

Objectives

To become familiar with:

- The components of a linear power supply;
- The function of these components;
- The relative position of these components in a block diagram;
- Monitoring the output of a power supply; and
- The basic function of a Switched Mode Power Supply.

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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.**

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A **power supply** is an electrical device that supplies **electric power** to an **electrical load**. The primary function of a power supply is to convert **electric current** from a source to the correct **voltage, current, and frequency** to power the load. As a result, power supplies are sometimes referred to as **electric power converters**. Some power supplies are separate standalone pieces of equipment, while others are built into the load appliances that they power. Examples of the latter include power supplies found in **desktop computers** and **consumer electronics** devices. Other functions that power supplies may perform include limiting the current drawn by the load to safe levels, shutting off the current in the event of an **electrical fault**, power conditioning to prevent **electronic noise** or **voltage surges** on the input from reaching the load, **power-factor correction**, and storing energy so it can continue to power the load in the event of a temporary interruption in the source power (**uninterruptible power supply**).

All power supplies have a *power input* connection, which receives energy in the form of electric current from a source, and one or more *power output* connections that deliver current to the load. The source power may come from the **electric power grid**, such as an **electrical outlet**, **energy storage** devices such as **batteries** or **fuel cells**, **generators** or **alternators**, **solar power** converters, or another power supply. The input and output are usually hardwired circuit connections, though some power supplies employ **wireless energy transfer** to power their loads without wired connections. Some power supplies have other types of inputs and outputs as well, for functions such as external monitoring and control.



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
- TS-890S HF Transceiver 22.5 amps

- All these require 13.8 VDC

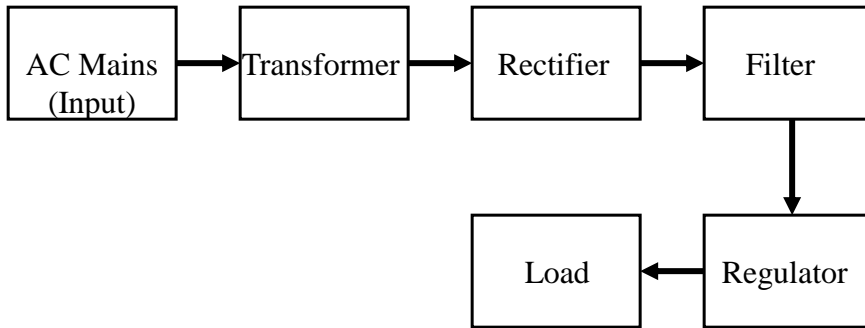
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Power Supply Requirements

- **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**.

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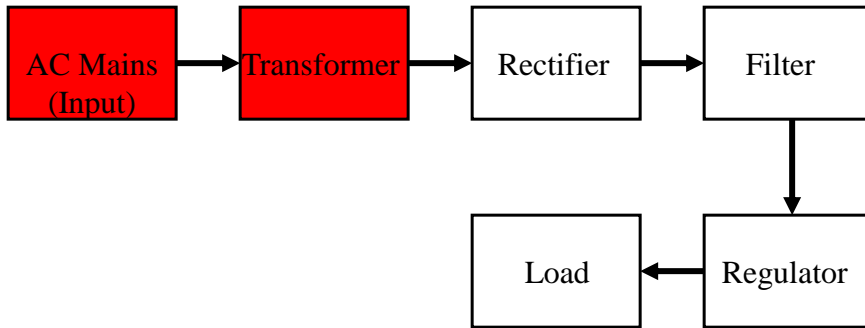
Linear Power Supply Diagram



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Know this diagram for the test!

Linear Power Supply Diagram



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AC Mains and Transformer

- **AC Mains** – Power from the wall plug; 120 VAC at 60 Hz in North America. 240 VAC circuits also available.
- **Transformer** – **Converts** the AC mains **voltage** up or down as required. Also provides **isolation** for the load from the mains.

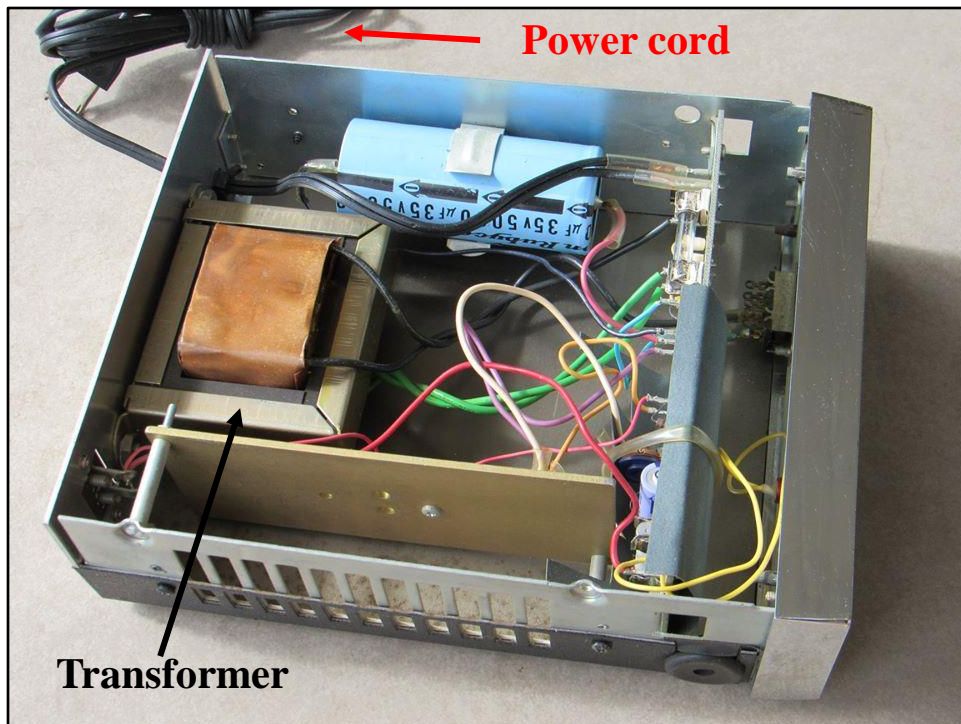
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Mains electricity (as it is known in the UK and some parts of Canada; US terms include **utility power**, **grid power**, **domestic power** and **wall power** in much of Canada it is known as **hydro**) is the general-purpose **alternating-current** (AC) **electric power** supply. It is the form of **electrical power** that is **delivered** to homes and businesses, and it is the form of electrical power that consumers use when they plug items such as domestic appliances, televisions and electric lamps into wall outlets.

The two principal properties of the electric power supply, **voltage** and **frequency**, differ between regions. A voltage of (nominally) 230 V and a frequency of 50 Hz is used in Europe, most of Africa, most of Asia, much of South America and Australia. In North America, the most common combination is 120 V and a frequency of 60 Hz. Other voltages exist, and some countries may have, for example, 230 V but 60 Hz. This is a concern to travellers, since portable appliances designed for one voltage and frequency combination may not operate with, or may even be destroyed by another. The use of different and incompatible **plugs and sockets** in different regions and countries provides some protection from accidental use of appliances with incompatible voltage and frequency requirements.

Transformers are devices **used** in **electrical** circuits to change the voltage of **electricity** flowing in the circuit. **Transformers** can be **used** either to increase the voltage (called "stepping up") or decrease the voltage ("step down").

An **isolation transformer** is a **transformer** used to transfer **electrical power** from a source of **alternating current** (AC) power to some equipment or device while isolating the powered device from the power source, usually for safety reasons. Isolation transformers provide **galvanic isolation** and are used to protect against **electric shock**, to suppress electrical noise in sensitive devices, or to transfer power between two circuits which must not be connected. A transformer sold for isolation is often built with special insulation between primary and secondary, and is specified to withstand a high voltage between windings.



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:

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

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Transformers are capable of either increasing or decreasing the voltage and current levels of their supply, without modifying its frequency, or the amount of electrical power being transferred from one winding to another via the magnetic circuit.

Notice that the two coil windings are not electrically connected but are only linked magnetically. A single-phase transformer can operate to either increase or decrease the voltage applied to the primary winding. When a transformer is used to “increase” the voltage on its secondary winding with respect to the primary, it is called a **Step-up transformer**. When it is used to “decrease” the voltage on the secondary winding with respect to the primary it is called a **Step-down transformer**.

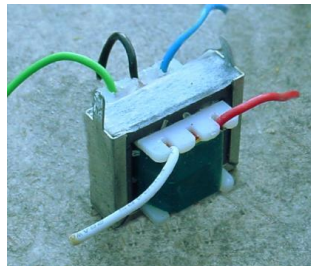
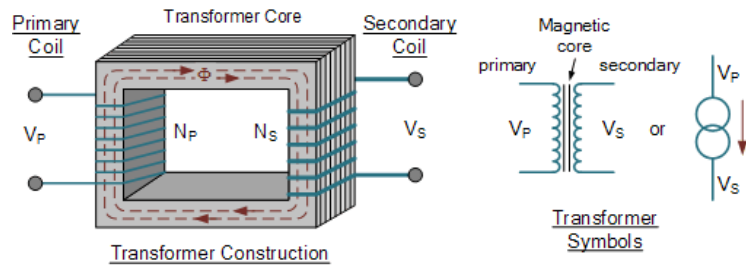
The difference in voltage between the primary and the secondary windings is achieved by changing the number of coil turns in the primary winding (N_p) compared to the number of coil turns on the secondary winding (N_s).

As the transformer is basically a linear device, a ratio now exists between the number of turns of the primary coil divided by the number of turns of the secondary coil. This ratio, called the ratio of transformation, more commonly known as a transformers “turns ratio”, (TR). This turns ratio value dictates the operation of the transformer and the corresponding voltage available on the secondary winding.

It is necessary to know the ratio of the number of turns of wire on the primary winding compared to the secondary winding. The turns ratio, which has no units, compares the two windings in order and is written with a colon, such as 3:1 (3-to-1). This means in this example, that if there are 3 volts on the primary winding there will be 1 volt on the secondary winding, 3 volts-to-1 volt. Then we can see that if the ratio between the number of turns changes the resulting voltages must also change by the same ratio, and this is true.

Transformers are all about “ratios”. The ratio of the primary to the secondary, the ratio of the input to the output, and the turns ratio of any given transformer will be the same as its voltage ratio. In other words for a transformer: “turns ratio = voltage ratio”. The actual number of turns of wire on any winding is generally not important, just the turns ratio and this relationship is given above.

Transformers



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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?*

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These are RMS voltages. Remember that peak voltages will be 1.414 times the RMS (or $\text{RMS} = 0.707 \times \text{Peak Voltage}$).

Example (2)

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

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Example (3)

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

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

- $T_{\text{sec}} =$

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Example (4)

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

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

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

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Example (5)

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

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

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

- $T_{\text{sec}} =$

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Example (6)

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

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

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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.

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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.

