THE POWER SUPPLY

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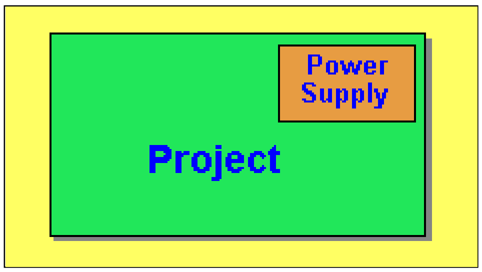
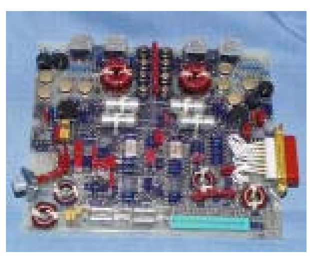
One of the most important sections of a project is the **POWER SUPPLY**. It will determine if everything works correctly. It is simply the most important part.
A power supply is also called a **PSU** (**P**ower **S**upply **U**nit) or Power Supply Module.



All projects need a Power Supply

Power supplies come in all different sizes, from very simple to extremely complex:



Quite often, we don't realise how important they are.
Some projects work on batteries, some from a plug pack and some from the mains. We just turn them on and expect them to work.
But what about the thought that has gone into designing a power supply?
It's an art to design a good power supply and it's a specialist field. Some companies concentrate only on power supply design, from a 1watt potted device to an un-interruptible power supply of several kilowatts.

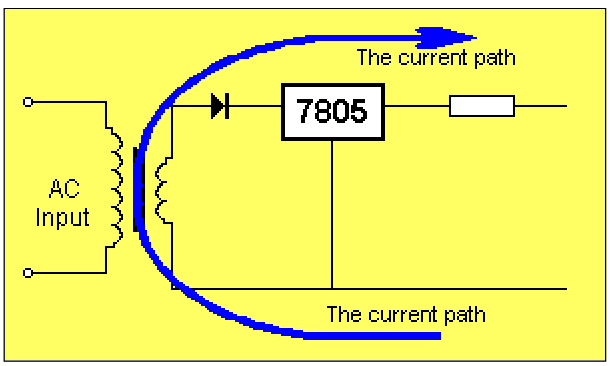
The simplest power supply is two cells connected to a project. We will start with this and show
the thought that goes into designing it.
The correct design of a power supply requires an understanding of many terms and we have discussed some of them on the previous pages of this course. Those terms will now be

needed.
Fortunately a number of chips and modules have come on the market to make designing a power supply a lot easier and one of the handiest components is the plug-pack.
It is simply a transformer in a plastic box with a plug on the side so it can be plugged directly into a power-point. This saves dealing with the mains voltage and provides guaranteed insulation.
But the biggest problem with a plug-pack is its "over-rating."
They do not supply the current stated on the label and don't make a very good device for powering a project. However with the advent of regulator chips, plug packs can be used very successfully.
That's why you need this discussion. You need to know how to interface a plug pack to a project and lots of other things relating the absolutely beginning of designing a power supply.
The first thing you need to understand is the meaning of IMPEDANCE. It is the most important feature of a power supply. It is the same as the "strength" of a bridge or skyscraper.

IMPEDANCE

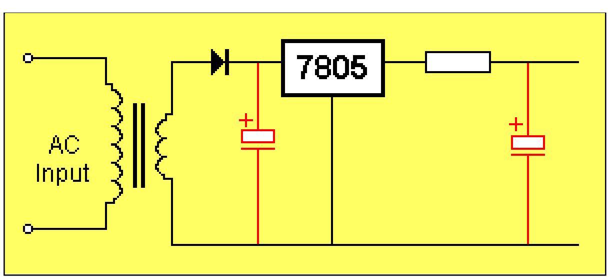
A power supply must have low impedance.
By this we mean:
A power supply must have low-resistance components in the CURRENT PATH. The current path starts at the 0v rail, through the secondary winding of the transformer, through the diode and regulator (or transistor) and through any resistor on the positive rail. This path supplies the current and any component with a high resistance will create a voltage-drop across it (when the high current flows) and the output voltage will be reduced.

The following shows the "current-path" we are discussing:



The Current Path

This is the path to look for when servicing a power supply. It is the path that will pass (deliver) the current.
Between the positive and negative rail we need a high-value electrolytic to reduce the impedance of the power supply even further.



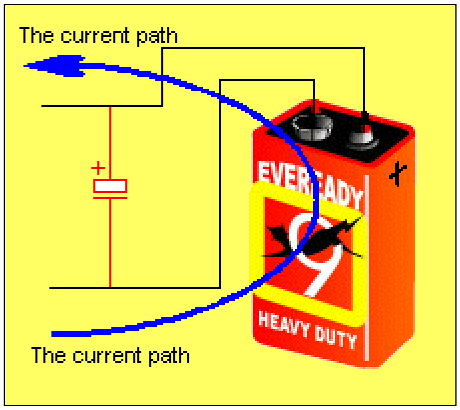
Electrolytics reduce the impedance of a power supply

An electrolytic is similar to a shock-absorber in a car. Without a shock-absorber, you will be able to push say the front-left part of a car up and down in a "bouncing" motion. This is the same as the output rail of a power supply. When the electrolytic is added, the rail does not move up and down. The electrolytic also adds to the ability of a power supply to deliver a high current. It is really an amazing component.

If a power supply cannot deliver a high current, the voltage on the output will drop and this can cause distortion or faulty operation of the rest of the project.

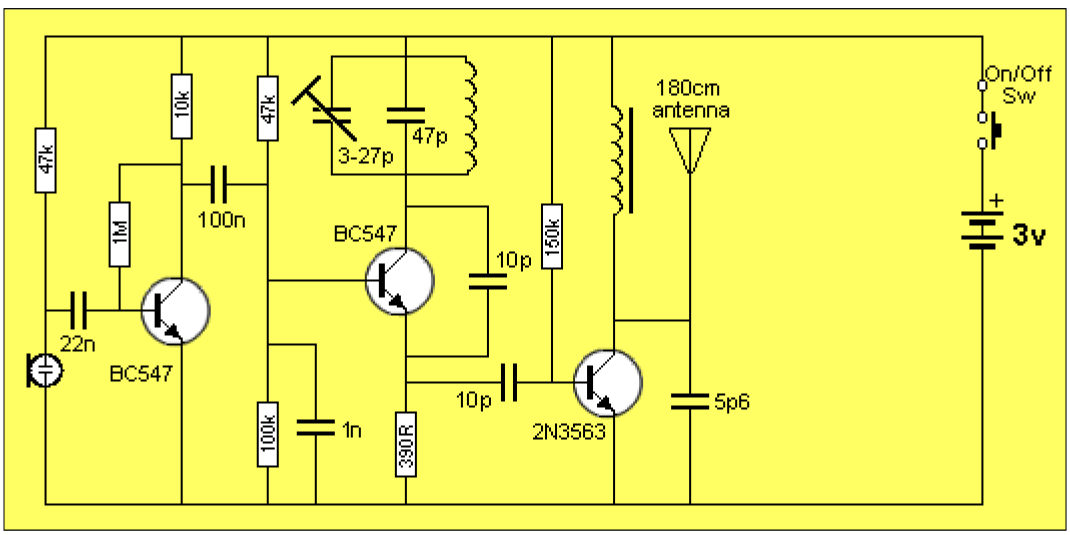
THE SIMPLEST POWER SUPPLY

The simplest power supply is a cell or battery. A cells is either 1.5v (or 3v). A battery is a number of cells.
The term IMPEDANCE still applies and the CURRENT PATH is though the cell or battery.



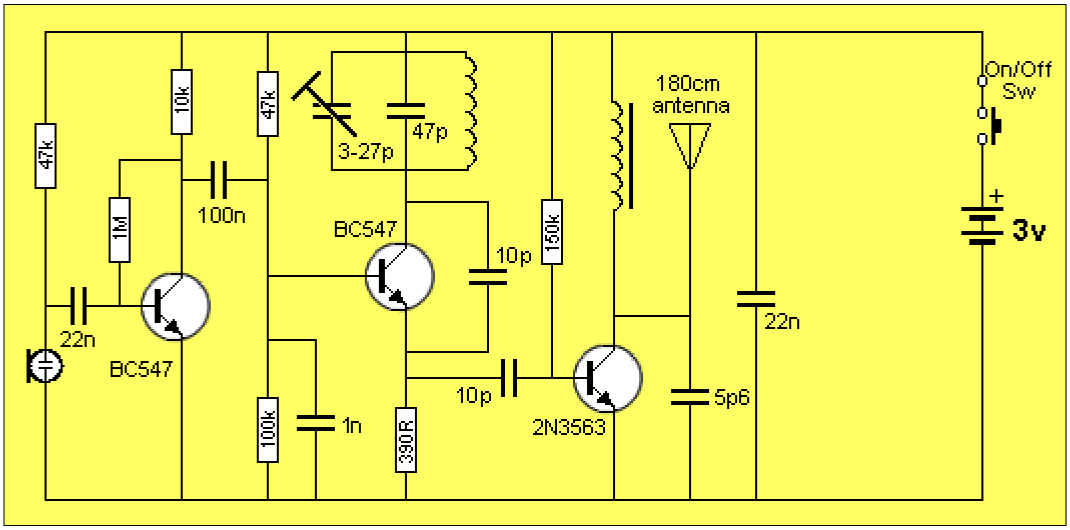
The current path

A new cell or battery has a low impedance as proven by its ability to deliver a high current.
As the battery gets older, the voltage across its terminals reduces and the maximum current it can deliver also reduces.
The reason is the active chemicals get used up, and the resistance of the by-products is higher.
All projects work perfectly with a new battery, but unless you remember some simple rules for correct designing, a new battery can still cause problems.
When deigning high frequency projects such as 100MHz "bugs" or FM transmitters, the leads to the battery must be as short as possible to keep the impedance of the power supply LOW.
Here is an example:
This FM transmitter circuit does not work:

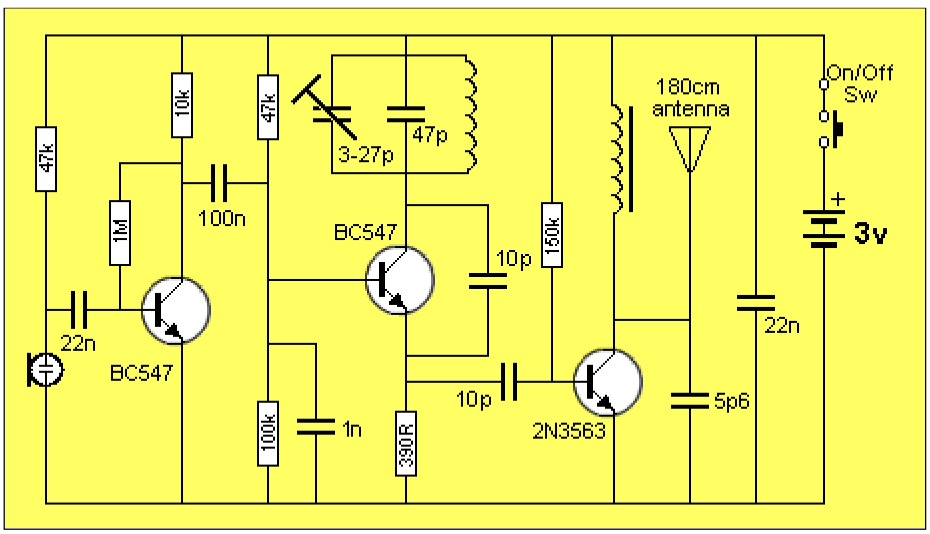


The 3v supply is too far from the circuit. The circuit is operating at approx 100MHz and the power-rail is moving up-and-down at this frequency and becomes an ANTENNA! It begins to radiate electromagnetic waves and in the process becomes a HIGH IMPEDANCE line.

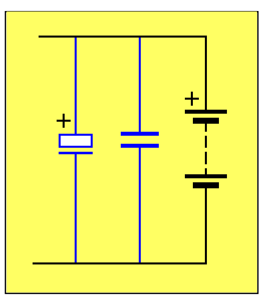
In other words it becomes a high resistance line and a voltage develops on it that opposes the 3v supply.
The current reduces and the circuit does not get the required energy from the battery.
This is equal to the power supply having a HIGH IMPEDANCE.
The impedance can be reduced by adding a capacitor across the power rails.
The performance of the following circuit will improve:



By placing the 3v supply very close to the circuit, the performance will increase enormously:



To keep the impedance of a power supply LOW, we need to:
(a) Add an electrolytic - for low-frequency circuits,
(b) Add a capacitor - for high-frequency circuits, and
(c) keep the leads short.



