NEAR EAST UNIVERSITY

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Department Of Electrical & Electronic Engineering

POWER SUPPLY

Graduation Project

EE 400

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ABSTRACT

This project is about to show us the importance and role of the power electrics in our lives.Also we want to give you enough informations about the improvemental and historical information with a short way and with summary.

The edit of a power supply can be group in three sections.First designing the circuit diagram of the device, second define the supplied voltage intevals.Third;Constructing the circuit with necessary components.

The main object of this Project is to teach us the general description of the power supply; The complete range of power supplies is very broad, and could be considered to include all forms of energy conversion from one form into another. Conventionally though, the term is usually confined to electrical or mechanical energy supplies. Constraints that commonly affect power supplies are the amount of power they can supply, how long they can supply it for without needing some kind of refueling or recharging, how stable their output voltage or current is under varying load conditions, and whether they provide continuous power or pulses.

The regulation of power supplies is done by incorporating circuitry to tightly control the output voltage and/or current of the power supply to a specific value. The specific value is closely maintained despite variations in the load presented to the power supply's output, or any reasonable voltage variation at the power supply's input. This kind of regulation is commonly categorised as a Stabilized power supply.

According to all the given informations explained in the project i managed to inform you detailed study about power supply and power electric devices wihch will be enough for an under-graduate student.

INTRODUCTION

Power supplies are devices that produce AC or DC power. This grouping includes current sources, DC power supplies, AC-DC adapters, DC-DC converters, AC power sources, and DC-AC inverters. Current sources provide reliable current for electrical component testing and for powering specialized components. DC power supplies accept AC input and provide one or more DC outputs for a wide variety of computer and industrial applications. AC / DC adapters accept AC input voltage directly from a wall outlet, and output DC voltage. DC-DC converters accept DC input and provide regulated DC outputs for computers, telecommunications, and process control applications. AC power sources provide alternating power and will typically have adjustable output values for the testing of component response at various voltage, current and frequency levels. DC to AC power inverters are used for converting direct current (DC) into alternating current (AC). They are also known as DC to AC converters. Rectifiers accept AC input and provide one or more DC outputs for a wide variety of computer and industrial applications. Style, output, display, application, and features are all important to consider when specifying power supplies.

Chapter 1

Equipment used in the project

1.1 Introduction:

Most of the electronic circuit devices and components are very small structured.In this chapter we aim to emphasize the definitions and give historical,developmental,general information about the circuit components.

1.2 Fuse:

Figure 1 Fuse (electrical)

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In electronics and electrical engineering a fuse, short for 'fusible link', is a type of overcurrent protection device. It has as its critical component a metal wire or strip that will melt when heated by a prescribed electric current, opening the circuit of which it is a part, and so protecting the circuit from an overcurrent condition.

A practical fuse was one of the essential features of Edison's electrical power distribution system. An early fuse was said to have successfully protected an Edison installation from tampering by a rival from a gas-lighting concern.

Properly-selected fuses (or other overcurrent devices) are an essential part of a power distribution system to prevent fire or damage due to overload or short-circuits. Usually the maximum size of the overcurrent device for a circuit is regulated by law. For example, the Canadian Electrical Code, the United States National Electrical Code (NFPA 70), and the UK Wiring Regulations provide limits for overcurrent device ampere rating for a given conductor, insulation material and installation conditions. Local authorities will incorporate these national codes as part of law. An overcurrent device should normally be selected with a rating just over the normal operating current of the downstream wiring or equipment which it is to protect.

1.2.1 Fuse characteristics

Each type of fuse (and all other overcurrent devices) has a time-current characteristic which shows the time required to melt the fuse and the time required to clear the circuit for any given level of overload current. Where the fuses in a system are of similar types, simple ratios between ratings of the fuse closest to the load and the next fuse towards the source can be used, so that only the affected circuit is interrupted after a fault. In power system design, main and branch circuit overcurrent devices can be co-ordinated for best protection by plotting the time-current characteristics on a consistent scale, making sure that the source curve never crosses that of any of the branch circuits. To prevent damage to utilization devices, both "maximum clearing" and "minimum melting" fuse curves are plotted.

Fuses are often characterized as "fast-blow" or "slow-blow" | "time-delay", according to the time they take to respond to an overcurrent condition. Fast-blow fuses (sometimes marked 'F') open quickly when the rated current is reached. Ultrafast fuses (marked 'FF') are used to protect semiconductor devices that can tolerate only very short-lived overcurrents. Slow-blow fuses (household plug type are often marked 'T') can tolerate a transient overcurrent condition (such as the high starting current of an electric motor), but will open if the overcurrent condition is sustained.

A fuse also has a rated interrupting capacity, also called breaking capacity, which is the maximum current the fuse can safely interrupt. Generally this should be higher than the maximum prospective short circuit current though it may be lower if another fuse or breaker upstream can be relied upon to take out extremely high current shorts. Miniature fuses may have an interrupting rating only 10 times their rated current. Fuses for low-voltage power systems are commonly rated to interrupt 10,000 amperes, which is a minimum capacity regulated by the electrical code in some jurisdictions. Fuses for larger power systems must have higher interrupting ratings, with some low-voltage current-limiting "high rupturing capacity" (HRC) fuses rated for 300,000 amperes. Fuses for high-voltage equipment, up to 115,000 volts, are rated by the total apparent power (megavoltamperes, MVA) of the fault level on the circuit.

Overcurrent devices installed inside of enclosures are "derated" at least per the US NEC. This is a hold-over from the first mounting of electrical devices on the surface of slate slabs. The slate was the insulating material between devices mounted in air. So, rather than change the fuse rating, it became common to allow only 80% of the current value of the overcurrent device when the circuit is in operation for 3 hours or more (continuous loading).

As well as a current rating, fuses also carry a voltage rating indicating the maximum circuit voltage in which the fuse can be used. For example, glass tube fuses rated 32 volts should never be used in line-operated (mains-operated) equipment even if the fuse physically can fit the fuseholder. Fuses with ceramic cases have higher voltage ratings. Fuses carrying a 250 V rating can be safely used in a 125 V circuit, but the reverse is not true as the fuse may not be capable of safely interrupting the arc in a circuit of a higher voltage.

1.2.2 Fuse packages

Figure 2 Bosch type fuse (used in old cars)

Fuses are often sold in standardised packages to make them easily interchangeable. Cartridge fuses are cylindrical and are made in standard lengths such as 20 mm, 1 in (25 mm) and 1.25 in (32 mm). Smaller fuses often have a glass body with nothing but air inside so that the fuse wire can be inspected. Under extremely high current or voltage, such fuses can arc over and therefore continue to supply a current. Fuses used in higher energy circuits (for example building wiring installations) have a strong ceramic body which prevents arc over, and are filled with sand to quench any arcs. Small fuses may be held by metal clips on their end ferrules, but larger fuses (100 amperes and larger) are usually bolted into the fuse holder.

High-voltage fuses used outdoors may be of the expulsion type, allowing arc by-products to be discharged to the air with considerable noise when they operate.

1.2.3 Plug-in type

Plug-in fuses (also called blade or spade fuses), with a plastic body and two prongs that fit into sockets, are used in automobiles. These types of fuses come in three different physical dimensions: mini (or minifuse), ATO® (or ATC) and maxi (or maxifuse).

The physical dimensions, including the connector, of the fuses are as follows (LxWxH) (ampere ratings in the parenthesis):

- mini: 10.9x3.6x16.3 mm (1A, 2A, 3A, 4A, 5A, 7.5A, 10A, 15A, 20A, 25A, 30A)
- ATO: 19.1x5.1x18.5 mm (2A, 3A, 4A, 5A, 7.5A, 10A, 15A, 20A, 25A, 30A, 40A)
- maxi: 29.2x8.5x34.3 mm (20A, 30A, 40A, 50A, 60A, 70A, 80A)

1.2.4 Replacement circuit breaker

It is possible to replace an ATO-type plug-in fuse with a circuit breaker that has been designed to fit in the socket of a ATO-sized fuse holder. These circuit protectors are more expensive than a regular fuse.

1.2.5 Bosch type

Bosch type fuses are used in older (often European) automobiles, and can also be used instead of glass type fuses in inline fuse holders (but not in ganged fuse holders). The physical dimension of this type of fuse is 6x25 mm.

1.2.6 Color coding of Bosch type fuses

Most fuses of the Bosch type usually use the same color coding for the rated current.

Color	Ampere
Yellow	5A
White	8A
Red	16A
Blue	25A

1.2.7 Power circuit fuses

Figure 3

The Swiss electric fuses (6 and 10 A) that are still in use in some older European buildings. In the three room flat, the 6 A fuse guards two rooms, and the 10 A fuse guards the remaining room and kitchen. The lower end (as in the picture) of the 10 A fuse is wider. So it is not possible to insert it into the socket for the 6 A fuse. When the wire melts, the colored point disappears

Fuses for power circuits are available in a wide range of ratings. Critical values in the specification of fuses are the normal rated current, the circuit voltage, and the maximum level of current available on a short-circuit. For example, in North America, a so-called "code" fuse may only be safely used in circuits with no more than 10,000 amperes available on a short circuit.

Fuses are used on power systems up to 115,000 volts AC. High-voltage fuses are used to protect instrument transformers used for electricity metering, or for small power transformers where the expense of a circuit breaker is not warranted. For example, in distribution systems, a power fuse may be used to protect a transformer serving 1-3 houses. A circuit breaker at 115 kV may cost up to five times as much as a set of power fuses, so the resulting saving can be tens of thousands of dollars.

