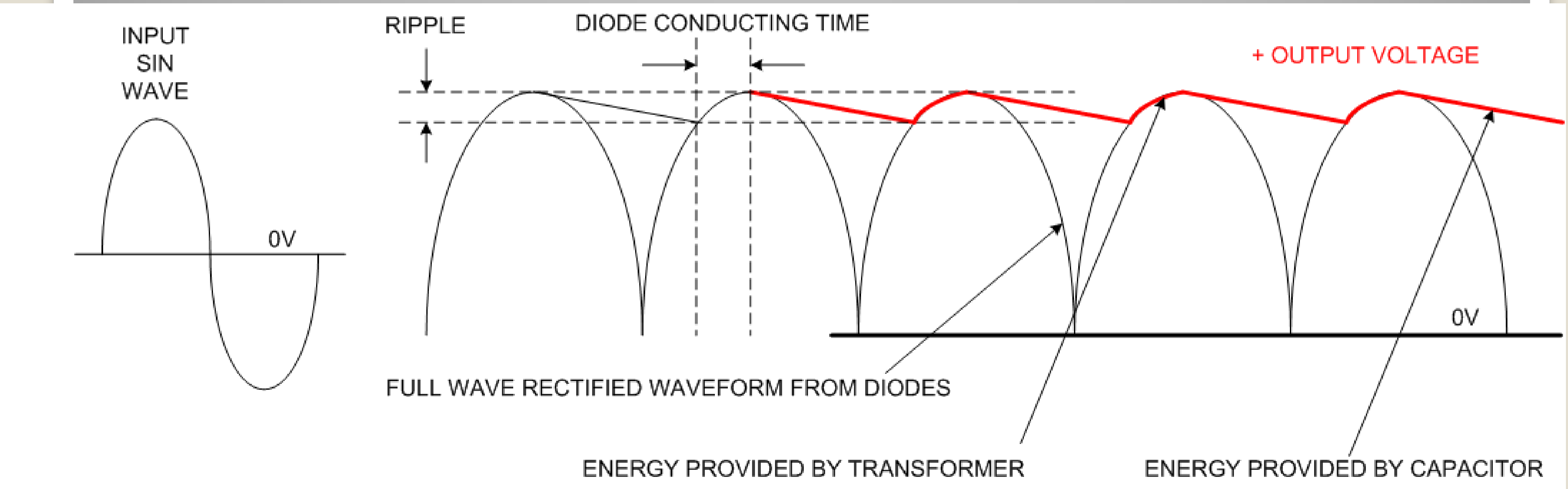
This full wave rectification arrangement only has one diode drop in the dc path, but requires a centre tapped (or dual windings) secondary on the transformer.

More efficient on low voltage supplies because the diode drop represents a significant loss at low voltage (despite additional transformer losses).

2V drop (2 diodes) at 10V is 20% loss, whilst 1V drop (1 diode) at 10V is 10% loss

Diodes could be positioned on the –Ve path, so allowing direct mount to chassis.

THE SMOOTHING CAPACITOR



The output from the transformer and rectifiers follows the sin waveform.

The smoothing capacitor ‘fills in’ the low voltage portions, so reducing the ripple voltage amplitude.

The larger the capacitor (for a given load), the smaller the ripple voltage, but the higher the peak current through the rectifiers.

THE SMOOTHING CAPACITOR

Close approximation calculations;

C x E = I x t where C is the capacitance in uF
E is the peak to peak ripple in Volts
I is the full load current in mA
t is the diode conduction time in ms, ~ 9ms @ 50Hz

So if you are building a 13.8V, 2A output power supply (full wave bridge rectifier),

With a 20Vrms output from the transformer the maximum voltage will be about (20V x 1.414) less 2 diode drops, = 28.28V – 1.4V = 26.88V.

The minimum output (at full load) will be (28.28V x 0.9) – 2V = 23.4V

With a 4700uF smoothing capacitor the peak to peak ripple will be

(I x t)/C = (2000mA x 9ms)/4700uF = 3.83V this is the peak to peak ripple.

i.e. at full load the minimum voltage will be 23.4V – 3.83V = 19.5V

THE SMOOTHING CAPACITOR

Taking our example,

The maximum voltage on the capacitor will be the no load value of 26.88V, so the capacitor needs to be rated for >>27V, say at least 35V or (better) 40V.