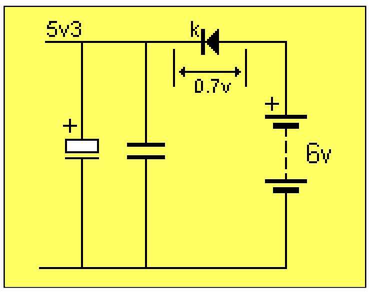
Keeping the impedance LOW

HOW THE CAPACITORS WORK

The capacitor or electrolytic across the battery is effectively a miniature battery with a very low internal resistance and is capable of delivering a very high current for a very short period of time.
When the project does not require a high current, the rail voltage is a maximum and the electrolytic or capacitor charges.
When the project requires a heavy current, the rail voltage drops slightly and the voltage across the electrolytic is higher and it begins to deliver its energy to the rail.
An electrolytic takes time to charge and discharge so it is only suitable for low-frequency fluctuations. A ceramic capacitor can be charged and discharged at a high rate and thus it is suitable for high-frequency fluctuations. By adding both to the power rail, we cater for the full range of frequencies.

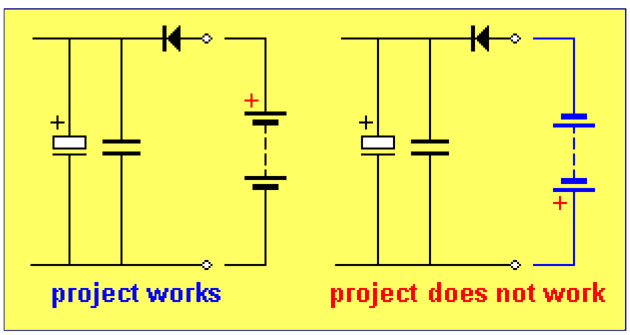
0.7v DIODE DROP

Next we can add a diode to convert a 6v supply to 5.3v.
TTL chips require a 5v supply and will operate up to a maximum of 5.5v.
The following circuit shows a diode added to the positive rail.
A "normal" power diode drops 0.6v to 0.7v when it is conducting. This is called the "characteristic" voltage drop of a diode.



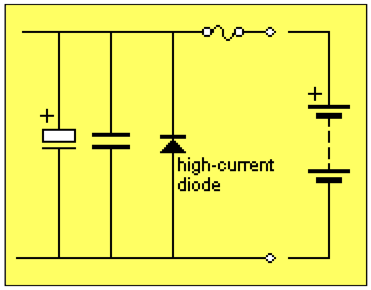
Adding a diode to produce a 5.3v rail

The diode also provides protection from reverse voltage:



Reverse-voltage protection

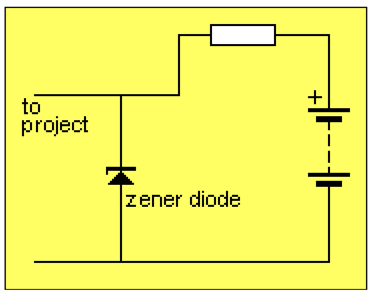
If you need the full battery voltage to be delivered to the circuit, the diode can be placed as shown and a fuse added. If the battery is connected incorrectly, the fuse will blow.



Reverse-voltage protection

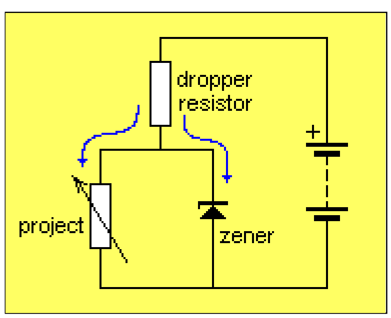
ZENER DIODE REGULATION

The simplest regulator is a zener diode. It is called a SHUNT REGULATOR as it goes directly across the power rails. It is a very wasteful way to produce a steady voltage. It is a bit like turning on a tap and putting a bucket so that it gets some of the flow. The flow into the bucket is the constant voltage and if the tap is turned on harder, the bucket is pulled slightly out of the flows so that it fills at the same rate. What a waste of water! What a waste of current!



A zener diode shunt regulator

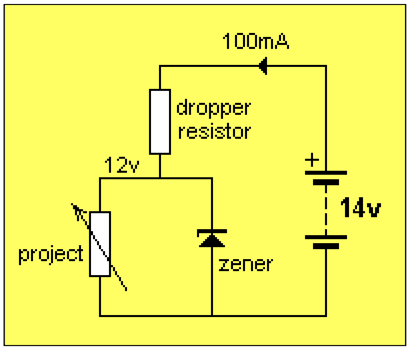
With a zener diode shunt regulator, current is flowing through the zener at all times and this is wasted current. If the main circuit requires no current, the zener consumes all the current.
If the main circuit requires current, the rail voltage drops slightly and the zener turns off a small amount and less current flows through it. This current is then available for the main circuit.
The same amount of current is always taken from the battery, it just gets diverted from the zener to the project. The following diagram shows how the current is divided between the load and the zener:



The current is divided between the project and zener

A zener diode is only suitable for small values of current.
It works like this:
If a project takes 10mA when idle and 100mA when processing a signal, the range is 90mA.
If the rail voltage is 12v, the zener will be required to pass 90mA when the project is idle and 10mA when operating.

The wattage rating of the zener will be 12 x 0.9 = 1.08watt. Use 1watt zener.
If another project takes 350mA @ 12v when idle and 440mA when operating, the difference is 90mA and the same zener can be used.
The dropper resistor also represents waster power and its value is worked out as follows:



The resistance of the dropper resistor

The resistance of the dropper resistor:

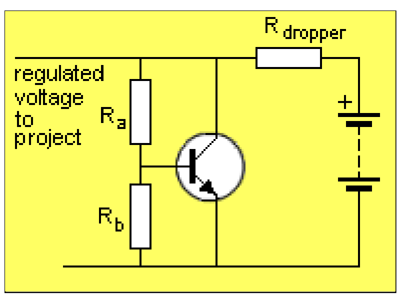
$$= \frac{\text{(the voltage across it)}}{\text{(the current through it)}}$$

$$= \frac{2v}{0.1}$$

= 20 ohms

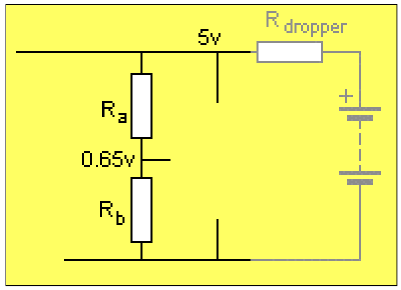
TRANSISTOR SHUNT REGULATOR

In place of the zener diode we can use a transistor. It is still the same wasteful design but the rail voltage can be set via two resistors and this saves stocking lots of different voltage zeners.
You will notice, we are adding components to create improvements to power-supply designs and this is the best way to understand how a power-supply works.



A transistor shunt regulator

The analysis and design of the circuit above starts with resistor Rb.
When the voltage across this resistor reaches 0.65v, the transistor starts to turn on and pull the regulated rail to the desired voltage.
In other words, the only two critical values are: the value of Rb and the characteristic voltage between the base and emitter of the transistor (0.65v).
Nothing else matters! Isn't that a surprise!
Once you know the secret of where to begin, things start to make sense.
Now we come to the skill of working out the value of Ra and Rb to produce a voltage of 0.65v at the join.
Suppose we require 5v for the regulated rail.
We have the following circuit:



The voltage-divider Ra:Rb

To work out the value of Ra and Rb, we need to know the current flowing through the voltage divider. This is a technical decision. In other words you have to decide what current you want to flow through the divider. Theoretically it can be ANY VALUE. That's right, it can be any value above a certain minimum. To arrive at the minimum value we need to know the current flowing through the regulator transistor (we will assume 100mA).
If the gain of the transistor is 100, the base current needs to be 1mA.
This means 1mA must flow through Ra.

The value of Ra:

$$= \frac{5 - 0.65}{0.001}$$

$$= \frac{4.35}{0.001}$$

$$= 4{,}350 \text{ ohms}$$

This value is non-standard.
Use a standard value. Select 3k9.
The value of Rb:

current flow:

$$= \frac{5 - 0.65}{3900}$$

$$= 0.0011 \text{ amp}$$

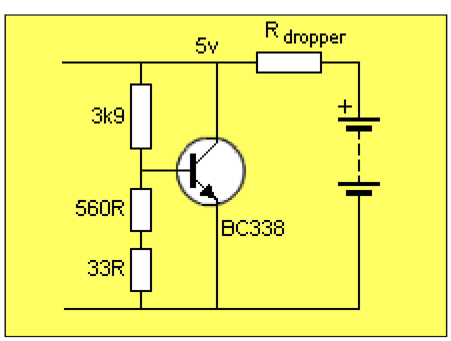
The value of R_b:

$$= \frac{0.65}{0.0011}$$

$$= 590 \text{ ohms}$$

Use a 560R and 33R in series.

The final circuit:

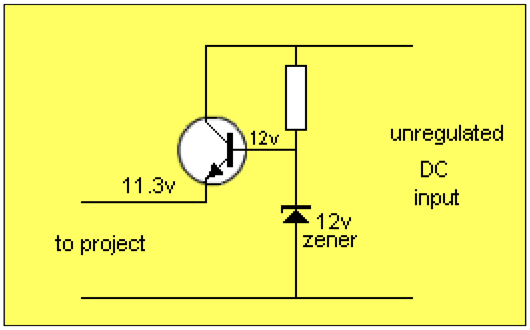


The transistor shunt regulator circuit

An improved transistor regulator is the:

TRANSISTOR SERIES REGULATOR

The series transistor regulator is a more-efficient design and caters for a high current load and wide fluctuations. It wastes almost no energy when no current is being taken by the project but the transistor must be heat-sinked when a high current is required.
A simple series regulator is shown in the diagram below.
It is effectively an EMITTER-FOLLOWER:



Simple series transistor regulator

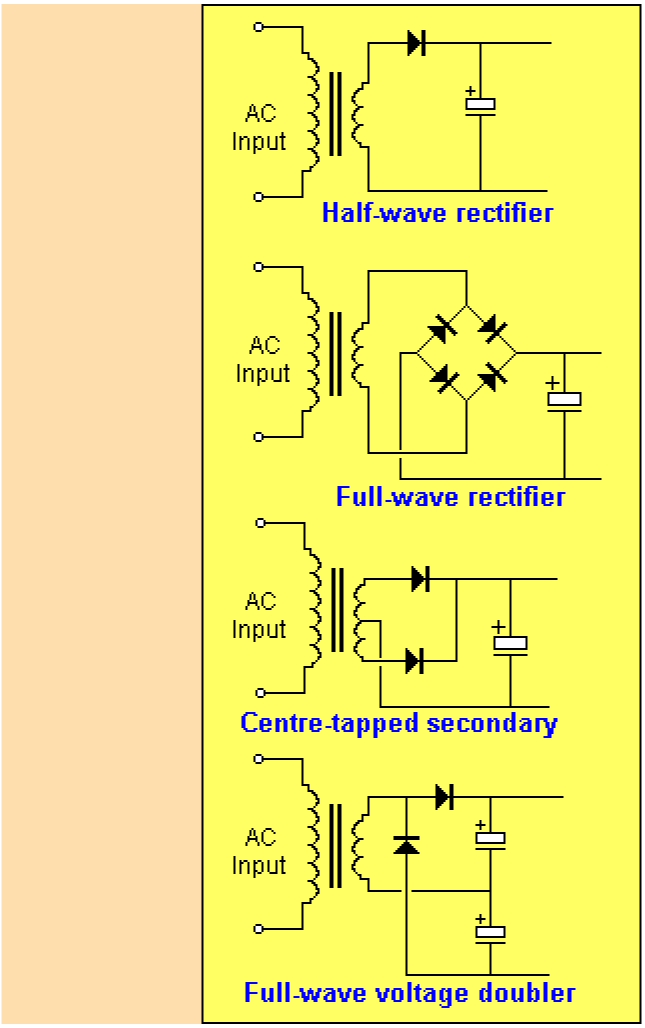
The emitter of the transistor "follows" the base and is approx 0.7v below the base.
The base is fixed at 12v by the zener diode and the voltage to the project is 12v - 0.7v = 11.3v

THE TRANSFORMER

There is not a lot you can do about designing a transformer.
They are "off the shelf" components and you have to take the manufacturers specifications as accurate. But they are often misleading. Especially with small transformers (5VA to 30VA).
The size of a transformer indicates its VA rating (volt-amp rating).
There are basically three types of transformers:
1.The square-looking type made from "E's" and "I's" (or a solid ferrite material).
2. The toroidal-type, looking like a large doughnut and
3. The enclosed-type called a pot-core.
There are lots of variations and shapes, such as elongated-types to fit certain spaces or inductor-types that look look a choke.
But we will concentrate on three types and two different frequencies of operation.
The "E" and "I" type is used for low frequency (50 - 60Hz) and the ferrite type is used for high frequency (50kHz - 1MHz).
But the big problem is the data provided with some of them - especially "plug packs."
Some transformers are rated at 500mA, while some smaller types claim to be 500mA. This is an error and you have to be aware of false identification.
The VA rating of a transformer depends on its size in each category ("E" and "I" - toroidal and high frequency).
There is no "super transformer" that is 50% better than the others in the same style and you can accurately go by size, shape and weight for each category.
The largest and heaviest transformer (per VA) is the "E" and "I" type. The toroidal will deliver about 200 -300% more (watts) for the same weight and the high-frequency ferrite types will deliver 6 times to 10 times more (watts).