Transformers are an energy transfer device that transfers power from the primary side to the secondary side without altering the energy level (considering zero power loss). Iron loss and copper loss occurring in the transformer are also independent of the power factor. Moreover, the output power factor of the transformer purely depends on the connected load. The transformer does not alter the power factor of its output power. VA is the unit of apparent power. It is a combination of real power and reactive power. Transformers are manufactured without considering the load being connected. So any kind of electrical load can be connected to it (either resistive, capacitive, inductive or combination loads). If the transformer is rated in Watts, there may be confusions regarding the type of load being connected. This is why the transformer is rated in VA. By doing so we can eliminate the confusions regarding the type of load being connected.

Power Rating Example

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

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Power Rating Example (2)

- Power = Voltage x Current
- Power =

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Power Rating Example (3)

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

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Power Rating Example (4)

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

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Power Rating Example (5)

- Power = Voltage x Current
- Power = 13.8 VDC x 20 Amps = 276 Watts
- Transformer is rated at 250 VA, so....

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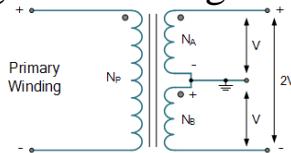
Power Rating Example (6)

- 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!

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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!



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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 $12 \text{ V} \times 10 \text{ A}$, 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 (kVA). 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 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.

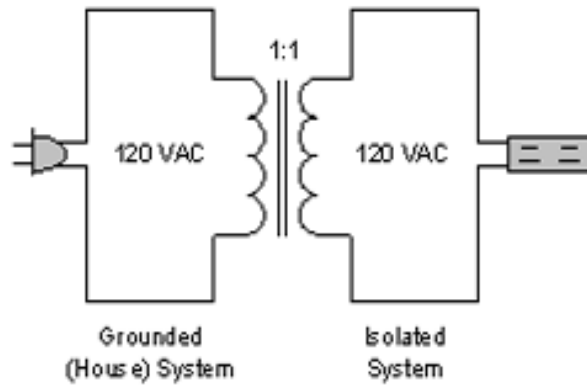
Isolation

- 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**.

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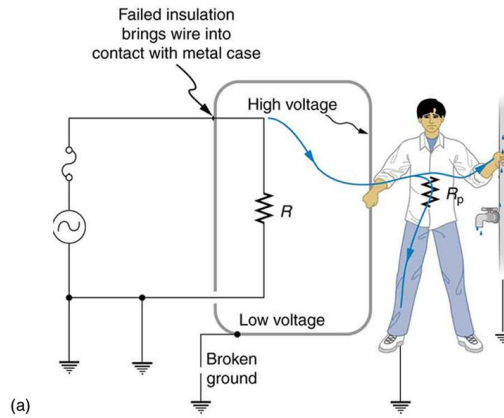
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Isolation Transformer



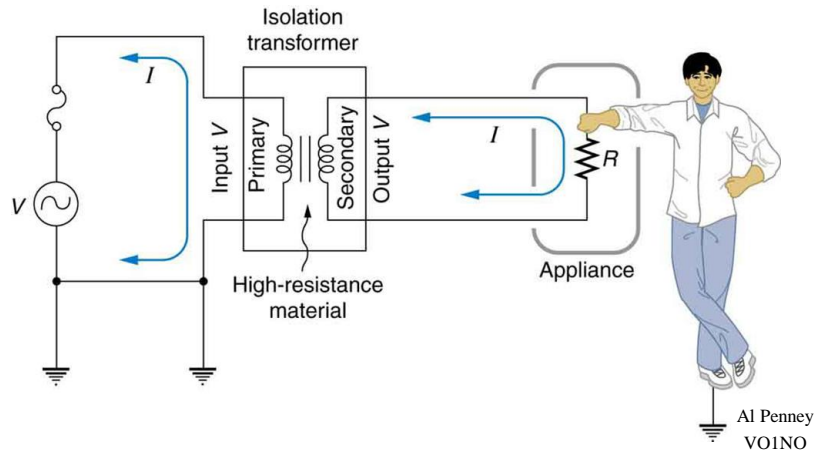
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Without Isolation Transformer

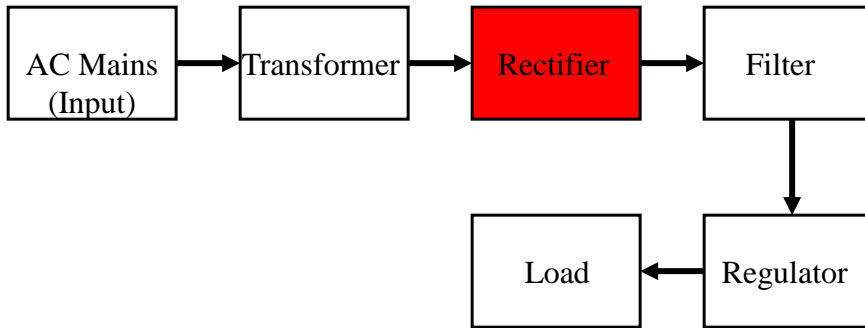


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With Isolation Transformer



Linear Power Supply Diagram



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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.

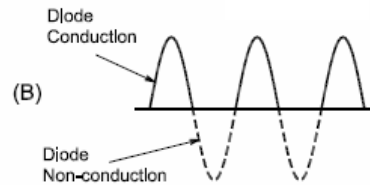
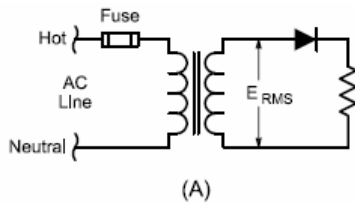
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A **rectifier** is an electrical device that **converts alternating current** (AC), which periodically reverses direction, to **direct current** (DC), which flows in only one direction.

The process is known as *rectification*, since it "straightens" the direction of current. Physically, rectifiers take a number of forms, including **vacuum tube diodes**, wet chemical cells, **mercury-arc valves**, stacks of copper and selenium oxide plates, **semiconductor diodes**, **silicon-controlled rectifiers** and other silicon-based semiconductor switches. Historically, even synchronous electromechanical switches and motors have been used. Early radio receivers, called **crystal radios**, used a "cat's whisker" of fine wire pressing on a crystal of **galena** (lead sulfide) to serve as a point-contact rectifier or "crystal detector".

Rectifiers have many uses, but are often found serving as components of DC **power supplies** and **high-voltage direct current** power transmission systems. Rectification may serve in roles other than to generate direct current for use as a source of power.

Half Wave Rectification



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The half wave rectifier circuit is the simplest form of rectifier circuit that can be used, and although it may not provide the highest level of performance in some aspects, it is nevertheless very widely used.

Half wave diode rectifier applications

The half wave diode rectifier is used in a variety of ways and in a host of different types of circuit.

•**Power rectification:** One of the most obvious ways for a half wave diode rectifier to be used is within a power rectifier. A line or mains power input normally passes through a transformer to transform the voltage to the required level.

•**Signal demodulation:** A simple half wave diode rectifier can be used for signal demodulation of amplitude modulated signals. The rectification process enables the amplitude modulation to be recovered. (will cover this in Chapter 14 – Receivers).

The basics of the operation of a half wave rectifier circuit are quite straightforward. The incoming signal is passed through a diode. As this can only pass current in one direction, it only passes that part of the waveform that for which the diode is forward biased.

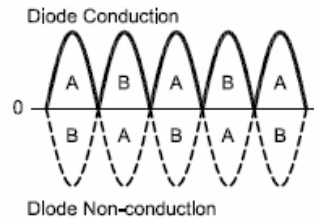
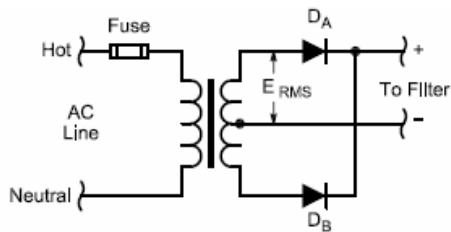
The half wave rectifier circuit normally utilises a single diode. The incoming signal is connected directly to the diode and the diode is in turn connected to a load as shown in the half wave rectifier circuit above.

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.

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Full Wave Rectification Center-Tap Transformer



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Full Wave Rectifier Circuit

The bridge rectifier provides significant advantages over the half wave rectifier, allowing better smoothing and better efficiency.

The full wave rectifier is more complicated than the half wave version, but the full wave rectifier offers some significant advantages, and as a result it is almost exclusively used in this area.

Full wave rectifier: basics

The concept of the full wave rectifier is that it utilises both halves of the waveform to provide an output and this greatly improves its efficiency.

A further advantage when used in a power supply is that the resulting output is much easier to smooth. When using a smoothing capacitor, the time between the peaks is much greater for a half wave rectifier than for a full wave rectifier.

Like the half wave circuit, a full wave rectifier circuit produces an output voltage or current which is purely DC or has some specified DC component. Full wave rectifiers have some fundamental advantages over their half wave rectifier counterparts. The average (DC) output voltage is higher than for half wave, the output of the full wave rectifier has much less ripple than that of the half wave rectifier producing a smoother output waveform.

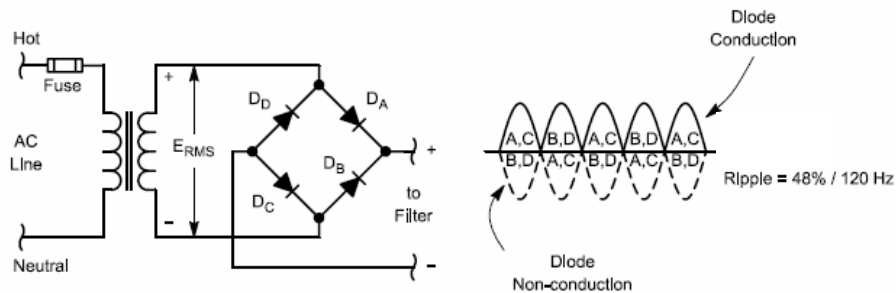
Full Wave Rectification Center-Tap Transformer

- **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**.

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Like the half wave circuit, a full wave rectifier circuit produces an output voltage or current which is purely DC or has some specified DC component. Full wave rectifiers have some fundamental advantages over their half wave rectifier counterparts. The average (DC) output voltage is higher than for half wave, the output of the full wave rectifier has much less ripple than that of the half wave rectifier producing a smoother output waveform.

Full Wave Rectification Without a Center Tap Transformer



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Bridge rectifier circuit: The full wave bridge rectifier circuit configuration is far more widely used these days. It offers a more efficient use of the transformer as well as not requiring a centre-tapped transformer. The additional cost is two additional diodes - not an expensive addition these days. Often four diode bridges can be bought as single items, making construction of the overall circuit much simpler.

In view of their advantages, full wave rectifier circuits are virtually always used in preference to half wave circuits. The increased efficiency coupled with the better smoothing ability arising from the shorter time between peaks means that their advantages outweigh the disadvantages by a long way. Only occasionally, often for low requirement supplies would a half wave rectifier be used in preference to the full wave rectifier circuit.

The Full Wave Bridge Rectifier

Another type of circuit that produces the same output waveform as the full wave rectifier circuit above, is that of the **Full Wave Bridge Rectifier**. This type of single phase rectifier uses four individual rectifying diodes connected in a closed loop "bridge" configuration to produce the desired output.