With a PSU output voltage of 13.8V and a full load minimum voltage of 19.5V, the PSU regulator has to be able to work with a minimum 'headroom' (difference between input and output) of 19.5V – 13.8V = 5.7V.

You can now work out the maximum power dissipation in the PSU output stage.

At full load, maximum dc level is 23.4V and the PSU output is 13.8V at 2A

So dissipation is (23.4V – 13.8V) x 2A = 19.2W use a largish heatsink!

3.83V peak to peak ripple on a 23.4V supply represents just over 16%.

Rule of thumb, with about 20V transformer output, full wave rectified 50Hz, using a capacitance of 2000uF per Amp loading will give you about 20% ripple.

DC POWER SUPPLY CIRCUITS

Now we have converted our mains supply to a dc supply, albeit with some ripple, we can look at regulating dc supplies.

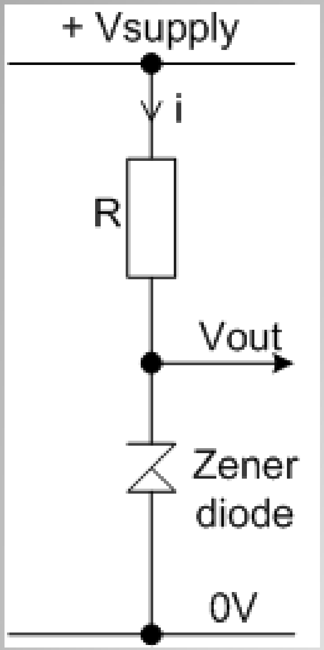
This section also applies where we already have dc input supplies, for example from a car battery or from a ‘wall wart’ power supply that was used for something else, or even if we want to add some extra circuitry to an existing unit.

We will start with basic, low power, circuitry and then increase the power, whilst trying to keep the technicalities to a minimum.

Switched mode circuits are not discussed here because, generally, they are beyond the capabilities of home constructors, needing specially wound magnetic components and quite complex circuitry.

The basic building block

For any power regulation circuit to work, it needs a reference. By comparing the output from the regulation circuit to this reference, an error signal is produced and this error signal is then used to drive the regulation circuit.



The simplest reference that is independent of source variations is the Zener diode. Other references are available which provide better performance, but cost more.

The Zener diode is a shunt device, it maintains a constant voltage across itself by varying the current it conducts.

Taking the circuit to the left, if the Zener diode is a 6.2V device and the resistor R is 1k, then with V supply at 12V, the Zener diode will ‘conduct’ 5.8mA, so V out is 6.2V.

Here, the Zener diode dissipates (6.2V x 5.8mA) = 36mW and the resistor dissipates (5.8mA x 5.8mA x 1k) = 34mW

If V supply increases to 18V, then the Zener diode increases its current conduction to 11.8mA, so V out remains at 6.2V.

Now, , the Zener diode dissipates (6.2V x 11.8mA) = 73mW and the resistor dissipates (11.8mA x 11.8mA x 1k) = 140mW

A BIT MORE ABOUT ZENER DIODES

Since Zener diodes are the fundamental voltage reference , it is worth while saying a bit more about them.

For small Zener diodes (the ones most commonly used for reference purposes) don’t cause too much current to flow through them. They drift with temperature (see next slide). Usually about 5mA is the optimum.

If possible, use a Zener diode around 5V to 6V for your design – these have the smallest temperature coefficient (see next slide).

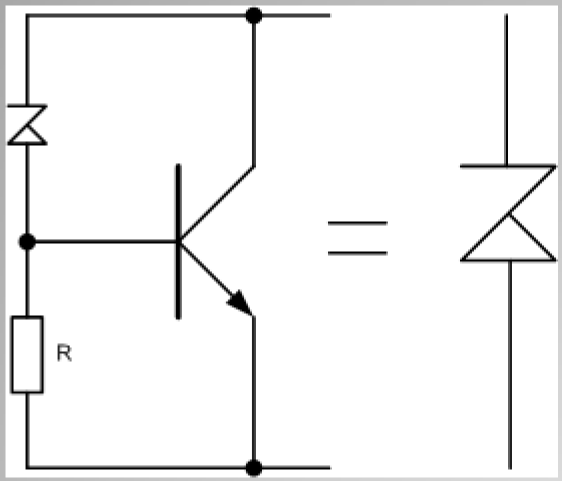
Zener diodes do produce wideband noise (they are often used as a noise source) – do decouple them with a capacitor – 1nF is usually sufficient.