Large power fuses use fusible elements made of silver or copper to provide stable and predictable performance. High voltage expulsion fuses surround the fusible link with gasevolving substances, such as boric acid. When the fuse blows, heat from the arc causes the boric acid to evolve large volumes of gases. The associated high pressure (often greater than 100 atmospheres) and cooling gases rapidly extinguish (quench) the resulting arc. The hot gases are then explosively expelled out of the end(s) of the fuse. Other special High Rupturing Capacity (HRC) fuses surround one of more parallel connected fusible links with an energy absorbing material, typically silicon dioxide sand. When the fusible link blows, the sand absorbs energy from the arc, rapidly quenching it, creating an artificial fulgurite in the process.

1.2.8 Fuses compared with circuit breakers

Fuses have the advantages of often being less costly and simpler than a circuit breaker for similar ratings. The blown fuse must be replaced with a new device which is less convenient than simply resetting a breaker and therefore likely to discourage people from ignoring faults. On the other hand replacing a fuse without isolating the circuit first (most building wiring designs do not provide individual isolation switches for each fuse) can be dangerous in itself, particularly if the fault is a short circuit.

High rupturing capacity fuses can be rated to safely interrupt up to 300,000 amperes at 600 V AC. Special current-limiting fuses are applied ahead of some molded-case breakers to protect the breakers in low-voltage power circuits with high short-circuit levels.

"Current-limiting" fuses operate so quickly that they limit the total "let-through" energy that passes into the circuit, helping to protect downstream equipment from damage. These fuses clear the fault in less than one cycle of the AC power frequency. Circuit breakers cannot offer similar rapid protection.

Circuit breakers which have interrupted a severe fault should be removed from service and inspected and replaced if damaged.

In a multi-phase power circuit, if only one of the fuses opens, the remaining phases will have higher than normal currents, and unbalanced voltages, with possible damage to the coils of motors or solenoids. Fuses only sense overcurrent, or to a degree, over-temperature, and cannot usually be used with protective relaying to provide more advanced protective functions, for example, ground fault detection.

Some manufacturers of medium-voltage distribution fuses combine the overcurrent protection characteristics of the fusible element with the flexibility of relay protection by adding a pyrotechnic device to the fuse operated by external protection relays

1.2.9 Fuse boxes

Figure 4 Fuse box

Old electrical consumer units (also called fuse boxes) were fitted with fuse wire that could be replaced from a supply of spare wire that was wound on a piece of cardboard. Modern consumer units contain magnetic circuit breakers instead of fuses. Cartridge fuses were also used in consumer units and sometimes still are as miniature circuit breakers (MCBs) are rather prone to nuisance tripping. (In North America, fuse wire was never used in this way, although so-called "renewable" fuses were made that allowed replacement of the fuse link. It was impossible to prevent putting a higher-rated or double links into the holder ("overfusing") and so this type must be replaced.)

The box pictured is a "Wylex standard". This type was very popular in the United Kingdom up until recently when the wiring regulations started demanding Residual-Current Devices (RCDs) for sockets that could feasibly supply equipment outside the equipotential zone. The design does not allow for fitting of RCDs (there were a few wylex standard models made with an RCD instead of the main switch but that isn't generally considered acceptable nowadays either because it means you lose lighting in the event of almost any fault) or residual-current circuit breakers with overload (RCBOs) (an RCBO is the combination of an RCD and an MCB in a single unit). The one pictured is fitted with rewirable fuses but they can also be fitted with cartridge fuses and MCBs. There are two styles of fuse base that can be screwed into these units—one designed for the rewirable fusewire carriers and one designed for cartridge fuse carriers. Over the years MCBs have been made for both styles of base. With both styles of base higher rated carriers had wider pins so a carrier couldn't be changed for a higher rated one without also changing the base. Of course with rewirable carriers a user could just fit fatter fusewire or even a totally different type of wire object (hairpins, paper clips, nails etc.) to the existing carrier.

In North America, fuse boxes were also often used, especially in homes wired before about 1950. Fuses for these panels were screw-in "plug" type (not to be confused with what the British refer to as plug fuses), in holders with the same threads as Edison-base incandescent lamps, with ratings of 5, 10, 15, 20, 25, and 30 amperes. To prevent installation of fuses with too high a current rating for the circuit, later fuse boxes included rejection features in the fuseholder socket. Some installations have resettable miniature thermal circuit breakers which screw into the fuse socket. One form of abuse of the fuse box was to put a penny in the socket, which defeated the overcurrent protection function and resulted in a dangerous condition. Plug fuses are no longer used for branch circuit protection in new residential or industrial construction.

1.2.10 British plug fuse

Figure 5

20 mm 200 mA glass cartridge fuse used inside equipment and 1 inch 13 A ceramic British plug fuse.

The BS 1363 13 A plug has a BS 1362 cartridge fuse inside. This allows the use of 30 A/32 A (30 A was the original size; 32 A is the closest European harmonised size) socket circuits safely. In order to keep cable sizes manageable these are usually wired in ring mains. It also provides better protection for small appliances with thin flex as a variety of fuse ratings (1 A, 2 A, 3 A, 5 A, 7 A, 10 A 13 A with 3, 5 and 13 being the most common) are available and a suitable fuse should be fitted to allow the normal operating current while protecting the appliance and its cord as well as possible. With some loads it is normal to use a slightly higher rated fuse than the normal operating current. For example on 500 W halogen floodlights it is normal to use a 5 A fuse even though a 3 A would carry the normal operating current. This is because halogen lights draw a significant surge of current at switch on as their cold resistance is far lower than their resistance at operating temperature.

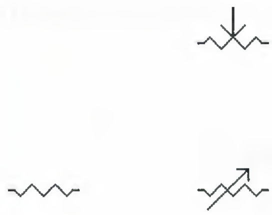
In most other wiring practices the wires in a flexible cord are considered to be protected by the branch circuit overcurrent device, usually rated at around 15 amperes, so a plug-mounted fuse is not used. Small electronic apparatus often includes a fuseholder on or in the equipment, to protect internal components only.

1.2.11 Other types of fuse

So-called "self-resetting" fuses use a thermoplastic conductive element that opens the circuit on overload, then restores the circuit when they cool. These are useful in aerospace applications where replacement is difficult. Common kind is the Polyswitch self-repairing fuses.

A "thermal fuse" is often found in consumer heating equipment such as coffee makers or hair dryers; it contains a fusible alloy which opens when the temperature is too high due to reduced air flow or other fault.

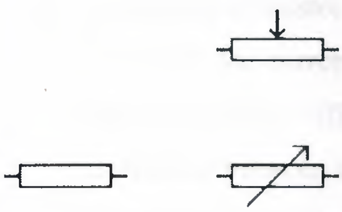
1.3 Resistors



Resistor

Variable Resistor

Table of Resistor symbols (US and Japan)



Resistor

Variable resistor

Table of Resistor symbols (Europe, IEC)

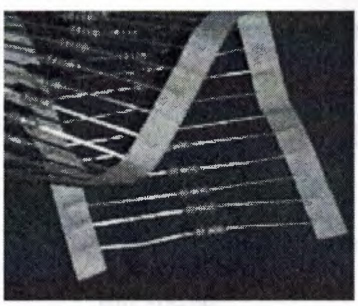


Figure 1 A pack of resistors

A resistor is a two-terminal electrical or electronic component that resists an electric current by producing a voltage drop between its terminals in accordance with Ohm's law. (Certain ultra-precise resistors have 2 extra terminals, for a total of 4.)

$$R = \frac{V}{I}$$ Formula (1)

The *electrical resistance* is equal to the voltage drop across the resistor divided by the current through the resistor. Resistors are used as part of electrical networks and electronic circuits.

1.3.1 Applications

- In general, a resistor is used to create a known voltage-to-current ratio in an electric circuit. If the current in a circuit is known, then a resistor can be used to create a known potential difference proportional to that current. Conversely, if the potential difference between two points in a circuit is known, a resistor can be used to create a known current proportional to that difference.
- Current-limiting. By placing a resistor in series with another component, such as a light-emitting diode, the current through that component is reduced to a known safe value.
- A series resistor can be used for speed regulation of DC motors, such as used on locomotives and trainsets.
- An attenuator is a network of two or more resistors (a voltage divider) used to reduce the voltage of a signal.
- A line terminator is a resistor at the end of a transmission line or daisy chain bus (such as in SCSI), designed to match impedance and hence minimize reflections of the signal.
- All resistors dissipate heat. This is the principle behind electric heaters.

1.3.2 The ideal resistor

The SI unit of electrical resistance is the ohm (Ω). A component has a resistance of 1 Ω if a voltage of 1 volt across the component results in a current of 1 ampere, or amp, which is equivalent to a flow of one coulomb of electrical charge (approximately 6.241506×10^{18} electrons) per second. The multiples kiloohm (1 kΩ = 1000 Ω) and megaohm (1 MΩ = 10^6 Ω) are also commonly used.

In an ideal resistor, the resistance remains constant regardless of the applied voltage or current through the device or the rate of change of the current. Whereas real resistors cannot attain this goal, they are designed to present little variation in electrical resistance when subjected to these changes, or to changing temperature and other environmental factors.