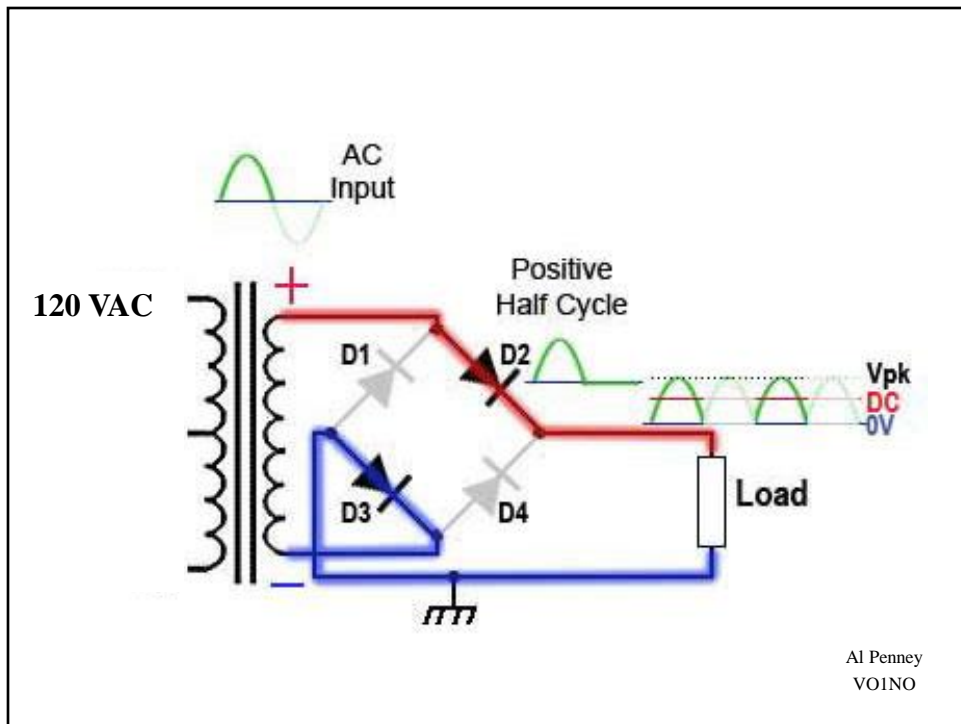
The main advantage of this bridge circuit is that it does not require a special centre tapped transformer, thereby reducing its size and cost. The single secondary winding is connected to one side of the diode bridge network and the load to the other side as shown

Full Wave Rectification Without a Center Tap Transformer

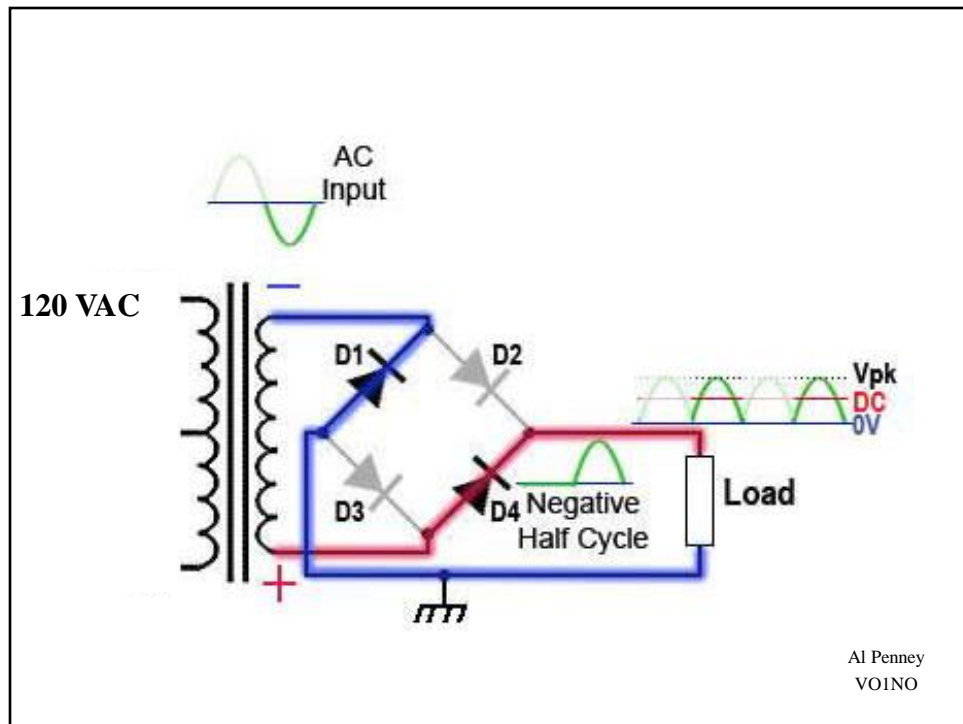
- This method **eliminates** the requirement for a **center tap transformer**.
- It uses a **Full Wave Bridge Rectifier**.
- Note the polarity of the diodes – two will conduct and two will not conduct on each half-cycle.
- For a given transformer, this gives **twice the output voltage** as the full wave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

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During positive half cycle, D2 and D3 conduct.



During negative half cycle D1 and D4 conduct.

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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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

- $I_{f_{avg}}$ – **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.

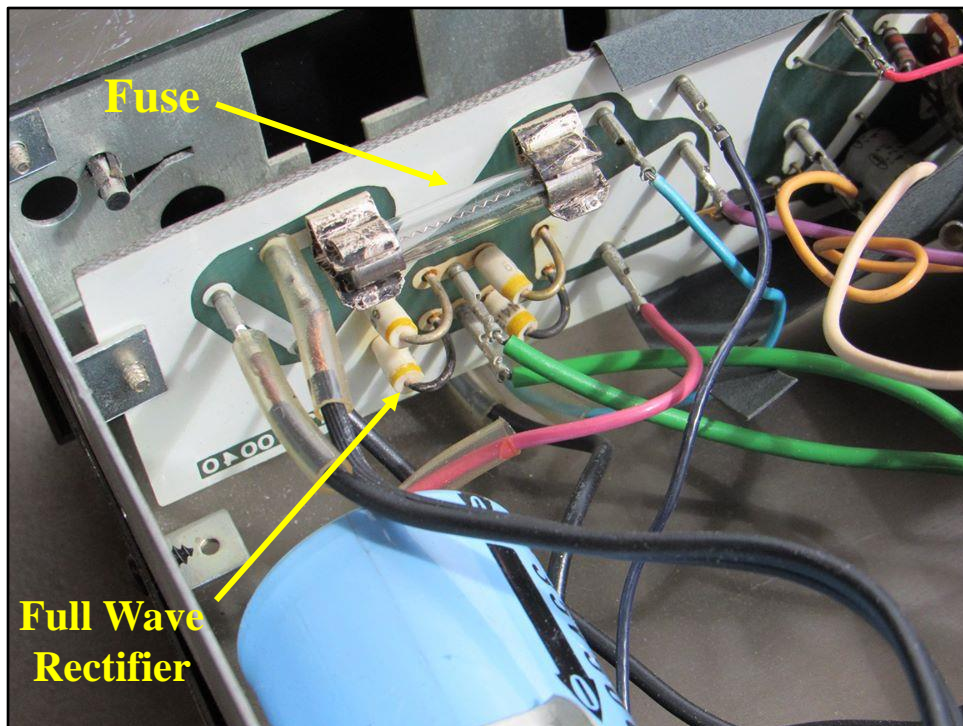
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Maximum Forward Current

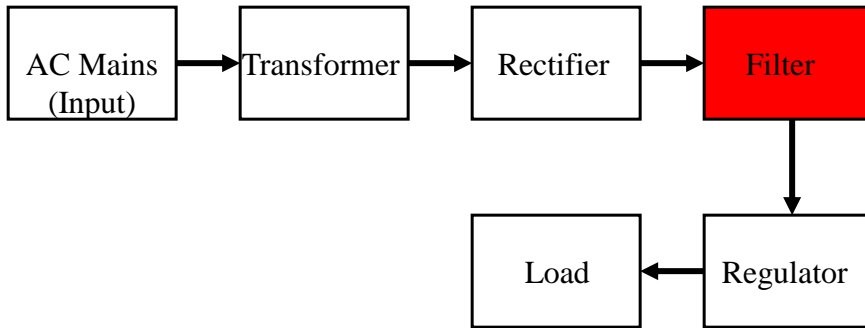
The **Maximum Forward Current** ($I_{F(max)}$) is as its name implies the *maximum forward current* allowed to flow through the device. When the diode is conducting in the forward bias condition, it has a very small “ON” resistance across the PN junction and therefore, power is dissipated across this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



Linear Power Supply Diagram



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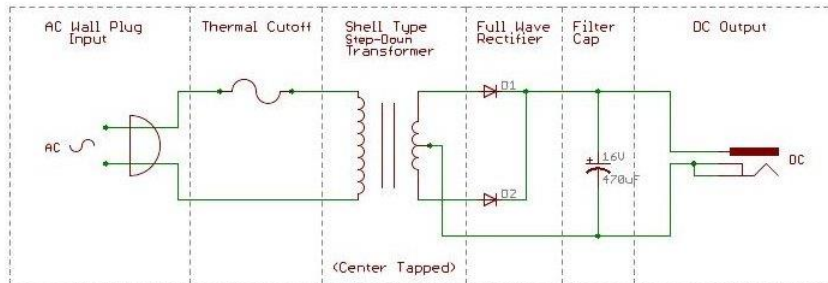
Filtering the DC

- 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**.
- The most basic basic filtering circuit is a single **capacitor**.

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Simple Full Wave Power Supply

6VDC 300mA Rated AC Adaptor (Wall Wart)



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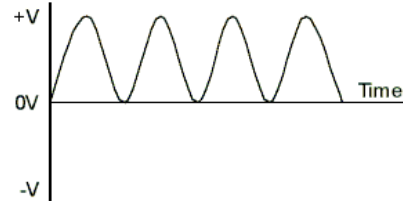
We can improve the average DC output of the rectifier while at the same time reducing the AC variation of the rectified output by using smoothing capacitors to filter the output waveform. Smoothing or reservoir capacitors connected in parallel with the load across the output of the full wave bridge rectifier circuit increases the average DC output level even higher as the capacitor acts like a storage device as shown below.

Voltage Output

Straight from
Rectifier stage

After filtering by
the Capacitor

Input from Rectifier



Smoothed Output

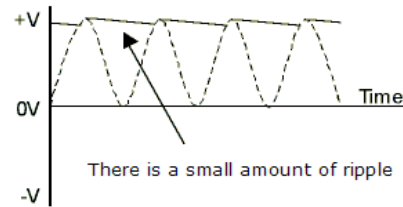
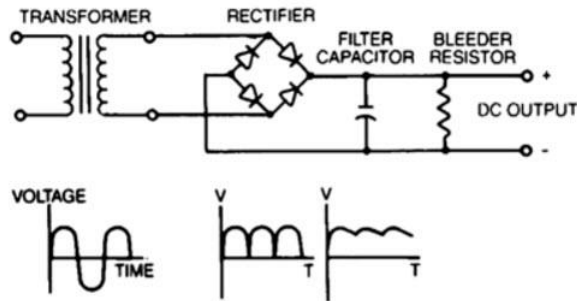


Figure 2: Smoothing

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Capacitor alternately charges and discharges in an attempt to keep the voltage from changing.

