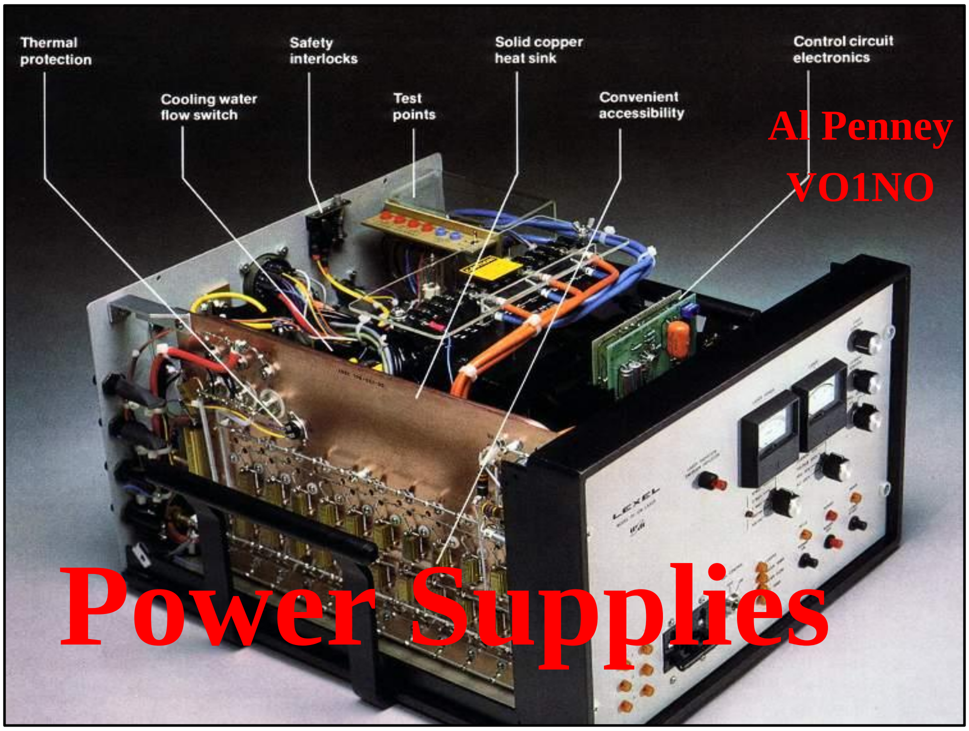
Thermal protection
Safety interlocks
Solid copper heat sink
Control circuit electronics
Cooling water flow switch
Test points
Convenient accessibility
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Power Supplies

Power Requirements

- Most Amateur Radio gear today requires **13.8 volts DC (Direct Current).**
- Wall outlets provide **120 volts AC (Alternating Current)** however.
- **To convert AC to DC** at the **proper voltage**, we use **Power Supplies.**

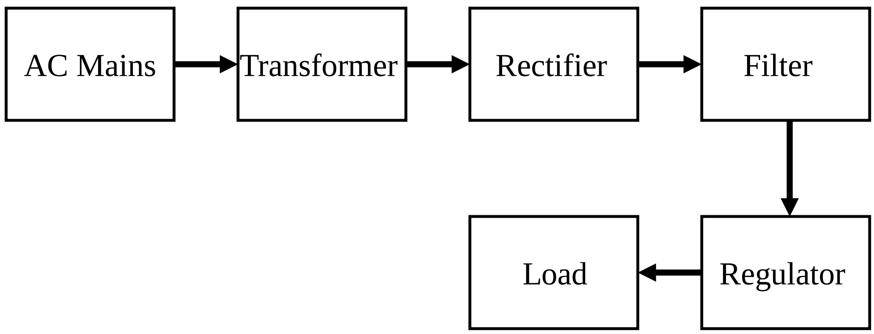
Typical Power Requirements

• TS-870S HF Transceiver	20.5 amps
• FT-7800R Dual Band FM Txcvr	8.5 amps
• FT-100 HF/VHF/UHF Transceiver	22.0 amps
• IC-7600 HF/6M Transceiver	23.0 amps

Power Supply Requirements

- **Voltage** must be **raised or lowered** to the desired value.
- **Voltage** must be changed from **AC to DC.**
- The DC that is produced will contain a lot of **ripple**, and must be **filtered.**
- The DC voltage must be **regulated** so that it **remains fairly constant.**

Linear Power Supply Diagram



The Load

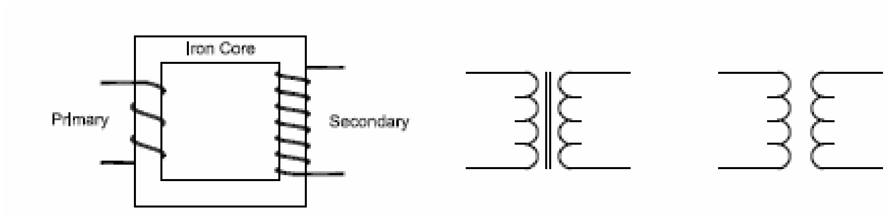
- The device that **absorbs the power** produced by the power supply.
- Load defines the voltage and current requirements, and how much each can vary.
- Bleeder resistor current must also be included in calculations.
- Remember that load may have **Reactive** component, so power supply must be designed to be stable under such conditions, and not oscillate or resonate.

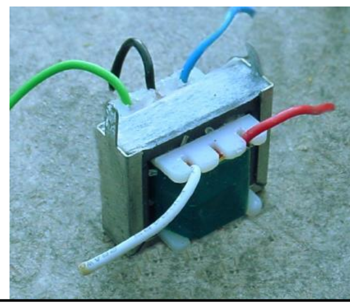
Changing the Voltage

- A transformer is used to step the voltage up or down.
- The ratio of turns in the primary and secondary windings determine the amount of voltage change:

$$\frac{\text{Primary Voltage}}{\text{Secondary Voltage}} = \frac{\text{\# Turns Primary winding}}{\text{\# Turns Secondary winding}}$$

Transformers





Example

- *Input voltage is 120 VAC. You require an output voltage of 13.8 VAC. The Primary winding has 240 turns. How many turns does the Secondary winding need?*

These are RMS voltages. Remember that peak voltages will be 1.414 times the RMS (or RMS = 0.707 x Peak Voltage).

Example (2)

$$\frac{\text{Primary Voltage}}{\text{Secondary Voltage}} = \frac{\text{\# Turns Primary winding}}{\text{\# Turns Secondary winding}}$$

Example (3)

$$\frac{\text{Primary Voltage}}{\text{Secondary Voltage}} = \frac{\text{\# Turns Primary winding}}{\text{\# Turns Secondary winding}}$$

- 120 / 13.8 = 240 / T_{sec}
- T_{sec} =

Example (4)

$$\frac{\text{Primary Voltage}}{\text{Secondary Voltage}} = \frac{\text{\# Turns Primary winding}}{\text{\# Turns Secondary winding}}$$

- $120 / 13.8 = 240 / T_{sec}$
- $T_{sec} = 240 \times 13.8 / 120$

Example (5)

$$\frac{\text{Primary Voltage}}{\text{Secondary Voltage}} = \frac{\text{\# Turns Primary winding}}{\text{\# Turns Secondary winding}}$$

- 120 / 13.8 = 240 / T_{sec}
- T_{sec} = 240 x 13.8 / 120
- T_{sec} =

Example (6)

$$\frac{\text{Primary Voltage}}{\text{Secondary Voltage}} = \frac{\text{\# Turns Primary winding}}{\text{\# Turns Secondary winding}}$$

- $120 / 13.8 = 240 / T_{sec}$
- $T_{sec} = 240 \times 13.8 / 120$
- T_{sec} = 27.6 turns, rounded to 28 turns

Power Rating of the Transformer

- Determined by the **size of the core** and the **diameter of the wire.**
- Power rating usually **stamped on the side** of the transformer, and is **expressed in Volt-Amperes** (abbreviated **VA**).
- **Power = Voltage x Current**
- Calculate power requirements of the equipment using the power supply and compare it with the Power rating of the transformer.

Power transformers are rated in Volt-Amps (VA). Using Watts is of no use, since a load that is completely reactive dissipates no power, but there are still Volts and Amps. It is the product of 'real' voltage and current that is important - a wattmeter may indicate that there is little or no real power in the load, but the transformer is still supplying a voltage and a current, and will get hot due to internal losses regardless of the power.

Power Rating Example

- *Radio draws 20 amps at 13.8 VDC.*
- *Transformer rated at 250 VA.*
- *Is the transformer big enough for the job?*

Power Rating Example (2)

- Power = Voltage x Current
- Power =

Power Rating Example (3)

- Power = Voltage x Current
- Power = 13.8 VDC x 20 Amps =

Power Rating Example (4)

- Power = Voltage x Current
- Power = 13.8 VDC x 20 Amps = 276 Watts

Power Rating Example (5)

- Power = Voltage x Current
- Power = 13.8 VDC x 20 Amps = 276 Watts

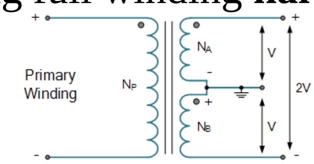
- Transformer is rated at 250 VA, so….

Power Rating Example (6)

- Power = Voltage x Current
- Power = 13.8 VDC x 20 Amps = 276 Watts
- Transformer is rated at 250 VA, so….
- The transformer is **NOT** big enough for the task!

Exceeding Xformer Power Rating

- Windings may overheat and burn out, or trip a thermal fuse.
- Core may saturate, causing symptoms that may be difficult to track down.
- Remember – if secondary current rating is specified for half of winding (end to tap), then using full winding **halves** the current rating!



Core Saturation

Transformers are also constrained in their performance by the magnetic flux limitations of the core. For ferromagnetic core transformers, we must be mindful of the saturation limits of the core. Remember that ferromagnetic materials cannot support infinite magnetic flux densities: they tend to “saturate” at a certain level (dictated by the material and core dimensions), meaning that further increases in magnetic field force (mmf) do not result in proportional increases in magnetic field flux (Φ). When a transformer’s primary winding is overloaded from excessive applied voltage, the core flux may reach saturation levels during peak moments of the AC sine wave cycle. If this happens, the voltage induced in the secondary winding will no longer match the wave-shape as the voltage powering the primary coil. In other words, the overloaded transformer will *distort* the waveshape from primary to secondary windings, creating harmonics in the secondary winding’s output. As we discussed before, harmonic content in AC power systems typically causes problems.

Transformer Ratings

Engineers rate power transformers according to the maximum output voltage and current they deliver. For a given unit, we'll often read or hear about the volt-ampere (VA) capacity, which equals product of the nominal output voltage and maximum deliverable current.

A transformer with 12 V output, capable of providing up to 10 A of current, has a VA capacity of 12 V x 10 A, or 120 VA. The nature of power-supply filtering makes it necessary for the power-transformer VA rating to significantly exceed the actual power in watts that the load consumes.

A high-quality, rugged power transformer, capable of providing the necessary currents and/or voltages, constitutes an integral and critical part of a well-engineered power supply. The transformer is usually the most expensive power-supply component to replace if it burns out, so transformer engineers always choose the appropriate transformer ratings when designing and building a power supply.

Serious injury or damage may result from installing a transformer with an improper voltage, current, or power rating. When a transformer is to be used in a circuit the voltage, current, and power-handling capabilities of the primary and secondary windings must be taken into consideration. When nominal values of voltage, current, and power are specified they represent the middle point of the respective maximum and minimum rated values.

The maximum voltage that can safely be applied to any winding is determined by the type and thickness of the insulation used. When a better (and thicker) insulation is used between the windings, a higher maximum voltage can be applied to the windings.

The maximum current that can be carried by a distribution transformer winding is determined by the diameter of the wire used for the winding. If current is excessive in a winding, a higher-than-ordinary amount of power will be dissipated by the winding in the form of heat. This heat may be sufficiently high to cause the insulation around the wire to break down. Therefore, to keep the transformer temperature at an acceptable level, we must set limits to both the applied voltage and the current drawn by the kVa load requirements.

Transformer ratings power points are measured in volt-amperes (VA) or kilovolt-amperes (WA). This means that the primary winding and the secondary winding are designed to withstand the VA or kVA ratings stamped on the transformer nameplate. The primary and secondary full-load rating transformer currents usually are not given but can be calculated from the rated VA or kVA as follows:

Full Load Current = Volt Amp rating / Voltage

Excessive temperature rise is the main cause of transformer failure. The heat generated in transformer operation causes temperature rise in the internal structures of the transformer. In general, more efficient transformers tend to have lower temperature rise, while less efficient units tend to have higher temperature rise. Transformer temperature rise is defined as the average temperature rise of the windings above the ambient (surrounding) temperature when the transformer is loaded at its nameplate rating. This value is usually based on an ambient temperature of 40°C. As an example, a 150°C rise dry transformer will operate at an average winding temperature of 190°C when at full-rated load in a 40°C ambient environment. Although the resultant temperature rise is averaged over the whole winding, the inside of a winding is hotter than is its outside. The hottest spot is at some point inside the coil having the longest thermal paths to the outside air. This "hot spot temperature" differential is determined by the manufacturer on prototype units; it's usually expressed as a temperature increase over the average temperature.

Adequate cooling must be provided to prevent deterioration of the insulating materials inside a transformer and ensure its long life expectancy. Transformers are cooled using air, water, oil, or natural and forced convection. Basically, there are two distinct types of transformers: dry-type and liquid-filled (Figure 25-14). Dry-type transformers depend on the circulation of air over or through their enclosure. Liquid-filled transformers have the transformer's coils and core submerged in an approved insulating liquid such as mineral oil or synthetic fluid for cooling purposes.

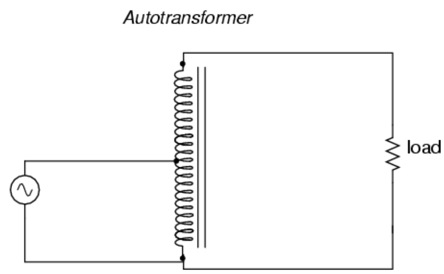
The NEC requires that transformers be installed in a manner which does not block or obstruct openings that are designed for cooling purposes. In addition, transformers are required to be marked with a minimum distance or clearance from walls or other obstructions to facilitate the dissipation of heat. Methods used to remove the heat caused by core losses and copper losses include:

•Normal airflow around the transformer's enclosure.

•Additional tubes or fins installed on the enclosure assembly to increase the cooling surface area.

Auto Transformer

- Transformer that utilizes a **single winding.**
- Often used to **adjust** a line voltage that is consistently **too low or high.**
- Auto Transformer provides **No Isolation!**



An **autotransformer** is an electrical transformer with only one winding. The "auto" (Greek for "self") prefix refers to the single coil acting alone, not to any kind of automatic mechanism. In an autotransformer, portions of the same winding act as both the primary winding and secondary winding sides of the transformer. In contrast, an ordinary transformer has separate primary and secondary windings which are not connected to each other.

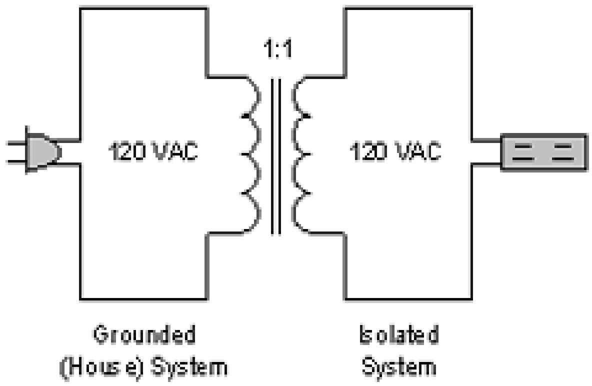
The autotransformer winding has at least three taps where electrical connections are made. Since part of the winding does "double duty", autotransformers have the advantages of often being smaller, lighter, and cheaper than typical dual-winding transformers, but the disadvantage of not providing electrical isolation between primary and secondary circuits. Other advantages of autotransformers include lower leakage reactance, lower losses, lower excitation current, and increased VA rating for a given size and mass.

An example of an application of an autotransformer is one style of traveller's voltage converter, that allows 230 volt devices to be used on 120 volt supply circuits, or the reverse.