1.3.3 Nonideal characteristics

A resistor has a maximum working voltage and current above which the resistance may change (drastically, in some cases) or the resistor may be physically damaged (overheat or burn up, for instance). Although some resistors have specified voltage and current ratings, most are rated with a maximum power which is determined by the physical size. Common power ratings for carbon composition and metal-film resistors are 1/8 watt, 1/4 watt, and 1/2 watt. Metal-film and carbon film resistors are more stable than carbon resistors against temperature changes and age. Larger resistors are able to dissipate more heat because of their larger surface area. Wire-wound and resistors embedded in sand (ceramic) are used when a high power rating is required.

Furthermore, all real resistors also introduce some inductance and a small amount of capacitance, which change the dynamic behavior of the resistor from the ideal.

Non-ideal characteristics include temperature dependence (when the resistor is not an NTC or PTC type - see below Types of Resistor), as well as inductance and/or capacitance, but it also includes types of noise, and voltage dependence.

All resistors will have some degree of voltage dependence. Some types, such as Carbon resistors, suffer from this more than others. Thick film resistors in small package sizes (0402,0603) can also have significant voltage dependence.

Most resistor manufacturers will not quote the voltage dependence on any of their resistors. Some will do so on some high voltage types, or on very specialised types that have an exceptionally low voltage dependence (at an exceptionally high cost).

Normally, voltage dependence has a negligible effect, but in applications with high voltages, or those with low distortions and wide dynamic ranges, it can be significant.

In (professional) audio applications, for instance, THD+N ratio, (Total Harmonic Distortion and Noise ratio), needs to be at levels above 100dB when measured at maximum signal levels (typically 12.4Vrms). In this environment, this non-ideal characteristic can become a problem. For this reason, one will usually see metal film (axial or MELF) resistors, wirewound, or thin film resistors, used in such applications.

Note that sometimes the voltage dependence of a resistor is deliberately used in an audio application to give an effect that is "pleasing to the ear". Valve amplifiers typically used carbon resistors, whose voltage dependence is approximately square law. The valves also have a square law grid voltage dependence and this gave "valve amplifiers" the tone that many audio buffs enjoy. Remember that a musical chord consists of even order harmonics.

All resistors must have thermal noise, which is equal to:

$$Vt = SQRT(4kTBR);$$

where k is Boltmann's constant, T is the temperature in Kelvin, B is the frequency bandwidth over which one is measuring the noise, and R is the resistance. Such thermal noise is a simple consequence of thermodynamics, and isn't a "non-ideal characteristic".

On the other hand two other types of noise can be, or are associated with resistors, and these noise sources do form non-ideal characteristics.

These noise sources are usually referred to as Contact noise and Shot Noise.

Contact noise is dependent on both current and the resistor's shape and size.

Contact noise has a 1/f frequency characteristic.

Contact noise (also called flicker noise, excess noise, low frequency noise, or 1/f noise) is usually explained as being the result of dynamic variations in conductivity, due to imperfect contact between two (or more) materials.

Contact noise is particulary bad in carbon resistors because these resistors are made up of many tiny particles that are moulded together. Thick film resistors are also made by the fusion of finely sintered glass and this is the explanation for the Contact Noise from these resistors (usually significantly less than for carbon composition resistors).

Contact noise can be significant in metal oxide, and some metal film resistors as well, but wirewound resistors, by contrast, generally have negligible contact noise.

See the section Shot Noise for an explanation of that type of resistor noise.

1.3.4 Types of resistor

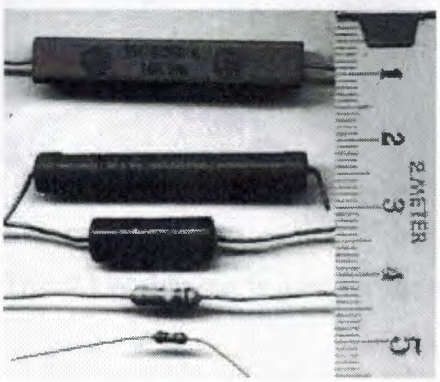


Figure 2 A few types of resistors

1.3.5 Fixed resistors

Some resistors are cylindrical, with the actual resistive material in the center (composition resistors, now obsolete) or on the surface of the cylinder (film) resistors, and a conducting metal lead projecting along the axis of the cylinder at each end(axial lead). There are carbon film and metal film resistors. The photo above right shows a row of common resistors. Power resistors come in larger packages designed to dissipate heat efficiently. At high power levels, resistors tend to be wire wound types. Resistors used in computers and other devices are typically much smaller, often in *surface-mount* packages without wire leads. Resistors can also be built into integrated circuits as part of the fabrication process, using the semiconductor material as a resistor. But resistors made in this way are difficult to fabricate and may take up a lot of valuable chip area, so IC designers alternatively use a transistor-transistor or resistor-transistor configuration to simulate the resistor they require.

1.3.6 Variable resistors

Construction of a wire-wound variable resistor. The effective length of the resistive element (1) varies as the wiper turns, adjusting resistance.

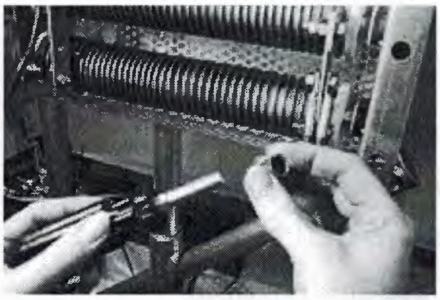


Figure 3
This 2 kW rheostat is used for the dynamic braking of a wind turbine.

The variable resistor is a resistor whose value can be adjusted by turning a shaft or sliding a control. They are also called potentiometers or rheostats and allow the resistance of the device to be altered by hand. The term rheostat is usually reserved for higher-powered devices, above about 1/2 watt. Variable resistors can be inexpensive single-turn types or multi-turn types with a helical element. Some variable resistors can be fitted with a mechanical display to count the turns. Variable resistors can sometimes be unreliable, because the wire or metal can corrode or wear. Some modern variable resistors use plastic materials that do not corrode and have better wear characteristics.

Some examples include:

- a rheostat: a variable resistor with two terminals, one fixed and one sliding. It is used with high currents.
- a potentiometer: a common type of variable resistor. One common use is as volume controls on audio amplifiers and other forms of amplifiers.

1.3.7 Other types of resistors

- A metal oxide varistor (**MOV**) is a special type of resistor that changes its resistance with rise in voltage: a very high resistance at low voltage (below the trigger voltage) and very low resistance at high voltage (above the trigger voltage). It acts as a switch. It is usually used for short circuit protection in power strips or lightning bolt "arrestors" on street power poles, or as a "snubber" in inductive circuits.
- A thermistor is a temperature-dependent resistor. There are two kinds, classified according to the sign of their temperature coefficients:
  - A *Positive* Temperature Coefficient (**PTC**) resistor is a resistor with a positive temperature coefficient. When the temperature rises the resistance of the PTC increases. PTCs are often found in televisions in series with the demagnetizing_coil where they are used to provide a short-duration current burst through the coil when the TV is turned on. One specialized version of a PTC is the polyswitch which acts as a self-repairing fuse.
  - A Negative Temperature Coefficient (**NTC**) resistor is also a temperature-dependent resistor, but with a negative temperature coefficient. When the temperature rises the resistance of the NTC drops. NTCs are often used in simple temperature detectors and measuring instruments.

- A sensistor is a semiconductor-based resistor with a negative temperature coefficient, useful in compensating for temperature-induced effects in electronic circuits.
- Light-sensitive resistors are discussed in the photoresistor article.
- All wire except superconducting wire has some resistance, depending on its cross-sectional area and the conductivity of the material it is made of. Resistance wire has an accurately known resistance per unit length, and is used to make wire-wound resistors.

1.3.8 Identifying resistors

Most axial resistors use a pattern of colored stripes to indicate resistance. SMT ones follow a numerical pattern. Cases are usually brown, blue, or green, though other colors are occasionally found like dark red or dark gray.

One can use a multimeter to test the values of a resistor.

1.3.9 Resistor Standards

- MIL-R-11
- MIL-R-39008
- MIL-R-39017
- BS 1852
- EIA-RS-279

There are other MIL-R- standards.

1.3.10 Four-band axial resistors

Four-band identification is the most commonly used color coding scheme on all resistors. It consists of four colored bands that are painted around the body of the resistor. The scheme is simple: The first two numbers are the first two significant digits of the resistance value, the third is a multiplier, and the fourth is the tolerance of the value. Each color corresponds to a certain number, shown in the chart below. The tolerance for a 4-band resistor will be 2%, 5%, or 10%.

Table of The Standard EIA Color Code Table per EIA-RS-279 is as follows:

Color	**1st band**	**2nd band**	**3rd band (multiplier)**	**4th band (tolerance)**	**Temp. Coefficient**
Black	0	0	$\times 10^0$		
Brown	1	1	$\times 10^1$	±1% (F)	100 ppm
Red	2	2	$\times 10^2$	±2% (G)	50 ppm
Orange	3	3	$\times 10^3$		15 ppm
Yellow	4	4	$\times 10^4$		25 ppm
Green	5	5	$\times 10^5$	±0.5% (D)	
Blue	6	6	$\times 10^6$	±0.25% (C)	
Violet	7	7	$\times 10^7$	±0.1% (B)	
Gray	8	8	$\times 10^8$	±0.05% (A)	
White	9	9	$\times 10^9$		

Gold			×0.1	±5% (J)	
Silver			×0.01	±10% (K)	
None				±20% (M)	

Note: red to violet are the colors of the rainbow where red is low energy and violet is higher energy.