If there is a large variation in the supply voltage providing their current, think about using a constant current source rather than a series resistor.

EXAMPLE OF ZENER DIODE VOLTAGE RANGE

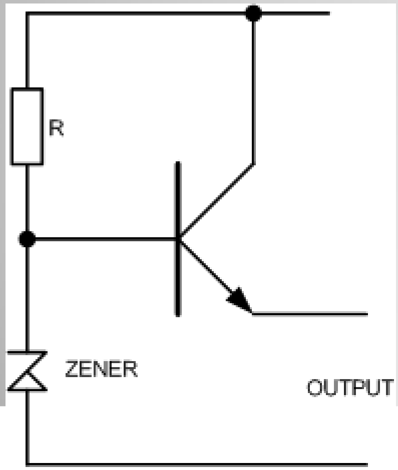
BZY88 ...	WORKING VOLTAGE V_Z AT I_Z = 1 mA				TEMPERATURE COEFFICIENT S_Z AT I_Z = 1 mA				DIFFERENTIAL RESISTANCE r_{diff} AT I_Z = 1 mA		
	MIN.	NOM.	MAX.		MIN.	TYP.	MAX.		TYP.	MAX.	
C2V7	1,9	2,15	2,4	V	−4,5	−1,7	−0,6	mV/°C	310	390	Ω
C3V0	2,1	2,4	2,7	V	−5,0	−1,8	−0,6	mV/°C	340	420	Ω
C3V3	2,4	2,75	3,0	V	−4,5	−1,9	−0,5	mV/°C	360	440	Ω
C3V6	2,7	3,0	3,3	V	−4,5	−2,05	−0,5	mV/°C	410	430	Ω
C3V9	3,0	3,3	3,6	V	−3,5	−2,4	−0,5	mV/°C	410	430	Ω
C4V3	3,3	3,6	3,9	V	−2,7	−2,25	−0,5	mV/°C	410	430	Ω
C4V7	3,7	4,1	4,3	V	−2,5	−2,0	−0,3	mV/°C	390	420	Ω
C5V1	4,3	4,65	5,0	V	−2,1	−1,9	−0,3	mV/°C	340	370	Ω
C5V6	4,8	5,3	5,7	V	−1,8	−1,4	0	mV/°C	310	350	Ω
C6V2	5,7	5,9	6,5	V	0	+1,6	+3,0	mV/°C	100	250	Ω
C6V8	6,3	6,7	6,9	V	+2	+3,2	+3,7	mV/°C	15	70	Ω
C7V5	7,0	7,45	7,8	V	+3	+4,2	+5,9	mV/°C	8,0	20	Ω
C8V2	7,8	8,1	8,5	V	+4,3	+5,0	+6,0	mV/°C	10	20	Ω
C9V1	8,55	9,0	9,5	V	+4,5	+6,0	+7,0	mV/°C	12	24	Ω
C10	9,3	9,9	10,5	V	+6,0	+6,6	+7,0	mV/°C	20	50	Ω
C11	10,3	10,9	11,5	V	+7,1	+8,3	+9,0	mV/°C	25	70	Ω
C12	11,3	11,9	12,5	V	+7,6	+8,7	+9,2	mV/°C	25	80	Ω
C13	12,3	12,9	13,0	V	+9,1	+10,1	+11,1	mV/°C	25	90	Ω
C15	13,8	14,9	15,5	V	+11	+12,5	+13	mV/°C	35	95	Ω
C16	15,3	15,8	16,9	V	+12	+13	+14	mV/°C	45	100	Ω
C18	16,7	17,8	18,9	V	+14	+15	+16,5	mV/°C	50	120	Ω
C20	18,7	19,8	21,0	V	+16	+17	+18,5	mV/°C	60	140	Ω
C22	20,6	21,8	23,1	V	+17	+19	+21	mV/°C	70	150	Ω
C24	22,5	23,8	25,7	V	+19	+21	+23	mV/°C	85	200	Ω
C27	24,7	26,6	28,5	V	+21	+22,5	+25	mV/°C	90	300	Ω
C30	27,5	29,5	31,5	V	+22	+24	+29	mV/°C	180	350	Ω
C33	29,5	32,5	34,5	V	+23	+26	+35	mV/°C	250	450	Ω

BOOSTING ZENER CIRCUITS



If you need a more powerful Zener (for example, to replace a busted motor cycle regulator) then connecting a transistor as shown will do the job.