There are three types of secondary winding:
It can be a single winding, centre-tapped or two separate windings.
You can use a single diode for half-wave rectification or 2 diodes for full-wave from a centre-tapped secondary or 4 diodes in a bridge for full-wave rectification.
Half-wave rectification is very inefficient and is no longer used.
Full-wave is the best design.
The centre-tapped secondary was designed many years ago to get around the problem of PIV rating for diodes (see below).
The full-wave voltage doubler was also designed many years ago as a low-cost way to

generate a high voltage for the accelerating anode on a Cathode Ray Tube.
Here are 4 different ways to connect to the secondary of a transformer:



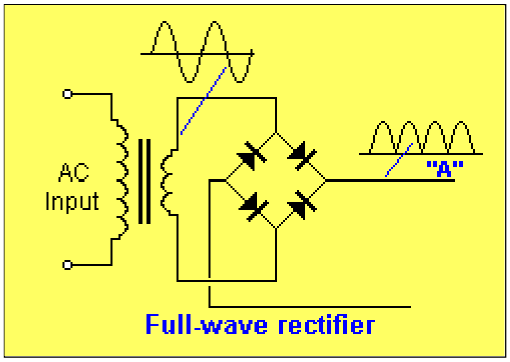
There are a number of reasons why four different circuits were designed.
In the early days of electronics, power supplies were designed to meet the requirements of valve amplifiers and these required a plate voltage of 285v or more. In the full-wave circuit, the PIV (peak-inverse-voltage) rating for each diode must be equal to at least twice the peak load voltage and since this was higher than some of the diodes in the early days, a number of alternatives were produced - such as the centre-tapped secondary.
The full-wave voltage doubler circuit was very clever as it produced a smoothed DC output from a low voltage winding. It was much cheaper to wind a lower-voltage winding as it had fewer turns of thick wire.
All these "clever designs" are now no longer needed as the voltage requirements of modern electronics is much lower and regulation is provided with IC's.
The only design you need to study is the **Full-wave rectifier**. All modern power supplies use a single secondary winding and a bridge rectifier (four diodes in a block that looks like a chip).

THE HALF-WAVE RECTIFIER

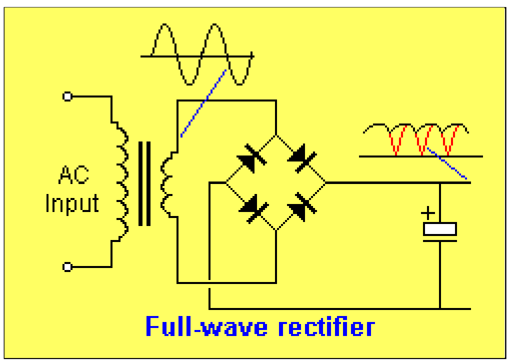
The half-wave rectifier produces a waveform with a very large AC component called "ripple" and requires a lot of smoothing to make it acceptable for electronic circuits. By adding another diode, we can get "full-wave" rectification and this requires less smoothing.
For this reason the half-wave rectifier is no longer used.

THE FULL-WAVE RECTIFIER

The full-wave rectifier delivers both the positive and negative part of each cycle to the input of the "electronics." When we talk about a "full-wave rectifier" we mean the "bridge rectifier" made up of 4 diodes:



Two opposite diodes pass the waveform to the output line during one half of the waveform and the other two diodes pass the signal to the output during the second half of the waveform.
At point **"A"**, an electrolytic smoothes the pulses by charging and discharging at the appropriate times to create a fairly smooth waveform.
It is very important to make this waveform as smooth as possible (with the aid of a large electrolytic) as the "electronics" (the regulator) will improve the "smoothness" 1,000 times or more.



The smoothing effect of the electrolytic

REGULATION

Regulation is one of the hidden words in power supply design.
It applies to both the output voltage of a power supply and a transformer.
When referring to a transformer, it is its ability to deliver a fixed voltage, over a wide range of current.
It is impossible for a transformer to maintain a constant output voltage when a load is applied as the secondary winding has a resistance (impedance) and the flux density changes.
The loaded voltage of some transformers can drop as much as 20% - 50% and unless there is a circuit to compensate for the change, we will get "hum'" "ripple," "drop-out" and faulty operation of the project.
To get around this voltage-drop, manufacturers add extra turns to the secondary and deliver a higher "no-load" voltage.
This means some transformers will produce 16-18v on no-load and drop to 12v when full current is being delivered.
The maximum voltage for CMOS chip is 16v and they will be damaged if supplied with 18v.
We need a circuit to take the 18v and convert it to a fixed voltage - preferably 12v or less.
The circuit is called a **REGULATOR**.
A regulator has the amazing ability to convert a high voltage to a low voltage and maintain it accurately over a wide range of current requirements - even when the input voltage is rising and falling.

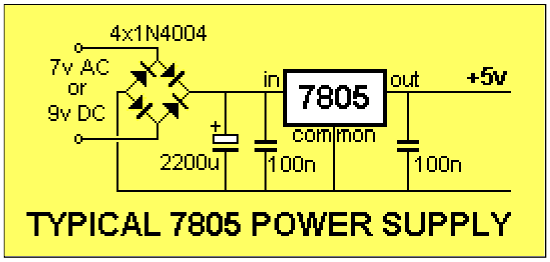
There are two types of circuits:
Type A provides a constant voltage from a **higher supply voltage**.
For instance, a 7805 will provide a constant 5v, from a supply of 8v to 20v.
If the supply drops below 7v, the 5v rail will drop.
The **Type A** circuit can use a **REGULATOR** in the form of a component that looks like a power transistor:

It actually contains more than 30 transistors and requires only a few external components to create a complete power supply. Basically it operates by chopping the input voltage and delivering small amounts to the output. It is called a 3-terminal regulator or linear regulator.
Type A circuits can also use switch-mode arrangements in which the output voltage is created via an inductor. The output voltage is entirely created by the energy from the inductor.

Type B circuits provide a constant voltage from a **lower supply voltage**.
This is called a step-up regulator. The voltage can be produced by charging a capacitor and placing this voltage on top of the rail voltage or it can be produced by passing a current through an inductor then turning it off and allowing the inductor to collapse and produce a high voltage. In all cases, the output voltage is monitored and accurately maintained.
That's why all these circuits are called REGULATED POWER SUPPLIES.

3-TERMINAL REGULATORS - also called Linear Regulators

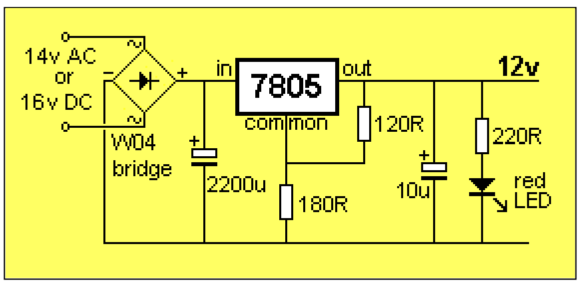
The common name given to "chip" regulators is "3-Terminal Regulators." This has made designing power supplies very easy. Simply add a 3-terminal regulator and a few surrounding components and you have a regulated power supply.
But there are some hidden secrets.
The most important fact to remember is to prevent the regulator dropping out of regulation. This means the input voltage must be 3v higher than the voltage you are delivering.
With very poor quality plug-packs, this can be quite a problem. They can drop below the required voltage when drawing a current. This will cause problems with the project and be very difficult to detect - unless you are aware of the problem!
3-terminal regulators work on the principle of delivering energy to the output in pulses.
When they are turned on, the voltage drop across the regulator is low and the heat generated is small. When they are off, the heat generated is zero.
In this way they can produce an accurate output voltage and high current demand, with minimal losses.
A typical 3-terminal regulator power supply is shown in the following diagram:



There are four important points to remember when designing a power supply:
1. The regulator must be close to the edge of the board so it can be attached to a heatsink.
2. The heatsink must also be attached to the PC board so that is does not move and allow the leads of the regulator to break.
3. The 2200u and both the 100n monoblocks must be mounted close to the regulator.
4. The input voltage must be higher than the output to allow for the voltage drop across the bridge and regulator. The minimum for a 5v output is 7v AC or 9v DC.
Note: It does not matter which way around the AC or DC supply is connected to the bridge as the bridge will automatically adjust for either polarity. This is one of the advantages of placing a bridge on the input of a project. It allows either-way connection to power the project.

INCREASING THE OUTPUT VOLTAGE

The output voltage of a supply can be increased by "jacking up" the voltage produced by the 7805. The way the 7805 works is this: It maintains a voltage of 5v between output and common terminal. If the voltage on the common terminal is increased (jacked up), the output voltage will be 5v higher. The 7805 always maintains 5v between output and common. The circuit below produces an output of 12v.



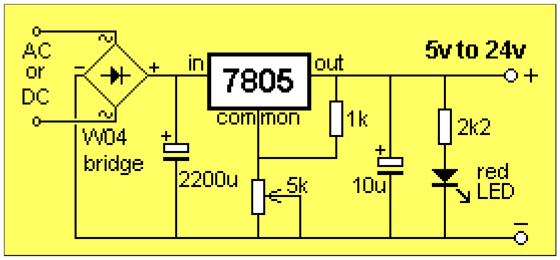
"Jacking up" the 7805 regulator

Almost any voltage between 5v and 30v can be obtained by this method. This saves stocking the complete range of regulators.
The output voltage is determined by two resistors in VOLTAGE DIVIDER MODE. Five volts is always present across the 120R resistor and if another resistor is placed in series, it will have a proportional voltage across it. In the circuit above, 7v is developed across the 180R resistor, making a total of 12v on the output.
To increase or decrease the voltage, only one resistor has to be changed in the circuit above. The 120R is retained and the 180R is changed. If it is increased to 220R, the output voltage will be 14v, for a 330R, the output voltage will be 18v. The resistor in the common line can be a potentiometer. This will produce an adjustable output voltage. The dropper resistor for the LED will also have to be increased so the LED is not over-driven on the higher voltages.
A meter can be placed on the output to monitor the **voltage and current** taken by the load.
There is only one problem with an adjustable supply. The regulator must be heatsinked so it is capable of dissipating the heat for the worst condition. In addition, the input voltage must be sufficient to cater for the maximum output voltage.

ADJUSTABLE OUTPUT VOLTAGE

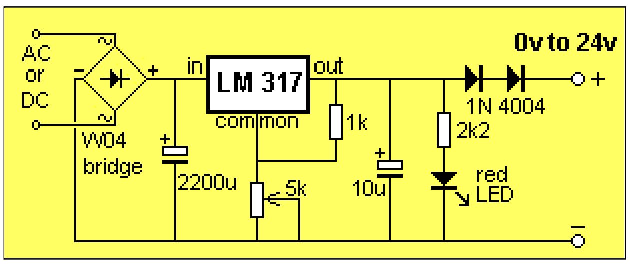
The output voltage can be adjusted (varied) from 5v to 24v via a potentiometer connected to the common line of the regulator. The input voltage and heatsinking of the regulator must be sufficient for the output voltage and current. The output may not deliver more than 100mA @

5v due to the heat produced by the regulator if the input voltage is say 24v - 36v. This is one of the disadvantages of a variable power supply if this design.