Single Capacitor Filter

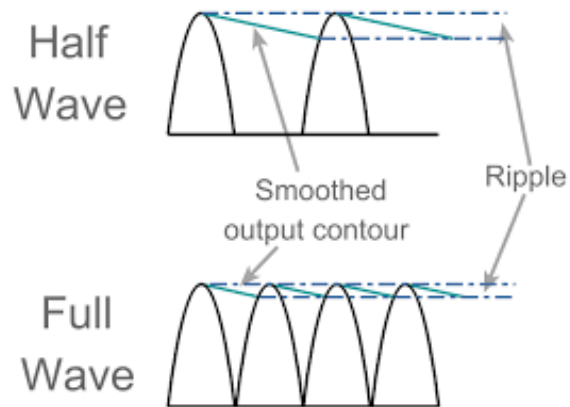


- Note that there is no series resistor to slow charging of capacitor when supply turned on.
- Inrush current will eventually damage rectifier.

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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](#).

Half Wave versus Full Wave



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Full wave rectifier advantages and disadvantages

Although the full wave rectifier circuit requires more diodes than a half wave rectifier circuit, it has advantages in terms of utilising both halves of the alternative waveform to provide the output.

Full wave rectifier advantages

- Utilises both halves of the AC waveform
- Easier to provide smoothing as a result of ripple frequency

Full wave rectifier disadvantages

- More complicated than half wave rectifier
- The twice frequency hum on an audio circuit may be more audible

Two diode full wave rectifier circuit: The two diode full wave rectifier circuit is not so widely used with semiconductor diodes as it requires the use of a **centre tapped transformer**. However this rectifier circuit was widely used in the days of thermionic valves / vacuum tubes. As a rectifier circuit using four valves would be large, the two diode version was much more preferable.

Filter Capacitor

- Ensure the filter capacitor has a voltage rating **at least 1.5 times** output voltage.
- Filter capacitors can leak or dry out, leading to AC hum on RX and/or TX.
- For **full wave rectifiers**, what most people call “60 cycle hum” is actually **120 Hz!**

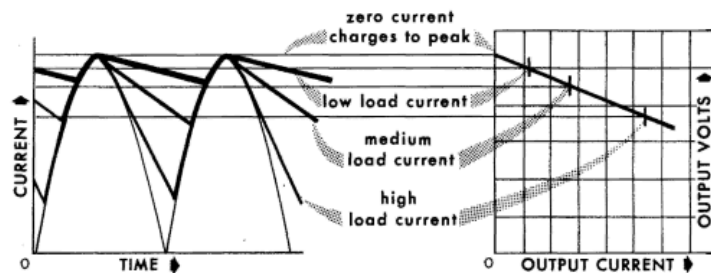
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Single Capacitor Filter

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

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Simple Capacitor Filter Shortcomings



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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 power is turned off.
- **Improves voltage regulation** by providing a minimum load resistance.
- Should draw ~5% of full load current.
- $\text{Power} = E^2 / R$
- Will have to **dissipate heat!**

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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.

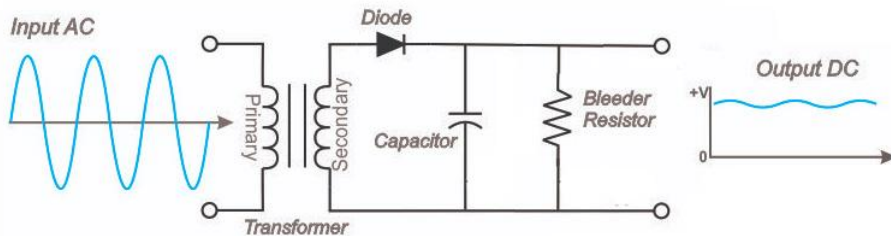
In case of bleeder resistor connected in the circuit, the difference between the no-load and full load voltage is very less. Consequently, this leads to improved voltage regulation.

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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In electronics, a **bleeder resistor** is a **resistor** connected in **parallel** with the output of a high-voltage **power supply** circuit for the purpose of discharging the electric charge stored in the power supply's **filter capacitors** when the equipment is turned off, for safety reasons. It eliminates the possibility of a leftover charge causing **electric shock** if people handle or service the equipment in the off state, believing it is safe. A bleeder resistor is usually a standard resistor rather than a specialized component.

The **power supply** circuits in electronic equipment that produce **direct current** (DC) needed by the device from the **alternating current** (AC) supplied by **mains** use **filter capacitors** to smooth the DC current. A large **electric charge** can remain in these capacitors after the unit is turned off, constituting a shock hazard. For example **switching mode power supplies** use a **bridge rectifier** to convert mains AC power into DC at 320 V (for 220 V mains) or 160 V (for 115 V. mains), before the voltage is reduced by the **chopper**. These incorporate one or more **filter capacitors** to smooth the pulsing output voltage from the rectifier. These must typically store enough energy at this high voltage to power the load during the zero crossings of the AC input. In addition, the capacitors in many supplies are made large enough to supply the load during AC outages lasting for a significant fraction of a second. This stored charge is often enough to deliver a lethal shock. The capacitors in high voltage DC power supplies used in devices such as **lasers**, **x-ray machines**, **radio transmitters** and old style **CRT computer monitors** and **televisions** can have higher, more dangerous voltages.

This stored **charge** can remain in the capacitors for a long time after the unit has been turned off. It can be a potentially lethal shock hazard for the user or maintenance and servicing personnel, who may believe that because the device is turned off or unplugged it is safe. Therefore, to discharge the capacitor after the supply has been turned off, a large-value **resistor** is connected across its terminals. After it is switched off, the charge on the capacitor will drain off through this "bleeder resistor", causing the voltage to decay quickly to safe levels.

While the power supply is on, a small current flows through the bleeder resistor, wasting a small amount of power. The value of the resistor is chosen to be low enough that the charge on the capacitor bleeds off quickly, but high enough that the resistor will not consume too much power while the supply is on.

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.

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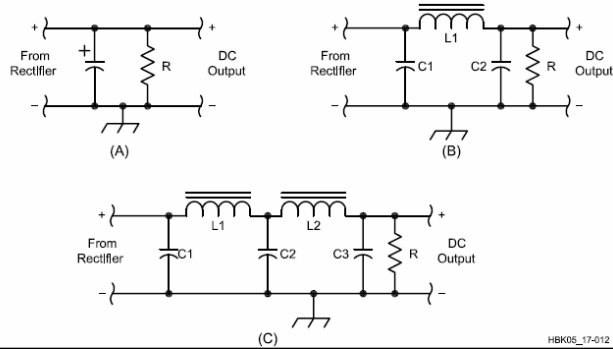
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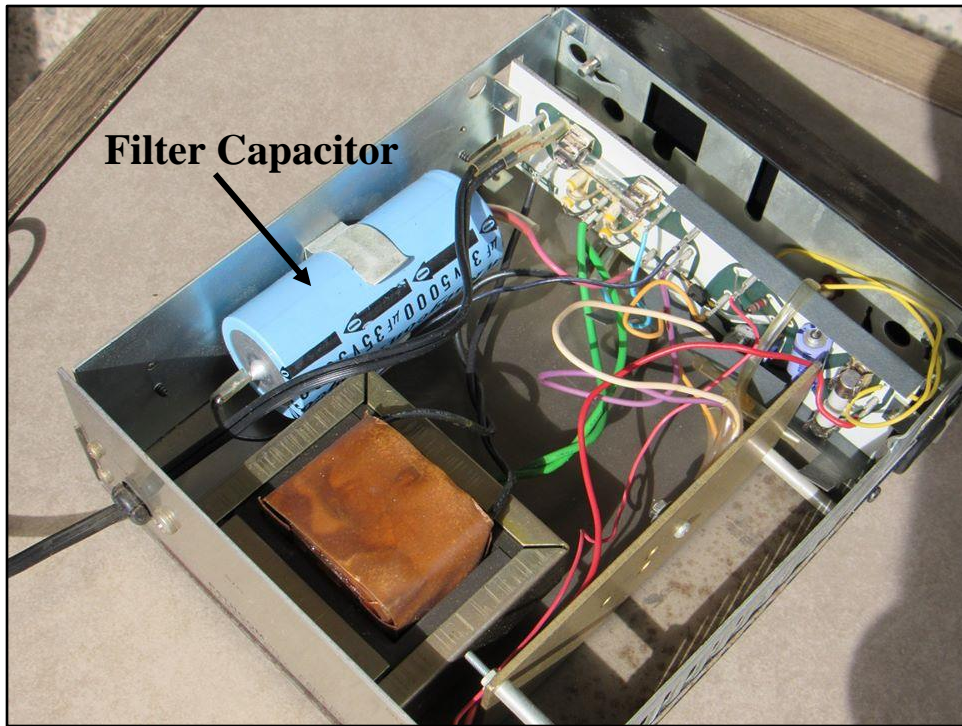
Power Supply Filters

- For applications where more stringent filtering is required, extra stages of capacitors and inductors can be added:

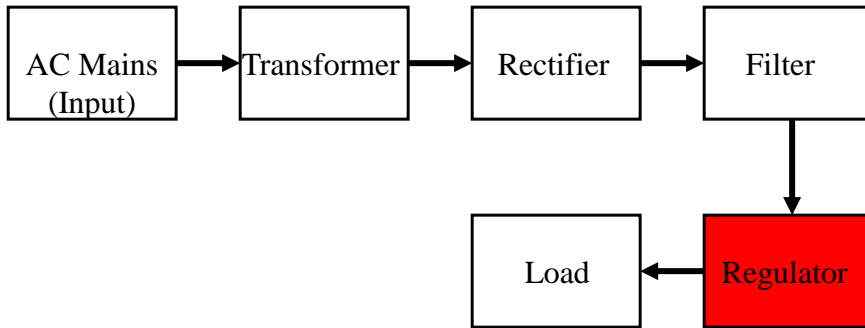


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Linear Power Supply Diagram



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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!

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In [electronics](#), a **linear regulator** is a system used to maintain a steady voltage. The resistance of the regulator varies in accordance with both the input voltage and the load, resulting in a constant voltage output. The regulating device is made to act like a variable [resistor](#), continuously adjusting a [voltage divider](#) network to maintain a constant output voltage and continually dissipating the difference between the input and regulated voltages as [waste heat](#). By contrast, a [switching regulator](#) uses an active device that switches on and off to maintain an average value of output. Because the regulated voltage of a linear regulator must always be lower than input voltage, efficiency is limited and the input voltage must be high enough to always allow the active device to drop some voltage.