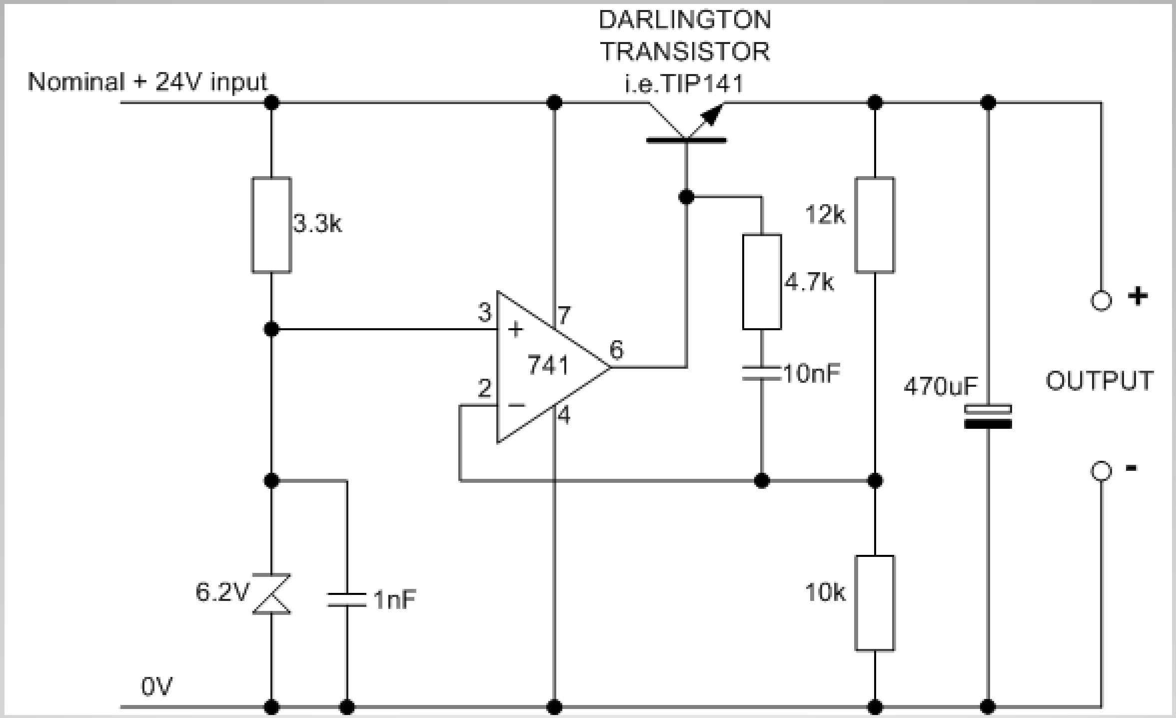
The transistor can be a power device, mounted on a heatsink. R needs to be about 1k. Power Zener voltage = small Zener voltage plus 0.6V.



This simple circuit can be used for low power regulation. The transistor is connected in the Emitter Follower mode. The output voltage will be about 0.6V lower than the Zener diode voltage.

The resistor R has to provide the base current for the transistor as well as the Zener current. Transistor dissipation can be reduced by adding a resistor in series with its Collector.