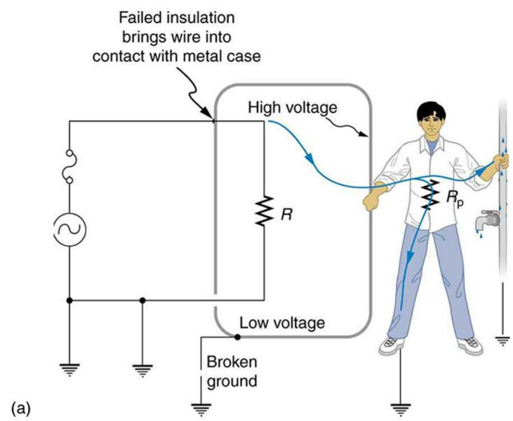
Isolation

- The **load** attached to the transformer is **not physically connected** to the **primary**, as the windings are insulated.
- Much consumer equipment is powered without transformers to keep costs down.
- As a result the **chassis is directly connected** to one side of the **AC line**, and must therefore be enclosed in an insulated cabinet for safety reasons.
- Amateur gear **must be capable of interconnection**, and so such construction is unacceptable for us.
- **Fuse** in the AC line **provides additional safety.**

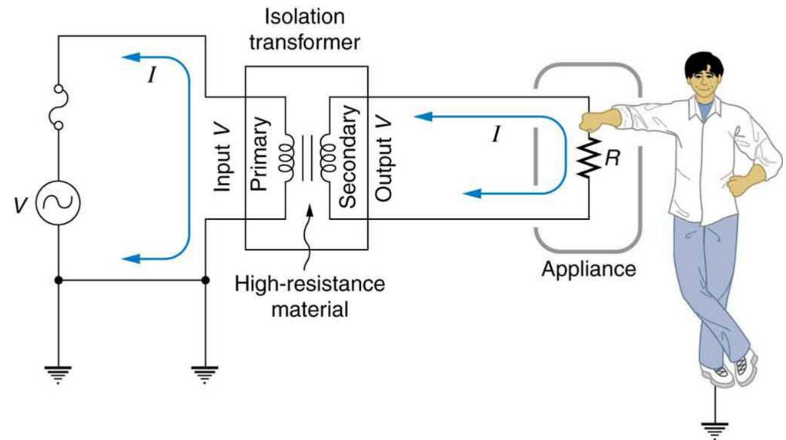
Isolation Transformer



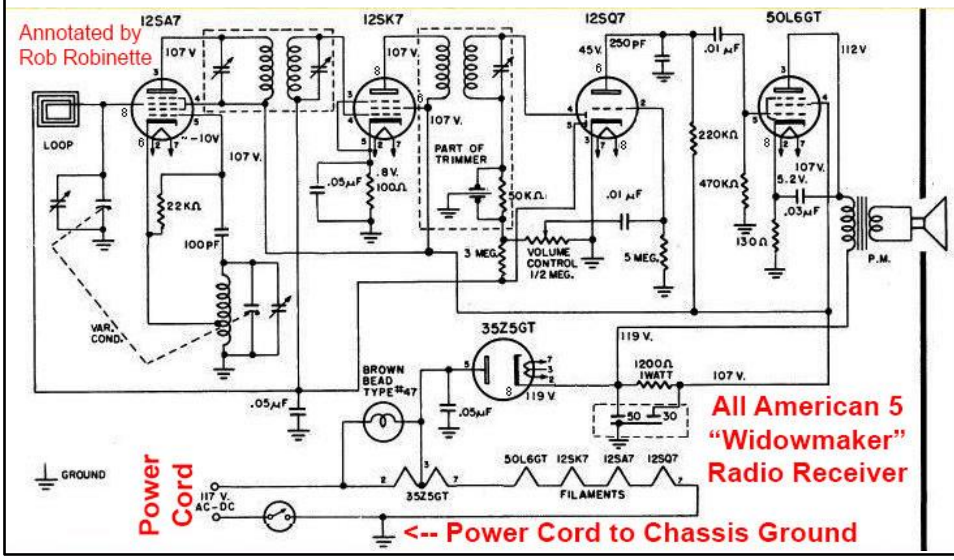
Without Isolation Transformer



With Isolation Transformer



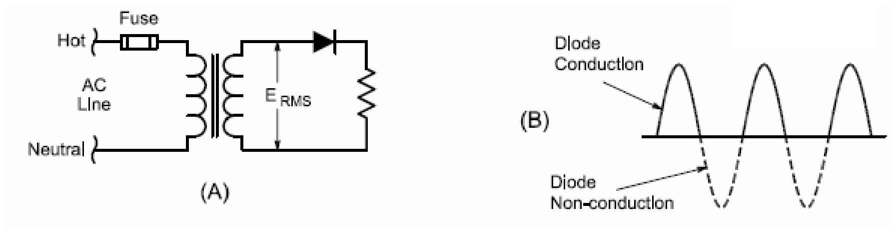
Hot Chassis "Widowmaker"



Rectification

- The process by which **AC is converted to DC** is called **Rectification.**
- Broadly classified as either:
  - **Half Wave:** rectify only the positive or negative half of each AC cycle; or
  - **Full Wave:** rectify both halves of the AC cycle.

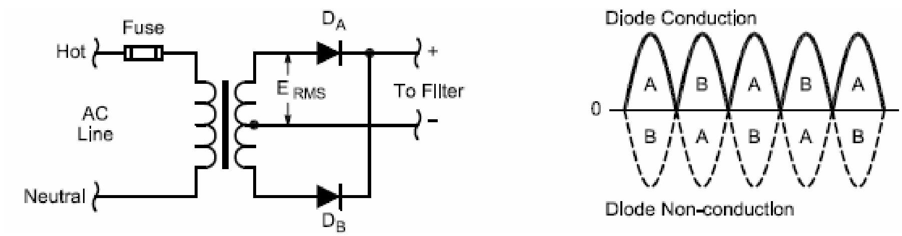
Half Wave Rectification



Half Wave Rectification

- Half Wave rectification only **passes half** of the energy thru to the output.
- Resulting DC is very **rough** and needs **heavy filtering.**
- DC Ripple Frequency is **60 Hz.**
- If current requirements are small however, it provides a simple and low-cost solution.

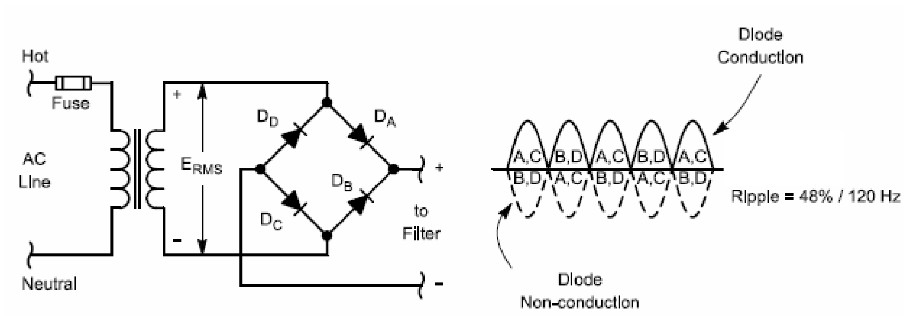
Full Wave Rectification
Center-Tap Transformer



Full Wave Rectification
Center-Tap Transformer

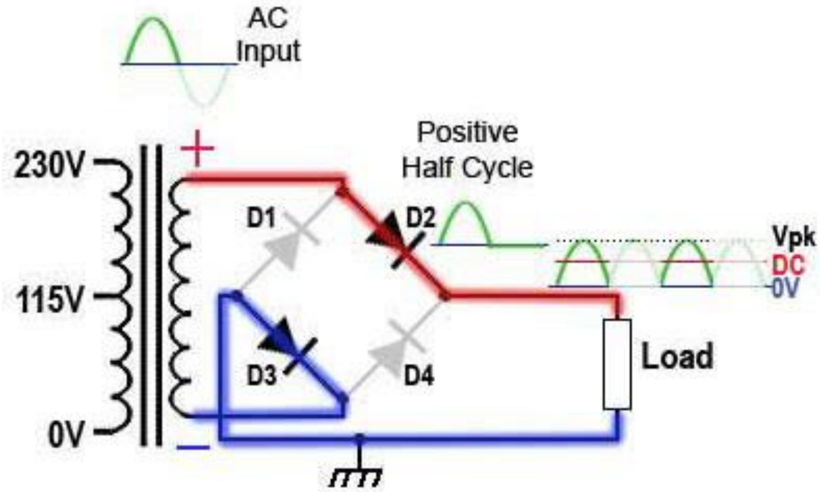
- **Passes all the energy** thru to the output.
- This method **requires a center tap** however.
- The diodes work alternately, handling the full current load but only for half the time.
- Essentially this is **two half wave rectifiers** operating on **opposite polarities of the AC cycle.**
- An advantage of this method is that the resulting DC **ripple frequency** is 120 Hz (twice 60 Hz), making it **easier to filter.**

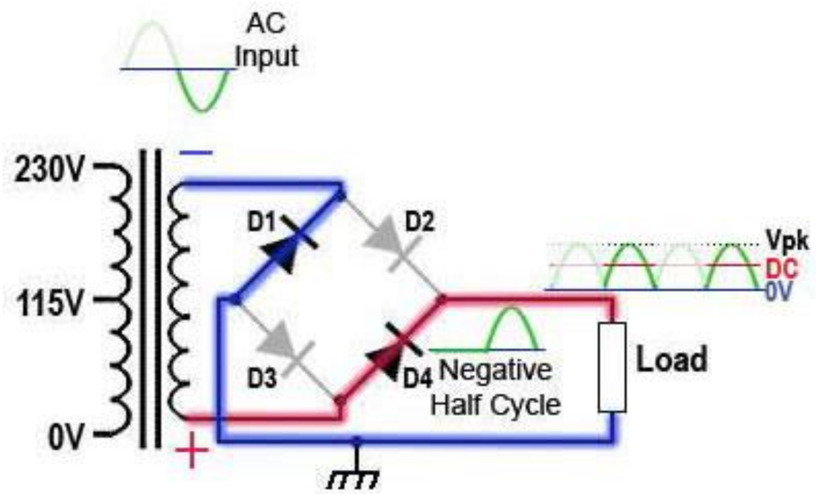
Full Wave Rectification Without a Center Tap Transformer



Full Wave Rectification Without a Center Tap Transformer

- This method **eliminates** the requirement for a **center tap transformer.**
- It uses a **Full Wave Bridge Rectifier.**
- Note the polarity of the diodes – two will conduct and two will not conduct on each half-cycle.
- For a given transformer, this gives **twice the output voltage** as the full wave center tap rectifier.


AC
Input
Positive
Half Cycle
230V
115V
0V
+
D1
D2
D3
D4
Vpk
DC
0V
Load


AC
Input
230V
115V
0V
D1
D2
D3
D4
Negative
Half Cycle
Load
Vpk
DC
0V

Voltage Doubler

- **Use both halves of AC waveform to double voltage.**
- Other combinations possible that can produce tens of thousands of volts, but very low current.
- Multipliers suffer from inefficiencies and poor regulation as number of steps increases.

Although it is usual in electronic circuits to use a voltage transformer to increase a voltage, sometimes a suitable step-up transformer or a specially insulated transformer required for high voltage applications may not always be available. One alternative approach is to use a diode voltage multiplier circuit which increases or "steps-up" the voltage without the use of a transformer.

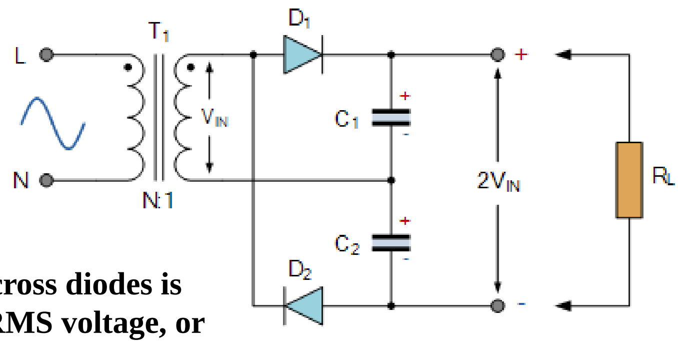
Voltage multipliers are similar in many ways to rectifiers in that they convert AC-to-DC voltages for use in many electrical and electronic circuit applications such as in microwave ovens, strong electric field coils for cathode-ray tubes, electrostatic and high voltage test equipment, etc, where it is necessary to have a very high DC voltage generated from a relatively low AC supply.

Generally, the DC output voltage (Vdc) of a rectifier circuit is limited by the peak value of its sinusoidal input voltage. But by using combinations of rectifier diodes and capacitors together we can effectively multiply this input peak voltage to give a DC output equal to some odd or even multiple of the peak voltage value of the AC input voltage. Consider the basic voltage multiplier circuit below

The voltage produced by a *voltage multiplier* circuit is in theory unlimited, but due to their relatively poor voltage regulation and low current capability there are generally designed to increase the voltage by a factor less than ten.

However, if designed correctly around a suitable transformer, voltage multiplier circuits are capable of producing output voltages in the range of a few hundred to tens's of thousand's of volts, depending upon their original input voltage value but all with low currents in the milliamperes range.

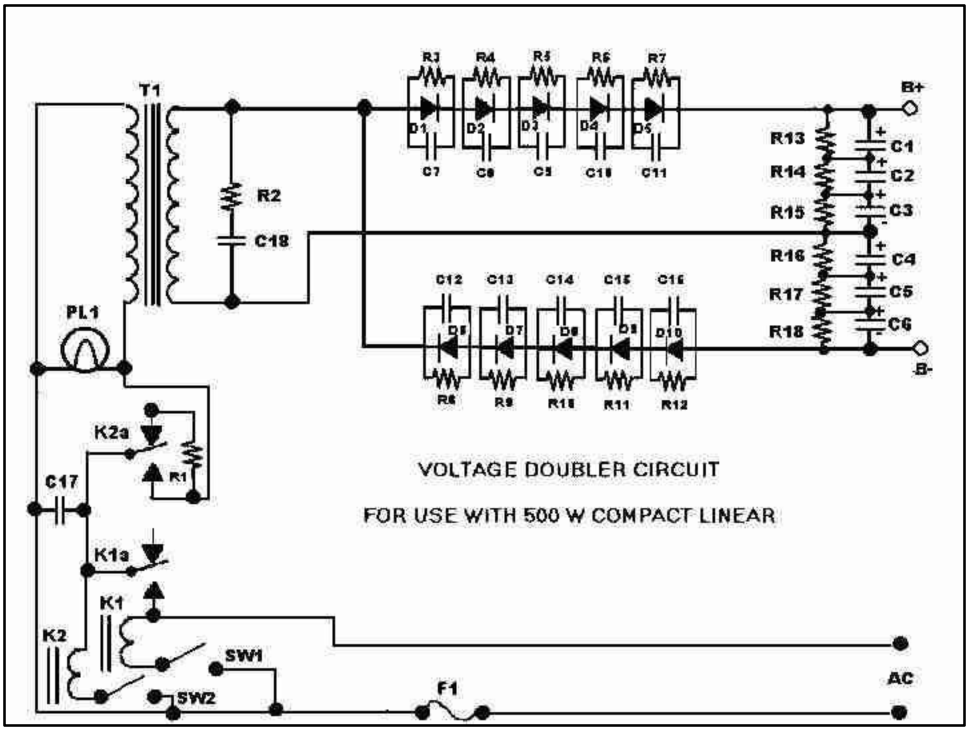
Full Wave Voltage Doubler



PIV across diodes is 2.8 x RMS voltage, or twice the peak voltage.

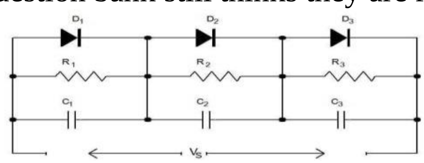
The above circuit shows a basic symmetrical voltage multiplier circuit made up from two half-wave rectifier circuits. By adding a second diode and capacitor to the output of a standard half-wave rectifier, we can increase its output voltage by a set amount. This type of voltage multiplier configuration is known as a **Full Wave Series Multiplier** because one of the diodes is conducting in each half cycle, the same as for a full wave rectifier circuit.

When the sinusoidal input voltage is positive, capacitor C_1 charges up through diode D_1 to 1.4 x RMS voltage (to peak voltage) and when the sinusoidal voltage is negative, capacitor C_2 charges up through diode, D_2 to 1.4 x RMS voltage (to peak voltage). The output voltage $2V_{IN}$ is taken across the two series connected capacitors, equal to 2.8 x RMS voltage (or twice peak voltage).


VOLTAGE DOUBLER CIRCUIT
FOR USE WITH 500 W COMPACT LINEAR
T1
R2
C18
PL1
K2a
R1
C17
K1a
K1
K2
SW1
SW2
F1
AC
B+
B-
R13
R14
R15
R16
R17
R18
C1
C2
C3
C4
C5
C6
C12
C14
R11
R12

Diodes Stacks

- If PIV will exceed diode’s rating, two or more identical diodes can be connected in series to increase PIV rating.
- Former practice was to attach resistors in parallel to equalize voltage drops and capacitors to suppress transients.
- ARRL Handbook says this is no longer necessary – modern diodes will go into Zener conduction before PN junction is destroyed.
- Note that question bank still thinks they are required!



Diodes in Series

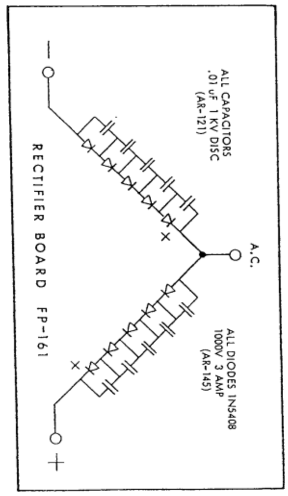
When the PIV rating of a single diode is not sufficient for the application, similar diodes may be used in series. (Two 500 PIV diodes in series will withstand 1000 PIV and so on.) There used to be a general recommendation to place a resistor across each diode in the string to equalize the PIV drops. With modern diodes, this practice is no longer necessary.