Resistors use specific values, which are determined by their tolerance. These values repeat for every exponent; 6.8, 68, 680, and so forth. This is useful because the digits, and hence the first two or three stripes, will always be similar patterns of colors, which make them easier to recognize.

1.3.11 Preferred values

Resistors are manufactured in values from a few milliohms to about a gigaohm; only a limited range of values from the IEC 60063 preferred number series are commonly available. These series are called E6, E12, E24, E96 and E192. The number tells how many standarized values exist in each decade (e.g. between 10 and 100, or between 100 and 1000). So resistors confirming to the E12 series, can have 12 distinct values between 10 and 100, whereas those confirming to the E24 series would have 24 distinct values. In practice, the discrete component sold as a "resistor" is not a perfect resistance, as defined above. Resistors are often marked with their tolerance (maximum expected variation from the marked resistance). On color coded resistors the color of the rightmost band denotes the tolerance:

silver 10%
gold 5%
red 2%

brown 1%

green 0.5%.

Closer tolerance resistors, called *precision resistors*, are also available.

Manufacturers will measure the actual resistance of new resistors and sort them by tolerance according to how close they were to the intended value. Subsequently, if you buy 100 resistors of the same value with a tolerance of +/- 10%, you *won't* get some resistors with the correct value, some off by a little and the worst off by 10%; what you'll probably find if you measure them, is that about half of the resistors are between 5% and 10% too low in value, and the other half are between 5% and 10% too high in value. Those off by less than 5%, would've been marked and sold as more expensive 5% resistors. This is something to consider when calculating specifications on the components for a project: that *all* resistors will be "off" by the specified tolerance, and not just the "worse" of them.

E12 preferred values : 10, 12, 15, 18, 22, 27, 33, 39, 47, 56, 68, 82

Multiples of 10 of these values are used, eg. 0.47Ω, 4.7Ω, 47Ω, 470Ω, 4.7k, 47k, 470k, and so forth.

E24 preferred values, includes E12 values and : 11, 13, 16, 20, 24, 30, 36, 43, 51, 62, 75, 91

1.3.12 5-band axial resistors

5-band identification is used for higher tolerance resistors (1%, 0.5%, 0.25%, 0.1%), to notate the extra digit. The first three bands represent the significant digits, the fourth is the multiplier, and the fifth is the tolerance. 5-band standard tolerance resistors are sometimes encountered, generally on older or specialized resistors. They can be identified by noting a standard tolerance color in the 4th band. The 5th band in this case is the temperature coefficient.

1.3.13 Mnemonic phrases for remembering codes

There are many mnemonic phrases used to remember the order of the colors.

They are, but are not limited to, and variations of:

- **B**ad **B**oys **R**avish **O**ur **Y**oung **G**irls **B**ut **V**iolet **G**ives **W**illingly
- **B**ad **B**eer **R**ots **O**ur **Y**oung **G**uts **B**ut **V**odka **G**oes **W**ell. **G**et **S**ome **N**ow!
- **B.B. ROY** of **G**reat **B**ritain had a **V**ery **G**ood **W**ife
- **B**uffalo **B**ill **R**oamed **O**ver **Y**ellow **G**rass **B**ecause **V**istas **G**rand **W**ere **G**od's **S**anctuary
- **B**ully **B**rown **R**an **O**ver a **Y**odeling **G**oat, **B**ecause **V**iolet's **G**ranny **W**as **G**one **S**norkeling
- **B**uy **B**etter **R**esistance **O**r **Y**our **G**rid **B**ias **M**ay **G**o **W**rong

Black Brown Red Orange Yellow Green Blue Violet Gray White (Gold Silver)

1.3.14 SMD resistors

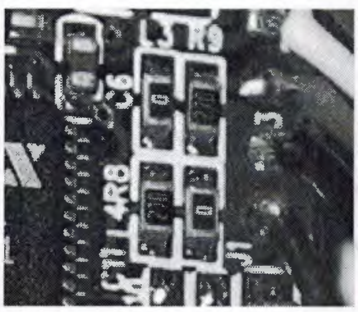


Figure 5

This image shows some surface mount resistors, including two zero-ohm resistors. Zero-ohm links are often used instead of wire links, so that they can be inserted by a resistor-inserting machine.

Surface mounted resistors are printed with numerical values in a code related to that used on axial resistors. Standard-tolerance SMD resistors are marked with a three-digit code, in which the first two digits are the first two significant digits of the value and the third digit is the power of ten (the number of zeroes). For example:

"334" = 33 × 10,000 ohms = 330 kiloohms

"222" = 22 × 100 ohms = 2.2 kiloohms

"473" = 47 × 1,000 ohms = 47 kiloohms

"105" = 10 × 100,000 ohms = 1 megaohm

Resistances less than 100 ohms are written: 100, 220, 470. The final zero represents ten to the power zero, which is 1. For example:

"100" = 10 × 1 ohm = 10 ohms

"220" = 22 × 1 ohm = 22 ohms

Sometimes these values are marked as "10" or "22" to prevent a mistake.

Resistances less than 10 ohms have 'R' to indicate the position of the decimal point. For example:

"4R7" = 4.7 ohms

"0R22" = 0.22 ohms

"0R01" = 0.01 ohms

Precision resistors are marked with a four-digit code, in which the first three digits are the significant figures and the fourth is the power of ten. For example:

"1001" = 100 × 10 ohms = 1 kiloohm

"4992" = 499 × 100 ohms = 49.9 kiloohm

"1000" = 100 × 1 ohm = 100 ohms

"000" and "0000" sometimes appear as values on surface-mount zero-ohm links, since these have (approximately) zero resistance.

Industrial type designation.

Table of power rating and tolerance code

Power Rating at 70°C

Type No.	Power rating (Watts)	MIL-R-11 Style	MIL-R-39008 Style
BB	1/8	RC05	RCR05
CB	¼	RC07	RCR07
EB	½	RC20	RCR20
GB	1	RC32	RCR32
HB	2	RC42	RCR42
GM	3	-	-
HM	4	-	-

Tolerance Code

Industrial type designation	Tolerance	MIL Designation
5	±5%	J
2	±20%	-
1	±10%	K
-	±2%	G
-	±1%	F
-	±0.5%	D
-	±0.25%	C
-	±0.1%	B

Note:- You can easily learn these through a simple sentence - "BB Roy Great Britain Very Good Wife" the numbers start from 0 The operational temperature range distinguishes commercial grade, industrial grade and military grade components.

- Commercial grade: 0°C to 70°C
- Industrial grade: −40°C to 85°C (sometimes −25°C to 85°C)
- Military grade: −55°C to 125°C

1.3.15Calculations

1.3.15.1 Ohm's law

The relationship between voltage, current, and resistance through a metal wire, and some other materials, is given by a simple equation called Ohm's Law:

$V = IR$

where V (or U in some languages) is the voltage (or potential difference) across the wire in volts, I is the current through the wire in amperes, and R, in ohms, is a constant called the resistance—in fact this is only a simplification of the original Ohm's law (see the article on that law for further details). Materials that obey this law over a certain voltage or current range are said to be ohmic over that range. An ideal resistor obeys the law across all frequencies and amplitudes of voltage or current.

Superconducting materials at very low temperatures have zero resistance. Insulators (such as air, diamond, or other non-conducting materials) may have extremely high (but not infinite) resistance, but break down and admit a larger flow of current under sufficiently high voltage.

1.3.15.2 Power dissipation

The power dissipated by a resistor is the voltage across the resistor multiplied by the current through the resistor:

Formula of power $$P = I^2 R = I \cdot V = \frac{V^2}{R}$$

All three equations are equivalent. The first is derived from Joule's law, and other two are derived from that by Ohm's Law.

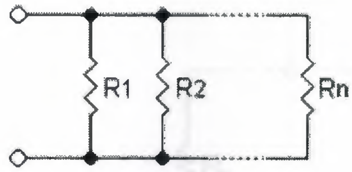
The total amount of heat energy released is the integral of the power over time:

$$W = \int_{t_1}^{t_2} v(t) i(t)\, dt$$ formula of heat energy

If the average power dissipated exceeds the power rating of the resistor, then the resistor will first depart from its nominal resistance, and will then be destroyed by overheating.