Linear regulators may place the regulating device in parallel with the load ([shunt](#) regulator) or may place the regulating device between the source and the regulated load (a series regulator). Simple linear regulators may only contain as little as a [Zener diode](#) and a series resistor; more complicated regulators include separate stages of voltage reference, error amplifier and power pass element. Because a linear [voltage regulator](#) is a common element of many devices, single-chip regulators [ICs](#) are very common. Linear regulators may also be made up of assemblies of discrete solid-state or [vacuum tube](#) components.

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.

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The shunt regulator or shunt voltage regulator is a form of voltage regulator where the regulating element shunts the current to ground.

The shunt regulator operates by maintaining a constant voltage across its terminals and it takes up the surplus current to maintain the voltage across the load.

One of the most common examples of the shunt regulator is the simple Zener diode circuit where the Zener diode acts as the shunt element.

As such the shunt voltage regulator is an essential element within linear power supply technology.

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.

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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 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

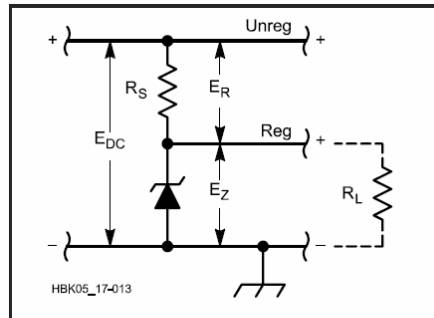
be as low as $1\ \Omega$ or less in a low-voltage, high-power diode or as high as $1000\ \Omega$ in a high-voltage, low-power diode.

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**.

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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.

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One of the most common and simple forms of shunt regulator is the simple Zener diode regulator circuit shown below. Its operation is very straightforward. Once over its small minimum current, the Zener diode maintains an almost constant voltage across its terminals.

In this circuit, the series resistor drops the voltage from the source to the Zener diode and load. As the Zener diode maintains its voltage, any variations in load current do not affect the voltage across the Zener diode.

It takes up the current variations required to ensure the correct drop across the series resistor. In this way it shunts sufficient current to maintain the voltage across its terminals and hence the load.

Shunt voltage regulators are not particularly effective or efficient in high current situations,. The simple Zener diode voltage regulator, when used as a low current voltage reference is widely used, and its inefficiency can be tolerated in view of the low current. Often shunt regulators are used as voltage reference sources from which much higher current series regulators are driven.

Series Regulator

- Most common approach for power supplies that require higher levels of performance.
- Variable element in series with the load.
- Resistance inside the element changes to adjust voltage drop across it and ensure load voltage remains constant.
- More efficient than Shunt Regulators.

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The series voltage regulator or as it is sometimes called the series pass regulator is the most commonly used approach for providing the final voltage regulation in a linear regulated power supply.

The series linear regulator provides a high level of performance, especially when low noise, ripple and transients are required in the regulated output.

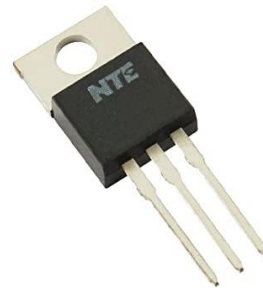
The series voltage regulator or series pass voltage regulator uses a variable element placed in series with the load. By changing the resistance of the series element, the voltage dropped across it can be varied to ensure that the voltage across the load remains constant.

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 voltage regulator, the series regulator does not draw the full current even when the load does not require any current. As a result the series voltage regulator is considerably more efficient.

Instead of drawing the current not required by the load to maintain the voltage, it drops the voltage difference between the input voltage and the required stabilised voltage.

Three Terminal Regulators

- Common type of Series Regulator.
- 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.

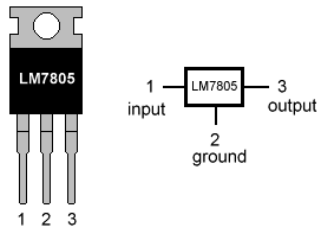


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Three Terminal Voltage Regulator is IC based voltage regulator designed with fixed predetermined output voltage value. It does not require external feedback elements.

Three Terminal Regulators

LM7805 PINOUT DIAGRAM

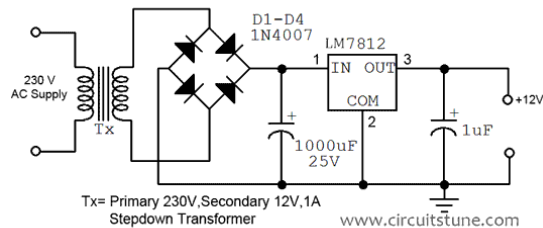


- LM7800/7900 series regulators produce regulated outputs ranging from 5 to 24 VDC up to 5 amps, positive for 7800 series, negative for 7900 series.

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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.

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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 convert 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 1000µF, 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 12V 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).

Even though a series regulator is considerably more efficient than a shunt regulator, it is considerably less efficient than a switch mode power supply. The efficiency of a series voltage regulator and any linear power supplies using them will depend on the load, etc, but often efficiency levels of less than 50% are achieved, whereas switch mode power supplies can achieve levels greater than 90%.

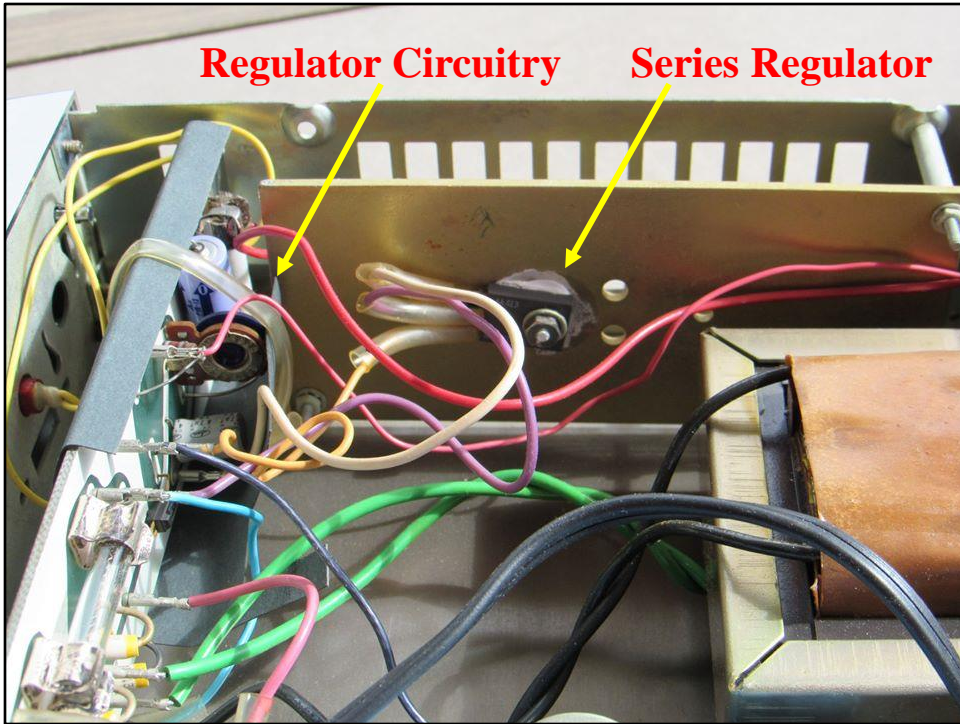
Series voltage regulators have relatively low levels of efficiency when compared to a switch mode power supply, but they have the advantages of simplicity and also their output is free of the switching spikes seen on some switch mode supplies, although SMPSs are improving and the performance of many is exceptionally good nowadays.

Crowbar Protection

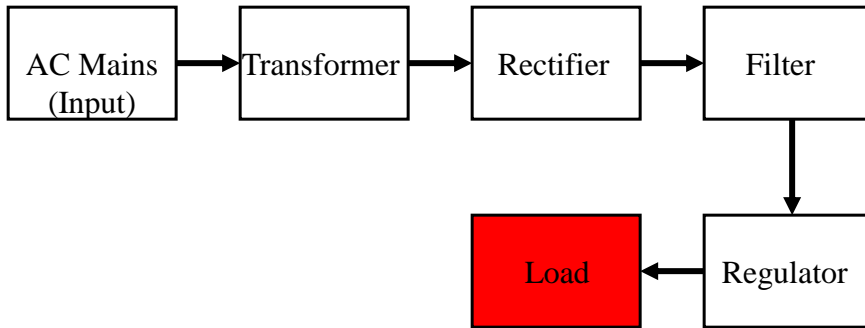
- Circuit that protects load equipment in the event of **overvoltage** caused by failure of the regulator.
- Circuit senses overvoltage and activates a device to short circuit the power supply.
- This causes power supply's **fuse to blow**.

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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 – Silicon Controlled Rectifier) 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.



Linear Power Supply Diagram



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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.

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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.
- Chirp can also be caused by RF feedback and insufficient isolation between transmitter's stages.

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CHIRP

"Chirp" is a change in frequency when the transmitter is keyed on (by pressing the Morse key) and keyed off (the release of the Morse key) when the Morse characters are being formed. - thus the change in frequency would be heard on a receiver at the start and end of each keying stroke.

Chirp Causes

There are three main causes of chirp :-

Poor design of the transmitter

1. DC Instability caused by poor voltage regulation.
2. Pulling

RF Feedback

1. RF Feedback getting back into the frequency determining stage (oscillators)

DC Instability - changes in voltage of the supply rail going to the oscillator of the transmitter when the transmitter is keyed. This particularly happens when the power supply to the oscillator is the same as the power supply to the PA.

REMEDY Use separate power supplies for the oscillator and PA and ensure high level of regulation and stabilisation to power supply of the oscillator.

Pulling This is where the frequency of other stages changes due to the keying of the transmitter.

REMEDY Provide better isolation of the oscillator from the other stages .

RF Feedback This is where stray RF signals are finding there way back into earlier stages. Such feed back might be by poor constructional layout.

REMEDY Greater attention to the detail of screening leads carrying RF and keeping leads as short as possible and the use of decoupling capacitors on the power lines.

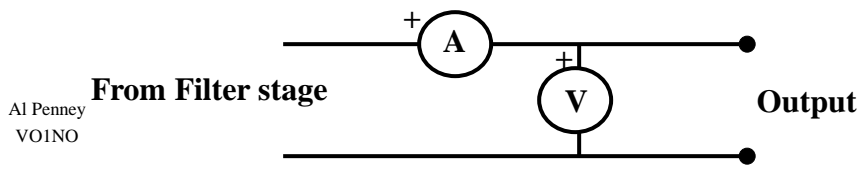
Monitoring the Output

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

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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.



A **voltmeter** is an instrument used for measuring [electrical potential](#) difference between two points in an electric circuit. Analog voltmeters move a pointer across a scale in proportion to the voltage of the circuit; digital voltmeters give a numerical display of voltage by use of an [analog to digital converter](#).

Voltmeters are made in a wide range of styles. Instruments permanently mounted in a panel are used to monitor generators or other fixed apparatus. Portable instruments, usually equipped to also measure current and resistance in the form of a [multimeter](#), are standard test instruments used in electrical and electronics work.