Modern silicon rectifier diodes are constructed to have an avalanche characteristic. Simply put, this means that the diffusion process is controlled so the diode will exhibit a Zener characteristic in the reverse biased direction before destructive breakdown of the junction can occur. This provides a measure of safety for diodes in series. A diode will go into Zener conduction before it self destructs.

If other diodes in the chain have not reached their avalanche voltages, the current through the avalanched diode will be limited to the leakage current in the other diodes. This should normally be very low.

For this reason, shunting resistors are generally not needed across diodes in series rectifier strings. In fact, shunt resistors can actually create problems because they can produce a low-impedance source of damaging current to any diode that may have reached avalanche potential.

AL-80A Rectifier Board



Power Supply Diode Considerations

- **Peak Inverse Voltage (PIV) -** maximum allowable **Reverse** operating voltage that can be applied across the diode without avalanche or **Zener** breakdown and damage occurring to the device.
- Because filter capacitor can add to transformer reverse voltage under some conditions, PIV could reach 2.8 RMS volts in secondary winding (i.e.: twice the peak voltage).
- Always give lots of safety margin – 100% or more!

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VO1NO

Peak Inverse Voltage

The **Peak Inverse Voltage** (PIV) or *Maximum Reverse Voltage* ($V_{R(max)}$), is the maximum allowable **Reverse** operating voltage that can be applied across the diode without reverse breakdown and damage occurring to the device. This rating therefore, is usually less than the "avalanche breakdown" level on the reverse bias characteristic curve. Typical values of $V_{R(max)}$ range from a few volts to thousands of volts and must be considered when replacing a diode.

The peak inverse voltage is an important parameter and is mainly used for rectifying diodes in AC rectifier circuits with reference to the amplitude of the voltage were the sinusoidal waveform changes from a positive to a negative value on each and every cycle.

Power Supply Diode Considerations

- **If_{avg} – Average forward current** rating must not be exceeded.
- Forward current can be many times the average circuit current, especially when supply first turned on and filter capacitors are charging.

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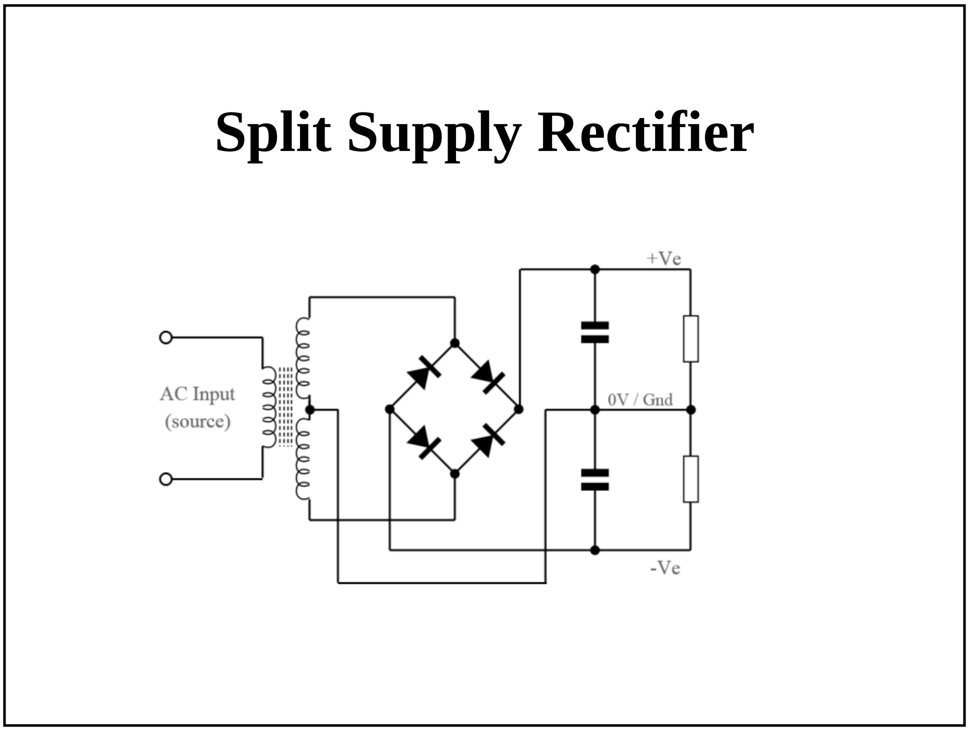
Maximum Forward Current

The **Maximum Forward Current** ($I_{F(max)}$) is as its name implies the *maximum forward current* allowed to flow through the device. When the diode is conducting in the forward bias condition, it has a very small "ON" resistance across the PN junction and therefore, power is dissipated across this junction (Ohm´s Law) in the form of heat.

Then, exceeding its ($I_{F(max)}$) value will cause more heat to be generated across the junction and the diode will fail due to thermal overload, usually with destructive consequences. When operating diodes around their maximum current ratings it is always best to provide additional cooling to dissipate the heat produced by the diode.

For example, our small 1N4148 signal diode has a maximum current rating of about 150mA with a power dissipation of 500mW at 25^{o}C. Then a resistor must be used in series with the diode to limit the forward current, ($I_{F(max)}$) through it to below this value.



Split supply bridge rectifier circuit

For many circuits like operational amplifiers, split supplies may be needed. It is possible to create a split supply for these and other applications very easily using a full wave bridge rectifier. Although it returns to the use of a split transformer, i.e. with a centre tap, it can be worth it to gain the combination of both negative and positive supplies using the bridge rectifier.

The circuit operates effectively and efficiently because both halves of the input waveform are used in each section of the transformer secondary winding.

The dual supply bridge rectifier solution does require the use of a centre tapped transformer, but a second winding would often be required anyway to provide the dual supply.

The full wave rectifier circuit based around the bridge of diodes performs well and is used in most full wave rectifier applications. It uses both halves of the waveform in the transformer winding and as a result reduces heat losses for a given level of output current when compared to other solutions. Also this solution does not require a centre tapped transformer (except for the dual supply version) and as a result the costs are reduced.

Crowbar Protection

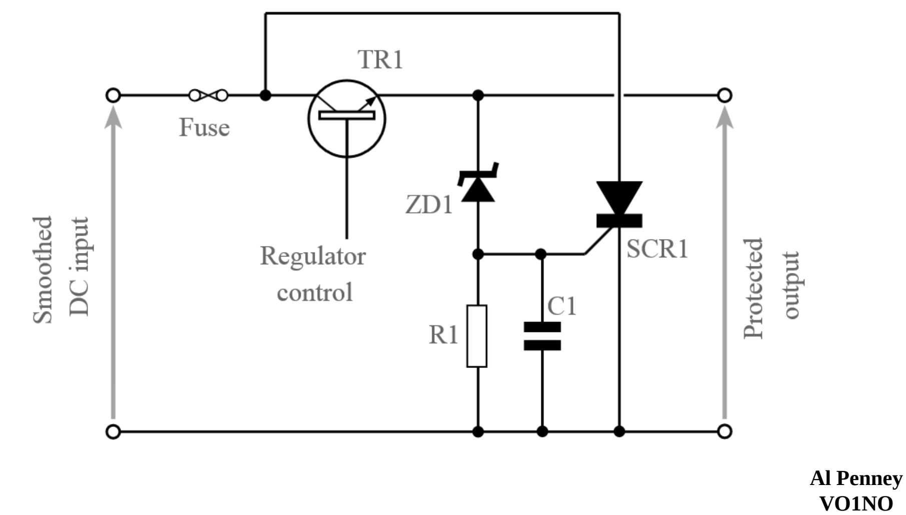
- Circuit that protects load equipment in the event of overvoltage caused by failure of the regulator.
- Circuit senses overvoltage and activates an SCR to short circuit the power supply.
- This causes power supply's fuse to blow.

Crowbar — A last-ditch protection circuit included in many power supplies to protect the load equipment against failure of the regulator in the supply. The crowbar senses

an overvoltage condition on the supply′s output and fires a shorting device (usually an SCR) to directly short-circuit the supply′s output and protect the load. This causes very

high currents in the power supply, which blow the supply′s input-line fuse.

Thyristor / SCR Overvoltage Circuit



It uses just four components: a silicon controlled rectifier or SCR, a zener diode, a resistor and a capacitor.

As a silicon controlled rectifier, SCR, or thyristor is able to carry a relatively high current - even quite average devices can conduct five amps and short current peaks of may be 50 and more amps, cheap devices can provide a very good level of protection for small cost. Also voltage across the SCR will be low, typically only a volt when it has fired and as a result the heat sinking is not a problem.

The small resistor, often around 100 ohms from the gate of the thyristor or SCR to ground is required so that the Zener can supply a reasonable current when it turns on. It also clamps the gate voltage at ground potential until the Zener turns on. The capacitor C1 is present to ensure that short spikes to not trigger the circuit. Some optimisation may be required in choosing the correct value although 0.1 microfarads is a good starting point.

If the power supply is to be used with radio transmitters, the filtering on the input to the gate may need to be a little more sophisticated, otherwise RF from the transmitter may get onto the gate and cause false triggering. The capacitor C1 will need to be present, but a small amount of inductance may also help. A ferrite bead may even be sufficient. Experimentation to ensure that the time delay for the thyristor to trigger is not too long against removing the RF. Filtering on the power line to / from the transmitter can also help.

Although this power supply overvoltage protection circuit is widely used, it does have some limitations.

•***Crowbar firing voltage:*** The firing voltage of the tthyristor crowbar circuit is set by the Zener diode. It is necessary to chose a Zener diode with the right voltage . Zener diodes are not adjustable, and they come with at best a 5% tolerance. The firing voltage must be sufficiently far above the nominal power supply output voltage to ensure that any spikes that may appear on the line do not fire the circuit.

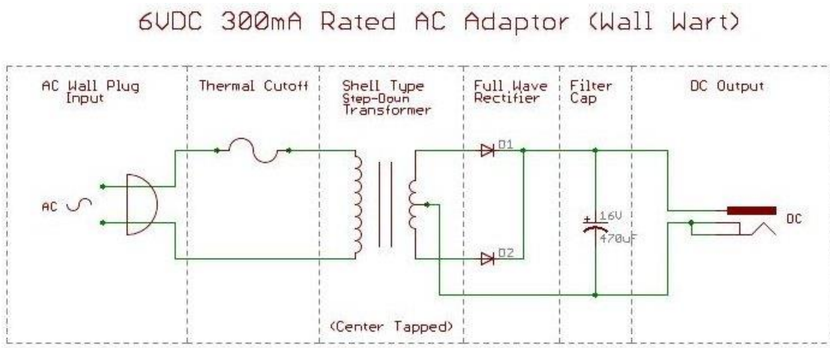
•***Susceptibility to RF:*** If the power supply is to be used to power a transmitter filtering on the line to / from the transmitter is required along with some careful design of the spike protection on the gate.

•***Circuit threshold :*** When taking into account all the tolerances and margins the guaranteed voltage at which the circuit may fire can be 20 - 40% above the nominal dependent upon the voltage of the power supply. The lower the voltage the greater the margins needed. Often on a 5 volt supply there can be difficulty designing it so that the overvoltage crowbar fires below 7 volts where damage may be caused to circuits being protected.

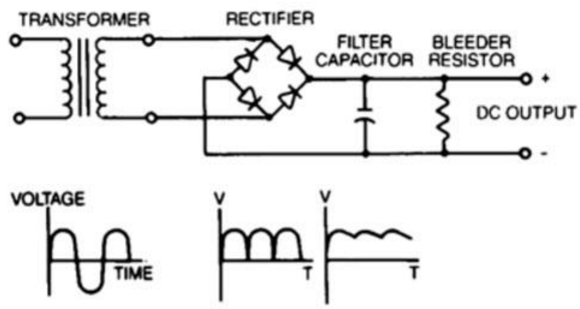
Filtering the DC

- Straight out of the rectifier stage, the **DC pulsates,** causing severe hum on transmitted and received signals, as well as a host of other problems.
- This **fluctuating DC** must be “smoothed out” by a **filter.**
- Three basic filtering circuits:
  - **Single capacitor;**
  - **Choke Input filter; and**
  - **Capacitor Input filter**.

Simple Full Wave Power Supply



Single Capacitor Filter



- Note that there is no series resistor to slow charging of capacitor when supply turned on.
- Inrush current will eventually damage rectifier.

An electrolytic capacitor used as a reservoir capacitor, so called because it acts as a temporary storage for the power supply output current. The rectifier diode supplies current to charge a reservoir capacitor on each cycle of the input wave. The reservoir capacitor is a large electrolytic, usually of several hundred or even a thousand or more microfarads, especially in mains frequency PSUs. This very large value of capacitance is required because the reservoir capacitor, when charged, must provide enough DC to maintain a steady PSU output in the absence of an input current; i.e. during the gaps between the positive half cycles when the rectifier is not conducting.

Voltage Output

Straight from Rectifier stage

After filtering by the Capacitor

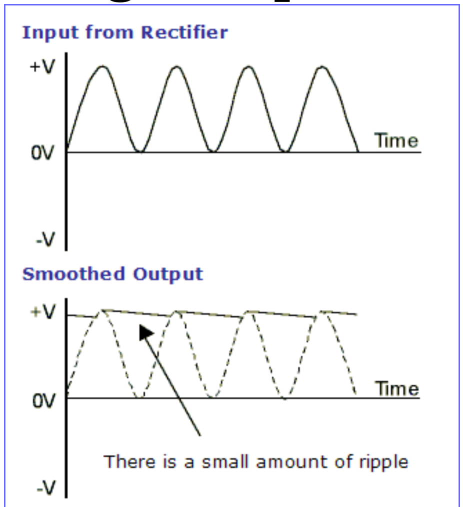
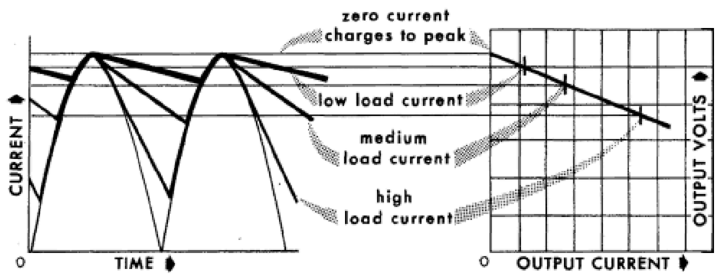


Figure 2: Smoothing

Single Capacitor Filter

- Advantages:
  - Higher output voltage vs other filters; and
  - Simple and cheap.
- Disadvantages:
  - Voltage ripple increases as load increases

Simple Capacitor Filter Shortcomings



A problem that arises with a capacitor-input filter is that the rectified output voltage always changes with load current. The reason for this is that the load current determines how much the voltage drops between charging pulses. The output voltage is averaged between these peaks and the amount that the voltage drops between them. A larger load current produces a bigger drop, and the average output voltage drops as well. Some kinds of audio circuits require considerable fluctuation in plate current of the output tubes. If the capacitor-input filter is used, the supply voltage also fluctuates with the current. This is where the choke-input filter has an advantage.

Input Versus Output Voltage

The average output voltage of a capacitor- input filter is generally poorly regulated with load-current variations. This is because the rectifier diodes conduct for only a small portion of the ac cycle to

charge the filter capacitor to the peak value of the ac waveform. When the instantaneous voltage of the ac passes its peak, the diode ceases to conduct. This forces the capacitor to support the load current until the ac voltage on the opposing diode in the bridge or full wave rectifier is high enough to pick up the load and recharge the capacitor.

For this reason, the diode currents are usually quite high. Since the cyclic peak voltage of the capacitor- filter output is determined by the peak of the input ac waveform, the minimum

voltage and, therefore, the ripple amplitude, is determined by the amount of voltage discharge, or “droop,” occurring in the capacitor while it is discharging and supporting the load. Obviously, the higher

the load current, the proportionately greater the discharge, and therefore the lower the average output.

Bleeder Resistor

- Connected across output of power supply
- **Discharges filter capacitors** when powered off.
- **Improves voltage regulation** by providing a minimum load resistance, especially for **choke input filter.**
- Should draw ~5% of full load current.
- Power = E^2 / R
- Will have to **dissipate heat!**

BLEEDER RESISTOR

A bleeder resistor is a resistance connected across the output terminals of the power supply. Its functions are to discharge the filter capacitors as a safety measure when the power is turned off and to improve voltage regulation by providing a minimum load resistance. When voltage regulation is not of importance, the resistance may be as high as 100-W per volt of power supply output voltage. The resistance value to be used for voltage-regulating purposes is discussed in later sections. From the consideration of safety, the power rating of the resistor should be as conservative as possible, since a burned-out bleeder resistor is dangerous!

For choke input filter, bleeder must draw at least the minimum current used to calculate the choke inductance when no load is present.

Functions of Bleeder Resistor

Effective Voltage Regulation

Bleeder resistor helps to achieve better and improved voltage regulation. Voltage regulation is the ratio of the difference between no-load voltage and full load voltage to the full load voltage in the denominator.

If the difference between no-load voltage and full load voltage will decimate, then the voltage regulation will be improved. The bleeder resistor is connected in parallel with both the capacitor of the filter circuit as well as the load resistor.