1.3.15.3 Series and parallel circuits

Resistors in a parallel configuration each have the same potential difference (voltage). To find their total equivalent resistance (R_{eq}):

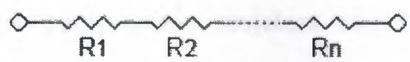


$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$$ **formula of parallel resistors**

The parallel property can be represented in equations by two vertical lines "||" (as in geometry) to simplify equations. For two resistors,

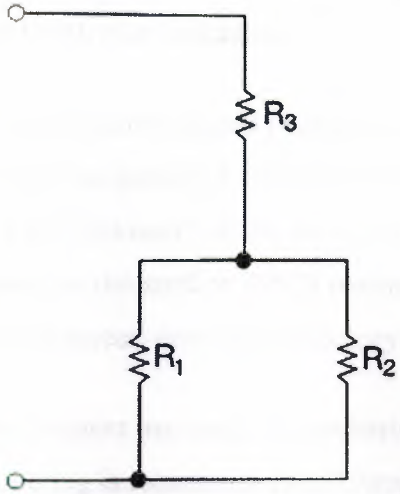
$$R_{eq} = R_1 \| R_2 = \frac{R_1 R_2}{R_1 + R_2}$$ **formula of parallel resistors(2)**

The current through resistors in series stays the same, but the voltage across each resistor can be different. The sum of the potential differences (voltage) is equal to the total voltage. To find their total resistance:



$$R_{eq} = R_1 + R_2 + \cdots + R_n$$ **formula of parallel resistors(3)**

A resistor network that is a combination of parallel and series can sometimes be broken up into smaller parts that are either one or the other. For instance,



formula of parallel resistors(4)

$$R_{eq} = (R_1 \| R_2) + R_3 = \frac{R_1 R_2}{R_1 + R_2} + R_3$$

However, many resistor networks cannot be split up in this way. Consider a cube, each edge of which has been replaced by a resistor. For example, determining the resistance between two opposite vertices requires matrix methods for the general case. However, if all twelve resistors are equal, the corner-to-corner resistance is 5/6 of any one of them.

1.3.15.4 Technology

Carbon composition resistors consist of a solid cylindrical resistive element with embedded wire leadouts or metal end caps to which the leadout wires are attached, which is protected with paint or plastic. A spiral is used to increase the length and decrease the width of the film, which increases the resistance.

The resistive element is made from a mixture of finely ground (powdered) carbon and an insulating material (usually ceramic). The mixture is held together by a resin. The resistance is determined by the ratio of the fill material (the powdered ceramic) and the carbon. Higher concentrations of carbon, being a weak conductor, result in lower resistance. Carbon composition resistors were commonly used in the 1960's and earlier, but are not so popular for general use now as other types have better specifications, such as tolerance, voltage dependence, and stress (carbon composition resistors will change value when stressed with over-voltages).

Thick Film resistors became popular during the 1970's, and most SMD resistors, today, are of this type. The principal difference between "thin film" and "thick film resistors" isn't necessarily the "thickness" of the film, but rather, how the film is applied to the cylinder (axial resistors) or the surface (SMD resistors). In thick film resistors the "film" is applied using traditional screen-printing technology.

Thin film resistors are made by sputtering the resistive material onto the surface of the resistor. Sputtering is sometimes called vacuum deposition. The thin film is then etched in a similar manner to the old (subtractive) process for making printed circuit boards: ie the surface is coated with a photo-sensitive material, then covered by a film, irradiated with UV light, and then the exposed photo-sensitive coating, and underlying thin film, are etched away.

Thin film resistors, like their thick film counterparts, are then usually trimmed to a relatively exact value by abrasive or laser trimmming.

Because the time during which the sputtering is performed can be controlled, the thickness of the film of a thin-film resistor, can be accurately controlled. The type of the material is also usually different consisting of one or more ceramic (cermet) conductors such as tantalum nitride (TaN), rubidium dioxide (RuO2), lead oxide (PbO), bismuth ruthenate (Bi2Ru2O7), nickel chromium (NiCr), and/or bismuth iridate (Bi2Ir2O7).

By contrast, thick film resistors, may use the same conductive ceramics, but they are mixed with sintered (powdered) glass, and some kind of liquid so that the composite can be screen-printed. This composite of glass and conductive ceramic (cermet) material is then fused (baked) in an oven at about 850C.

Traditionally thick film resistors had tolerances of 5%, but in the last few decades, standard tolerances have improved to 2% and 1%. But beware; temperature coefficients of thick film resistors, are tyically +/- 200 ppm, or +/- 250ppm, depending on the resistance.

Thus a 40 degree Celsius temperature change can add another 1% variation to a 1% resistor.

Thin film resistors are usually specified with tolerances of 0.1, 0.2, 0.5, and 1%, and with temperature coefficients of 5 to 25ppm. They are usually far more expensive than their thick film cousins. Note, though, that SMD thin film resistors, with 0.5% tolerances, and with 25ppm temperature coefficients, when bought in full size reel quantities, are about twice the cost of a 1%, 250ppm thick film resistors.

A common type of axial resistor today is referred to as a metal-film resistor. MELF (Metal Electrode Leadless Face) resistors often use the same technology, but are a cylindrically shaped resistor designed for surface mounting. [Note that other types of resistors, eg carbon composition, are also available in "MELF" packages].

Metal Film resistors are usually coated with nickel chromium (NiCr), but might be coated with any of the cermet materials listed above for thin film resistors. Unlike thin film resistors, the material may be applied using different techniques than sputtering (though that is one such technique). Also, unlike thin-film resistors, the resistance value is determined by cutting a helix through the coating rather than by etching. [This is similar to the way carbon resistors are made.] The result is a reasonable tolerance (0.5, 1, or 2%) and a temperature coefficient of (usually) 25 or 50ppm.

Wirewound resistors are commonly made by winding a metal wire around a ceramic, plastic, or fiberglass core. The ends of the wire are soldered or welded to two caps, attached to the ends of the core. The assembly is protected with a layer of paint, molded plastic, or an enamel coating baked at high temperature. The wire leads are usually between 0.6 and 0.8 mm in diameter and tinned for ease of soldering. For higher power wirewound resistors, either a ceramic outer case or an aluminium outer case on top of an insulating layer is used. The aluminium cased types are designed to be attached to a heatsink to dissipate the heat; the rated power is dependant on being used with a suitable heatsink, e.g., a 50W power rated resistor will overheat at around one fifth of the power dissipation if not used with a heatsink.

Note that wirewound resistors, by the very nature of their being "coils", are far more inductive than other types of resistor.

Types of resistors:

- Carbon composition
- Carbon film
- Metal film
- Metal oxide
- Wirewound (usually has higher parasitic inductance)
- Cermet
- Phenolic
- Tantalum

1.3.16 Foil resistor

Foil resistors have had the best precision and stability ever since they were introduced in 1958 by Berahard F. Telkamp. One of the important parameters influencing stability is the temperature coefficient of resistance (TCR). Although the TCR of foil resistors is considered extremely low, this characteristic has been further refined over the years.

1.4 Diodes:

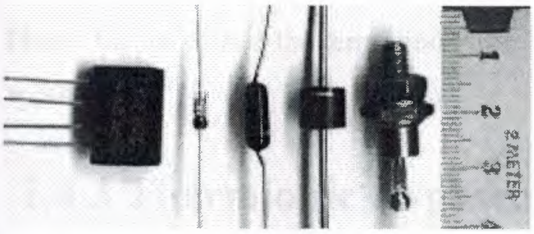


Figure of diodes

1.4.1 Types of diyotes

In electronics, a diode is a component that restricts the direction of movement of charge carriers. Essentially, it allows an electric current to flow in one direction, but blocks it in the opposite direction. Thus, the diode can be thought of as an electronic version of a check valve. Circuits that require current flow in only one direction will typically include one or more diodes in the circuit design.

Early diodes included "cat's whisker" crystals and vacuum tube devices (called thermionic valves in British English). Today the most common diodes are made from semiconductor materials such as silicon or germanium.

1.4.2 History

Thermionic and solid state diodes developed in parallel. The principle of operation of thermionic diodes was discovered by Frederick Guthrie in 1873. The principle of operation of crystal diodes was discovered in 1874 by the German scientist, Karl Ferdinand Braun [2].

Thermionic diode principles were rediscovered by Thomas Edison on February 13, 1880 and he took out a patent in 1883 (U.S. Patent 307031), but developed the idea no further. Braun patented the crystal rectifier in 1899 []. The first radio receiver using a crystal diode was built around 1900 by Greenleaf Whittier Pickard. The first thermionic diode was patented in Britain by John Ambrose Fleming (scientific adviser to the Marconi Company and former Edison employee[4]) on November 16, 1904 (U.S. Patent 80364 in November

1905). Pickard received a patent for a silicon crystal detector on November 20, 1906 [5] (U.S. Patent 836531).

At the time of their invention such devices were known as rectifiers. In 1919 William Henry Eccles coined the term diode from Greek roots; *di* means 'two', and *ode* (from *odos*) means 'path'.

1.4.3 Thermionic or gaseous state diodes

Figure 1

Thermionic diodes are vacuum tube devices (also known as thermionic valves), which are arrangements of electrodes surrounded by a vacuum within a glass envelope, similar in appearance to incandescent light bulbs.

In vacuum tube diodes, a current is passed through the cathode, a filament treated with a mixture of barium and strontium oxides, which are oxides of alkaline earth metals. The current heats the filament, causing thermionic emission of electrons into the vacuum envelope. In forward operation, a surrounding metal electrode, called the anode, is positively charged, so that it electrostatically attracts the emitted electrons. However, electrons are not easily released from the unheated anode surface when the voltage polarity is reversed and hence any reverse flow is a very tiny current.

For much of the 20th century vacuum tube diodes were used in analog signal applications, and as rectifiers in power supplies. Today, tube diodes are only used in niche applications, such as rectifiers in tube guitar and hi-fi amplifiers, and specialized high-voltage equipment.

1.4.4 Semiconductor diodes

Figure of semiconductors

1.4.4.1 Diode schematic symbol

Most modern diodes are based on semiconductor p-n junctions. In a p-n diode, conventional current can flow from the p-type side (the anode) to the n-type side (the cathode), but not in the opposite direction. Another type of semiconductor diode, the Schottky diode, is formed from the contact between a metal and a semiconductor rather than by a p-n junction.