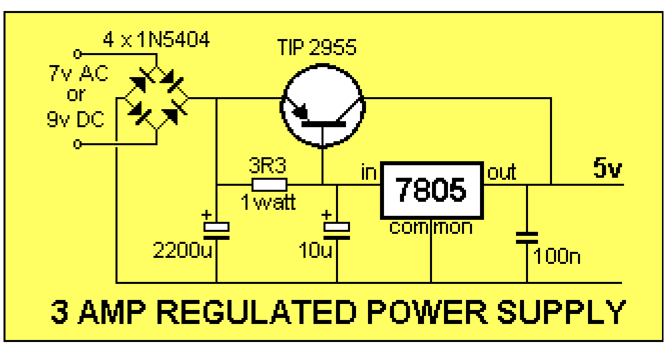
THE LM 317 REGULATOR

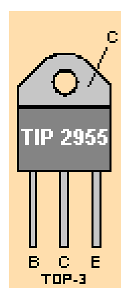
The advantage of an LM317 regulator is the supply will go down to 1.2v. If you add two diodes (in series with the output line), the voltage will go down to 0v as shown in the following circuit:



HIGHER CURRENT

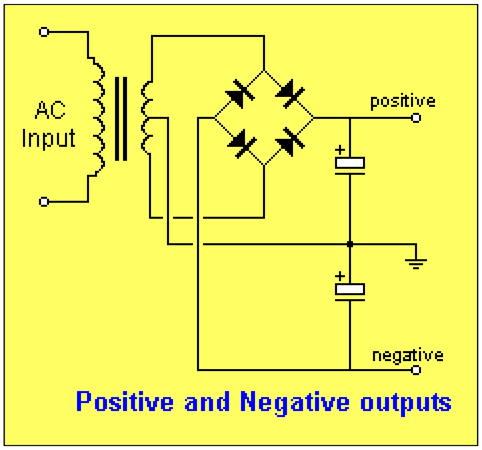
If you require more than 1 amp, the 7805 can be combined with other components to provide an output of up to 3 amps, with the circuit below. The current is switched through the TIP2955, so the 7805 can be run without a heatsink since it only regulates the voltage. Note the 3-amp diodes in the power supply.
For currents greater than 3 amps, additional TIP 2955 transistors can be "piggy-backed" on top of the TIP in the circuit. If the gain of each transistor is approximately the same, the transistors will current-share the load and get equally hot.





POSITIVE AND NEGATIVE SUPPLY

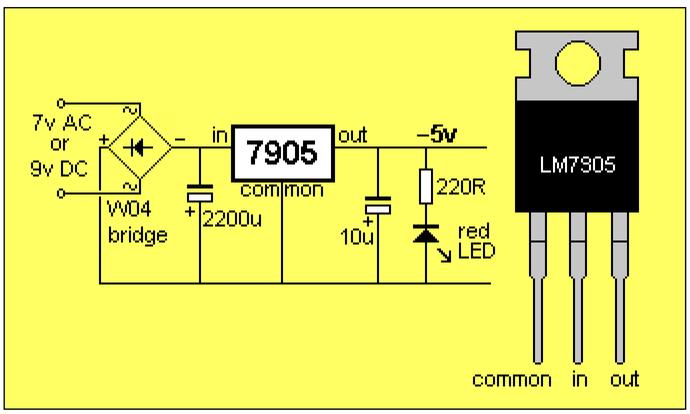
A positive and negative supply can be generated from a single bridge by using a centre-tapped transformer:



A NEGATIVE POWER SUPPLY

A negative power supply can be produced with a 7905 voltage regulator. Three things to be remembered are:

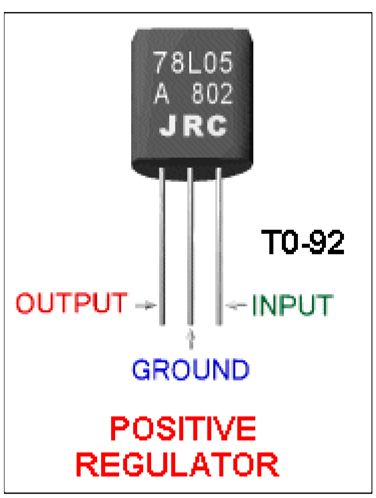
1. Check the connections of the 7905 before fitting it.
2. Reverse the 2200u and 10u electrolytics and LED.
3. Reverse the bridge so the negative goes to the "in" pin of the 7905.



The 7905 -5v regulated supply circuit

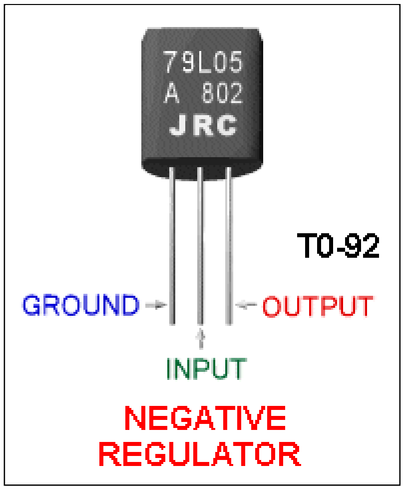
100mA POSITIVE REGULATORS

3-Terminal regulators are available in 100mA versions. They look like a small-signal transistor:



100mA NEGATIVE REGULATORS

3-Terminal regulators are available in 100mA negative output versions. They look like a small-signal transistor:

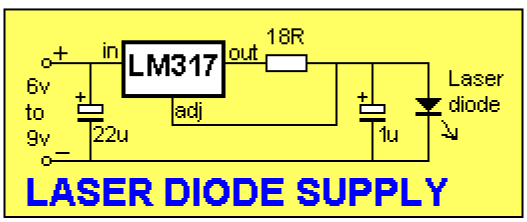


THE CONSTANT-CURRENT SUPPLY

The voltage regulator can be wired to produce a constant output current. This is not suitable for some applications as many devices require a high current at start-up (motors and globes) while others require a varying current (amplifiers) for their operation.
However there are a few devices that need a constant current for their correct operation and one device is the Laser Diode.
The actual current requirement depends on the output of the diode and a standard 1 milliwatt type requires between 70 and 100 milliamp.
The characteristic voltage developed across the diode is less than 3v so that a 3-terminal regulator that goes down to 1.2v will be needed.

HOW THE CIRCUIT WORKS

By simply connecting a resistor between the output of the regulator and the load, and taking the common or "adj" terminal as shown below, the output current can be set by the value of the resistor.

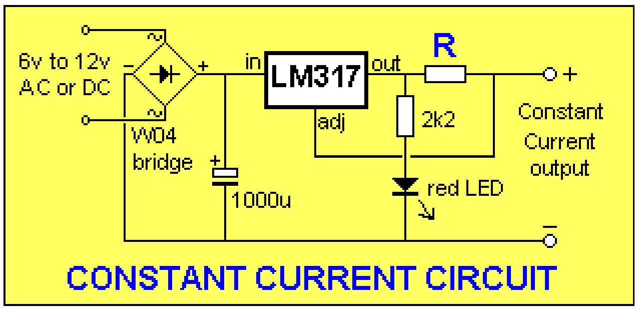


It works like this: No current "comes out" the adjust terminal. It is a "sense" line. It merely acts as the 0v reference line for the regulator. The only side issue is the current taken by the regulator flows through the adjust line and this is approximately 10mA. But in our discussion, this is ignored.
The voltage between the output terminal and "adjust" is fixed a 1.2v (for this type of regulator). The 18R resistor in the circuit is called a voltage dropping resistor. It is designed to produce a voltage across it according to the current flowing. If it is 18R, the current flow will be: 1.2/18 = 66milliamps. If the resistor is 10R, the current needed to produce 1.2v across the resistor is: 1.2/10 = 120milliamps. If we choose 15R, the current flow will be 1.2/15 = 80milliamps.

The laser diode in the example above requires a current between 70milliamps and 100 milliamps. You can choose 15R or 18R for the voltage-dropping resistor.

How the 3-terminal regulator keeps the output current constant, even if the input voltage is increased:

Firstly, the current through the "common" or "adj" lead is only about 10mA and this will not come into the discussion.
If the input voltage is increased, the output voltage will (may) increase and this will allow the load (the laser diode) to take more current. The increased current through the 15R or 18R resistor will increase the voltage across it ad this will be detected by the circuit inside the regulator. The circuit will "turn down" the output voltage and everything will be stabilised.
This type of circuit is needed to drive a laser diode from a battery supply. As the voltage drops, the constant-current circuit maintains the same current.
If the constant-current circuit is not included, the current to the laser diode would drop as the battery voltage falls and the laser diode would cease to operate if the current falls below a certain minimum.
All "Laser Pointers" have an inbuilt **constant current** circuit to maintain the operation of the laser.
The output current in the following circuit is determined by the value of resistor **R.**



You will also have to change the input voltage so that it is always at least 5v above the output voltage. The brightness of the indicator LED will depend on the voltage being supplied to the load. It does not indicate the current being delivered. Use the table below for the following currents:

Output Current	R
50mA	24R (use 18R or 27R)
100mA	12R (use 10R + 2R2)
150mA	8R (use 8R2)
200mA	6R (use 5R6)
500mA	2R4 (use 2R2)
1,000mA	1R2 (use 1R)

RIPPLE FACTOR

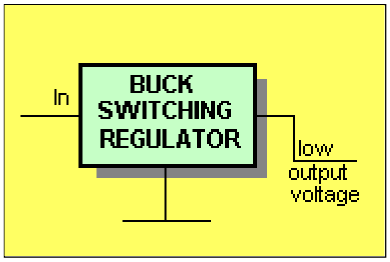
One characteristic of an electrolytic is rarely mentioned.
It is RIPPLE FACTOR.
This is the amount of current it is able to deliver without getting too hot.
It is one of the factors that determines the size of the electrolytic and since everything is being miniaturized, the Ripple Factor suffers.
The result is it warms up during operation and will dry out. The capacitance will reduce and all sorts of faults will develop.
One way to determine the suitability of an electrolytic is to fell it after the supply has been operating for a while. It it is hot, you can be sure it will suffer from overheating.
On the other hand, if it is cold, it could be dry.

3-terminal regulators are not very efficient and tend to get fairly hot.
The latest development is to design a switching power supply using an inductor or capacitor to produce the output voltage and current. This design is more efficient and the amazing feature is the ability to produce an output with a higher voltage or current than the supply.

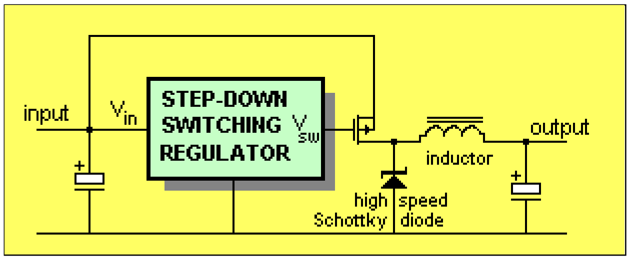
There are two types - Buck and Boost.

THE BUCK REGULATOR

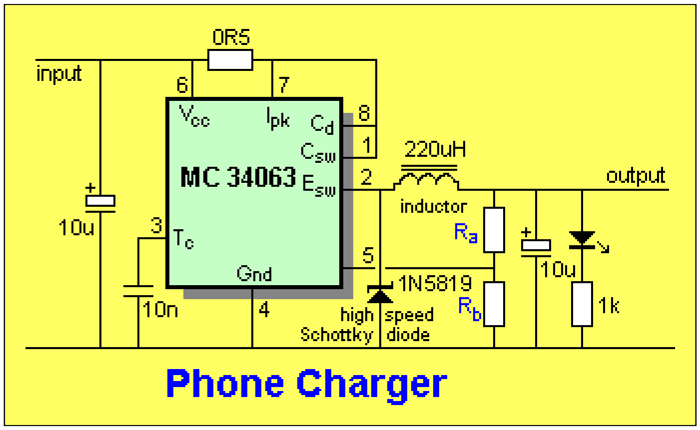
The Buck regulator requires a high input voltage and delivers a low voltage.
It is called a BUCK CONVERTER, BUCK REGULATOR, STEP-DOWN CONVERTER or STEP-DOWN SWITCHING REGULATOR.
A switching regulator, when in the buck mode, produces a voltage lower than the "in" voltage.



Buck switching-regulators have an internal high-frequency oscillator that turns a transistor on and off and delivers bursts of energy to an inductor. When the transistor turns off, the energy from the inductor is stored in a capacitor.
It will maintain an extremely stable output voltage even though the current required by the project may fluctuate and the input voltage may rise or fall.
Buck switching regulators are available in 100mA, 1A, 5A plus other values.
A buck switching regulator will take 12v @ 500mA and convert it to 5v @1Amp. In other words it will take a high voltage at low current and convert it to a low voltage at high current.
A step-down switching regulator chip requires only a few external components to create a complete supply. Some of the components in the diagram below are inside the chip.
A sense line (not shown) is connected to the output to monitor the voltage and maintain stability.