Thus, there will be two voltage drop, one across the bleeder resistor and one across the load resistor. In the absence of load resistor, the no-load voltage drop will be equal to the voltage drop across bleeder resistor.

Thus, when no load is connected then also there is some voltage drop. And after connection of the load, the voltage drop across the load will be taken into consideration. In previous cases, the voltage regulation without bleeder resistor is poor because the difference between no-load voltage and full load voltage is high.

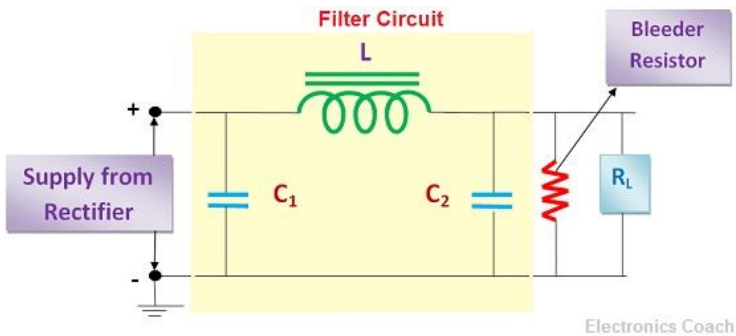
In case of bleeder resistor connected in the circuit, the difference between the no-load and full load voltage is very less. Consequently, this leads to improved voltage regulation.

Safety Purpose

Bleeder resistor proves to be a component which saves us from hazardous repercussions. Anyone working with the circuits may get electric shocks in the absence of bleeder resistor.

Thus, it is a crucial device for protection from electric shocks.

Bleeder Resistor



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Choke Input Filter

- Found primarily in switching supplies and older high voltage supplies for tube.
- Advantages:
  - **Better regulation and less ripple**.
- Disadvantages:
  - Lower output voltage;
  - Not suitable for low-voltage supplies;
  - Inductor is bulky and heavy; and
  - Possibility of **resonance of first inductor and first capacitor** with ripple frequency, causing abnormally high rectifier current and peak inverse voltages.

CHOKE-INPUT FILTERS

Choke-input filters have become less popular than they once were, because of the high surge current capability of silicon rectifiers. Choke-input filters provide the benefits of greatly improved output voltage

stability over varying loads and low peak-current surges in the rectifiers. On the negative side, however, the choke is bulky and heavy, and the output voltage is lower than that of a capacitor-input filter.

As long as the inductance of the choke is large enough to maintain a continuous current over the complete cycle of the input ac waveform, the filter output voltage will be the average value of the rectified

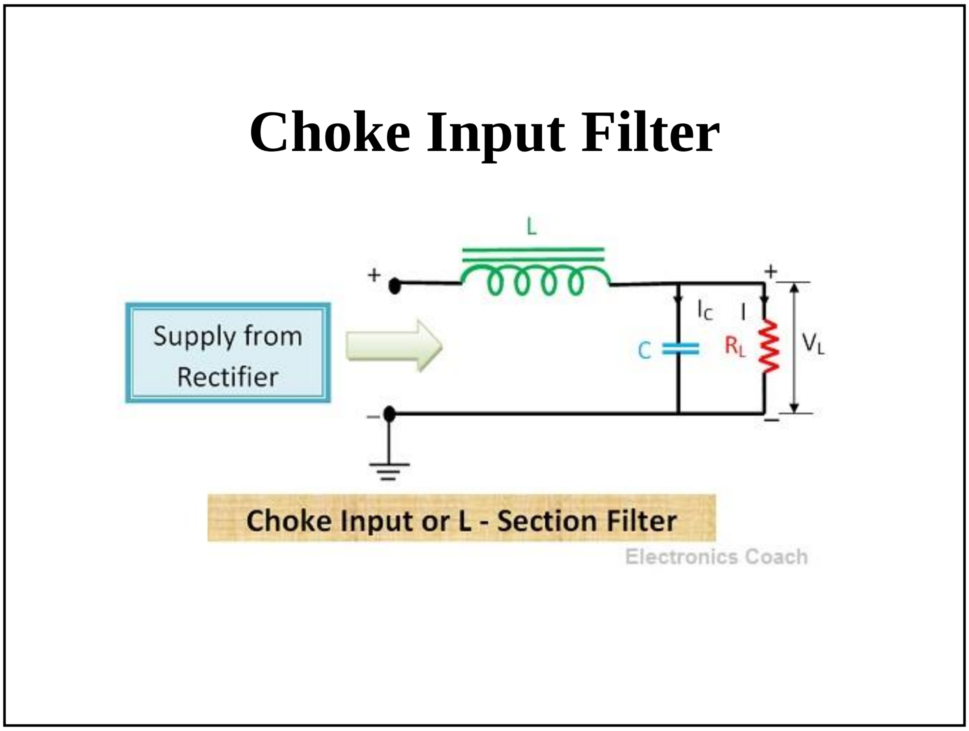
output. The average dc value of a fullwave rectified sine wave is 0.637 times its peak voltage. Since the RMS value is 0.707 times the peak, the output of the

choke input filter will be (0.637 / 0.707), or 0.90 times the RMS ac voltage. For light loads, however, there may not be enough energy stored in the choke during the input waveform crest to allow continuous current over the full cycle. When this happens, the filter output voltage will rise as the filter assumes more and more of the characteristics of a capacitor-input filter.

Choke-input filters see extensive use in the energy-storage networks of switchmode regulators.

The voltage at the output end of the choke (provided its resistance is reasonably low) is constant because the choke averages out a voltage fluctuation at its input end that is always the same - from zero to the peak of the alternating voltage. According to each half-wave of the rectifier waveform, the output of a choke input filter is always 0.637 times the peak alternating voltage which is (0.637/0.707) or 0.9 times its rms value.

In practice, the output will be slightly lower than this figure, owing to the voltage drop in the resistance of the choke. Further smoothing is achieved by means of a capacitor connected at the output end of the choke. It does not act as a reservoir capacitor as in the case of capacitor input, but merely serves to minimize voltage fluctuation by soaking up the slight current fluctuation in the choke.



Choke Filter

Definition: Choke filter consists of an inductor connected in series with rectifier output circuit and a capacitor connected in parallel with the load resistor. It is also called **L-section filter** because the inductor and capacitor are connected in the shape of inverted L. The output pulsating DC voltage from a rectifier circuit passes through the inductor or choke coil.

The inductor has low DC resistance and extremely high AC reactance. Thus, ripples get filtered through choke coil. Some of the residual ripples if present in filtered signal from inductor coil will get bypassed through the capacitor. The reason behind this is that capacitor allow AC and block DC.

Significance of Choke Filter or L-section filter

Choke filter came into existence due to shortcomings of the series inductor and shunt capacitor filter. A series inductor filter filters the output current but reduces the output current (RMS value and Peak value) up to a large extent. And the shunt capacitor filter performs filtering efficiently but increases the diode current. The excess of current in a diode may lead to its destruction.

Moreover, the ripple factor of series inductor filter is directly proportional to the load resistance it means as the load resistance increases, ripple factor also starts increasing. And in the case of shunt capacitor, the ripple factor is inversely proportional to the value of load resistance. It implies that in shunt capacitor filter the ripple factor decreases with increase in load resistance and increases with the decrease in load resistance.

Thus, for better performance, we need a filter circuit in which ripple factor is low and do not vary with the variation in load resistance. This can be achieved by using the combination of series inductor filter and shunt capacitor filter. The voltage stabilization property of shunt capacitor filter and current smoothing property of series inductor filter is utilized for the formation of choke filter or L-section filter.

The combination of series inductor filter and shunt capacitor filter is generally used for most of the applications. The combination results in two types, i.e. L-section filter and Pi filter. In this article, we will discuss the working of L-section or choke filter and in next article, we will discuss Pi filter in detail.

Working of Choke Filter or L-section filter

When the pulsating DC signal from the output of the rectifier circuit is feed into choke filter, the AC ripples present in the output DC voltage gets filtered by choke coil. The inductor has the property to block AC and pass DC. This is because DC resistance of an inductor is low and AC impedance of inductor coil is high. Thus, the AC ripples get blocked by inductor coil.

Although the inductor efficiently removes AC ripples, a small percentage of AC ripples is still present in the filtered signal. These ripples are then removed by the capacitor connected in parallel to the load resistor. Now, the DC output signal is free from AC components, and this regulated DC can be used in any application.

If the inductor of high inductive reactance (X_L), greater than the capacitive reactance at ripple frequency is used than filtering efficiency gets improved.

Choke Input Filter

- Filter choke inductors are selected based on **required inductance value**, and **current-handling capacity.**
- Minimum required inductance is determined at the lowest expected load current.
- $L_{min} = E_{out} / I_{min}$ where:
  - E_{out} is design voltage;
  - I_{min} is minimum unloaded current in milliamperes; and
  - L_{min} is the minimum inductance in henrys.

Capacitor Input Filter

- Also called a **Pi Filter**
- Advantages:
  - **Higher terminal voltage** output; and
  - More compact and less expensive than choke.
- Disadvantages:
  - **More ripple** than choke filter; and
  - **Not as well regulated** as a choke filter.

One circuit used for smoothing is the capacitor-input filter. It produces a starting voltage in the same way as a capacitor connected directly across the load. The load current is then passed through a choke and another capacitor is connected after the choke. Because the fluctuation at the input end of the choke is now quite small, the choke can do much more toward stabilizing the current passing through it. Any residual fluctuations in voltage that still might appear at its output end are "soaked up" by the second capacitor.

For low-current supplies, or even moderately larger current supplies (up to 100 or 200 milliamps in modern amplifiers), a resistor is sometimes used to replace the choke; this is an economy measure. (Resistors are considerably cheaper than chokes, and modern electrolytic-type capacitors can get very large values of capacitance into quite a small space at low cost.) The disadvantage of the resistor is that it produces a voltage drop so that the rectified voltage needed is appreciably higher than the required output voltage.

Advantages of Pi filter (π- filter)

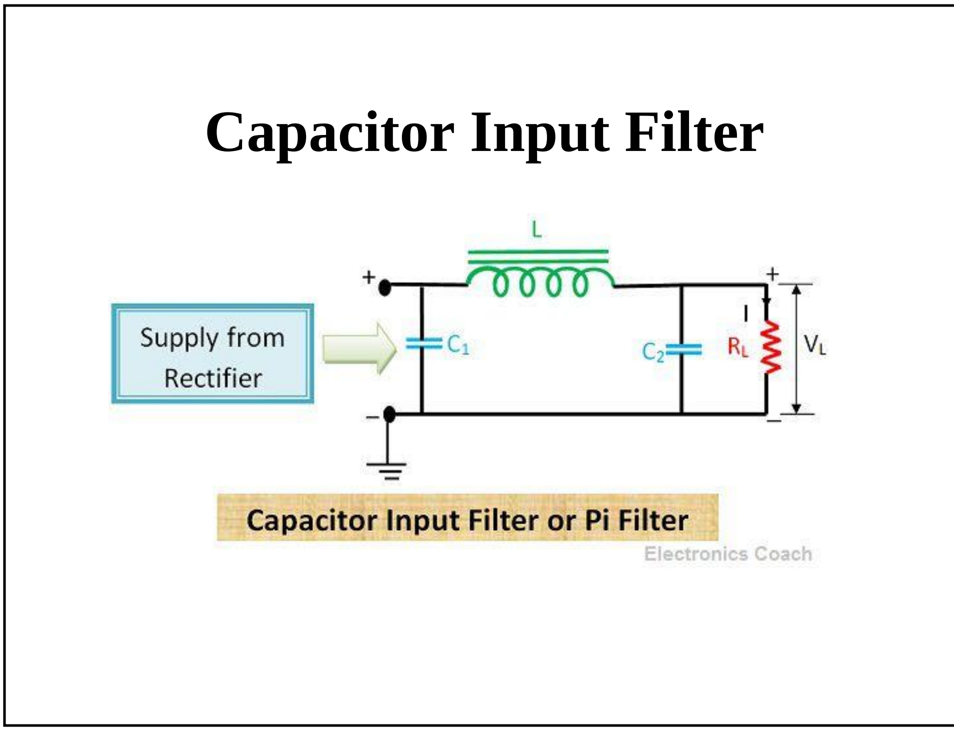
1. **High Output Voltage:** If you are dealing with the application which requires high output voltage after filtering, then this is the filter you should use. Pi

filter's significance is that it offers low voltage drop across choke coil and capacitor C_2 in order to main high output voltage across its output terminals.

2. **Low Ripple factor:** Due to the involvement of 2 capacitors in addition with one inductor it provides improved filtering action. This leads to decrement in ripple factor. A low ripple factor means the ratio of current due to AC ripples and direct Current is low. Thus, a low ripples factor signifies regulated and ripple free DC voltage.
3. **High PIV:** The peak inverse voltage in the case of Pi filters is more in comparison to L-section filter.

Disadvantage of Pi filter (π- filter)

Poor Voltage Regulation: We have discussed above that the output voltage varies with the load current. Thus, this capacitor is not suitable for varying loads. In an application where load current varies, pi filters are not suitable. Thus, in such application, we can use L-section filters as its output voltage do not vary largely with load current.



Pi Filter

Definition: Pi filter consists of a **shunt capacitor** at the input side, and it is followed by an **L-section filter.** The output from the rectifier is directly given across capacitor. The pulsating DC output voltage is filtered first by the capacitor connected at the input side and then by choke coil and then by another shunt capacitor.

The construction arrangement of all the components resembles the shape of Greek letter Pi (π). Thus it is called **Pi filter.** Besides, the capacitor is present at the input side. Thus, it is also called **capacitor input filter.**

Significance of Capacitor input filter or Pi filter (π- filter)

The ultimate aim of a filter is to achieve ripple free DC voltage. The filters we have discussed in our previous articles are also efficient in removing AC ripples from the output voltage of rectifier, but Pi filter is more efficient in removing ripples as it consists of one more capacitor at the input side.

Working of Pi filter (π- filter)

The output voltage coming from rectifier also consist of AC components. Thus it is a crucial need to remove these AC ripples to improve the performance of the device. The output from the rectifier is directly applied to the input capacitor. The capacitor provides a low impedance to AC ripples present in the output voltage and high resistance to DC voltage. Therefore, most of the AC ripples get bypassed through the capacitor in input stage only.

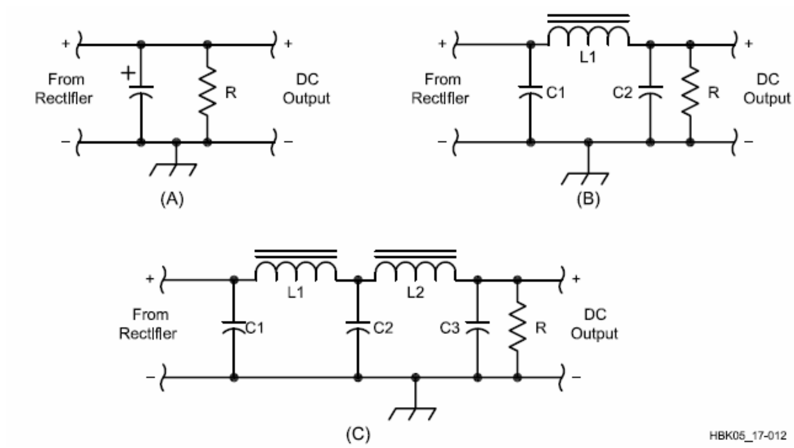
The residual AC components which are still present in filtered DC signal gets filtered when they pass through the inductor coil and through the capacitor connected parallel across the load. In this way, the efficiency of filtering increases multiple times.

In the case of L-section filter, one inductor and capacitor were present so if some AC ripples say 1% is left after filtering that can be removed in Pi-filter. Thus, Pi filter is considered more efficient.

Capacitor Input Filter

- No-load voltage across filter capacitors is ~ 90% of RMS voltage.
- Use capacitors rated for peak voltage from transformer secondary.
- If Bleeder Resistor fails, the no-load voltage would reach the **peak voltage** from the transformer.

Capacitor Input Filter – Extra Stages



CAPACITOR-INPUT FILTERS

Capacitor-input filter systems are shown above. Disregarding voltage drops in the chokes, all have the same characteristics except with respect to

ripple. Better ripple reduction will be obtained when LC sections are added as shown in Fig B and C.

Regulating Voltage

- The **output voltage** will tend to **drop** when a **load is applied.**
- A **regulator circuit** will ensure that the **voltage stays constant** when a heavy demand is placed on the supply.
- Two **Linear Regulating** methods:
  - **Shunt regulator**; and
  - **Series regulator**.
- Do not try to exceed the maximum output of the power supply!

Voltage Variations

- Voltage can vary for several reasons:
  - **Transformer winding resistance** causes losses as current increases;
  - Series **resistance in rectifier diodes**;
  - Losses in **series filter inductor**; and
  - **Variations in AC power** multiplied by transformer ratio.