An **ammeter** (from **Ampere Meter**) is a [measuring instrument](#) used to measure the [current](#) in a [circuit](#). Electric currents are measured in [amperes](#) (A), hence the name.

Since the ammeter [shunt](#) has a very low resistance, mistakenly wiring the ammeter in parallel with a voltage source will cause a [short circuit](#), at best blowing a fuse, possibly damaging the instrument and wiring, and exposing an observer to injury.



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.

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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**.

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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 where 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.

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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).

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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.

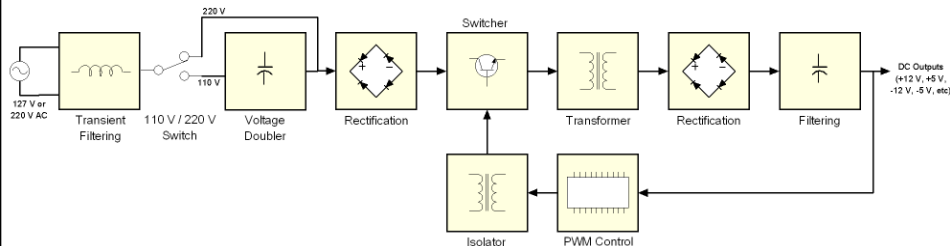
Versatile Design – Switchers can be designed to step up voltage (Boost) or step-down down voltage (Buck) as the application requires.

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.

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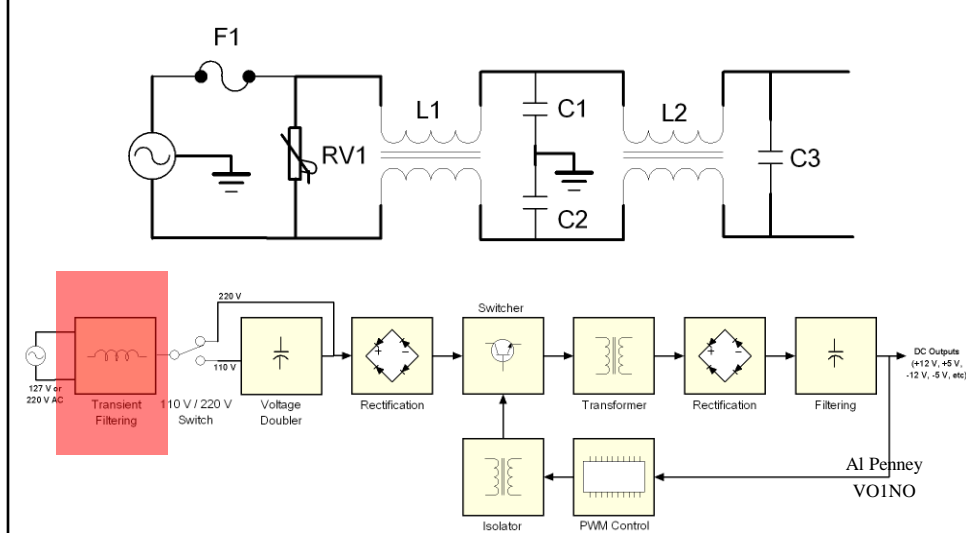
This example is of a multi-input voltage supply – 120/240 VAC – used for a personal computer.

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

SMPS Transient Filtering



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.

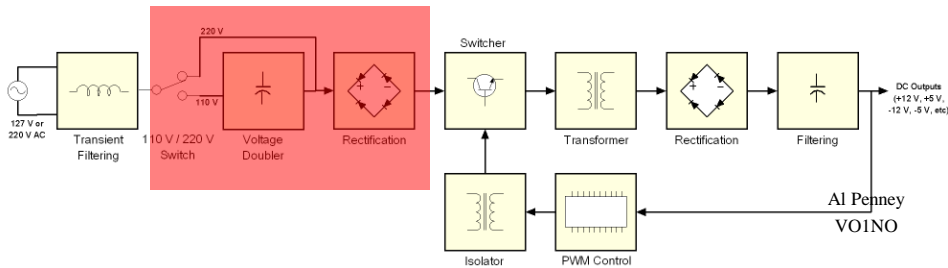
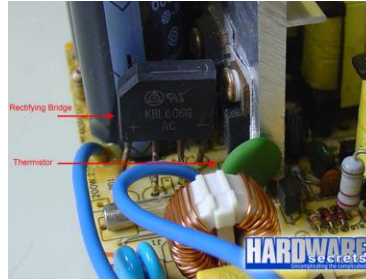
L1 and L2 are ferrite coils. C1 and C2 are disc capacitors, normally blue. These capacitors are also called "Y capacitors". C3 is a metalized polyester capacitor, normally with values like 100 nF, 470 nF or 680 nF. This capacitor is also called "X capacitor". Some power supplies have a second X capacitor, 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.

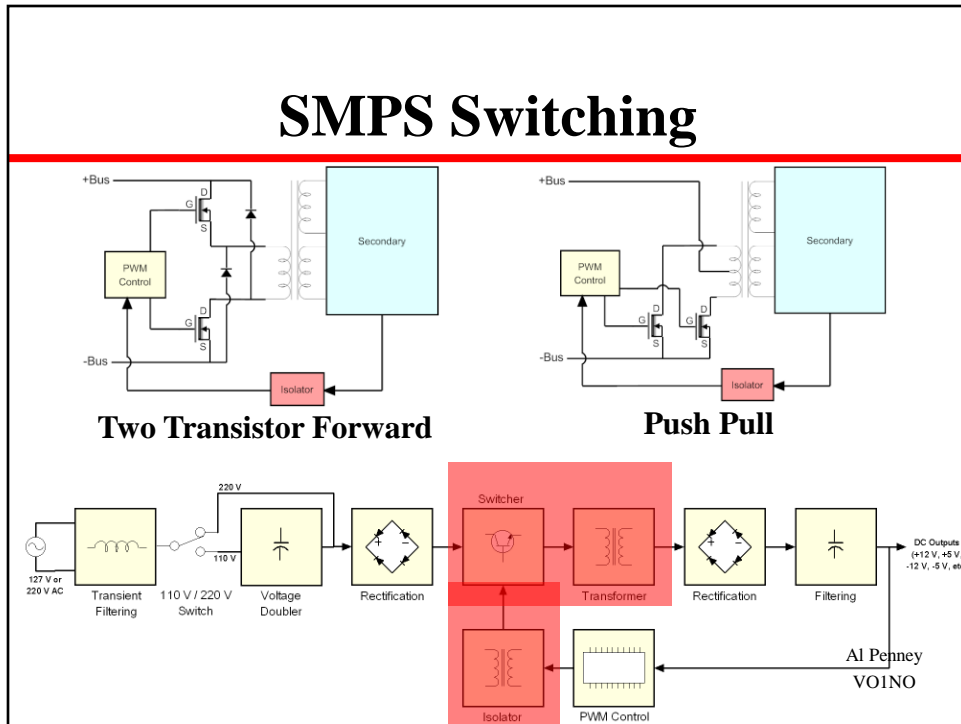
SMPS Voltage Doubler & Rectifier



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.

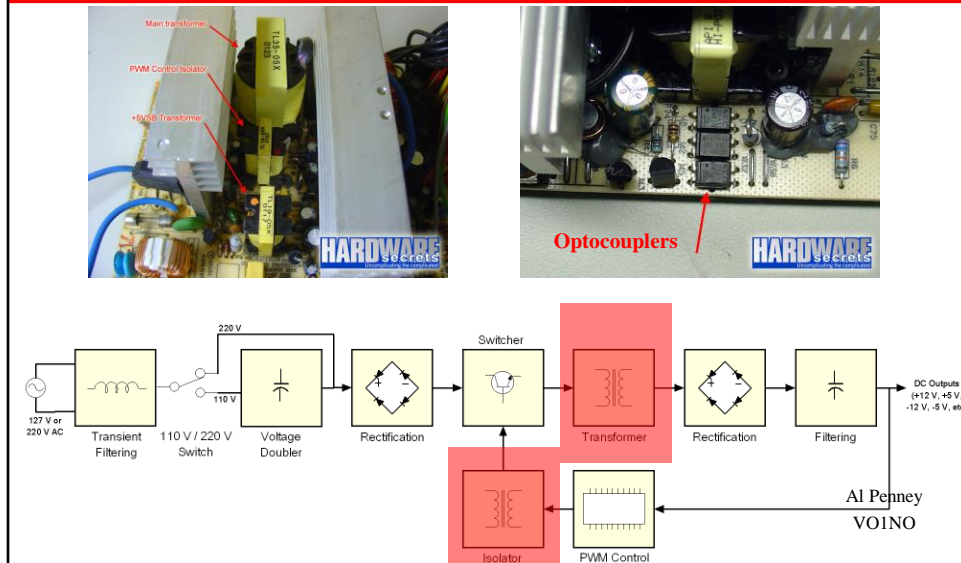


The switching section of switching mode power supplies can be built using one of several different configurations, using one to four MOSFETs in forward, half bridge, full bridge and push-pull configurations.

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.

SMPS Transformers



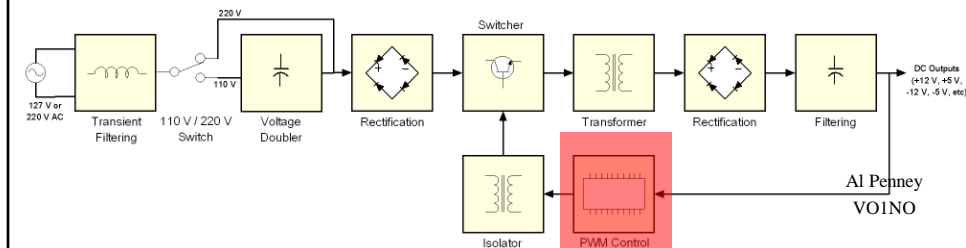
Transformers and Isolator

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 power 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.

SMPS Pulse Width Modulation

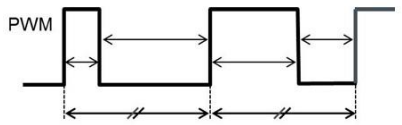


The PWM control circuit is based on an integrated circuit. Power supplies without active PFC usually use a [TL494 integrated circuit](#) (in the power supply pictured in Figure 26 a compatible part, DBL494, was used). On power supplies with active PFC sometimes an integrated circuit that combines both 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.

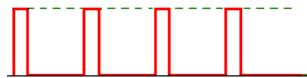
The switching regulator, as the name implies, converts an input voltage to a desired output voltage by switching the input voltage, that is, by turning it on and off. In simple terms this method involves chopping the input voltage and smoothing it out to match the required output voltage. There are two 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 non-switching power-supply for stand-by is added.

Pulse Width Modulation



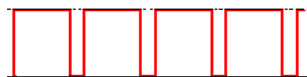
The cycle remains constant with a variable on/off time ratio



20% Duty Cycle



50% Duty Cycle



80% Duty Cycle

- 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.