An MC34063 IC in a step-down switching circuit:

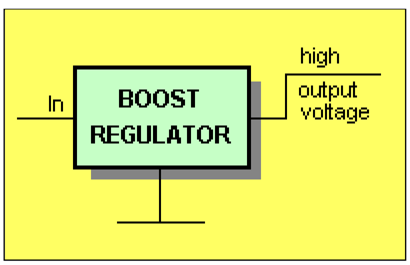


The output voltage is determined by the value (actually the ratio) of Ra:Rb.
The chip has a 1.25v detector on pin 5 and when the voltage across Rb is 1.25v the chip begins to shut-down.
The output voltage:

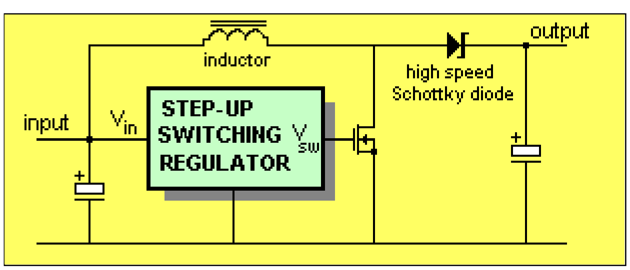
$$V = 1.25\left(1 + \frac{R_a}{R_b}\right)$$

THE BOOST REGULATOR - the step-up regulator

The BOOST switching regulator circuit has a low voltage supplied to it and delivers a high output voltage.
It is called a BOOST CONVERTER, BOOST REGULATOR, STEP-UP CONVERTER or STEP-UP SWITCHING REGULATOR.



Boost switching-regulators have an internal high-frequency oscillator that turns a transistor on and off and delivers bursts of energy to an inductor. When the transistor turns off, the energy from the inductor is stored in a capacitor, via a high-speed Schottky diode
It will maintain a constant output voltage even though the current required by the project may fluctuate and the input voltage may rise or fall.



Boost switching regulators are available in 100mA, 1A, 5A plus other currents.
A step-up switching regulator chip requires only a few external components to create a complete supply.
Note: A boost regulator can produce a voltage **higher or lower** than the "in" voltage.
The MC34063 IC can be used in a circuit to produce a higher or lower voltage than the "in" voltage.

SERVICING POWER SUPPLIES

Most faults in a power supply are due to the electrolytics. They play a vital part in the performance of the circuit and after a few years they can exhibit a lower capacitance due to overheating and drying out.
When servicing a power supply the electrolytic is bridged with another (WHEN THE SUPPLY IS TURNED OFF), to see if it is faulty.
Unusual effects can be created when an electrolytic dries out and the quickest and cheapest thing to do is replace ALL OF THEM.
They can cause low output voltage, hum, ripple, hiccupping, distortion and sometimes complete failure of the power supply.
The next component to check is the power supply IC such as the regulator or control chip. These are very reliable but can suffer damage if they are not heat-sinked correctly.
Many of them have in-built thermal shut down if the temperature rises excessively but if this feature is activated on a regular basis, the chip will gradually suffer from over-heating.
Another problem can be a thermal fuse or low-value resistor. These eventually suffer from heating and will fail. They are sometimes hidden in a fibre-glass sleeve.
Don't forget to check the plug-pack as a smaller version may have been substituted and will create all sorts of ripple problems.
Once you have covered these areas and the fault still persists, you will need to go to the rest of the project and determine if it is taking more current due to the fitting of additional devices.

CURRENT MEASUREMENT

It is very difficult to measure the current being delivered by a power supply.
If you insert a current detecting device, the additional resistance of the meter and leads will reduce the peaks. Even though the resistance of the meter is very small, the high current being taken by the circuit will cause a voltage drop to develop across the meter and the current peaks will be reduced.

That's why testing a power supply is very difficult.
Generally, there is very little to go wrong as it contains very few components, but when a fault develops, it can be quire technical.
This is due to the high currents and even short tracks on the PC board can introduce problems.
Make sure tracks have not burnt out and check the earth rail.
Sometimes a long earth rail will introduce problems.
For instance, a dry electrolytic on one of the rails may create a fault in a particular section that causes a low frequency hiccup and this is referred back to the power supply via another section.
Remember, a power supply is a LOW IMPEDANCE module and once this impedance is altered, a number of faults can develop.
Impedance is a very difficult thing to measure as it made up of so many factors.
That's why you have to use your skills when designing and servicing.
Don't forget to include 100n ceramic capacitors near the input and output of a 3-terminal regulator. They prevent it self-oscillating.
Make sure the tracks to a 3-terminal regulator are thick to reduce the impedance.
And make sure the 3-terminal regulator is adequately heatsinked.

HEATSINKING

One of the important points to remember is heatsinking the power supply regulator.
The amount of heat generated by a 3-terminal regulator depends on two factors:
1. The current being delivered to the project, and
2. The voltage delivered to it via the transformer or plug-pack.

We will take this simple example:
A 12v plug-pack is powering an audio amplifier project and the output is distorted.
The 300mA plug pack is replaced by a 500mA unit and the audio is perfect.
But the regulator gets hot and shuts down.
What is the problem?

The larger plug pack has better regulation. It is capable of supplying a higher voltage to the regulator - and thus a higher current.
The regulator is capable of maintaining a high rail voltage and the amplifier draws a higher current.
These two factors cause the regulator to dissipate a higher wattage and it heats up excessively.
The only solution is to increase the size of the heatsink.

CONCLUSION

This page has described power supplies up to about 1amp. These are cheap and easy to design as transformers, diodes and 3-terminal regulators are capable of delivering 1amp. This is the absolute maximum current as low-cost diodes are rated at 1amp and a 1amp transformer is rated at one-amp AC! This is only 0.707amp DC and it is not advisable to deliver more than this on a continuous basis.
Once you get over 1 amp, the design of a power supply becomes more critical.
The next page covers more (very interesting) power supply features . . .

Next Page

THE POWER SUPPLY

Page 1 Page 2

TESTING A POWER SUPPLY

One of the most difficult things to do is test the maximum current capability of a power supply.
The easiest thing to do is to connect it to a project and see if it operates correctly, but of you are designing a power supply for general use, you will need to know its capabilities.
There are 4 important features (parameters) you need to check:

1. The output voltage
2. The ripple
3. The current capability, and
4. The maximum short-term current.

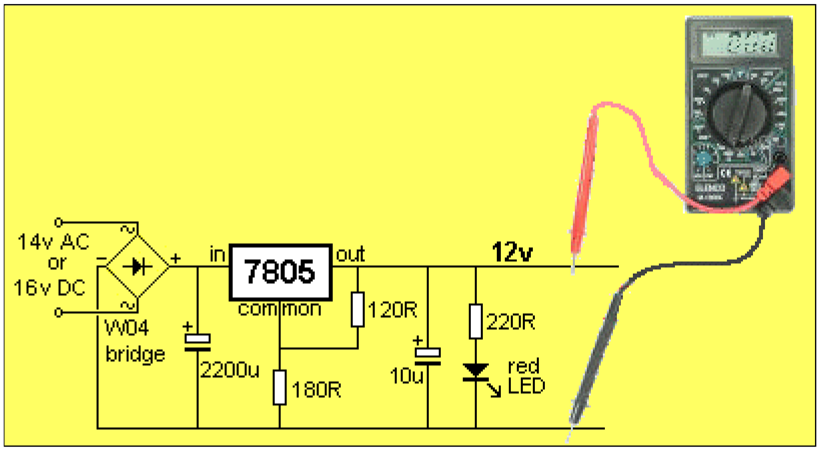
There are two ways to test a power supply:

1. A Dynamic load - such as an amplifier, computer etc.
2. A Static Load - also called a DUMMY LOAD.

We will now cover these 5 things:

MEASURING THE OUTPUT VOLTAGE:

You can measure the output VOLTAGE of a power supply with a multimeter as show in the following diagram:

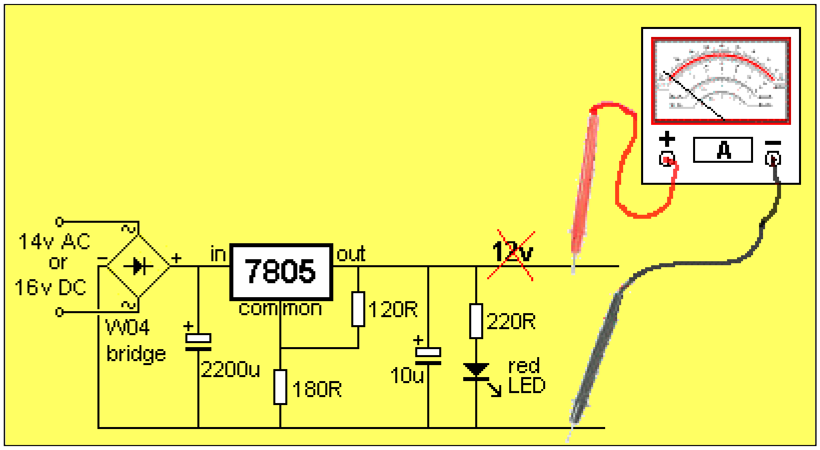


Measuring the output voltage of a power supply.

The power supply should be connected to a project. The reading on the multimeter will give an accurate indication of the rail voltage under load.

MEASURING THE OUTPUT CURRENT:

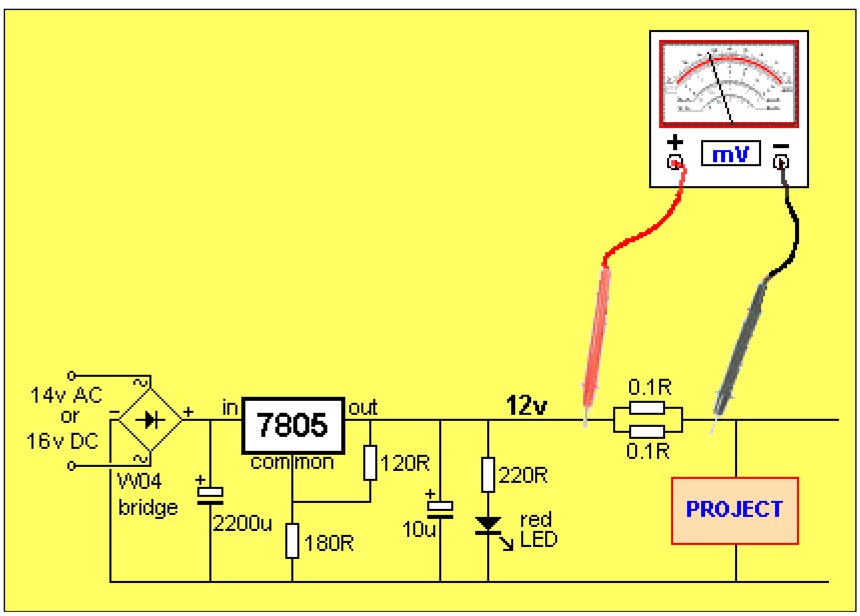
You CANNOT measure the output current with an ammeter:



You cannot measure the output current of a power supply via this method

The ammeter places a SHORT-CIRCUIT on the output of the power supply and it will give a false reading.
Some powers supplies will shut down completely and others will try to drive the maximum "designed-current" through the "short-circuit." The 3-terminal regulator will get very hot and may be damaged.

The only way to measure the output current is to add a low-value resistor in the positive line. The resistance must be less than 0.1ohm. (0R1 brown-black-silver-gold). Two 0R1 resistors in parallel will produce 0.05 ohms. When 1 amp is flowing, the voltage across the combination will be 50mV. Use a multimeter switched to mV scale and measure the voltage across the resistor(s).
The following diagram shows this procedure:



Measuring the output current

There are three reasons why this method is the best:
1. Most multimeters have a fairly high internal resistance (comparatively speaking) on the amps range and this creates a voltage drop when measuring current.
2. Few multimeters have a 0-1 amp range. Most have 0-200mA or 0-500mA or 0-10amp. These are not suitable when measuring 0-1 amp.
3. Our method of measurement creates the smallest voltage drop to the project and thus the

most-accurate reading is obtained.
If the project receives a lower voltage, it will draw a lower current and thus the reading will be inaccurate. The 50mV drop across the resistors in the power rail is a known value and you can add a similar value to see the effect on the current. It will not be a linear decline but our method will produce the smallest voltage-drop when measuring 0-1amp.