Power Supply Regulation Percentage

- **Regulation** refers to controlling voltage under varying resistive loads.
- Expressed as a percentage of **No Load voltage vs Full Load voltage** (maximum permissible secondary current in transformer)**.**

$$\text{Regulation Percentage} = \frac{E_{\text{no-load}} - E_{\text{full-load}}}{E_{\text{full-load}}}(100\%)$$

Voltage Regulation Formula

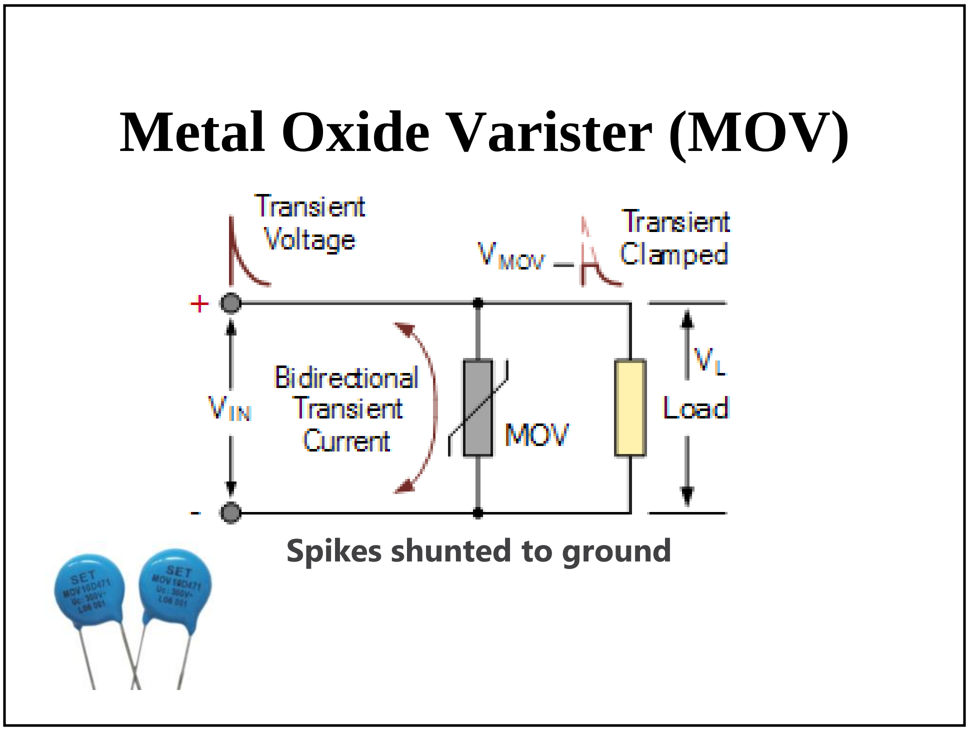
The measure of how well a power transformer maintains constant secondary voltage over a range of load currents is called the transformer's *voltage regulation*. It can be calculated from the following formula:

What is "Full Load"?

"Full-load" means the point at which the transformer is operating at maximum permissible secondary current. This operating point will be determined primarily by the winding wire size (ampacity) and the method of transformer cooling.

Dynamic vs Static Regulation

- **Dynamic** regulation deals with **transients** that can damage equipment.
  - Larger **output capacitors** and transient suppressors (MOVs).
- **Static** regulation deals with **long-term** voltage stability.
  - Zener diodes, Series pass transistors and Three-terminal regulators.



Transients are very steep voltage steps that occur in electrical circuits due to the sudden release of a previously stored energy, either inductive or capacitive, which results in a high voltage transient, or surge being created. This sudden release of energy back into the circuit due to some switching action creates a transient voltage spike in the form of a steep impulse of energy which can in theory be of any infinite value.

Discrete semiconductor transient suppression devices such as the Metal-oxide Varistor, or MOV, are by far the most common as they are available in a variety of energy absorbing and voltage ratings making it possible to exercise tight control over unwanted and potentially destructive transients or over voltage spikes.

Diverting a transient is usually accomplished using a voltage-clamping type device or by using what are commonly called a crowbar type device. These parallel connected devices exhibit a nonlinear impedance characteristic as the current flowing through them is not linear to the voltage across their terminals as given by Ohms Law.

A voltage-clamping device such as an MOV, has a variable impedance depending on the current flowing through the device or on the voltage across its terminal. Under normal steady-state operating conditions, the device offers a high impedance and has therefore no effect on the connected circuit.

However, when a voltage transient occurs, the impedance of the device changes increasing the current drawn through the device as the voltage across it rises. The result is an apparent clamping of the transient voltage. The volt-ampere characteristic of a clamping devices is generally time-dependent as the large increase in current results in the device dissipating a lot of energy.

Spikes shunted to ground.

Shunt Regulators

- Term given to a device **placed across the output** to control current through a **series-dropping resistance** in order to maintain a constant output voltage.
- **Shunt Regulators** used in applications requiring a **constant load** on the unregulated voltage source.
- **Zener Diodes** the most common shunt regulator.

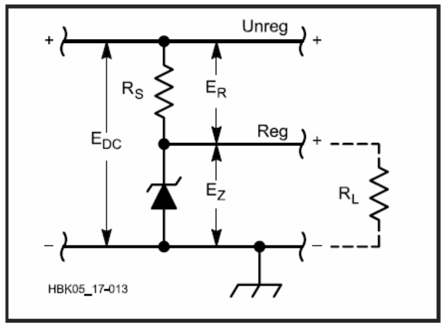
Zener Diodes

- A **Zener Diode** is a type of diode that permits current in the forward direction like a normal diode, but **also in the reverse direction** if the voltage is larger than the breakdown voltage known as the **"Zener voltage".**
- Important components of voltage regulation circuits.

Zener Diodes

- When **connected in parallel** with a variable voltage source so that it is **reverse biased**, a Zener diode **conducts** when the voltage reaches the diode's **reverse breakdown voltage.** From that point on, the relatively low impedance of the diode shunt keeps the **voltage across the diode at that value.**

Zener Diodes



Zener-diode voltage regulation. The voltage from a negative supply may be regulated by reversing the power-supply connections and the diode polarity.

ZENER DIODES

A Zener diode (named after American physicist Dr. Clarence Zener) can be used to maintain the voltage applied to a circuit at a practically constant value, regardless of the voltage regulation of the power supply or variations in load current. The typical circuit is shown above. Note that the cathode side of the diode is connected to the positive side of the supply.

Zener Diode

Zener diodes are used for protection on DC supplies (unidirectional) as they behave like normal diodes in their forward biased direction, but break down and conduct in their reverse biased direction. Thus a zener diode's reverse breakdown voltage, V_Z can be used as the reference or clamping voltage level.

In the reverse direction and below the their zener breakdown voltage, V_Z zener diodes exhibit high impedance to the supply and conducts very little leakage current. However, when the voltage across the zener is greater than its zener voltage, it starts to breakdown with its conduction increasing gradually as the voltage across it increases exhibiting a very low impedance path to the over voltage transient.

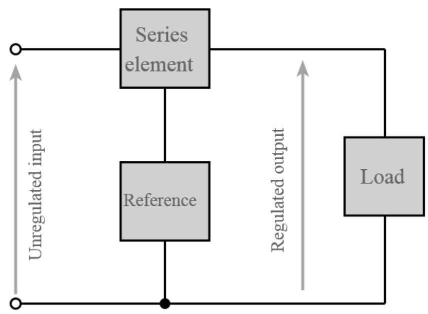
Zener Diodes

- Max Zener diode current capability given by **I = P / E**, where P is the max power dissipation and E is the Zener voltage (both in spec sheet).
- Zener Diodes require a **minimum current** to remain in the Zener region. In spec sheet, but usually 5% of maximum rated Zener current.

Zener diodes are available in a wide variety of voltages and power ratings. The voltages range from less than two to a few hundred, while the power ratings (power the diode can dissipate) run from less than 0.25 W to 50 W. The ability of the Zener diode to stabilize a voltage depends on the diode′s conducting impedance. This can be as low as 1 ∧ or less in a low-voltage, high-power diode or as high as 1000 ∧ in a high-voltage, low-power diode.

Series Regulators

- The **conduction of a control element** is varied in direct proportion to the line voltage or load current.

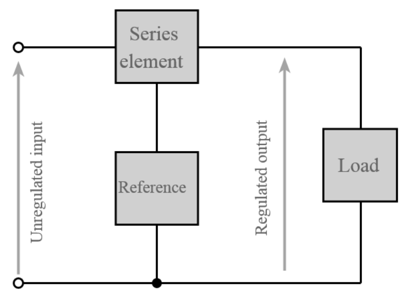


Series Regulator

- **More efficient** than Shunt / Zener diode regulator.
- Unlike Shunt regulators, Series regulators do not need to draw heavy current from power supply when there is no load.
- Two methods:
  - **Series Pass Transistor**; and
  - **Three Terminal Regulator**.

Series Pass Transistor

- **More efficient** than Zener shunt diode regulator.
- Transistor in series with output is controlled by a voltage reference (**usually a Zener**).
- Series transistor multiplies effect of Zener, giving **better regulation, higher current, and less wasted power.**



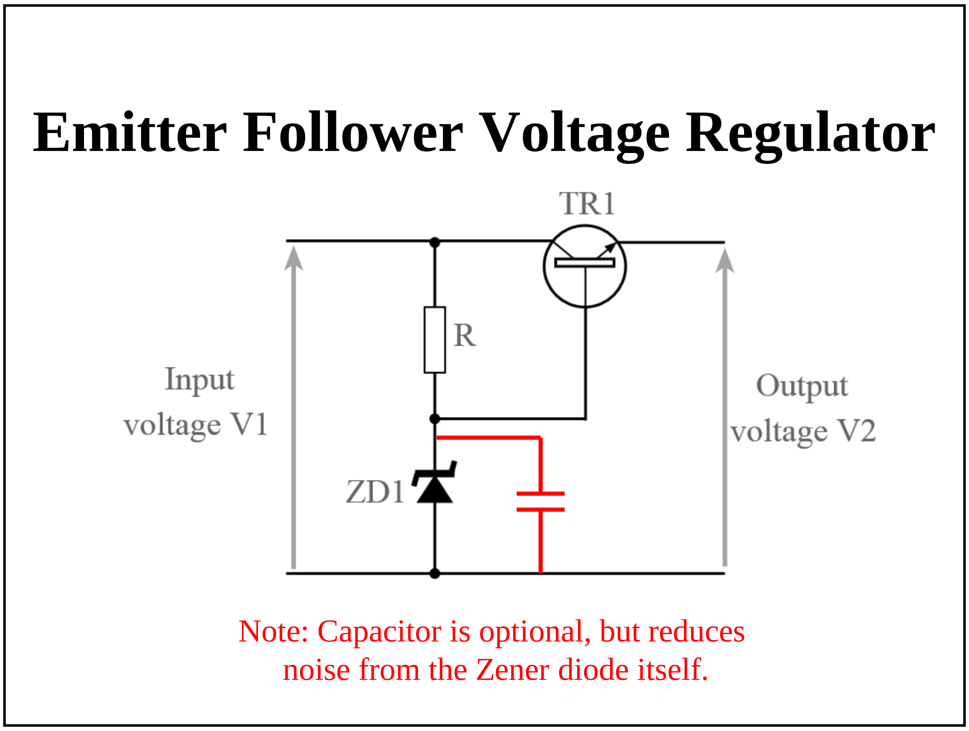
As the name suggests, the series voltage regulator or series pass voltage regulator operates by using a variable element in series with the load.

In this way a series voltage regulator provides an effective form of voltage regulation within a linear power supply.

Series voltage regulator basics

The series voltage regulator or series pass voltage regulator uses a variable element placed in series with the load. By changing the resistance of the series element, the voltage dropped across it can be varied to ensure that the voltage across the load remains constant.

The advantage of the series voltage regulator is that the amount of current drawn is effectively that used by the load, although some will be consumed by any circuitry associated with the regulator. Unlike the shunt regulator, the series regulator does not draw the full current even when the load does not require any current. As a result the series regulator is considerably more efficient.



Simple emitter follower voltage regulator

One of the simplest implementations of this concept is to use a single pass transistor in the form of an emitter follower configuration, and a single Zener diode drive by a resistor from the unregulated supply. This provides a simple form of feedback system to ensure the Zener voltage is maintained at the output, albeit with a voltage reduction equal to the base emitter junction voltage - 0.6 volts for a silicon transistor

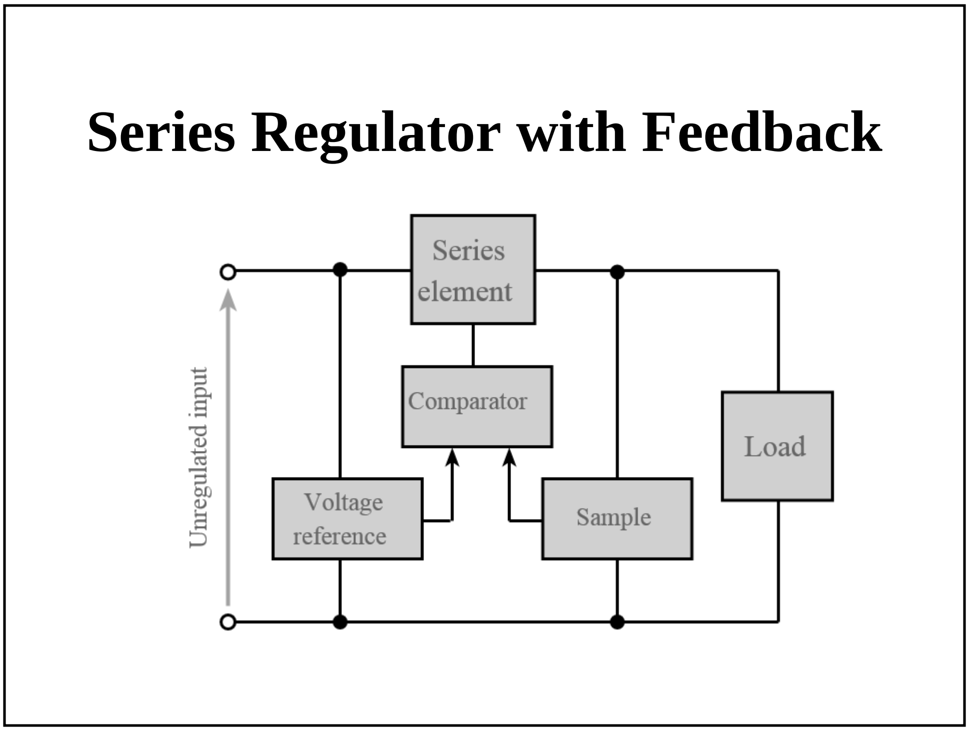
It is a simple matter to design a series pass voltage regulator circuit like this. Knowing the maximum current required by the load, it is possible to calculate the maximum emitter current. This is achieved by dividing the load current, i.e. transistor emitter current by the *B* or *hfe* of the transistor.

The Zener diode will generally need a minimum of around 10mA for a small Zener to keep its regulated voltage. The resistor should then be calculated to provide the base drive current and the minimum Zener current from a knowledge of the unregulated voltage, Zener voltage and the current required. [(Unregulated voltage - Zener voltage) / current]. A small margin should be added to the current to ensure that there is sufficient room for margin when the load, and hence the transistor base is taking the full current.

The power dissipation capacity for the Zener diode should be calculated for the case when the load current, and hence the base current is zero. In this case the Zener diode will need to take the full current passed by the series resistor.

Note: The transistor will have to dissipate substantial heat. A heat sink may be required, or two or more pass transistors can be connected in parallel.

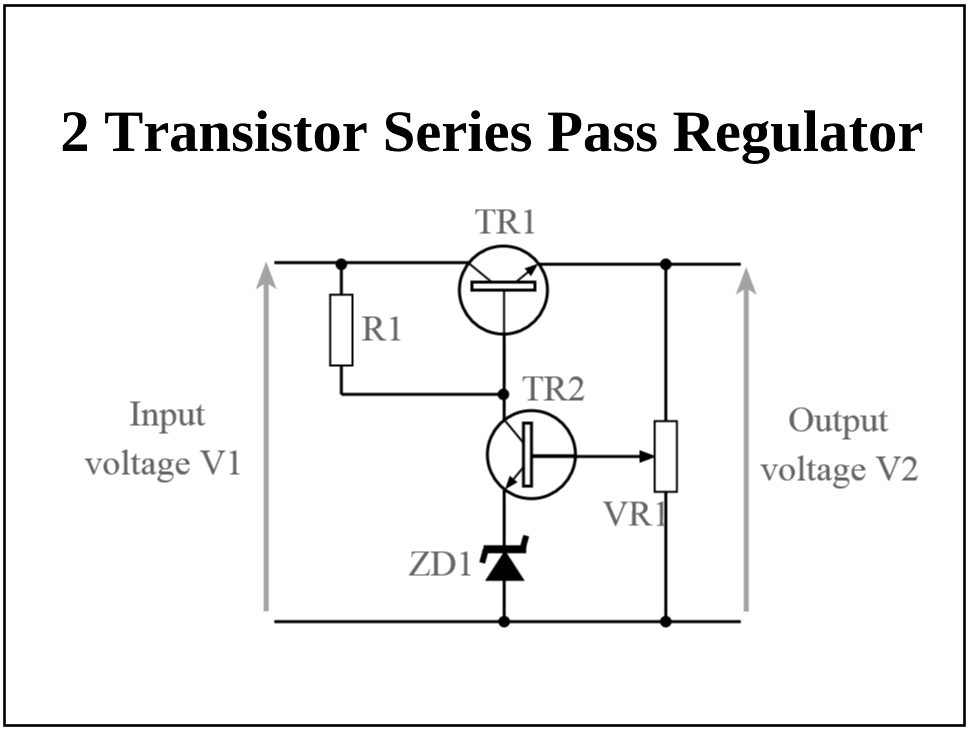
In critical applications a temperature-compensated reference diode would be used instead of the Zener diode.