Simple power supply with a Zener diode reference

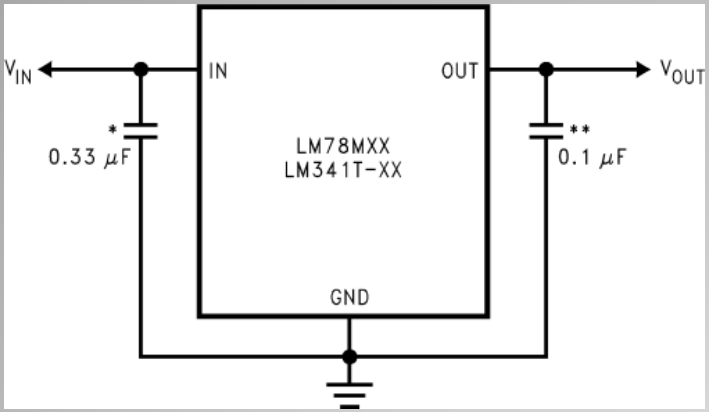


Uses transformer/rectifier stage discussed earlier

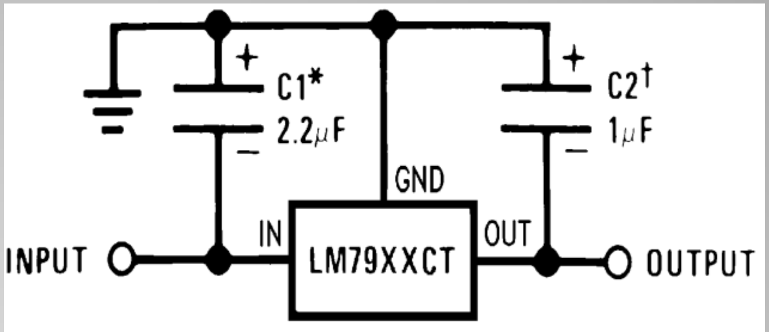
V out = [(12k + 10k) / 10k] x 6.2V = 13.64V

The feedback circuit (12K and 10k) could include a potentiometer

THREE TERMINAL REGULATORS



POSITIVE fixed regulator



NEGATIVE fixed regulator

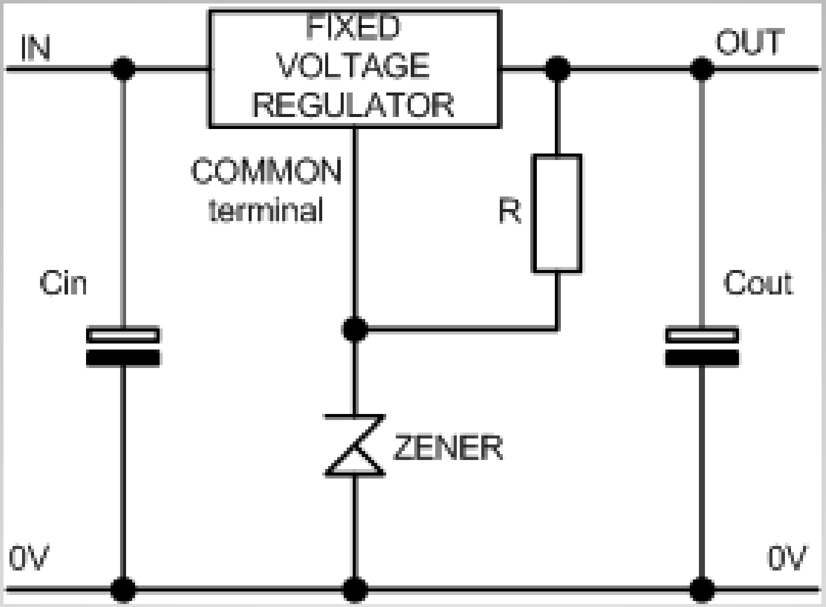
DC power regulators are readily available, both fixed voltage and variable voltage types, and for either positive or negative power supplies.

These regulators need decoupling capacitors located close to the devices.

Low, medium and high power versions are available

Note that a negative power supply can be made with a positive regulator chip, so long as decoupling is carefully considered

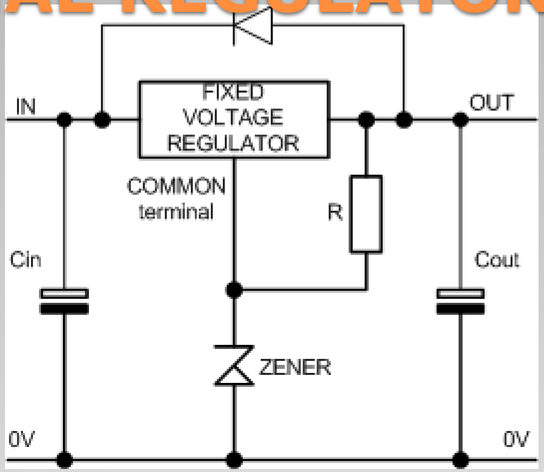
THREE TERMINAL REGULATORS



The output voltage from a three terminal regulator can be increased by the circuit shown above. Supposing you want an 8V supply, but only have 5V regulators to use.