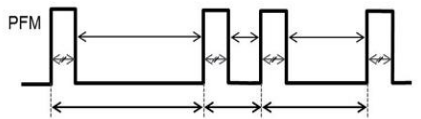
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PWM control (Pulse Width Modulation)

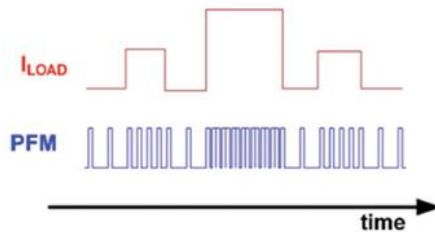
PWM represents the most commonly employed voltage control method. In this method, at fixed cycles the amount of power corresponding to the power that needs to be output is switched on to extract it from the input. Consequently, the ratio between on and off, that is, the duty cycle, changes as a function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

Pulse Frequency Modulation



On-time is constant with a variable off-time = cycle also fluctuates



- Pulse Frequency Modulation
 - Pulse width remains the same, but frequency increases as load increases.
 - Because frequency decreases with low load, efficiency remains high under low loads.
 - Because frequency varies however, it is more difficult to filter out noise, which could cause receive problems.

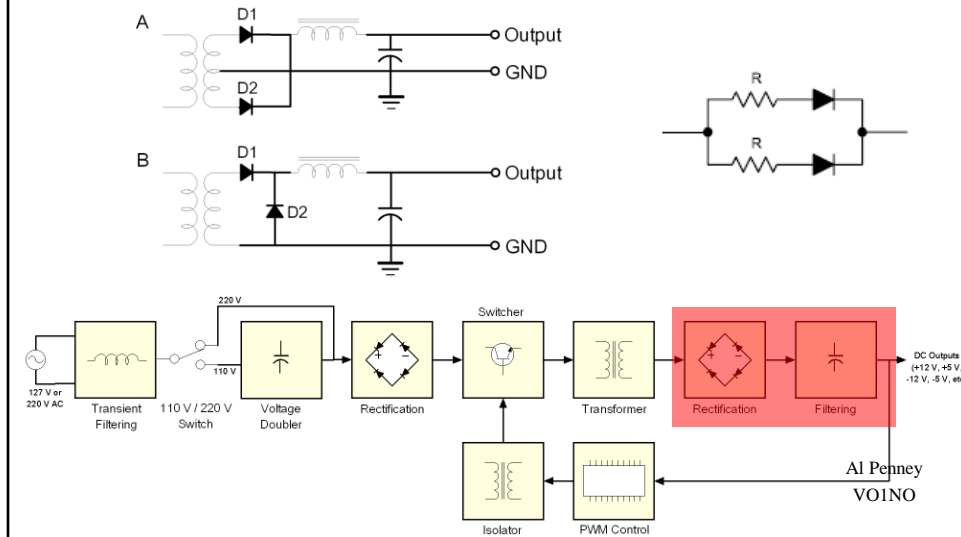
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• PFM control (Pulse Frequency Modulation)

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, which 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.

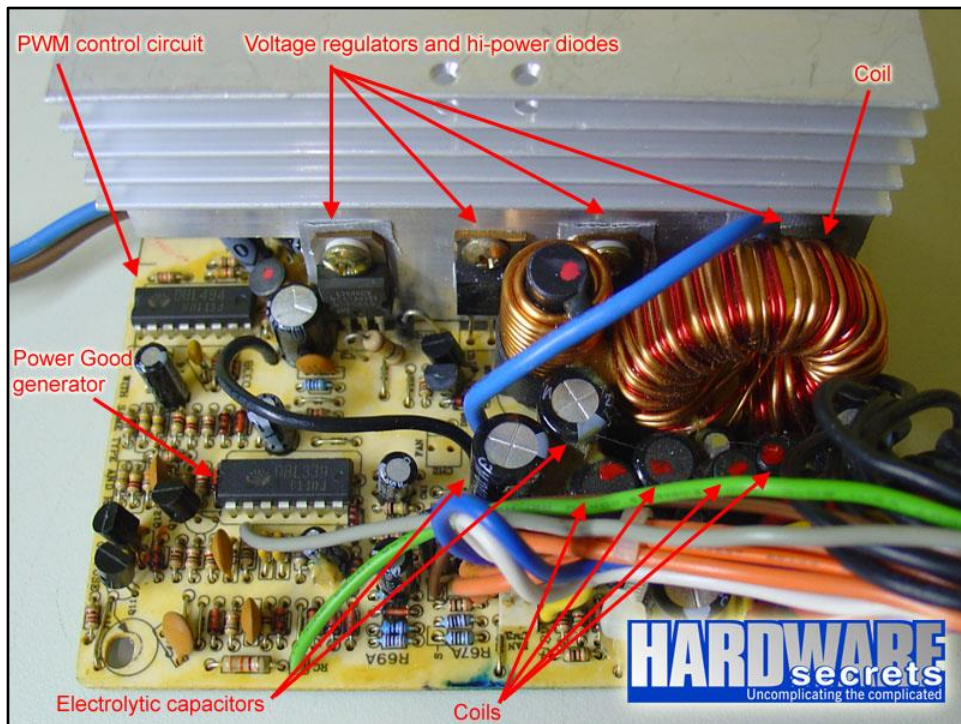
Also on high-end power supplies, in order to increase the maximum current the power supply can deliver two power diodes can be connected in parallel, thus doubling the maximum current the circuit can handle.

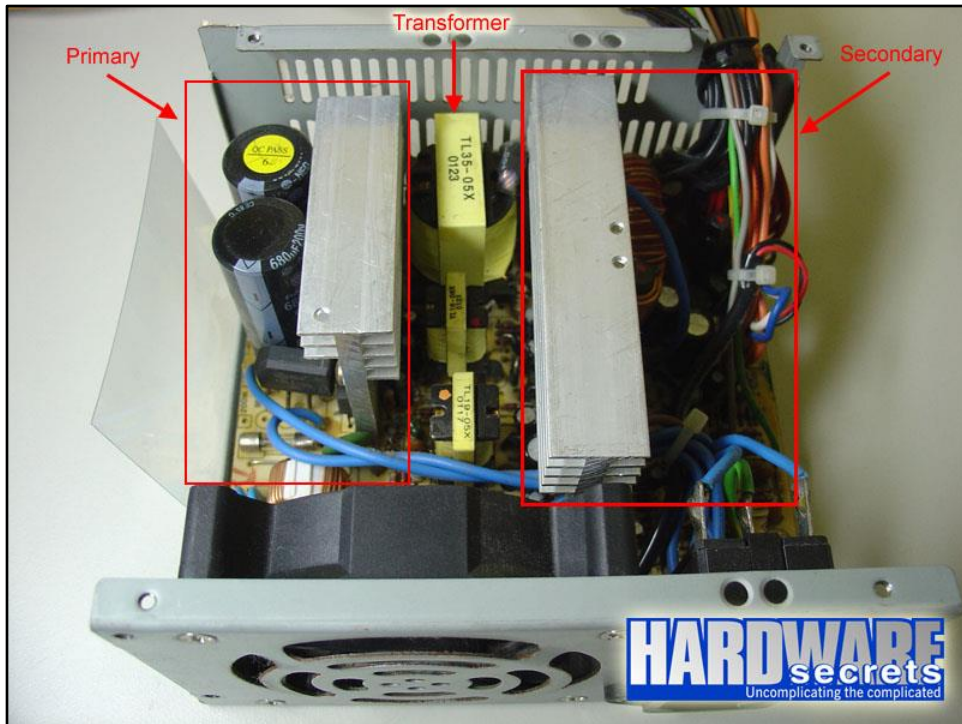
Diodes can be connected in parallel to increase the current-handling capability of the circuit. Each diode should have a series current-equalizing resistor, with a value selected to provide a few tenths of a volt drop at the expected current.

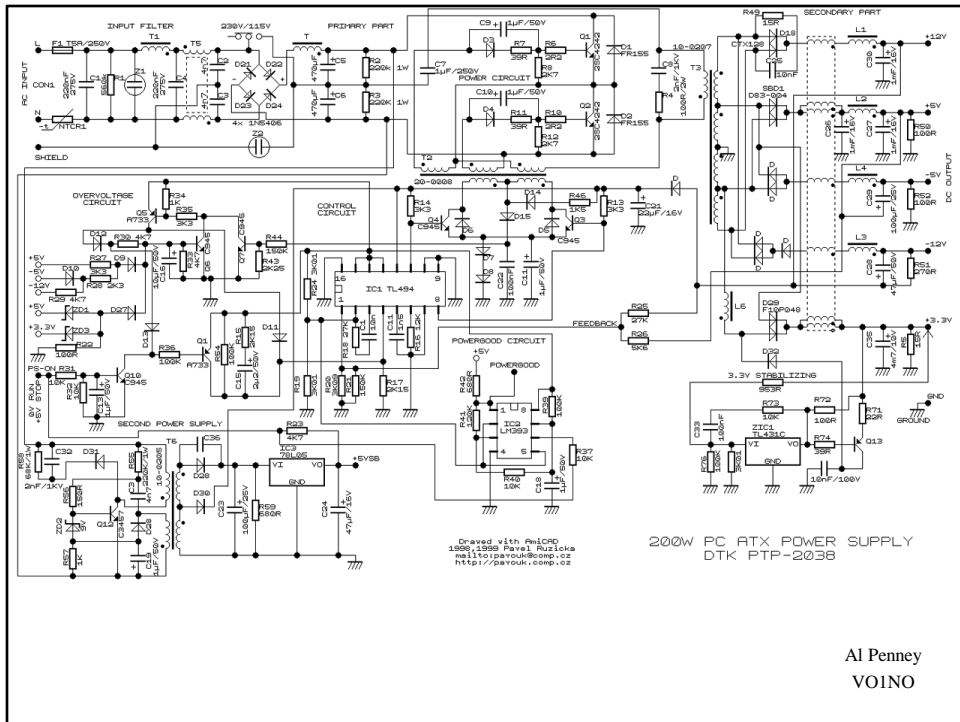
If the output is required to be isolated from the input, as is usually the case in mains power supplies, the inverted AC is used to drive the primary winding of a high-frequency [transformer](#). This converts the voltage up or down to the required output level on its secondary winding. The output transformer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