Series pass regulator with feedback

In order to provide improved levels of performance it is possible to add a more sophisticated feedback network into the regulator circuit.

Using feedback within a voltage regulator enables the output to be sampled, and compared with a stable reference voltage. The error is then used to correct the output voltage. In this way, a far higher level of performance can be obtained in terms of the required output voltage as well as ripple and spikes.



It is possible to use a simple two transistor circuit for a series pass regulator with voltage sensing and feedback. Although it is quite straightforward to use an operational amplifier, which will provide higher levels of feedback, and hence better regulation, this two transistor circuit illustrates the principles well.

In this circuit TR1 forms the series pass transistor. The second transistor, TR2 acts as the comparator, feeding the error voltage between the reference diode and the sensed output voltage which is a proportion of the output voltage as set by the potentiometer. The resistor, R1 provides the current for the collector of TR2 and the reference diode ZD1.

Voltage reference

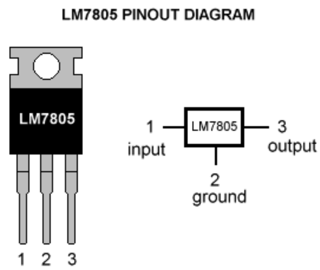
Any linear voltage regulator can only be as good as the voltage reference that is used as the basis of the comparison within the system. While a battery could in theory be used, this is not satisfactory for most applications. Instead Zener diode based references are almost universally used. In critical applications a temperature-compensated reference diode would be used instead of the Zener diode.

Integrated circuit regulators and references use sophisticated on-chip combinations of transistors and resistors to obtain temperature compensated and precise voltage reference sources.

Three Terminal Regulators

- Integrated circuit device that includes:
  - Short-circuit protection;
  - Automatic thermal shutdown;
  - Internal voltage reference source;
  - High gain error amplifier;
  - Error detection circuit;
  - Control circuit; and
  - Sensing resistors, pass transistors

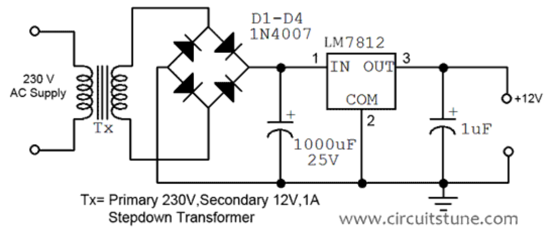
Three Terminal Regulators



- LM7800/7900 series regulators produce regulated outputs ranging from 5 to 24 VDC up to 5 amps, positive for 7800 series, negative for 7900 series.

Regulator monitors the output to the load via a feedback connection to the error amplifier. The voltage regulator controls the conduction of current through a control circuit, so that flow of current varies directly (linearly) with the line voltage or load current. Output is cleanest and most assured at the point where the error amplifier is connected.

Three Terminal Regulator



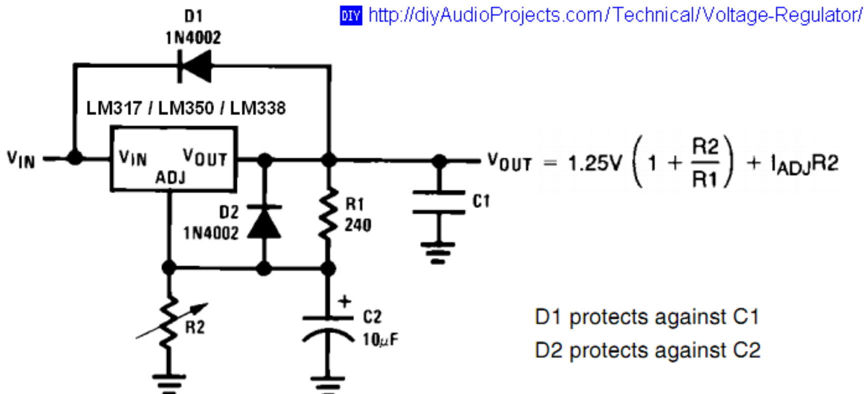
- Input voltage must be greater than desired output voltage by regulator’s “drop-out voltage”.
- Regulators dissipate heat, so heat sink required.
- Safety diode sometimes required between input and output.

Here this circuit diagram is for **+12V regulated (fixed voltage) DC power supply**. This **power supply circuit diagram** is ideal for an average current requirement of 1Amp. This circuit is based on IC **LM7812**. It is a 3-terminal (+ve) voltage regulator IC. It has short circuit protection , thermal overload protection. A transformer(Tx=Primary 230 Volt, Secondary 12 Volt , 1Amp step down transformer) is used to covert 230V to 12V from mains. Here used a bridge rectifier made by four 1N4007 or 1N4003 diode to convert AC to DC . The filtering capacitor 1000uF,25V is used to reduce the ripple and get a smooth DC voltage. This circuit is very easy to build. For good performance input voltage should be greater than 12Volt in pin-1 of IC LM7812. Use a heat sink to IC LM7812 for safeguarding it from overheating.

All linear regulators require a higher input than the output. If the input voltage approaches the desired output voltage, the regulator will "drop out". The input to output voltage differential at which this occurs is known as the regulator's drop-out voltage. Low-dropout regulators (LDOs) allow an input voltage that can be much lower (i.e., they waste less energy than conventional linear regulators).

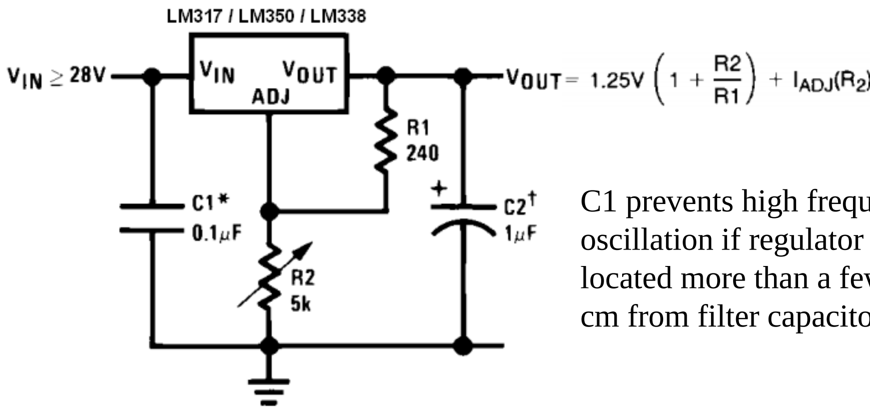
Regulator Protection Diodes

Regulator with Protection Diodes



When external capacitors are used with a voltage regulator it may be necessary to use protection diodes to prevent the capacitors from discharging through low current points into the voltage regulator. Even small capacitors can have a low enough internal series resistance to be able to deliver 20A spikes when shorted. Although the surge is very short in duration, there is enough energy to damage parts of the regulator IC. No protection diodes are required for output voltages of less than 25V or greater than 10 uF capacitance. Figure 3 shows the LM317 / LM338 / LM350 with protection diodes included for use with voltage outputs greater than 25V and high values of output capacitance.

1.2V–25V Adjustable Regulator



C1 prevents high frequency oscillation if regulator is located more than a few cm from filter capacitor

Full output current not available at high input-output voltages

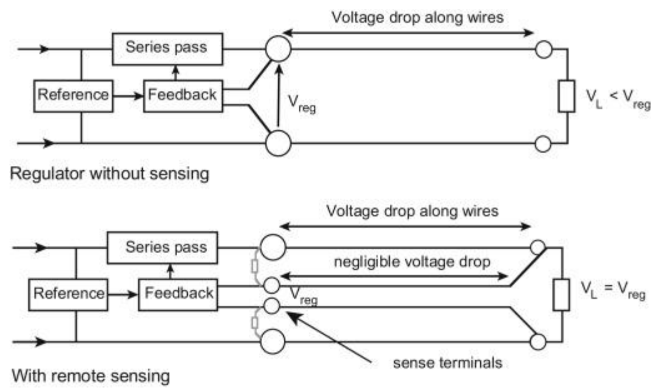
*Needed if device is more than 6 inches from filter capacitors.

†Optional—improves transient response. Output capacitors in the range of 1μF to 1000μF of aluminum or tantalum electrolytic are commonly used to provide improved output impedance and rejection of transients.

DIY http://diyAudioProjects.com/Technical/Voltage-Regulator/

Regulator Remote Sensing

- Feedback connection to an error amplifier is made directly to the load.
- Compensates for any voltage drop between supply and load.



The “stiffness” or tightness of regulation of a linear regulator depends on the gain of the error amplifier and the ratio of the output scaling resistors. In any regulator, the output

is cleanest and regulation stiffest at the point where the sampling network or error amplifier is connected. If heavy load current is drawn through long leads, the voltage drop

can degrade the regulation at the load. To combat this effect, the feedback connection to the error amplifier can be made directly to the load. This technique, called *remote sensing*, moves the point of best regulation to the load by bringing the connecting loads inside the feedback loop. This is shown in the figure above.

Uses 4 terminal Regulators.

No three-terminal regulator can maintain a constant voltage at anywhere other than its output terminals. It is common in larger systems for the load to be located at some distance from the power supply module, so that load-dependent voltage drops occur in the wiring connecting the load to the power supply output. This directly impacts the achievable load regulation.

The accepted way to overcome this problem is to split the regulator feedback path and incorporate two extra “sensing” terminals that are connected so as to sense the output voltage at the load itself. The voltage drop across this extra pair of wires is negligible because they only carry the signal current. The voltage at the regulator output is adjusted so as to regulate the voltage at the sensing terminals.

The minimum voltage at the regulator input must be increased to allow for the extra output voltage drop. It is wise to connect coupling resistors from the output to sense terminals, so as to ensure correct operation when the sense terminals are accidentally or deliberately disconnected. Sensing can only offer remote load regulation at one point and so is not really suited when one power supply module feeds several loads at different points.

Chirp

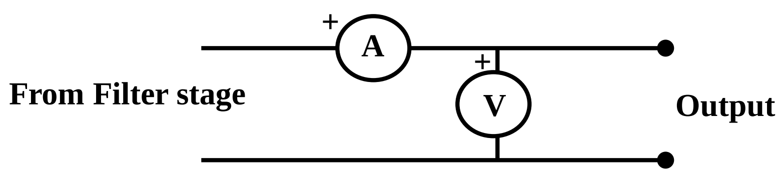
- A **poorly regulated power supply** can cause the transmitter **frequency to vary** as the radio is keyed.
- When this happens with a CW signal, the resulting frequency change is called a **chirp.**
- Check the **regulation of your power supply** if you receive a report of chirp.

Monitoring the Output

- Good commercial power supplies include a **voltmeter** and **ammeter** to monitor voltage and current.
- Homebrew power supplies should also incorporate voltmeters and ammeters.

Monitoring the Output

- **Voltmeters** are connected **in parallel** with (ie: across) the output of the power supply. Ensure that the meter's polarity is correct.
- **Ammeters** are usually placed **in series** with the positive output terminal, but can also be placed in the negative return line.



Safety

- Don’t forget to use a **fuse** on the AC line into the transformer main winding.
- **Transformerless** and **non-isolated** supplies have a **“hot” chassis** – be careful!
- Ensure capacitors are **discharged** before working on a power supply.
- Storage batteries contain **acid**, and produce **explosive hydrogen gas** when charging.

Switching Mode Power Supplies

- **Switching** Mode Power Supplies (SMPS) **switch a power transistor** between **saturation** (full on) and **cutoff** (completely off) with a variable duty cycle whose **average** is the **desired output voltage (Switching Voltage Regulator).**
- **Switching rate** is in the range of **tens to hundreds of kHz,** which can cause **electronic "noise"** on receivers.
- **Advantage** is that they are much **lighter** and **smaller** than conventional power supplies, but they are **more complex.**

The modern switch mode power supply, or SMPS, uses solid-state switches to convert an unregulated DC input voltage to a regulated and smooth DC output voltage at different voltage levels. The input supply can be a true DC voltage from a battery or solar panel, or a rectified DC voltage from an AC supply using a diode bridge along with some additional capacitive filtering.

In many power control applications, the power transistor, MOSFET or IGFET, is operated in its switching mode were it is repeatedly turned "ON" and "OFF" at high speed. The main advantage of this is that the power efficiency of the regulator can be quite high because the transistor is either fully-on and conducting (saturated) or full-off (cut-off).

A linear regulator provides the desired output voltage by dissipating excess power in ohmic losses (e.g., in a resistor or in the collector–emitter region of a pass transistor in its active mode). A linear regulator regulates either output voltage or current by dissipating the excess electric power in the form of heat, and hence its maximum power efficiency is voltage-out/voltage-in since the volt difference is wasted.

In contrast, a SMPS changes output voltage and current by switching ideally lossless storage elements, such as inductors and capacitors, between different electrical configurations. Ideal switching elements (approximated by transistors operated outside of their active mode) have no resistance when "on" and carry no current when "off", and so converters with ideal components would operate with 100% efficiency (i.e., all input power is delivered to the load; no power is wasted as dissipated heat). In reality, these ideal components do not exist, so a switching power supply cannot be 100% efficient, but it is still a significant improvement in efficiency over a linear regulator.

Linear Supply Disadvantages

- **Size** of transformer and capacitor **inversely proportional to frequency.**
- At 60 hz, both need to be big and heavy.
- **High current** requires **large components** as well.
- Linear supplies **draw current** even when load current is low.
- Lots of **heat** to be dissipated.

Although linear power supplies work very well for several low-power applications – cordless phones and video games consoles are two applications that come in mind –, when high power is needed, linear power supplies can be literally very big for the task.

The size of the transformer and the capacitance (and thus the size) of the electrolytic capacitor are inversely proportional to the frequency of the input AC voltage: the lower the AC voltage frequency, the bigger the size of those components and vice-versa. Since linear power supplies still use the 60 Hz (or 50 Hz, depending on the country) frequency from the power grid – which is a very low frequency –, the transformer and the capacitor are very big.

Also, the higher the current (i.e., the power) demanded by the circuit fed by the power supply, the bigger the transformer is.

SMPS Supply Advantages

- Much **more efficient** than linear supplies, generating **less heat**.
- Operate at much **higher frequencies**, so **components are smaller and lighter**.
- **Versatile** – can step up voltage (boost) or step down voltage (buck).

High Efficiency – They generate far less heat. Lower-powered units will often not require a heat shield which means that they can be mounted directly onto PCBs.

Compact Form Factor – Because switchers operate at a higher frequency, the value, and thereby the size of their associated filtering capacitors and inductors will be smaller and the overall unit will take up less space.

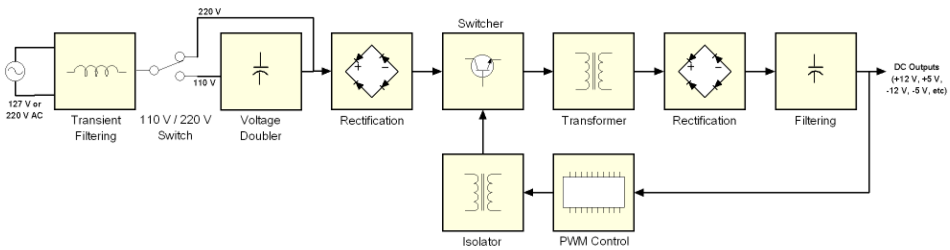
Versatile Design – Switchers can be designed to step up voltage (Boost) or step-down down voltage (Buck) as the application requires.

By definition, a switch mode power supply (SMPS) is a type of power supply that uses semiconductor switching techniques, rather than standard linear methods to provide the required output voltage. The basic switching converter consists of a power switching stage and a control circuit. The power switching stage performs the power conversion from the circuits input voltage, V_{IN} to its output voltage, V_{OUT} which includes output filtering.

The major advantage of the switch mode power supply is its higher efficiency, compared to standard linear regulators, and this is achieved by internally switching a transistor (or power MOSFET) between its “ON” state (saturated) and its “OFF” state (cut-off), both of which produces lower power dissipation. This means that when the switching transistor is fully “ON” and conducting current, the voltage drop across it is at its minimal value, and when the transistor is fully “OFF” there is no current flow through it. So the transistor is acting like an ideal switch.

As a result, unlike linear regulators which only offer step-down voltage regulation, a switch mode power supply, can offer step-down, step-up and negation of the input voltage using one or more of the three basic switch mode circuit topologies: *Buck*, *Boost* and *Buck-Boost*. This refers to how the transistor switch, inductor, and smoothing capacitor are connected within the basic circuit.