DAMAGING A POWER SUPPLY

The only way you can damage a power supply is by overloading it. Excess current will heat up the components and they will fail. This can apply to the transformer, diodes, regulator (either chip or transistor) and any fusible resistors. It can also be due to inadequate heatsinking of the regulator.
Overloading can take many forms. A high input voltage will create excess heating.
Excess output current will create over-heating and shorting the output can create excess heating.
Under normal conditions, power supplies do not fail. Electronic components are amazingly reliable and robust. If a component fails more than once, you need to look into the possibility of a spike, excess current or inadequate cooling. A dry joint on the PC board can create excess heating this can damage the component.

MEASURING THE RIPPLE

The ripple on the input or output of a power supply can only be interpreted with a CRO. You must SEE the waveform to understand if and why it is causing a problem. There is no definitive answer to the allowable amount of ripple or "dip" a project will accept without producing a problem. Some circuits are extremely critical and others are not affected at all. Some digital circuits are tolerant to glitches and dips but audio stages are critical as they are amplifying anything coming from a previous stage.
Any ripple on the power rail will be amplified by subsequent stages. Most stages have a gain of 50 - 100 and two stages will amplify ripple as low as 1mV to produce noticeable hum.

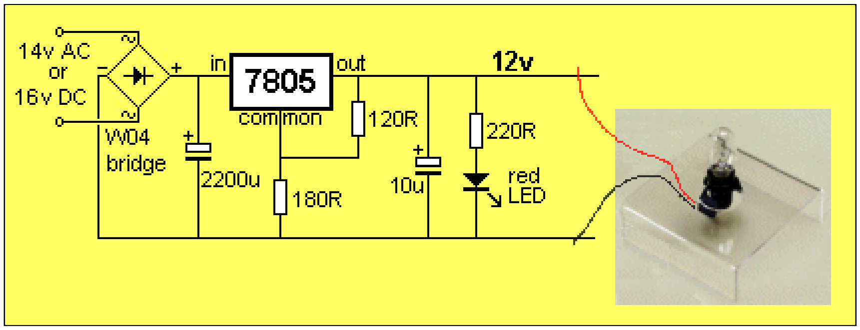
MEASURING THE MAXIMUM SHORT-TERM CURRENT

This is very difficult to measure. You really need to connect the power supply to a project and monitor the output with a CRO. Nothing is more accurate than using a "real" load.
"Instantaneous current" (short-term current) is very important. Many power supplies need to supply 10's of amps or 100's of amps for a very short period.
The output power of most amplifiers is measured for a very short period of time and that's how they arrive at very high wattage values.
To be able to deliver an extremely high current for a short period of time, a power supply needs very high-value electrolytics on the output.
It is the electrolytics that deliver the high current. To determine the capability of a power supply, connect the amplifier and listen to the output. If you are happy with the results, the power supply is doing its job.
If you detect distortion, place the CRO on the power rail.
If the voltage is dipping, add another electrolytic, preferably near the output of the project (near the speakers).
Monitor the improvement.
If the "dipping" is not fixed, the fault may lie in the regulator or the transformer.
You have to decide if the fault has always been present or if it has just developed.
You have to work out if something has to be "fixed" "changed" or "re-designed."

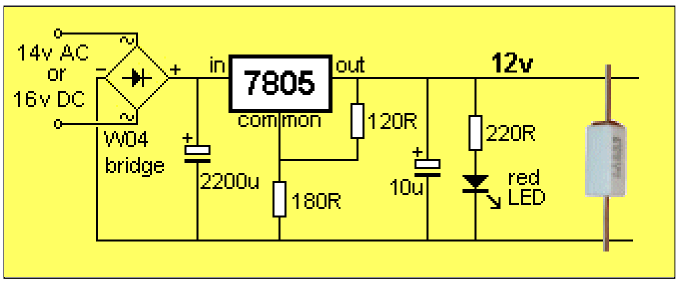
CONNECTING A DUMMY LOAD

A power supply can be tested with a dummy load such as a high-power resistor or globe.
Most power supplies do not deliver full rated output on a continuous basis. The demand is constantly rising and falling. A dummy load will put a constant demand on the supply and you have to be careful not to over-heat anything.
Once you have decided on the value of the dummy load, you will need a power resistor or a

globe.
There is one major problem with a globe. It requires about 6 times the normal current to get it to start to glow. This is because the filament is cold and its resistance is only one-sixth the operating resistance.
Many power supplies will not be able to deliver this current and a globe will not illuminate. You may think the power supply is faulty - so don't choose a globe.



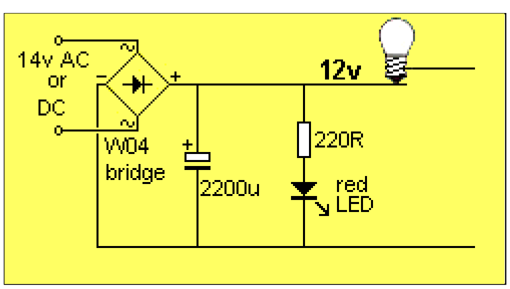
The best dummy load for a power supply is a high-wattage resistor. The resistor shown in the diagram will dissipate about 4 watts. Keep it away from the bench-top as it will get very hot and damage any polished surfaces.



Monitor the temperature of the regulator and diodes with your finger to make sure they do not get too hot.
Make sure you don't keep the dummy load connected too long as it can very easily overload the power supply.

PROTECTING A POWER SUPPLY

A power supply can be protected from overload (such as a short-circuit) by adding a globe to the positive rail. Make sure the globe has the voltage rating of the rail.
If the globe is rated at 12v/18watt, it will allow up to 1 amp to flow without illuminating and if a short-circuit occurs, the current will be limited to 3 amps.
This safety-feature is handy when experimenting with a high-current power supply (or car battery) as a short-circuit can allow hundreds of amps to flow and completely vaporize fine wires.



FAULT FINDING

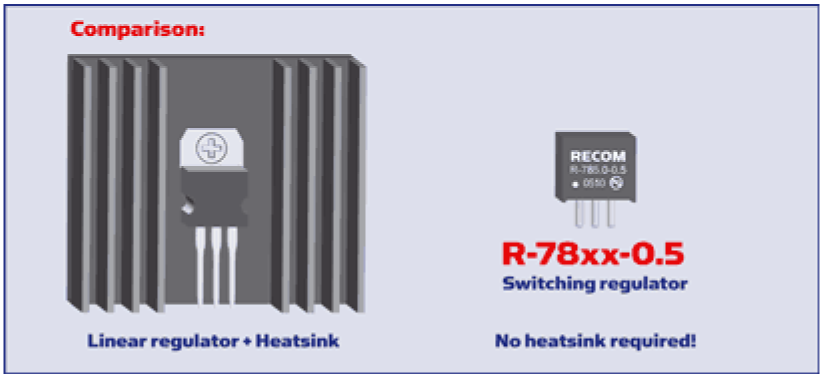
Most of the following problems apply to 3-terminal regulator and "power transistor" power supplies. They are the most common and give a number of problems due to the heat developed in some of the components.
The first components to check are always the electrolytics. They play a very big part in the operation of any power supply and can even cause complete failure. The give trouble because energy is passing in and out and this creates heat. The heat produces excess pressure and this forces microscopic particles through the seal and they eventually dry out.
Simply replace or bridge all of them with equivalent values and see if the output improves.
Another common fault is one of the diodes in a bridge breaking down under load. This will produce a lot of hum and the only way to detect it is to measure the temperature with your finger (if the diodes are separate components). A diode that breaks-down under load will measure ok when cold. This is a very difficult to detect if you don't know what to look for.
Simply solder 4 diodes across the bridge and see if the fault is fixed.
Another fault is thermal shut-down due to excess input voltage.
If the output voltage of the power supply can be varied, the input voltage will have to be 5v higher than the maximum required output voltage.
When the output voltage is low, the input voltage will be proportionally very high and the power supply will only be able to deliver a low current before thermal shut-down takes place.

NOW - THE LATEST IN POWER SUPPLY REGULATORS . . .

A new type of regulator has just been released on the market.
It is very similar to the 7805 voltage regulator but it has an efficiency as high as 97% and does not require a heatsink.
The following write-up has been provided by Mark Riley of:

Cutter Electronics
5 Highgate Way
Rowville, Vic 3178
Australia
Tel 03 9753 9911
Fax 03 9753 9455
Email: mark.riley@cutter.com.au
Mobile:0417 540 359
Web: www.cutter.com.au

PDF Datasheet and selection guide



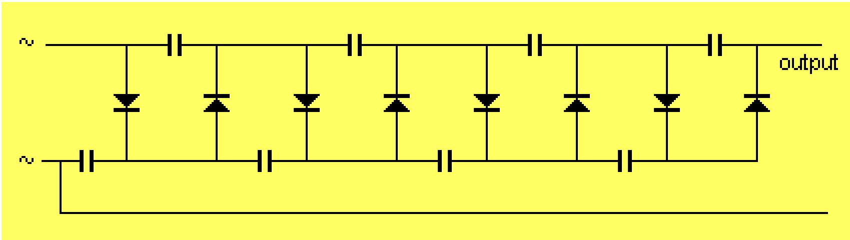
Everyone knows this situation. A regulated voltage supply is required.
In itself, there is nothing difficult. Not much board space is available - no problem. The input voltage supply is unstabilized and can vary over a wide range. The load is also not exactly steady.
But, what if everything must be accommodated in a small case without ventilation and no heat-sinking can be used? Or if the regulator losses must be kept low because the unit is battery powered and you can't afford to waste precious battery life as heat? Then it already looks more difficult using the standard off-the-shelf linear regulator solutions….
The remedy is the new switch-mode converter range from RECOM that unites both the specifications and the simple application of the ubiquitous 78xx linear regulators with an extremely high efficiency of up to 97% to give a minuscule heat generation that avoids all of the physical and mechanical problems associated with heat sinks and waste heat transportation.
Just like standard linear regulators, the R-78 series has a drop-out voltage of 1.5v (this is the difference between the input and output voltage) and an input voltage range that extends up to 34V: an input range of up to 7:1!
All of the R-78xx-0.5 series deliver an output current of up to 500mA and R-78xx-1.0 types with up to 1A output current.
The output voltages are available off the shelf in all of the usual values of 1.8V, 2.5V, 3.3V, 5V, 9V and 12V as standard.
Non-standard values can very simply be set in the production by special request. However, these are not the only advantages of this new converter. Another attention-grabber is the design: the R-78xx-0.5 is accommodated in a SIP3-plastic housing with the measurements of only 11.5 x 7.5 x 10.2mm, therefore approximating the footprint of a 78 series linear-regulator in TO220 casing without a heat-sink but with a clearance gap to the other components on the board. The pin-out is identical: Pin 1 is the input voltage, Pin 2 the common and Pin 3 the output.
An external trim of the output voltage by means of a fourth pin will be available as an option in the coming months, as well as a 79xx series for negative outputs as a counterpart to the analogue 79xx regulators and implementations for both types in SMD designs. The RECOM R-78xx-0.5 is continuous short circuit protected and incorporates a thermal shutdown protection function that switches off the converter if the internal temperature exceeds 160°C. The short circuit protection circuit restricts the input current with a shorted output to typically 25mA and so helps to avoid further damage to the supply circuitry during fault conditions. The operating temperature range is from -40°C to +70°C with full load, and extends from +70°C to +85°C with a derating to 80% of maximum load. The outstanding efficiency of up to 97% comes mainly through the use of a switch-mode design using the Buck principle.
The 30 years of experience of RECOM in the design and development of DC/DC converters has enabled the high specification of this non-isolated step down converter, in particular the reduction of internal losses to only a few percent. This switch-mode design inserts itself seamlessly into the recently introduced RECOM INNOLINE as a supplement to the non-isolated point-of-load converters with similar high efficiencies and consequently expands the range for lower power and miniaturised designs. It presents itself as ideal supplement for distributed power supplies, where together with the isolating DC/DC converters from the RECOM POWERLINE and the R-5xxx, R-6xxx and R-7xxx series from the RECOM INNOLINE, allow supply voltages to be down-converted as close to the load as possible.