In this case, make the Zener diode 3.3V (nearest preferred value) and run it at a current of around 5mA via R (the regulator chip requires around 0.5mA) so R = 5V/5.5mA = 909 Ohm. Here a 1k resistor will work just as well (the Zener current will then be around 4.5mA). Don't forget Cin and Cout

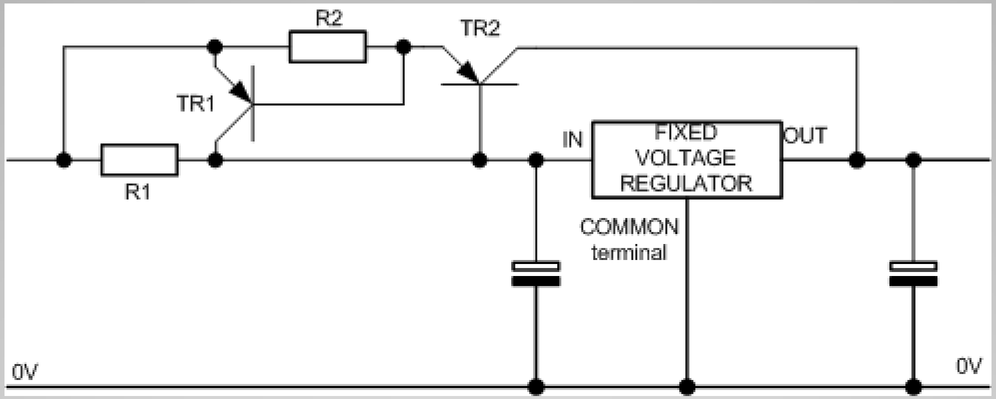
THREE TERMINAL REGULATORS



If there is any chance that when the input supply is switched OFF the output supply remains active after the removal of the input supply (for example if there is a very large capacitance on the output or the load is a motor which is still spinning), the connect a diode across the input to output as shown above (applies to a simple regulator as well as the increased output voltage version shown above).

This diode then prevents the regulator device from being reverse biased, which it does not like! If in any doubt, then fit the diode.

THREE TERMINAL REGULATORS

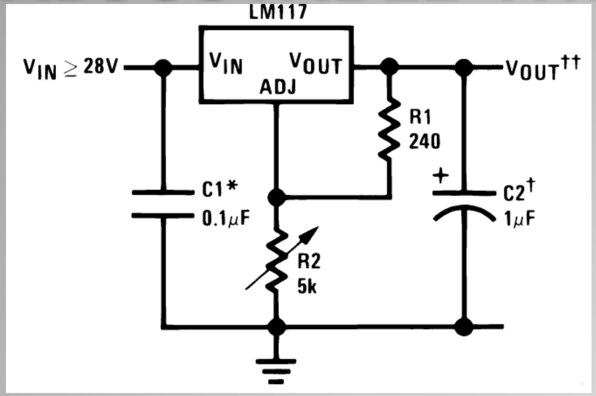


The TO220 size devices can deliver a maximum current of around 1A if well cooled. Sometimes you want a bit more current, where the circuit above can be used.

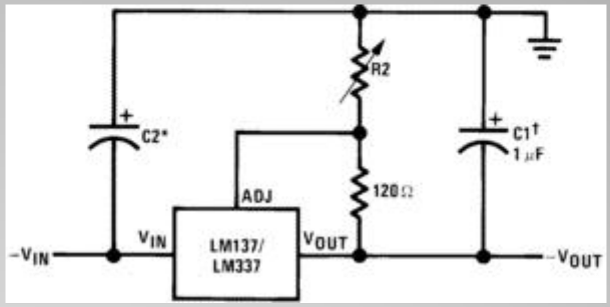
TR1 is a small signal PNP transistor like a BCY 70. TR2 is a PNP power transistor. R1 needs to be about 5.6Ω. R2 determines the maximum current through TR2 and needs to 'drop' about 0.6V at the desired current. So if you want 2A, R2 needs to be about 0.6V/2A = 0.3Ω.