Switching Mode Power Supply



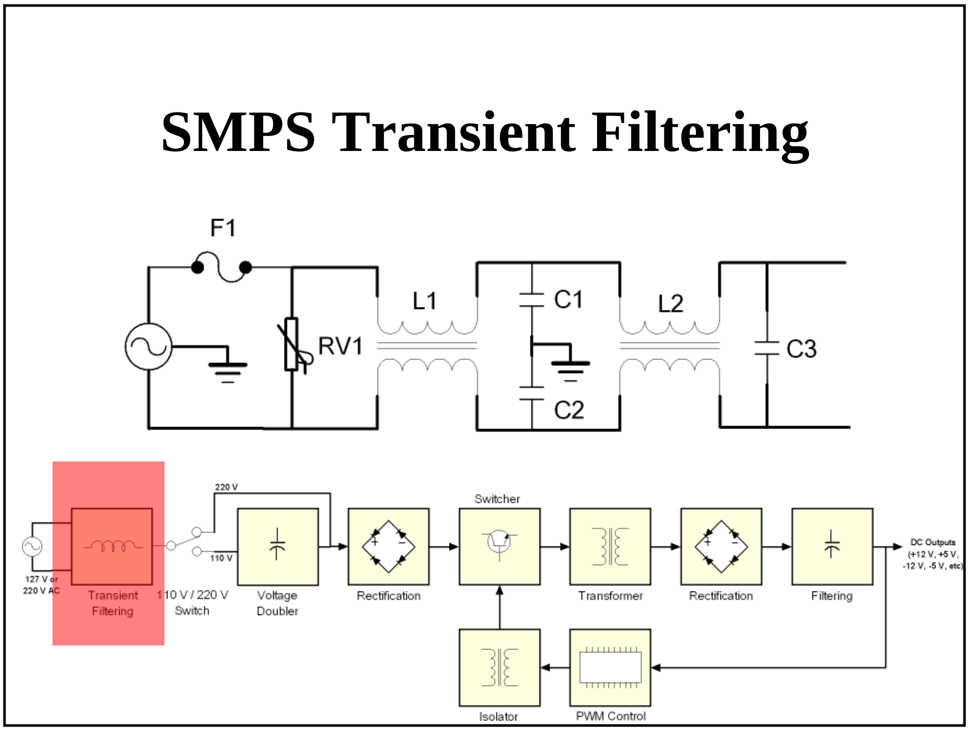
This example is a PC Switching Mode Power Supply, but the basic concepts are the same for all SMPS.

This example is of a multi-input voltage supply – 120/240 VAC – used for a personal computer.

On high-frequency switching power supplies, the input voltage has its frequency increased before going into the transformer (50-60 kHz are typical values). With input voltage frequency increased, the transformer and the electrolytic capacitor can be very small. This is the kind of power supply used on the PC and several other electronic equipments, like VCRs. Keep in mind that “switching” is a short for “high-frequency switching,” having nothing to do whether the power supply has an on/off switch or not…

The power supply used on the PC uses an even better approach: it is a closed loop system. The circuit that controls the switching transistor gets feedback from the power supply outputs, increasing or decreasing the duty cycle of the voltage applied to the transformer according to the PC consumption (this approach is called PWM, Pulse Width Modulation). So the power supply readjusts itself depending on the consumption of the device connected to it. When your PC isn’t consuming a lot of power, the power supply readjusts itself to deliver less current, making the transformer and all other components to dissipate less power – i.e., less heat is generated.

On linear power supplies, the power supply is set to deliver its maximum power, even if the circuit that is connected to it isn’t pulling a lot of current. The result is that all components are working at their full capacity, even if it isn’t necessary. The result is the generation of a greater heat



Transient Filtering

The first stage of a PC power supply is the transient filtering. You can see the schematics of the recommended transient filter for the PC power supply above.

Its main component is called MOV (Metal Oxide Varistor) or varistor, labeled RV1 on our schematics, which is responsible for cutting voltage spikes (transients) found on the power line. This is the exact same component found on surge suppressors. The problem, though, is that cheap power supplies don't carry this component in order to save costs. On power supplies with a MOV, external surge suppressors are useless, since they have already a surge suppressor inside them.

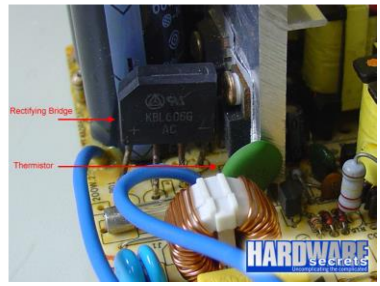
L1 and L2 are ferrite coils. C1 and C2 are disc capacitors, normally blue. These capacitors are also called “Y capacitors”. C3 is a metalized polyester capacitor, normally with values like 100 nF, 470 nF or 680 nF. This capacitor is also called “X capacitor”. Some power supplies have a second X capacitor, installed in parallel with the main power line, where RV1 is in the figure above..

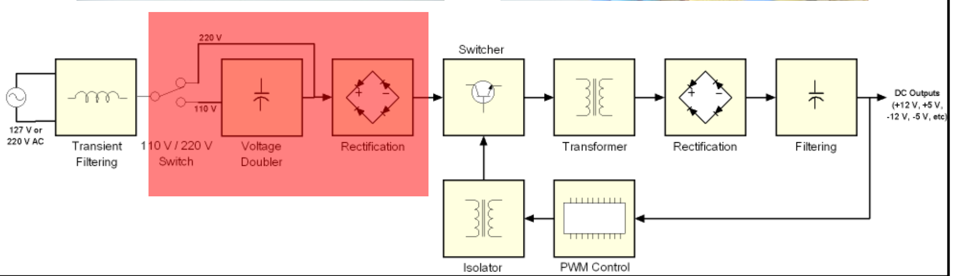
X capacitor is any capacitor that has its terminals connected in parallel to the main power line. Y capacitors come in pairs, they need to be connected together in serial with the connection point between them grounded, i.e., connected to the power supply chassis. Then they are connected in parallel to the main power line.

The transient filter not only filters the transients coming from the power line, but also prevents the noise generated by the switching transistors to go back to the power line, which would cause interference on other electronic equipments.

You should also find a fuse near the transient filter. If this fuse is blown, beware. Fuses don't blow by themselves and a blown fuse usually indicates that one or more components are defective. If you replace the fuse, the new one will probably blow right after you turn on your supply.

SMPS Voltage Doubler & Rectifier

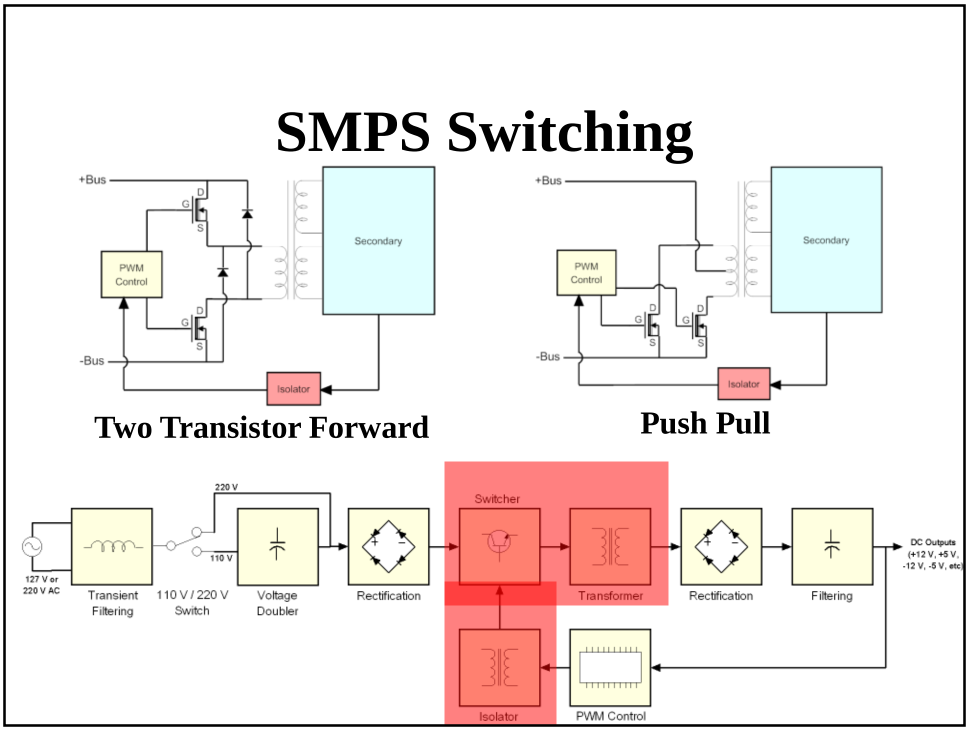




Some power supplies are designed to be used on 120 VAC and 240 VAC systems. The voltage doubler uses two big electrolytic capacitors as part of the system to convert 120 VAC to 240 VAC. The power supply automatically detects the input voltage and routes the AC as required.

Next to the two electrolytic capacitors you will find a rectifying bridge. This bridge can be made by four diodes or by a single component. On high-performance power supplies this rectifying bridge is connected to a heatsink.

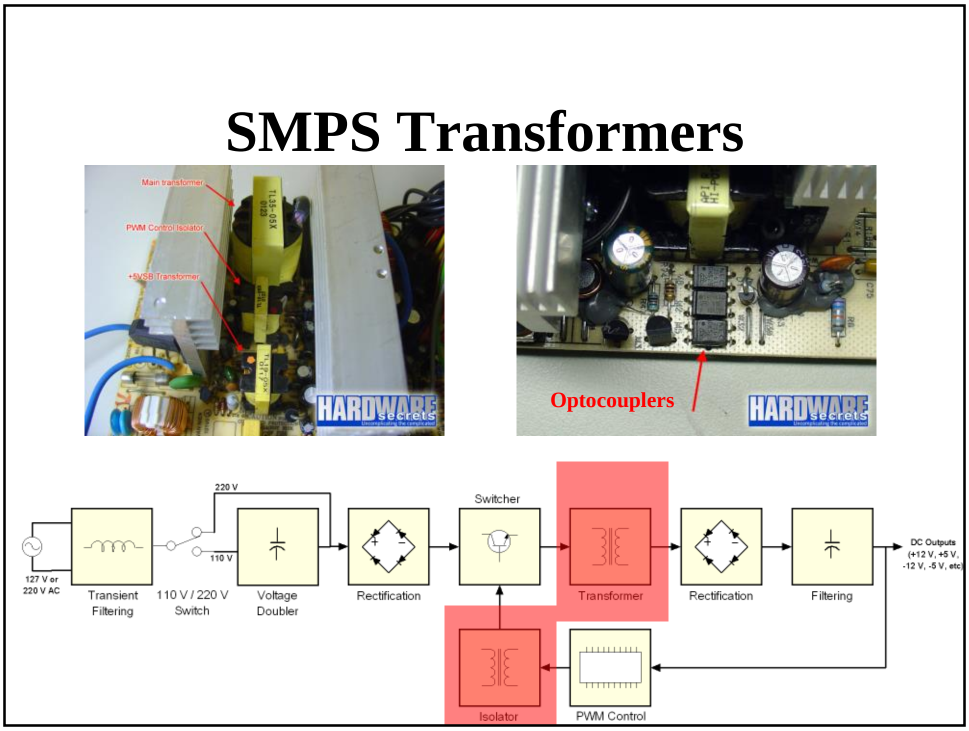
On the primary you will also find a NTC thermistor, which is a resistor that changes its resistance according to the temperature. It is used to reconfigure the power supply after it is used for a while and it is hot. NTC stands for Negative Temperature Coefficient. This component resembles a ceramic disc capacitor and is usually olive green.



The switching section of switching mode power supplies can be built using one of several different configurations, using one to four MOSFETs in forward, half bridge, full bridge and push-pull configurations.

The two most common configurations for PC power supplies are the two-transistor forward and the push-pull, and both use two switching transistors. The physical aspect of these transistors – which are power MOSFET transistors – can be seen in the previous page. They are attached to the heatsink found on the power supply primary section.

The switcher stage converts DC, whether directly from the input or from the rectifier stage described above, to AC by running it through a power oscillator, whose output transformer is very small with few windings at a frequency of tens or hundreds of kilohertz. The frequency is usually chosen to be above 20 kHz, to make it inaudible to humans. The switching is implemented as a multistage (to achieve high gain) MOSFET amplifier. MOSFETs are a type of transistor with a low on-resistance and a high current-handling capacity.

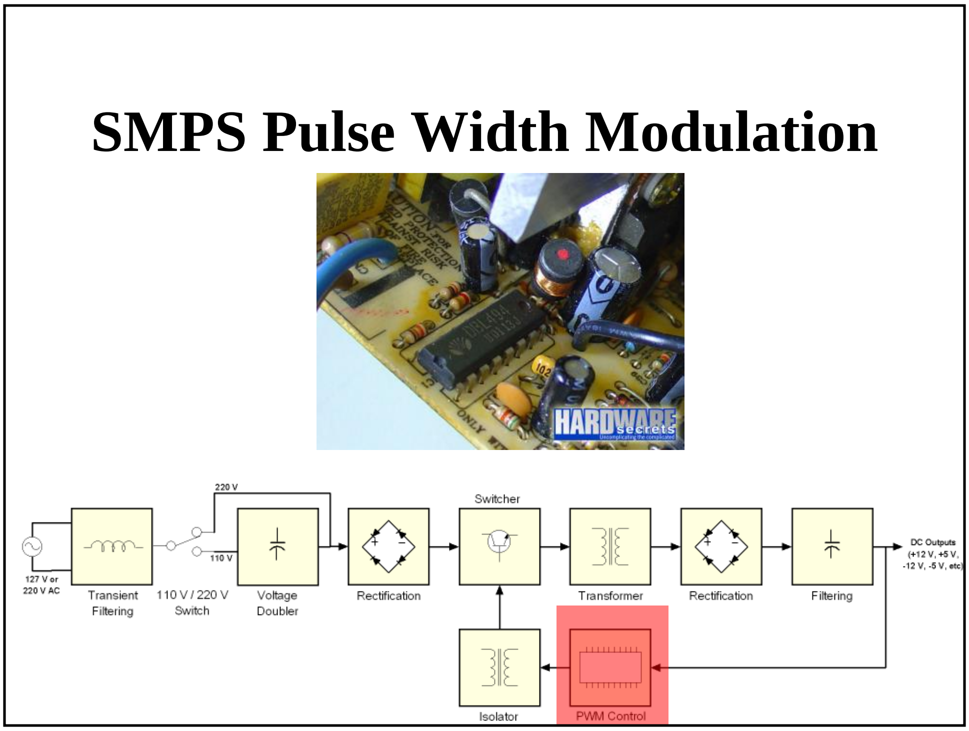


Transformers and Isolator

As we mentioned earlier, a typical PC power supply has three transformers. The big one is the one shown on our block diagram (Figures 3 and 4) and schematics (Figures 19 through 23), where its primary is connected to the switching transistors and its secondary is connected to the rectifying diodes and filtering circuits that will provide the power supply DC outputs. The second transformer is used to generate any other voltage required by the system, possibly an independent circuit generates this output, also known as “standby power”. The third transformer is an isolator transformer, connecting the PWM control circuit to the switching transistors (described as “isolator” on our block diagram). This third transformer may not exist, being replaced by one or more optocouplers, which look like a small integrated circuit (see Figure above on the right).

Any switched-mode power supply that gets its power from an AC power line requires a transformer for galvanic isolation. Some DC-to-DC converters may also include a transformer, although isolation may not be critical in these cases. SMPS transformers run at high frequency. Most of the cost savings (and space savings) in off-line power supplies result from the smaller size of the high frequency transformer compared to the 50/60 Hz transformers formerly used. There are additional design tradeoffs.

The terminal voltage of a transformer is proportional to the product of the core area, magnetic flux, and frequency. By using a much higher frequency, the core area (and so the mass of the core) can be greatly reduced. However, core losses increase at higher frequencies. Cores generally use ferrite material which has a low loss at the high frequencies and high flux densities used. The laminated iron cores of lower-frequency (<400 Hz) transformers would be unacceptably lossy at switching frequencies of a few kilohertz. Also, more energy is lost during transitions of the switching semiconductor at higher frequencies. Furthermore, more attention to the physical layout of the circuit board is required as parasitics become more significant, and the amount of electromagnetic interference will be more pronounced.

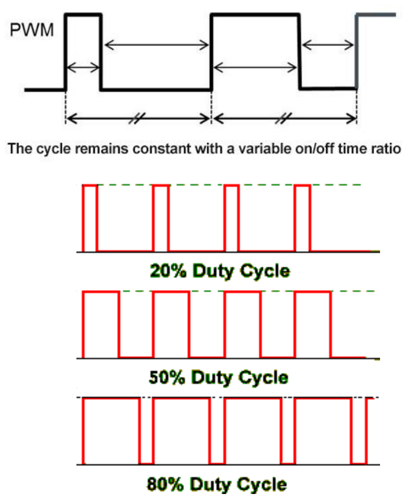


The PWM control circuit is based on an integrated circuit. Power supplies without active PFC usually use a TL494 integrated circuit (in the power supply pictured in Figure 26 a compatible part, DBL494, was used). On power supplies with active PFC sometimes an integrated circuit that combines both PWM and PFC control is used. CM6800 is a good example of PWM/PFC combo integrated circuit. Another integrated circuit is usually used on the power supply, to generate the power good signal.