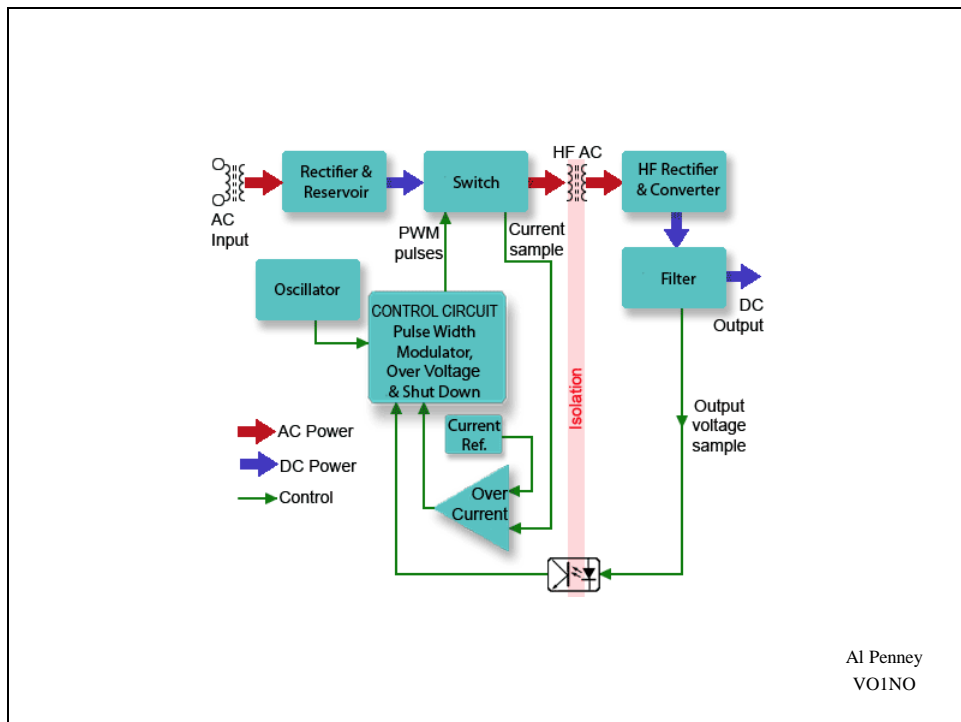
If a **DC** output is required, the **AC** output from the transformer is rectified. For output voltages above ten volts or so, ordinary silicon diodes are commonly used. For lower voltages, [Schottky diodes](#) are commonly used as the rectifier elements; they have the advantages of faster recovery 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.









<http://www.learnabout-electronics.org/PSU/psu30.php>



Review Question 1

In a regulated power supply, the transformer connects to an external source, which is referred to

as .

- regulator
- filter
- rectifier
- input

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Review Question 1

In a regulated power supply, the transformer connects to an external source, which is referred to

as .

- regulator
 - filter
 - rectifier
 - input
- < input >

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Review Question 2

In a regulated power supply, the _____ is between the input and the rectifier.

- output
- regulator
- filter
- transformer

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Review Question 2

In a regulated power supply, the _____ is between the input and the rectifier.

- output
 - regulator
 - filter
 - transformer
- < transformer >**

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Review Question 3

In a regulated power supply, the _____ is between the transformer and the filter.

- output
- regulator
- rectifier
- input

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Review Question 3

In a regulated power supply, the _____ is between the transformer and the filter.

- output
 - regulator
 - rectifier
 - input
- < rectifier >**

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Review Question 4

In a regulated power supply, the output of the rectifier is connected to the .

- transformer
- regulator
- filter
- output

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Review Question 4

In a regulated power supply, the output of the rectifier is connected to the .

- transformer
- regulator
- filter
- output
- < filter >

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Review Question 5

In a regulated power supply, the output of the filter connects to the .

- transformer
- rectifier
- output
- regulator

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Review Question 5

In a regulated power supply, the output of the filter connects to the .

- transformer
- rectifier
- output
- regulator
- < regulator >**

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Review Question 6

In a regulated power supply, the _____ is connected to the regulator.

- input
- transformer
- output
- rectifier

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Review Question 6

In a regulated power supply, the _____ is connected to the regulator.

- input
- transformer
- output
- rectifier
- < **output** >

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Review Question 7

If your mobile transceiver works in your car but not in your home, what should you check first?

- The power supply
- The speaker
- The microphone
- The SWR meter

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Review Question 7

If your mobile transceiver works in your car but not in your home, what should you check first?

- The power supply
 - The speaker
 - The microphone
 - The SWR meter
- < The power supply >**

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Review Question 8

What device converts household current to 12 volts DC?

- A low pass filter
- An RS-0232 interface
- A catalytic converter
- A power supply

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Review Question 8

What device converts household current to 12 volts DC?

- A low pass filter
 - An RS-0232 interface
 - A catalytic converter
 - A power supply
- < A power supply >

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Review Question 9

Which of these usually needs a high current capacity power supply?

- A receiver
- An SWR meter
- A transceiver
- An antenna switch

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Review Question 9

Which of these usually needs a high current capacity power supply?

- A receiver
- An SWR meter
- A transceiver
- An antenna switch

< A transceiver >

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Review Question 10

What may cause a buzzing or hum in the signal of an AC-powered transmitter?

- Energy from another transmitter
- Bad design of the transmitter's RF power output circuit
- A bad filter capacitor in the transmitter's power supply
- Using an antenna which is the wrong length

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Review Question 10

What may cause a buzzing or hum in the signal of an AC-powered transmitter?

- Energy from another transmitter
 - Bad design of the transmitter's RF power output circuit
 - A bad filter capacitor in the transmitter's power supply
 - Using an antenna which is the wrong length
- < A bad filter capacitor in the transmitter's power supply >**

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Review Question 11

A power supply is to supply DC at 12 volts at 5 amperes. The power transformer should be rated higher than:

- 6 watts
- 60 watts
- 17 watts
- 2.4 watts

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Review Question 11

A power supply is to supply DC at 12 volts at 5 amperes. The power transformer should be rated higher than:

- 6 watts
- 60 watts
- 17 watts
- 2.4 watts
- < 60 watts >**

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Review Question 12

The diode is an important part of a simple power supply. It converts AC to DC, since it:

- has a high resistance to DC but not to AC
- allows electrons to flow in only one direction from anode to cathode
- allows electrons to flow in only one direction from cathode to anode
- has a high resistance to AC but not to DC

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Review Question 12

The diode is an important part of a simple power supply. It converts AC to DC, since it:

- has a high resistance to DC but not to AC
- allows electrons to flow in only one direction from anode to cathode
- allows electrons to flow in only one direction from cathode to anode
- has a high resistance to AC but not to DC

< allows electrons to flow in only one direction from cathode to anode >

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Review Question 13

To convert AC to pulsating DC, you could use a:

- diode
- transformer
- capacitor
- resistor

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Review Question 13

To convert AC to pulsating DC, you could use a:

- diode
- transformer
- capacitor
- resistor

< diode >

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Review Question 14

Power-line voltages have been made standard over the years and the voltages generally supplied to homes are approximately:

- 120 and 240 volts
- 110 and 220 volts
- 100 and 200 volts
- 130 and 260 volts

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Review Question 14

Power-line voltages have been made standard over the years and the voltages generally supplied to homes are approximately:

- 120 and 240 volts
 - 110 and 220 volts
 - 100 and 200 volts
 - 130 and 260 volts
- < 120 and 240 volts >**

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Review Question 15

Your mobile HF transceiver draws 22 amperes on transmit. The manufacturer suggests limiting the voltage drop to 0.5 volt and the vehicle battery is 3 metres (10 feet) away. Given the losses below at that current, which minimum wire gauge must you use?

- Number 8, 0.05 V per metre (0.01 V per foot)
- Number 12, 0.11 V per metre (0.03 V per foot)
- Number 14, 0.19 V per metre (0.06 V per foot)
- Number 10, 0.07 V per metre (0.02 V per foot)

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Assume that the transceiver is being fed by twin lead, a B+ line and a ground line. So we double all the lengths. The voltage drop calculation is (length) x (V/unit length). Using metres, 12 gauge has a voltage drop of $(0.11) \times (6) = 0.66$ V. Similarly, for 8 gauge, the voltage drop would be 0.30 V; for 10 gauge, 0.42 V; for 14 gauge, 1.04 V. We can scrap 12 and 14 gauge as each exceeds the limit of 0.5 V. The larger the gauge number, the smaller the diameter and the lower the cost so 10 gauge wins. The key word is “minimum”.

Review Question 15

Your mobile HF transceiver draws 22 amperes on transmit. The manufacturer suggests limiting the voltage drop to 0.5 volt and the vehicle battery is 3 metres (10 feet) away. Given the losses below at that current, which minimum wire gauge must you use?

- Number 8, 0.05 V per metre (0.01 V per foot)
- Number 12, 0.11 V per metre (0.03 V per foot)
- Number 14, 0.19 V per metre (0.06 V per foot)
- Number 10, 0.07 V per metre (0.02 V per foot)
- < **Number 10, 0.07 V per metre (0.02 V per foot)** >

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Assume that the transceiver is being fed by twin lead, a B+ line and a ground line. So we double all the lengths. The voltage drop calculation is (length) x (V/unit length). Using metres, 12 gauge has a voltage drop of $(0.11) \times (6) = 0.66$ V. Similarly, for 8 gauge, the voltage drop would be 0.30 V; for 10 gauge, 0.42 V; for 14 gauge, 1.04 V. We can scrap 12 and 14 gauge as each exceeds the limit of 0.5 V. The larger the gauge number, the smaller the diameter and the lower the cost so 10 gauge wins. The key word is “minimum”.

Review Question 15

Assume that the transceiver is being fed by twin lead, a B+ line and a ground line. So we double all the lengths. The voltage drop calculation is (length) x (V/unit length). Using metres, 12 gauge has a voltage drop of $(0.11) \times (6) = 0.66$ V. Similarly, for 8 gauge, the voltage drop would be 0.30 V; for 10 gauge, 0.42 V; for 14 gauge, 1.04 V. We can scrap 12 and 14 gauge as each exceeds the limit of 0.5 V. The larger the gauge number, the smaller the diameter and the lower the cost so 10 gauge wins. The key word is "minimum".

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Review Question 16

You have a very loud low-frequency hum appearing on your transmission. In what part of the transmitter would you first look for the trouble?

- The driver circuit
- The power amplifier circuit
- The power supply
- The variable-frequency oscillator

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Review Question 16

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- The power amplifier circuit
- The power supply
- The variable-frequency oscillator

< The power supply >

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Review Question 17

The primary purpose of a Zener diode is to:

- regulate or maintain a constant voltage
- provide a voltage phase shift
- to boost the power supply voltage
- provide a path through which current can flow

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Review Question 17

The primary purpose of a Zener diode is to:

- regulate or maintain a constant voltage
 - provide a voltage phase shift
 - to boost the power supply voltage
 - provide a path through which current can flow
- < regulate or maintain a constant voltage >**

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Review Question 18

The action of changing alternating current to direct current is called:

- rectification
- amplification
- transformation
- modulation

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Review Question 18

The action of changing alternating current to direct current is called:

- rectification
- amplification
- transformation
- modulation

< **rectification** >

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Review Question 19

If alternating current is applied to the anode of a diode, what would you expect to see at the cathode?

- Pulsating alternating current
- Pulsating direct current
- No signal
- Steady direct current

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Review Question 19

If alternating current is applied to the anode of a diode, what would you expect to see at the cathode?

- Pulsating alternating current
 - Pulsating direct current
 - No signal
 - Steady direct current
- < Pulsating direct current >**

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For Next Class:

- Review Chapter 10 of Basic Study Guide;
- Read Chapter 11 of Basic Study Guide; and
- Go through the Question Bank.