As current is drawn from the output the voltage across R1 rises, until TR2 starts to turn ON, so adding to the output current. If excess current is demanded, then TR1 shunts away the drive to TR1, so limiting this current .

ADJUSTABLE THREE TERMINAL REGULATORS



POSITIVE variable regulator



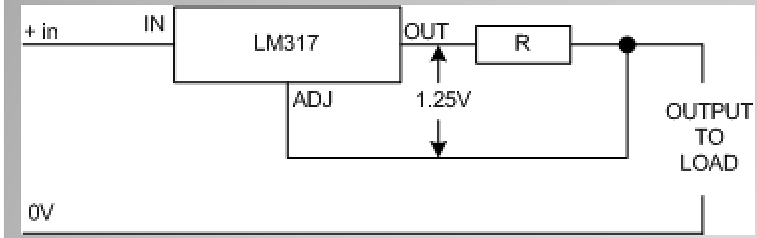
NEGATIVE variable regulator

These regulators function by maintaining a fixed level of 1.25V between the OUT and ADJ terminals and by ensuring that the current drawn by the ADJ terminal is very small. Provided the current through the potential divider from the output to the ground rail is large compared to the ADJ terminal, then the regulated output voltage is set by the resistors used for the potential divider. The recommended maximum resistor value between the ADJ terminal and the OUT terminal is 240Ω for the positive version (220Ω is OK) and 120Ω for the negative version.

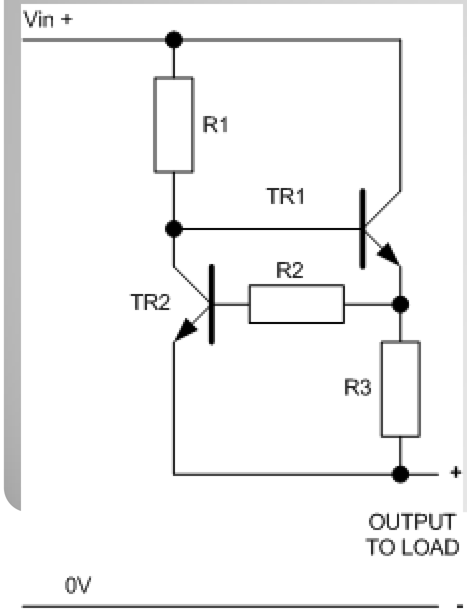
You want +12V out. R1 = 220Ω, so current through R1 = 1.25V/220Ω = 5.68mA
V across R2 is 12V – 1.25V = 10.75V, so R2 = 10.75V/5.68mA = 1.892KΩ which could be 1.8kΩ + 100Ω = 1.9kΩ. This will give an output of 10.792V + 1.25V = 12.042V.

CONSTANT CURRENT CIRCUITS

Constant current circuits are useful for charging batteries. There are many suitable circuits – here are a couple of simple ones.



Remembering that the LM317 maintains 1.25V between its OUT and ADJ terminals, selecting R to drop 1.25V at the desired current works well. Here, if you want about 100mA R = 1.25V/0.1A = 12.5Ω