The switching regulator, as the name implies, converts an input voltage to a desired output voltage by switching the input voltage, that is, by turning it on and off. In simple terms this method involves chopping the input voltage and smoothing it out to match the required output voltage. There are two principal methods by which the input voltage is chopped, as described on the next slide.

A feedback circuit monitors the output voltage and compares it with a reference voltage. Depending on design and safety requirements, the controller may contain an isolation mechanism (such as an opto-coupler) to isolate it from the DC output. Switching supplies in computers, TVs and VCRs have these opto-couplers to tightly control the output voltage. The feedback circuit needs power to run before it can generate power, so an additional nonswitching power-supply for stand-by is added.

Pulse Width Modulation

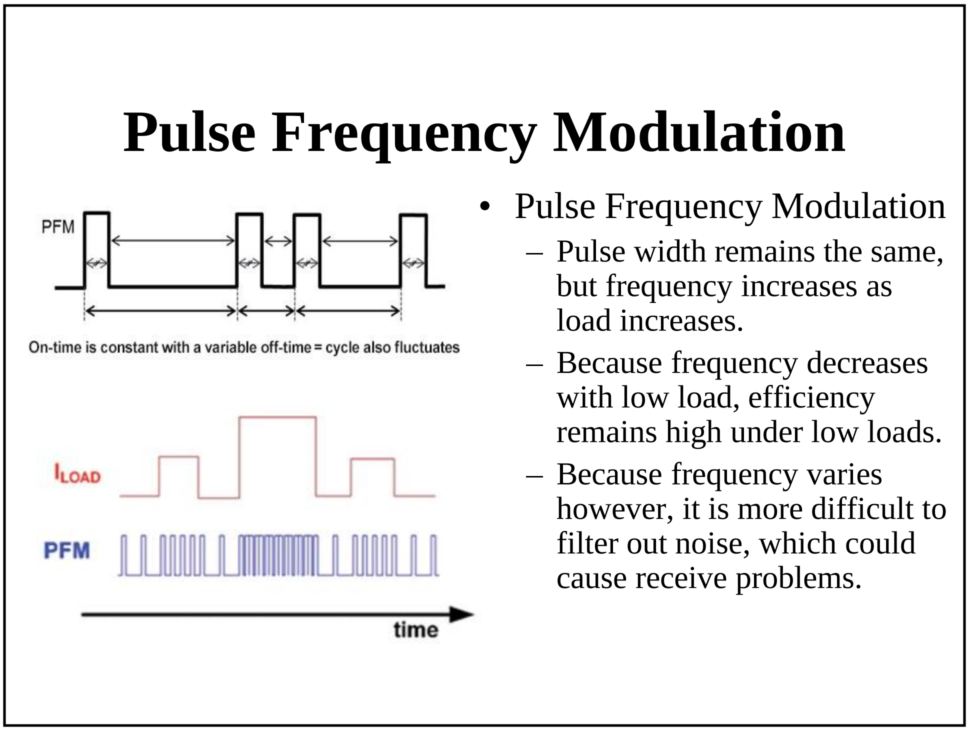


- Pulse Width Modulation
  - Switching freq remains the same but pulse width varies as required by load demands.
  - Most common method.
  - Because freq is constant, switching noise can be predicted and filtered out.
  - For light loads, switching loss predominates, so efficiency suffers.

PWM control (Pulse Width Modulation)

PWM represents the most commonly employed voltage control method. In this method, at fixed cycles the amount of power corresponding to the power that needs to be output is switched on to extract it from the input. Consequently, the ratio between on and off, that is, the duty cycle, changes as a function of the required output electric power.

An advantage of PWM control is that because the frequency is fixed, any switching noise that arises can be predicted, thus facilitating the filtering process. A drawback of the method is that also due to constant frequency, the number of switching operations remains the same whether the load is high or low, and consequently, the self-consuming current does not change. As a result, at times of light loads the switching loss becomes predominant, which reduces the efficiency significantly.

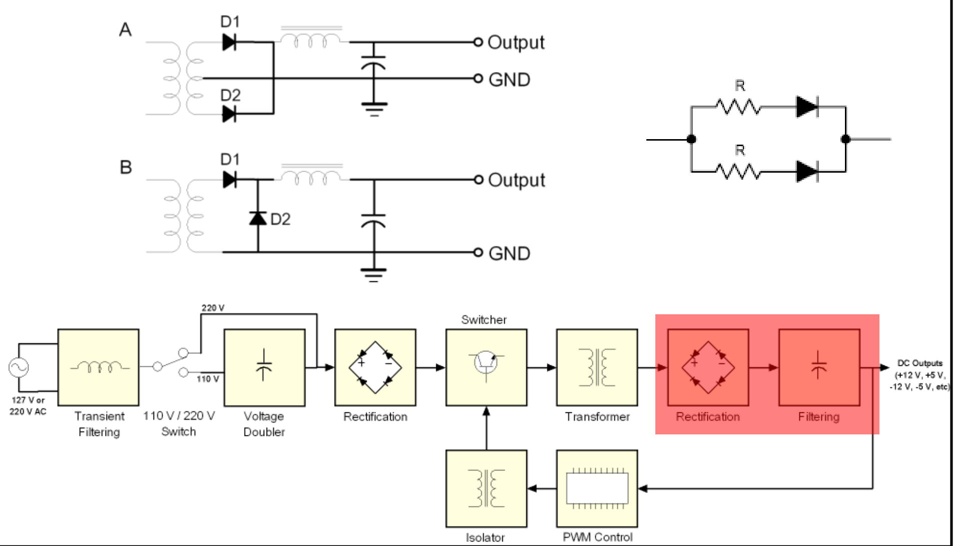


・PFM control (Pulse Frequency Modulation)

PFM is of two types: the fixed-on time type and the fixed-off time type. In the case of the fixed-on time type as an example (see the figure below), on-time is fixed with variable off-time. In other words, the length of time it takes for the power to turn on next time varies. When the load increases, the number of on-times in a given length of time is increased to keep pace with the load. Thus, under a heavy load, the frequency increases, and under a light load it diminishes.

On the positive side, because not a great deal of power needs to be added during a light-load operation, the switching frequency is reduced, and the number of required switching operations decreases, with reduces switching losses. As a consequence, the PFM method ensures that high efficiency is maintained even at a light load. On the negative side, because the frequency varies, the noise associated with the switching remains indefinite, making the filtering process difficult to control and the noise difficult to remove. Also, if noise enters below 20 kHz, which is an audible band, the problem of ringing can occur, which produces an adverse impact on S/N in audio devices. As far as noise is concerned, PWM may be preferable in many respects.

SMPS Rectifier & Filter



The Rectifier and Filter

Finally, the secondary stage. Here the outputs of the main transformer are rectified and filtered and then delivered to the PC. The rectification of the negative voltages (-5 V and –12 V) is done by conventional diodes, since they don’t demand a lot of power and current. But for the rectification of the positive voltages (+3.3 V, +5 V and +12 V) is done by power Schottky rectifiers, that are three-terminal components that look like power transistors but they have two power diodes inside. The way rectification is done depends on the power supply model and two configurations are possible, shown in Figure above.

Configuration “A” is more used by low-end power supplies. As you can see, this configuration needs three pins from the transformer. Configuration “B” is more used by high-end power supplies. Here only two transformer pins are used, however the ferrite coil must be physically bigger and thus more expensive, and that is one of the main reasons low-end power supplies don’t use this configuration.

Also on high-end power supplies, in order to increase the maximum current the power supply can deliver two power diodes can be connected in parallel, thus doubling the maximum current the circuit can handle.

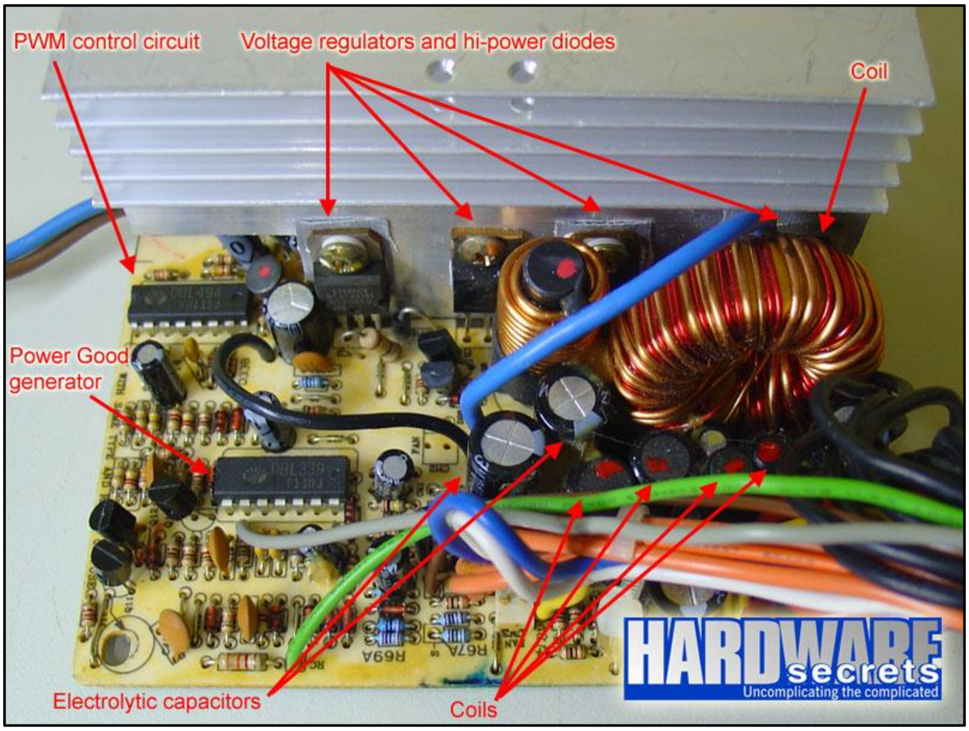
Diodes can be connected in parallel to increase the current-handling capability of the circuit. Each diode should have a series current-equalizing

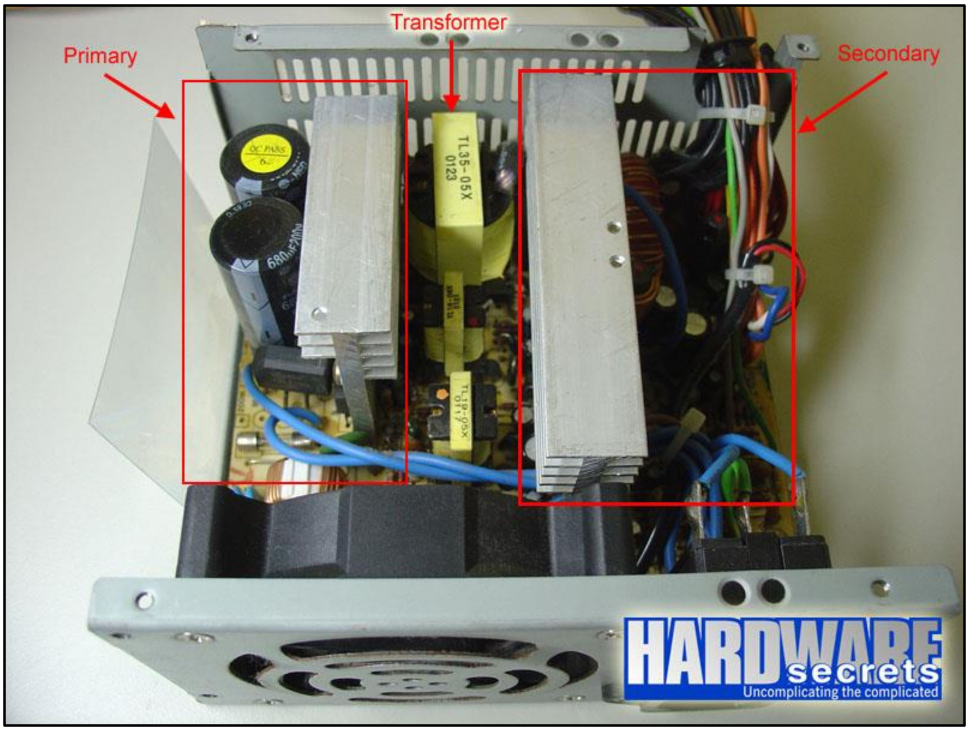
resistor, with a value selected to provide a few tenths of a volt drop at the expected current.

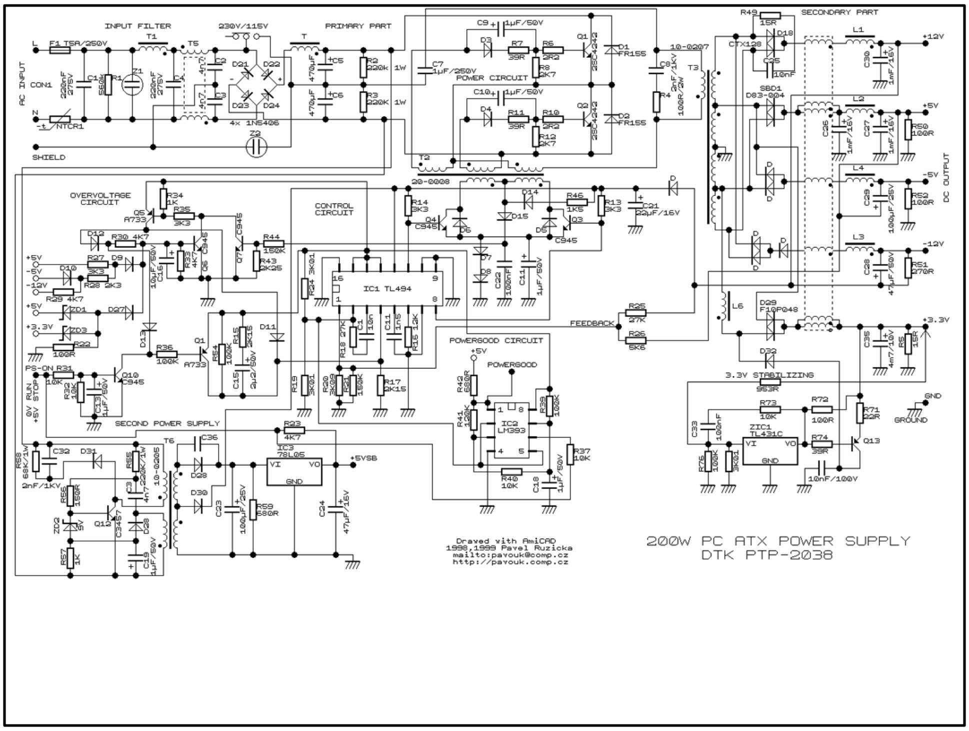
If the output is required to be isolated from the input, as is usually the case in mains power supplies, the inverted AC is used to drive the primary winding of a high-frequency transformer. This converts the voltage up or down to the required output level on its secondary winding. The output transformer in the block diagram serves this purpose.

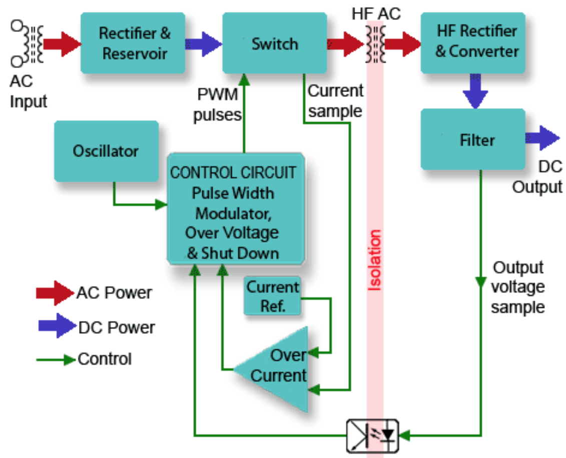
If a **DC** output is required, the **AC** output from the transformer is rectified. For output voltages above ten volts or so, ordinary silicon diodes are commonly used. For lower voltages, Schottky diodes are commonly used as the rectifier elements; they have the advantages of faster recovery times than silicon diodes (allowing low-loss operation at higher frequencies) and a lower voltage drop when conducting. For even lower output voltages, MOSFETs may be used as synchronous rectifiers; compared to Schottky diodes, these have even lower conducting state voltage drops.

The rectified output is then smoothed by a filter consisting of inductors and capacitors. For higher switching frequencies, components with lower capacitance and inductance are needed.


PWM control circuit
Voltage regulators and hi-power diodes
Coil
Power Good generator
Electrolytic capacitors
Coils
HARDWARE secrets
Uncomplicating the complicated


Primary
Transformer
Secondary
TL35-05X
0123
HARDWARE secrets
Uncomplicating the complicated


200W PC ATX POWER SUPPLY
DTK PTP-2038
Drawed with AmiCAD
1998,1999 Pavel Ruzicka
mailto:pavouk@comp.cz
http://pavouk.comp.cz
INPUT FILTER
PRIMARY PART
SECONDARY PART
POWER CIRCUIT
CONTROL CIRCUIT
OVERVOLTAGE CIRCUIT
POWERGOOD CIRCUIT
SECOND POWER SUPPLY
3.3V STABILIZING
FEEDBACK
AC INPUT
DC OUTPUT
SHIELD
GROUND



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