A semiconductor diode's current-voltage, or *I-V,* characteristic curve is ascribed to the behavior of the so-called depletion layer or depletion zone which exists at the p-n junction between the differing semiconductors. When a p-n junction is first created, conduction band (mobile) electrons from the N-doped region diffuse into the P-doped region where there is a large population of holes (places for electrons in which no electron is present) with which the electrons "recombine". When a mobile electron recombines with a hole, the hole vanishes and the electron is no longer mobile. Thus, two charge carriers have vanished. The region around the p-n junction becomes depleted of charge carriers and thus behaves as an insulator.

However, the depletion width cannot grow without limit. For each electron-hole pair that recombines, a positively-charged dopant ion is left behind in the N-doped region, and a negatively charged dopant ion is left behind in the P-doped region. As recombination proceeds and more ions are created, an increasing electric field develops through the depletion zone which acts to slow and then finally stop recombination. At this point, there is a 'built-in' potential across the depletion zone.

If an external voltage is placed across the diode with the same polarity as the built-in potential, the depletion zone continues to act as an insulator preventing a significant electric current. This is the reverse bias phenomenon. However, if the polarity of the external voltage opposes the built-in potential, recombination can once again proceed resulting in substantial electric current through the p-n junction. For silicon diodes, the built-in potential is approximately 0.6 V. Thus, if an external current is passed through the diode, about 0.6 V will be developed across the diode such that the P-doped region is positive with respect to the N-doped region and the diode is said to be 'turned on' as it has a *forward bias*.

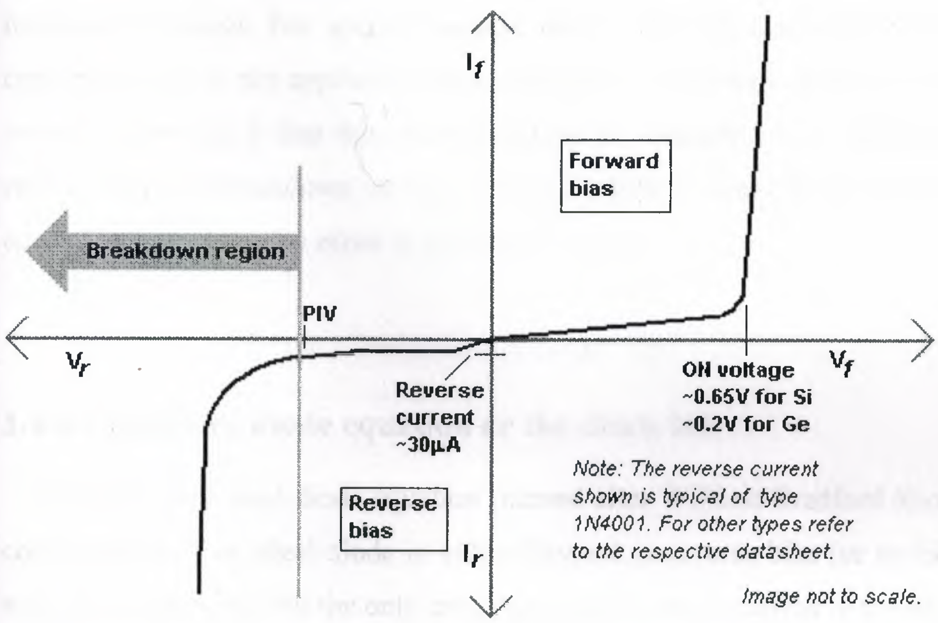


Figure of I-V characteristics of a P-N junction diode (not to scale).

A diode's I-V characteristic can be approximated by two regions of operation. Below a certain difference in potential between the two leads, the depletion layer has significant width, and the diode can be thought of as an open (non-conductive) circuit. As the potential difference is increased, at some stage the diode will become conductive and allow charges to flow, at which point it can be thought of as a connection with zero (or at least very low) resistance. More precisely, the transfer function is logarithmic, but so sharp that it looks like a corner on a zoomed-out graph .

In a normal silicon diode at rated currents, the voltage drop across a conducting diode is approximately 0.6 to 0.7 volts. The value is different for other diode types - Schottky diodes can be as low as 0.2 V and light-emitting diodes (LEDs) can be 1.4 V or more (Blue LEDs can be up to 4.0 V).

Referring to the I-V characteristics image, in the reverse bias region for a normal P-N rectifier diode, the current through the device is very low (in the μA range) for all reverse voltages up to a point called the peak-inverse-voltage (PIV). Beyond this point a process called reverse breakdown occurs which causes the device to be damaged along with a large increase in current. For special purpose diodes like the avalanche or zener diodes, the concept of PIV is not applicable since they have a deliberate breakdown beyond a known reverse current such that the reverse voltage is "clamped" to a known value (called the zener voltage or breakdown voltage). These devices however have a maximum limit to the current and power in the zener or avalanche region.

1.4.4.2 Shockley diode equation or the diode law

The Shockley ideal diode equation (named after William Bradford Shockley) is the I-V characteristic of an ideal diode in either forward or reverse bias (or no bias). It is derived with the assumption that the only processes giving rise to current in the diode are drift (due to electrical field), diffusion, and thermal recombination-generation. It also assumes that the recombination-generation (R-G) current in the depletion region is insignificant. This means that the Shockley equation doesn't account for the processes involved in reverse breakdown and photon-assisted R-G. Additionally, it doesn't describe the "leveling off" of the I-V curve at high forward bias due to internal resistance, nor does it explain the practical deviation from the ideal at very low forward bias due to R-G current in the depletion region.

$$I = I_S \left(e^{V_D/(nV_T)} - 1\right),$$

where

I is the diode current,

I_S is a scale factor called the saturation current,

V_D is the voltage across the diode,

V_T is the thermal voltage,

and n is the emission coefficient.

The emission coefficient n varies from about 1 to 2 depending on the fabrication process and semiconductor material and in many cases is assumed to be approximately equal to 1 (thus omitted). The thermal voltage V_T is approximately 25.2 mV at room temperature (approximately 25 °C or 298 K) and is a known constant. It is defined by:

$$V_T = \frac{kT}{e},$$

where

e is the magnitude of charge on an electron (the elementary charge),

k is Boltzmann's constant,

T is the absolute temperature of the p-n junction.

1.4.4.3 Types of semiconductor diode

Diode Zener Schottky Tunnel

	Diode	Diode	Diode
			
Light-emitting diode	Photodiode	Varicap	SCR

Table of Some diode symbols

There are several types of semiconductor junction diodes:

1.4.5 Normal (p-n) diodes

Usually made of doped silicon or, more rarely, germanium. Before the development of modern silicon power rectifier diodes, cuprous oxide and later selenium was used; its low efficiency gave it a much higher forward voltage drop (typically 1.4–1.7 V per "cell," with multiple cells stacked to increase the peak inverse voltage rating in high voltage rectifiers), and required a large heat sink (often an extension of the diode's metal substrate), much larger than a silicon diode of the same current ratings would require.

'Gold doped' diodes

As a dopant, gold (or platinum) acts as recombination centers, which help a fast recombination of minority carriers. This allows the diode to operate at signal frequencies, at the expense of a higher forward voltage drop [1]. A typical example is the 1N914.

1.4.6 Zener diodes

Diodes that can be made to conduct backwards. This effect, called Zener breakdown, occurs at a precisely defined voltage, allowing the diode to be used as a precision voltage reference. In practical voltage reference circuits Zener and switching diodes are connected in series and opposite directions to balance the temperature coefficient to near zero. Some devices labeled as high-voltage Zener diodes are actually avalanche diodes (see below). Two (equivalent) Zeners in series and in reverse order, in the same package, constitute a transient absorber (or Transorb, a registered trademark). They are named for Dr. Clarence Melvin Zener of Southern Illinois University, inventor of the device.

1.4.7 Avalanche diodes

Diodes that conduct in the reverse direction when the reverse bias voltage exceeds the breakdown voltage. These are electrically very similar to Zener diodes, and are often mistakenly called Zener diodes, but break down by a different mechanism, the avalanche effect. This occurs when the reverse electric field across the p-n junction causes a wave of ionization, reminiscent of an avalanche, leading to a large current. Avalanche diodes are designed to break down at a well-defined reverse voltage without being destroyed. The difference between the avalanche diode (which has a reverse breakdown above about 6.2 V) and the Zener is that the channel length of the former exceeds the 'mean free path' of the electrons, so there are collisions between them on the way out. The only practical difference is that the two types have temperature coefficients of opposite polarities.

1.4.8 Transient voltage suppression (TVS) diodes

These are avalanche diodes designed specifically to protect other semiconductor devices from high-voltage transients. Their p-n junctions have a much larger cross-sectional area than those of a normal diode, allowing them to conduct large currents to ground without sustaining damage.

1.4.9 Photodiodes

Semiconductors are subject to optical charge carrier generation and therefore most are packaged in light blocking material. If they are packaged in materials that allow light to pass, their photosensitivity can be utilized. Photodiodes can be used as solar cells, and in photometry.