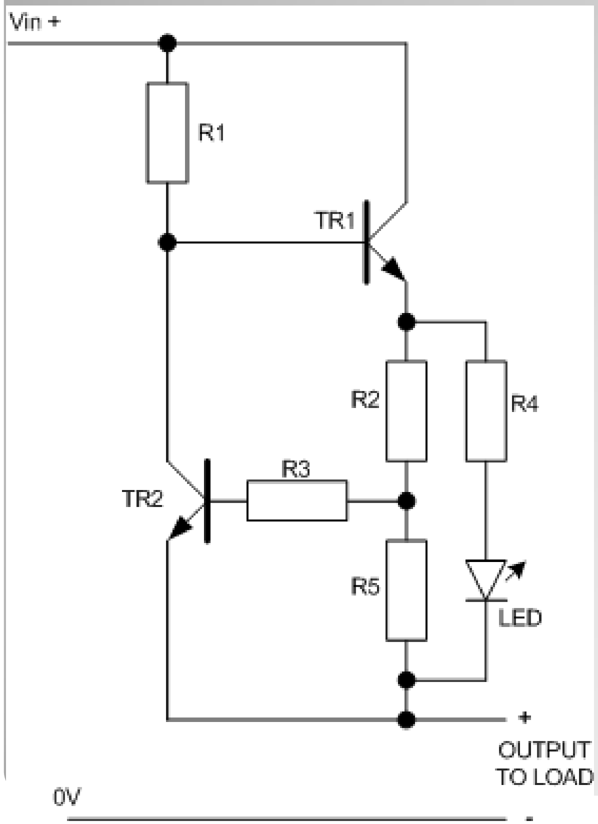


This simple circuit is not as accurate as the one above because it relies on the V_{BE} of TR2, which varies with temperature. R1 turns ON TR1 so current flows through R3 to the load. When the voltage across R3 reaches around 0.6V, TR2 turns on, which reduces the drive current to TR1, so TR1 sources a constant current.

With 13.8V input and a 7.2V battery pack to charge, with R1 at 1kΩ, R2 at 1kΩ and R3 at 0.68Ω, then the battery will be charged at about 90mA (0.6V/ 0.68Ω)

CONSTANT CURRENT CIRCUITS

Here is a development of the previous simple circuit which has the advantage that a LED illuminates when the battery is charging (so you know that it is connected OK)



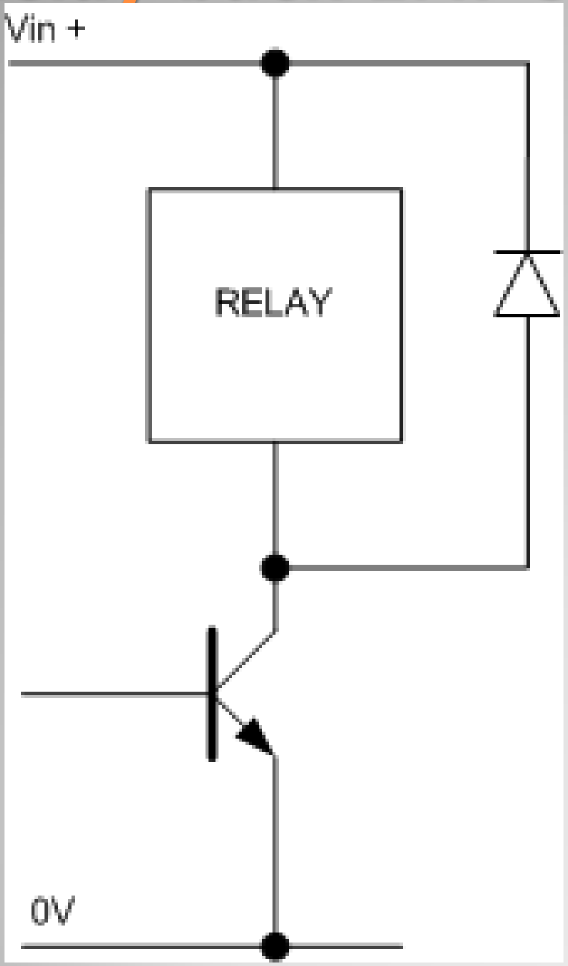
A RED LED has a forward voltage drop of around 1.7V.

With a LED current of 10mA and R4 at 100Ω, then the voltage across R4 + the LED = 2.7V. You want a current of 100mA so the current through R2 + R5 = 90mA.

So R2 + R5 = 2.7V/90mA = 30Ω. The voltage across R5 has to be around 0.6V, so R5 = 0.6V/90mA = 6.66Ω.This then means that R2 = 30Ω - 6.66Ω = 23.33Ω.

In this case you would fit 6.8Ω for R5 and 22Ω for R2, which would mean that the current through the LED would be a little bit higher. R1 and R3 remain the same as before, 1kΩ each.

Relay back EMF suppression



Whilst this is not really a power supply subject, to answer the frequently asked question, “what sort of diode should be used to suppress the relay coil’s back EMF at its switch off”?

The golden rules are;

Always fit a diode which is rated to conduct at least (or more than) the maximum relay coil current.

Always fit a diode whose blocking voltage rating is at least (or more than) twice the supply voltage.