Consequently the entire distributed power supply chain can be supported by RECOM products. A frequent and normally justifiable point of criticism concerning switch mode designs over linear designs is the noise generated on the outputs as well as the disturbances reflected back into the input supply. The RECOM R-78xx-0.5 series has a relatively high operating frequency of around 300kHz which is easy to filter out internally and so generates very low inherent noise, as the first EMC-tests confirmed. The switch-mode converter requires no external components and has typical values of ripple and noise of 30-50mVpp, which can be even further reduced with external filters. RECOM recommends that designers who need very low ripple and noise levels should insert low pass filters: a simple first order LC-low pass output filter with a corner frequency of approximately 10% of the operating frequency brings the ripple and noise levels down to 5mVpp or below.
Also the reflected noise (disturbances that a switch-mode design generates on its inputs due to its switching frequency) are inherently very low with the R-78xx-0.5 and can be further reduced with external filtering of the input supply.
The compromises that a designer must make in order to insert a switch mode regulator are therefore not great, as in most cases the standard application with no external components is perfectly acceptable.
Of course, this switched mode converter won't replace completely the analogue linear regulator that is used the world over. For one thing, the price is a deciding factor. A linear regulator can be bought even in small quantities for a few tens of cents while any switched-mode solution will always be many times more expensive. But the total costs needs to be examined: input and output capacitors are recommended for analogue linear regulators, but these components are already integrated into the standard switching regulator design and while the switching regulator needs no heat sink, the linear regulator requires one in most cases which both uses up valuable board space and costs money and assembly time.
However, this is not all: presuppose that the circuit is placed in a small, non-metallic, airtight case - then a heat sink rapidly loses its effectiveness.
Even a large heat sink will become useless if air convection and air circulation are blocked. The only help here is to solve the problem at the root cause. If the regulator is highly efficient with low internal losses, then almost no heat is generated that needs to be taken care of. Here, the switching regulator comes to the fore because it generates so little waste heat in the first place. If one now compares the entire costs of a power supply solution - i.e. switched mode regulator vs. linear regulator + heat sink + assembly + maybe forced cooling with fans, as well as the further expenditure for external components, then clearly the cost relationship is not so unbalanced.
Possible problems in design, production and assembly of heat-pipe or chilled circuits and the question of whether it makes any sense at all for sub-15W supplies are left to the interested reader and will not be discussed further here. If all of the above points mentioned above in this article are considered, even if only some of the aspects apply, then maybe the alternative of using a switching voltage regulator makes more sense than at first meets the eye.

THE TRANSFORMERLESS POWER SUPPLY

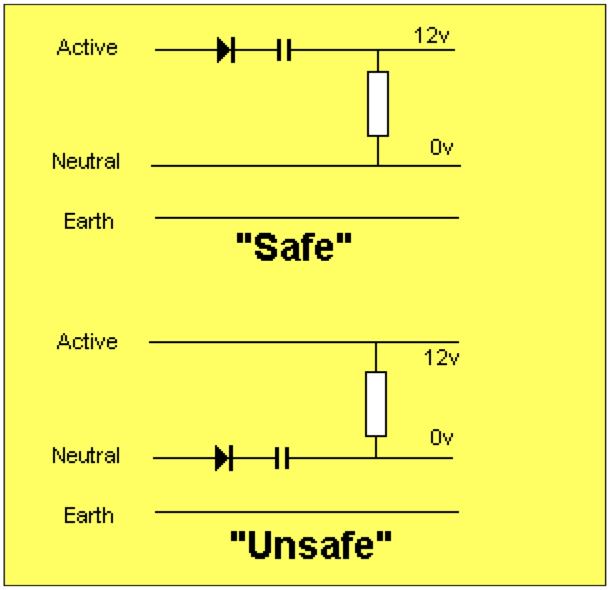
There is another type of power supply. It is called a transformerless power supply.
It is a power supply that does not use a transformer.
Let me say from the start, this type of power supply is very dangerous and can supply only a very small current.
It is not a power supply I suggest for any type of application as the project is effectively "LIVE."
Even though a project may be operating on 5v or 12v, any component on the project will have a potential of 120v or 240v when referenced to earth.
In other words, touching any component in or on the power supply AND the chassis of a radiator or toaster, will result in a shock of 120v or 240v AC.
I should say "up to" 240v (but since we are talking about AC voltages, this voltage is really up to about 340v) and although the transformerless power supply will not deliver the high current that can be delivered from the mains, some transformerless supplies will deliver more than 100mA and it only requires 30 - 50mA to deliver a lethal shock.
The Earth Leakage Detector, fitted to all new homes, trips at 15mA, so you can see the danger of getting a 240v shock!

It may surprise you, but a transformerless power supply is ideally suited to high-voltage applications.
A transformerless power supply can be created using diodes and capacitors that INCREASES the supply voltage. This type of circuit is called a voltage multiplier, and by using multiple stages, the voltage can be doubled, tripled and even increased ten or more times.
The end result is a very high voltage and if this voltage is delivered to a pointed conductor, the electronics will stream off and produce an "electric wind." The "electricity" will ionise the air and cause any particles of matter in the air to join together and "drop out."
These circuit are often called "air fresheners."



A Voltage Multiplier

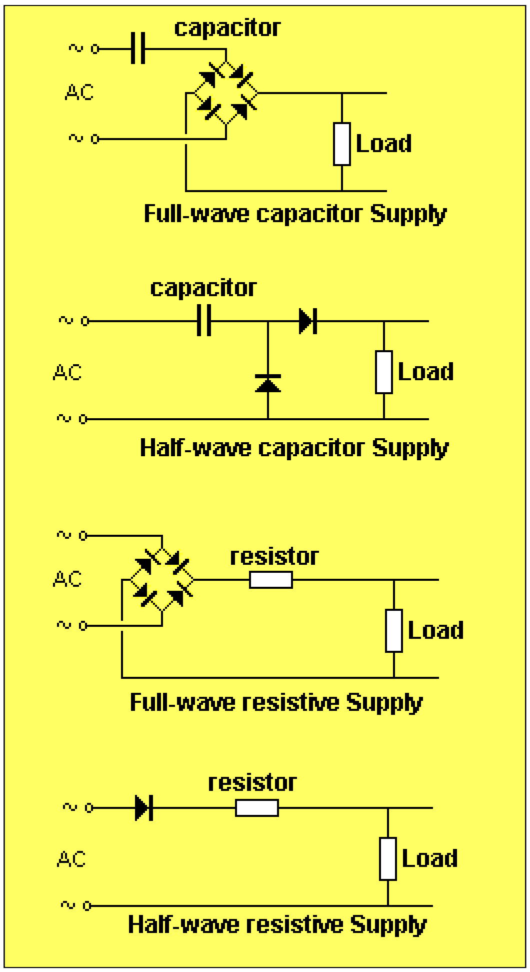
But we are mainly talking about using a transformerless power supply to deliver 5v to 12v.
You may think this type of power supply using capacitors is insulated or isolated from the mains. But this is not so.
A capacitor has a "resistance" - called CAPACITIVE REACTANCE and this resistance depends on the frequency of the supply. In our case the frequency is 50 or 60Hz and the capacitive reactance will be large, however the capacitor will be able to deliver a shock and in some cases this can be fatal.
If the transformerless supply is connected to the "mains socket" around the "correct" way, the shock potential will be only 12v, but you cannot guarantee how the project will be connected.



In the top diagram, the voltage of the power supply is 12v. But in the lower diagram, if you touch the 12v line and earth, a totally lethal shock will result. This is because the "neutral" line has been "lifted above earth." The "Neutral" is actually just 12v below "Active."
If the project is totally sealed, you can consider using a transformerless design. Otherwise it is out of the question.

Now we come to the current capability of a transformerless design.
It is the current that determines the "size of the components."
By size I mean the physical size - the wattage dissipating capability.

Transformerless designs are very inefficient. They waste a lot of energy and accordingly they get very hot.
Transformerless designs have very high ripple. To be more accurate, they are really only designed for a constant current - a steady current.
Equipment such as amplifiers require a wide range of current. The idle current may be 10mA but the peak current may be 150mA. This is totally unsuitable for a transformerless design as the voltage will drop when the current increases and distortion will result.
There are two ways to design a transformerless circuit. One design uses resistors and the other uses capacitors.
Both designs have the same losses and thus they both dissipate the same heat and they both get "just as hot."
When designing a "capacitor supply" you must consider the "working voltage" of the capacitor(s) as well as the "ripple current."
For a 240v supply, the capacitor should be rated "400v." You may not be able to obtain the ripple current of a certain type of capacitor on a specification sheet and the only way to determine the suitability is to test it for a period of time and make sure you are able to touch the case. It must not get too hot to touch. If the capacitor is physically very small, it will get very hot.
There are basically 4 designs as shown in the diagrams below:



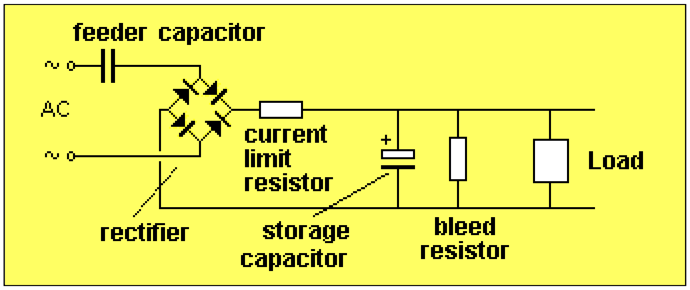
Two circuits can be designed around a capacitor as the "current limiting device" and two can be designed around a resistor as the current liming device.
The circuits above are only basic examples.

THE CAPACITOR SUPPLY

The "Power Supply" is the positive and negative lines above and below the block called the LOAD.
You will need 5 things to create a CAPACITOR SUPPLY:

1. A Rectifier diode or diodes,
2. A Current Limiting Resistor,
3. A Capacitor to deliver (or limit) the current to the "Supply" - the feeder capacitor,
4. A Storage or Filter Capacitor (usually an electrolytic).
5. A Bleed Resistor, and
6. A Load

The diagram below shows these 6 items:

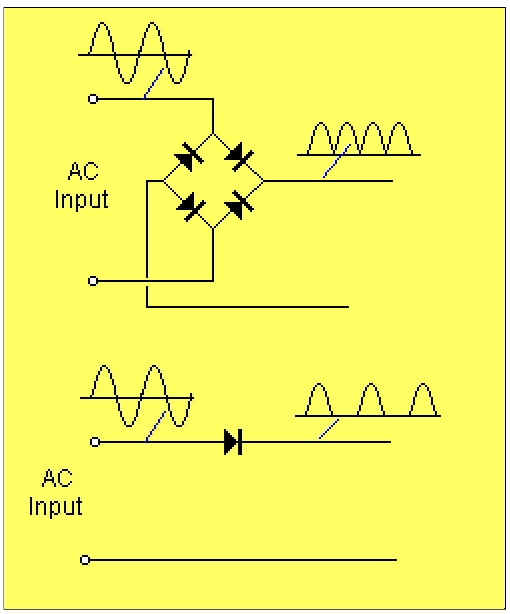


The 6 items of a Capacitor Power Supply

We will now cover each item.

THE RECTIFIER

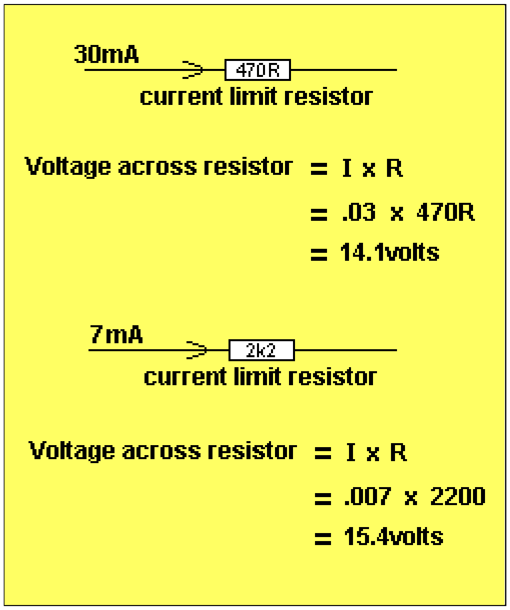
The rectifier is a single diode or set of diodes that will change AC waveform to pulses as shown in the diagram below. The full wave rectifier will allow both the positive and negative excursions to appear on the output. The half-wave (single diode) will only allow the positive part of the waveform to appear on the output.



THE CURRENT LIMIT RESISTOR

This resistor prevents spikes from the mains entering the "Supply" and it limits the current entering the storage capacitor (electrolytic). This resistor reduces the efficiency of the circuit but is a handy inclusion. It is generally 470R for 4 x 0.1u feeder capacitors and 2k2 for a single 0.1u feeder capacitor.

Why have these values been chosen? The reason is the voltage drop. The voltage drop across a 470R when 30mA is flowing, will be the same as the voltage drop across a 2k2 when 7mA is flowing.