1.4.10 Light-emitting diodes (LEDs)

In a diode formed from a direct band-gap semiconductor, such as gallium arsenide, carriers that cross the junction emit photons when they recombine with the majority carrier on the other side. Depending on the material, wavelengths (or colors) from the infrared to the near ultraviolet may be produced. The forward potential of these diodes depends on the wavelength of the emitted photons: 1.2 V corresponds to red, 2.4 to violet. The first LEDs were red and yellow, and higher-frequency diodes have been developed over time. All LEDs are monochromatic; 'white' LEDs are actually combinations of three LEDs of a different color, or a blue LED with a yellow scintillator coating. LEDs can also be used as low-efficiency photodiodes in signal applications. An LED may be paired with a photodiode or phototransistor in the same package, to form an opto-isolator.
Laser diodes

When an LED-like structure is contained in a resonant cavity formed by polishing the parallel end faces, a laser can be formed. Laser diodes are commonly used in optical storage devices and for high speed optical communication.
Schottky diodes

Schottky diodes are constructed from a metal to semiconductor contact. They have a lower forward voltage drop than a standard PN junction diode. Their forward voltage drop at forward currents of about 1 mA is in the range 0.15 V to 0.45 V, which makes them useful in voltage clamping applications and prevention of transistor saturation. They can also be used as low loss rectifiers although their reverse leakage current is generally much higher than non Schottky rectifiers. Schottky diodes are majority carrier devices and so do not suffer from minority carrier storage problems that slow down most normal diodes. They also tend to have much lower junction capacitance than PN diodes and this contributes towards their high switching speed and their suitability in high speed circuits and RF devices such as mixers and detectors.

Snap-off or 'step recovery' diodes

The term 'step recovery' relates to the form of the reverse recovery characteristic of these devices. After a forward current has been passing in an SRD and the current is interrupted or reversed, the reverse conduction will cease very abruptly (as in a step waveform). SRDs can therefore provide very fast voltage transitions by the very sudden disappearance of the charge carriers. Esaki or tunnel diodes have a region of operation showing negative resistance caused by quantum tunneling, thus allowing amplification of signals and very simple bistable circuits. These diodes are also the type most resistant to nuclear radiation.

1.4.11 Current-limiting field-effect diodes

These are actually a JFET with the gate shorted to the source, and function like a two-terminal current-limiting analog to the Zener diode; they allow a current through them to rise to a certain value, and then level off at a specific value. Also called CLDs, constant-current diodes, or current-regulating diodes.[6], [7]

Other uses for semiconductor diodes include sensing temperature, and computing analog logarithms (see Operational amplifier applications#Logarithmic).

Related devices

- Thyristor or silicon controlled rectifier (SCR)
- TRIAC

- Diac
- Transistor
- Applications

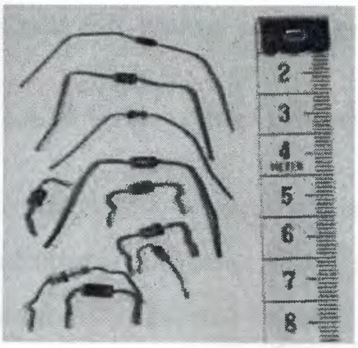


Figure of several types of diodes

1.4.12 Radio demodulation

The first use for the diode was the demodulation of amplitude modulated (AM) radio broadcasts. The history of this discovery is treated in depth in the radio article. In summary, an AM signal consists of alternating positive and negative peaks of voltage, whose amplitude or 'envelope' is proportional to the original audio signal, but whose average value is zero. The diode (originally a crystal diode) rectifies the AM signal, leaving a signal whose average amplitude is the desired audio signal. The average value is extracted using a simple filter and fed into an audio transducer, which generates sound.

When power is shut off to the regulator the output voltage should fall faster than the input. In case it doesn't, a diode can be connected across the input/output terminals to protect the regulator from possible reverse voltages. A 1uF tantalum or 25uF electrolytic capacitor across the output improves transient response and a small 0.1uF tantalum capacitor is recommended across the input if the regulator is located an appreciable distance from the power supply filter. The power transformer should be large enough so that the regulator input voltage remains 3 volts above the output at full load, or 16.6 volts for a 13.6 volt output.

1.4.13 Power conversion

Rectifiers are constructed from diodes, where they are used to convert alternating current (AC) electricity into direct current (DC). Similarly, diodes are also used in Cockcroft-Walton voltage multipliers to convert AC into very high DC voltages.

1.4.14 Over-voltage protection

Diodes are frequently used to conduct damaging high voltages away from sensitive electronic devices. They are usually reverse-biased (non-conducting) under normal circumstances, and become forward-biased (conducting) when the voltage rises above its normal value. For example, diodes are used in stepper motor and relay circuits to de-energize coils rapidly without the damaging voltage spikes that would otherwise occur. Many integrated circuits also incorporate diodes on the connection pins to prevent external voltages from damaging their sensitive transistors. Specialized diodes are used to protect from over-voltages at higher power (see Diode types above).

1.4.15 Logic gates

Diodes can be combined with other components to construct AND and OR logic gates. This is referred to as diode logic.

Ionising radiation detectors

In addition to light, mentioned above, semiconductor diodes are sensitive to more energetic radiation. In electronics, cosmic rays and other sources of ionising radiation cause noise pulses and single and multiple bit errors. This effect is sometimes exploited by particle detectors to detect radiation. A single particle of radiation, with thousands or millions of electron volts of energy, generates many charge carrier pairs, as its energy is deposited in the semiconductor material. If the depletion layer is large enough to catch the whole shower or to stop a heavy particle, a fairly accurate measurement of the particle's energy can be made, simply by measuring the charge conducted and without the complexity of a magnetic spectrometer or etc. These semiconductor radiation detectors need efficient and uniform charge collection and low leakage current. They are often cooled by liquid nitrogen. For longer range (about a centimetre) particles they need a very large depletion depth and large area. For short range particles, they need any contact or un-depleted semiconductor on at least one surface to be very thin. The back-bias voltages are near breakdown (around a thousand volts per centimetre). Germanium and silicon are common materials. Some of these detectors sense position as well as energy. They have a finite life, especially when detecting heavy particles, because of radiation damage. Silicon and germanium are quite different in their ability to convert gamma rays to electron showers.

Semiconductor detectors for high energy particles are used in large numbers. Because of energy loss fluctuation, accurate measurement of the energy deposited is of less use.

1.4.16 Temperature measuring

A diode can be used as a temperature measuring device, since the forward voltage drop across the diode depends on temperature. This temperature dependence follows from the Shockley ideal diode equation given above and is typically around 2.2 mV per degree Celsius.

1.4.17 Charge coupled devices

Digital cameras and similar units use arrays of photo diodes, integrated with readout circuitry.

1.5 Bridge Rectifier

A rectifier is basically a thresholding non linear component : below a given voltage, no (or a very small) current will flow, then, this value beeing exceeded, conduction occurs. Altough almost all rectifiers have a threshold of 0 volts (what do not mean, at least for high vacuum valves, that their voltage drop is small at full load), it exists a special category of rectifiers, the gaz filled diodes, for which behaviour is far more complex. For those components, below the trigger voltage, no conduction occurs, then, after that, chain ionisation begins (tube will glow!). As soon as the discharge is started, voltage drop at the tube terminals is almost constant (internal impedance is very low). The tube will switch off only when voltage will fall below the extinction threshold, which is different from the ignition threshold! Gaz filled diodes must never be used with a capacitive load, except when explicity mentionned in the data sheet (in which case maximum value for the capacitor should never be exceeded) : internal impedance is so low that charge current at start up will destroy the tube (the same phenomenon can occur will silicon diodes).

Notation We will use the following symbol for all rectifiers (except gaz filled ones), regardless of the technology :

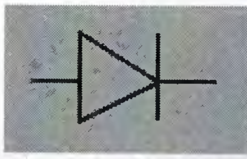
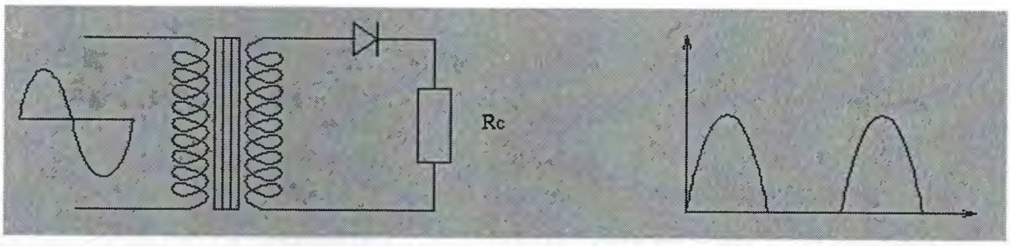


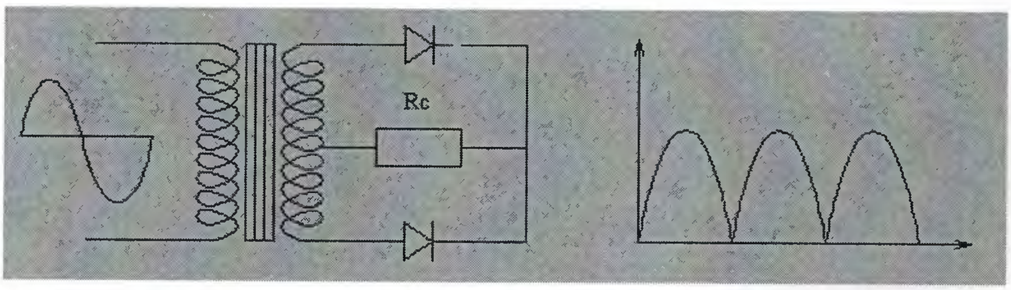
figure of diodes

For a mains supply, three basic schemas can be used (wave at load terminals is indicated to the right) :