This voltage drop is the "buffer" or the "safety valve" that allows spikes to be present on the input and are prevented from appearing on the "supply" side of the project.

THE FEEDER CAPACITOR

The capacitor that delivers energy to the "Supply" is called the "feeder capacitor." Obviously no electrons or "current " or "electricity" flows through the capacitor as it is an "open circuit." So the electrons that charge the electrolytic must come via the 0v rail. The way the feeder capacitor works is very simple.

It's a bit like a magician drawing a flower out of the ground by "magnetic attraction."

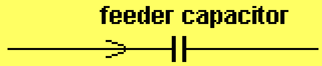
As the incoming voltage rises, it raises the left side of the capacitor and this pulls the right side up. But the voltage on the right side is only a small fraction of the left side. That's the best a small capacitor can do. As the capacitor is increased in value, the voltage on the right-side is increased.

A 100n capacitor will deliver 7mA from a full-wave rectifier or 3.5mA from a half-wave rectifier.

This value of current relates to a 12v power supply, operating from 240v mains. If the voltage of the power supply is higher, the current will be slightly less.

The current delivered by a capacitor is worked out by "Ohm's Law," which is: **I** = **V/R** where **I** is the value in amps, **V** is the voltage across the capacitor and **R** is the resistance of the capacitor. A capacitor has a "resistance to current" called capacitive reactance with the symbol Xc. In our case the 100n capacitor at 50Hz, has a capacitive reactance of 33k and this will allow the same current to flow as a 33k resistor.

If the load takes 7mA, the 100n capacitor will only be able to raise the voltage across the load to about 12v. If the current taken by the load is less than 7mA, the "supply" voltage will be higher. If the current taken by the load is more than 7mA, the supply voltage will be lower. The actual voltage of the supply is "fine tuned" by adjusting the value of the BLEED RESISTOR.



Voltage across feeder capacitor = 240v - 24v
= 220v

Using Ohm's Law: $I = \frac{V}{R}$

R is X_C for a capacitor

$$X_C = \frac{1}{2 \pi f c}$$

$$= \frac{1 \times 10^6}{2 \times 3.1 \times 50 \times 0.1}$$

$$= \frac{10^7}{300} = 3.3 \times 10^4 = 33k$$

$$I = \frac{220}{33} \times 10^{-3}$$

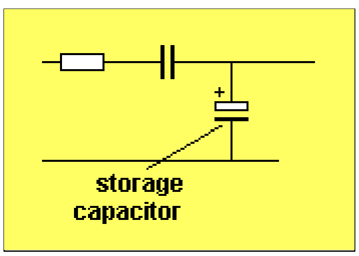
$= .007A$

$= 7mA$

Two capacitors in parallel will double the current. You can use 4 capacitors to get 30mA.
You will also need a 470R resistor to limit voltage-surges. These "surges" are the natural charging current as the AC voltage rises to charge the capacitor. The capacitor we are talking about is the STORAGE CAPACITOR or filter capacitor.

THE STORAGE CAPACITOR

The storage capacitor is designed to hold each of the pulses of energy and accumulate them to produce the maximum voltage the circuit will deliver.
This voltage is called the "supply voltage."
In more-technical terms, the electrolytic reduces the impedance of the "supply" and allows a higher current to be drawn for very short periods of time.
This needs more explanation.
A "higher current" is a current greater than the current entering the electrolytic. Suppose this is 7mA. And suppose the voltage on the electrolytic is 12v.
If a higher current is drawn by the load, the voltage across the electrolytic will drop. Suppose it drops to 10v. This is the purpose of the electrolytic. The actual value of current will depend on the value of the electrolytic and the drop in voltage that will occur.



The actual value of the Storage Capacitor (electrolytic) will depend on the current delivered by the "Supply" and the allowable voltage drop of the supply, when it is delivering maximum current. The electrolytic can be 10u, 47u or 100u.

THE BLEED RESISTOR

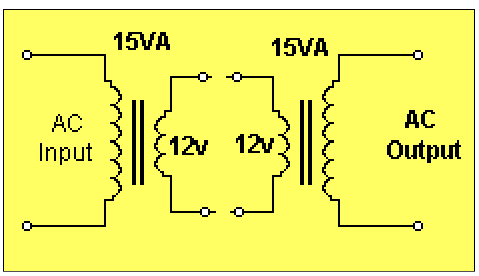
The power supply needs a "bleed resistor" so that if the load decreases, or is removed, the terminal voltage of the supply will not rise to 240v.
The bleed current should be at least 30% to 50% of the current required by the project and this must be added to the current required by the project. This adds more complexity to the

design and more heat, but without it, the "supply" voltage will rise to dangerous levels when the current drops to zero.
To determine the value for the Bleed Resistor, the easiest way is to experiment with values until the correct situation is obtained.
Working out the value mathematically is very complex, but you can see that if a bleed resistor is not included, the "Supply" voltage will rise to 240v when the load current reduces to zero.
This will destroy the electrolytic (storage capacitor) and possibly destroy the sensitive components in the load.
If the Bleed Resistor takes 50% of the current required by the Load, it will take 2mA, while the Load will take 4mA. This makes a total of 6mA. If the Load is removed, the "Supply" will rise from 12v to 36v and you can see this is a dangerous value.

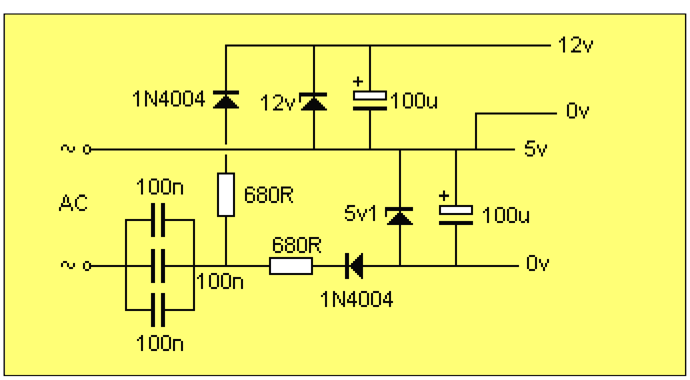
THE LOAD
This is the item you are "powering." It might be a microcontroller, a LED, transistor circuit or similar.
Some loads require a constant current while others need a varying current.
This type of power supply is not designed for high currents or widely varying current.

DETERMINING THE VALUES

The values for the items such as the Current Limit Resistor, Feeder Capacitor, Storage Capacitor and Bleed Resistor, can be worked out mathematically, but the simplest way is to build a power supply and experiment with the values.
A simple "safe" 240v power supply can be made by connecting two 15VA transformers "back-to-back," so the output is 240v with a limited current.
This is called a "safe" power supply in that it isolated from the mains and will not blow a fuse if momentarily shorted. It also allows items such as CRO's and earthed soldering irons to be connected without tripping the circuit-breaker. You can also work on the supply without extreme danger, if you know what you are doing. Even a set of 15VA transformers (15 volt-amp - the AC way of saying wattage) is enough to be lethal, so don't underestimate the potential of zapping you.
The two transformers are connected as shown in the diagram below:

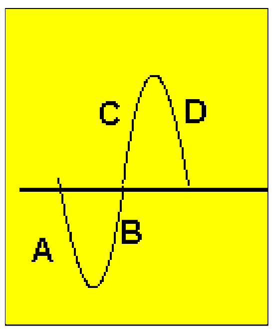


The following circuit is an example of a low-current capacitor-fed power supply.



A CAPACITOR-FED POWER SUPPLY

Each 100n "X2" capacitor (these are Mains rated capacitors) will deliver 7mA to each power supply (the 12v supply and the 5v supply). The only problem is the two supplies must be kept separate and no component can have a DC path from one supply to the other.
Each supply will deliver 21mA and obviously this can be slightly higher for short periods of time.
Each zener needs about 3mA to keep it in conduction, so the output is 18mA.
Each additional 100n mains capacitor will add 7mA to the outputs.
The 680R resistors provide a "buffering" for the zeners to prevent them being damaged by spikes.
Both power supplies must be connected.
If the lower is removed, the top supply will not generate any voltage.
Here is how the supply works:
Assume the centre-line of the circuit is connected to the neutral of the mains. (It does not matter which way the circuit is connected. Either way, the circuit is considered "live" and dangerous. It is only to be used for a project that is fully housed and insulated from any human contact.)
The Active input will travel minus 340v below the neutral line and then 340v above the neutral. This voltage is obtained by 240v x $\sqrt{2}$ = 240 x 1.414 = 340v.
The 240v is the RMS value and simply means the voltage equivalent to DC. This comes from the original supply being DC and when AC was introduced, people wanted to know the voltage needed to heat up a kettle of water in the same time as the original DC voltage, when say 5amps was flowing.
340v is dangerous and that's why this supply is dangerous.
The capacitors are initially uncharged.



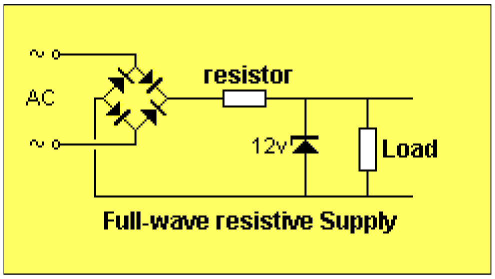
The "Mains"

A complete cycle of the mains consists of 4 parts as shown in the diagram above. The active line follows path "A" in the diagram above and this charges the lower 100u electrolytic, via the lower power diode. When it reaches the lowest point on the curve, the capacitors are fully charged and will produce a voltage across them equal to 340v minus 5v and minus the voltage developed across the lower 680R.
As the mains voltage passes around the bottom of the curve on the diagram, you can think of the capacitors as a 330v battery and the top of the battery is the point connected to the two 680R resistors.
The top of the "battery" rises say 1v higher than the join of the two resistors and it is effectively 4v away fro the centre-line of the circuit.
This means the lower power diode will not conduct any current and thus the top power diode starts to conduct.
All the energy in the 3 capacitors will now be passed through the top power diode and into the 100u electrolytic. In other words, all the 330v at a low current will be "squeezed" into 100u and produce a lower voltage at a higher current. This is the amazing feature of a capacitor and this have never been mentioned before in any text book. This is the "secret" to the operation of the "caps."
This continues until the mains-waveform reaches 12.6v above the centre-line of the circuit. At this point the capacitors have exactly 12.6v on each side and no current passes in or out of them. They are fully discharged.
The waveform rises further and now the capacitors begin to charge **in the opposite**

direction via the 12v zener. This charging current also passes through the top 100u and "tops it up."
The waveform now reaches the top of the cycle and the caps are fully charged.
As the mains passes over the top of the cycle, the bottom of the fully charged caps drop below 12v (think of the caps as a 340v battery as before) and the top diode ceases to conduct. Nothing happens until the voltage drops 12v + 0.6v + 5v + 0.6v and then the lower diode starts to conduct. There is also a small voltage drop across the lower 680R resistor.
Notice the 18v gap between the top and bottom. If you want higher voltage supplies, this gap becomes noticeable and the capacitors will not charge fully and thus the current they can deliver, will reduce. There is also some importance about the equal voltages on the two supplies as a very high voltage on one supply will not charge the cap fully to deliver the energy to the other supply.

The advantage of the capacitor supply above is the fact that the capacitors do not get hot. If they were replaced by a set of resistors, the losses would be considerable, as you will see:

THE RESISTIVE POWER SUPPLY



When designing a resistive power supply, the value of the "dropper resistor" is obtained by taking 12v from 240v = 230v. This is the voltage across the dropper resistor.
Let us allow 20mA current through the dropper resistor.
The value of the dropper resistor is: 230/0.02 = 11,500 ohms = 11k5.
The wattage of the resistor = 4.6watts The resistor can be made up of a number of resistors placed at different locations on the board to improve heat dissipation.
You can see the advantage of a capacitor-fed power supply.

CONCLUSION

Power supplies are very important to the correct operation of any project.
It doesn't matter if the power supply is one button-cell or a 1000 watt supply with multi outputs; the result is the same. It must be correctly designed.
The author has serviced over 50,000 electronic items and power supply failure accounts for about 5% of all repairs.
Over half these faults were electrolytics. The rest were diodes, dry joints, fusible resistors and occasionally the regulator transistor.
We live in a throw-away world and most electronic items get thrown out at the first sign of a fault.
Updating is quite often a good idea as all products are improved with each new model, but if it is a rarely-used fax machine for example, the cost of a few electrolytics and two hours work will generally get it operational again.