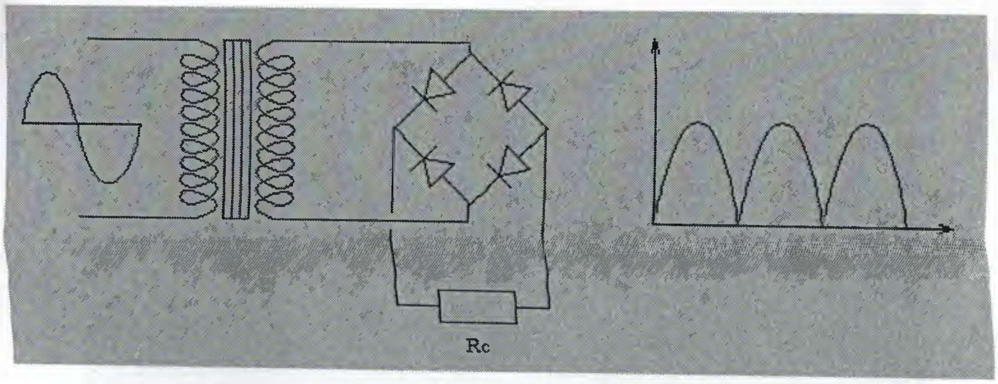
Monophased rectifying : graph 1



Biphased rectifying : graph 2



Graetz brige rectifying : graph3



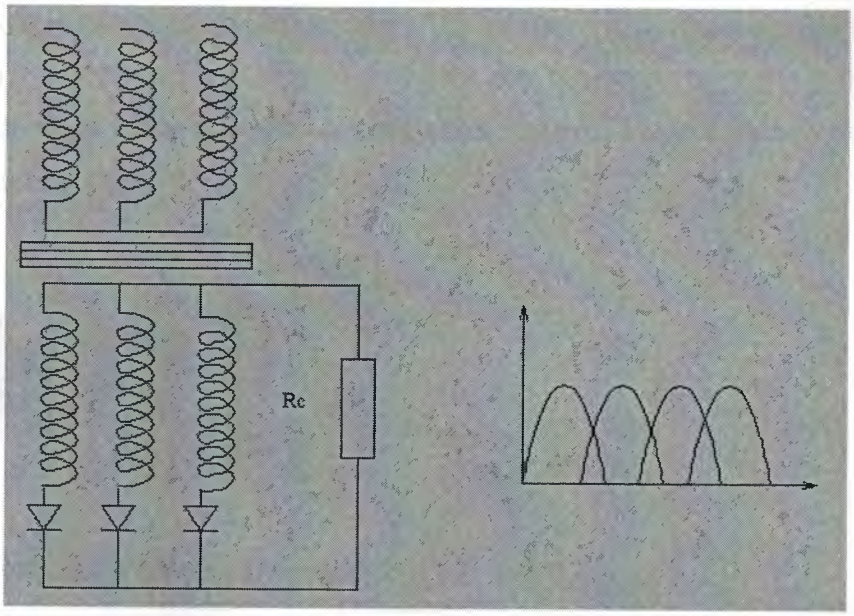
If we denote internal impedance of rectifier plus that of windings (see article on transformers) by R_g and if the load can be modelled as a pure resistance R_c, instantaneous value of voltage at load terminals is :

$$V_c = V_g \frac{R_c}{R_c + R_g}$$ formula 1

where V_g is the unloaded transformer voltage. An elementary computation shows that mean value of V_c is :

$$V_c = \frac{V_g}{\pi} \frac{R_c}{R_c + R_g} \quad \text{monophased}$$
$$V_c = \frac{2V_g}{\pi} \frac{R_c}{R_c + R_g} \quad \text{biphased}$$ formula 2

Previous schemas can be generalised to multiphased current : here is an example of triphased rectifying, used in high power applications :



In the following, the number of phases will be denoted by n, and this will be a parameter of all formula. An amateur will probably not be using hexaphased current, however, it will appear in the following that filtering is easier when number of phases increases. Purist audiophile can try to reconstruct multiphase waves with an onduler.

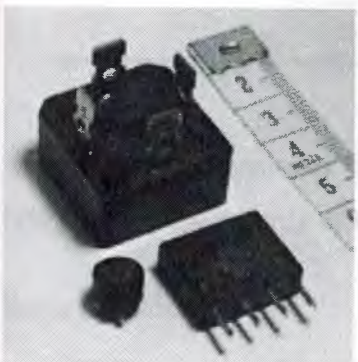


Figure of Three bridge rectifiers. The size is generally related to the power handling capability.

A diode bridge or bridge rectifier (occasionally called a Graetz bridge) is an arrangement of four diodes connected in a bridge circuit as shown below, that provides the same polarity of output voltage for any polarity of the input voltage. When used in its most common application, for conversion of alternating current (AC) input into direct current

(DC) output, it is known as a bridge rectifier. The bridge recitifier provides full wave rectification from a two wire AC input (saving the cost of a center tapped transformer) but has two diode drops rather than one reducing efficiency over a center tap based design for the same output voltage.

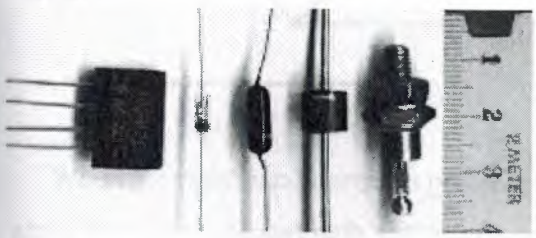
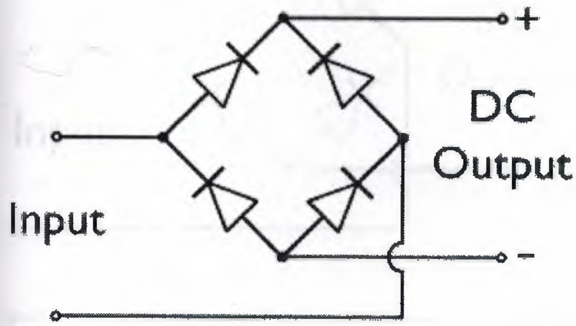


Figure 1

Diodes; the one on the left is a diode bridge

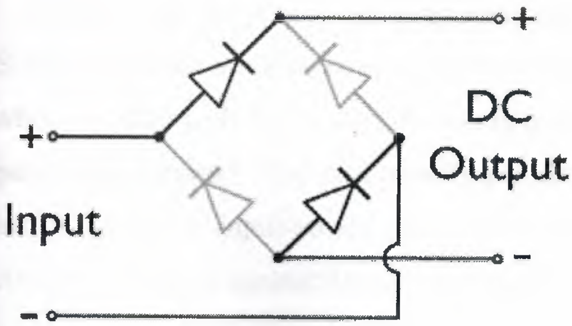


graph of bridge rectifier

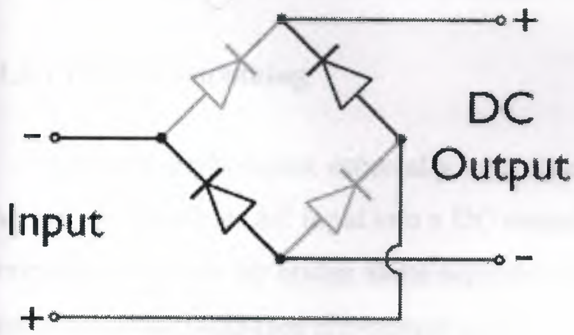
The essential feature of this arrangement is that for both polarities of the voltage at the bridge input, the polarity of the output is constant.

Basic operation

When the input connected at the left corner of the diamond is positive with respect to the one connected at the right hand corner, current flows to the right along the upper colored path to the output, and returns to the input supply via the lower one.



When the right hand corner is positive relative to the left hand corner, current flows along the upper colored path and returns to the supply via the lower colored path.



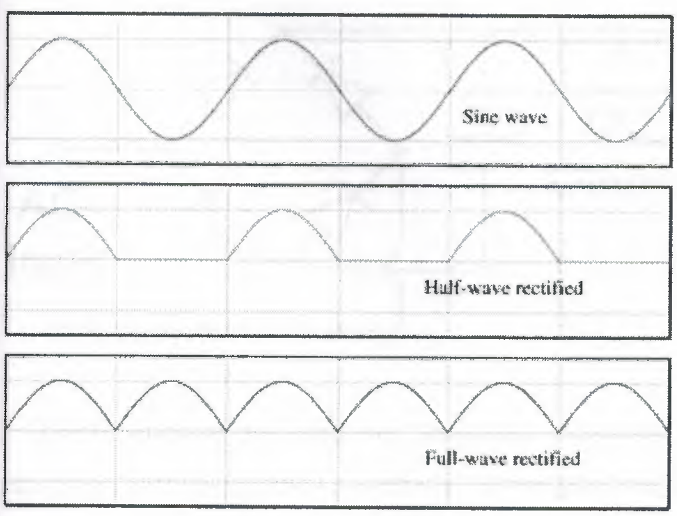


figure 1

AC, half-wave and full wave rectified signals

In each case, the upper right output remains positive with respect to the lower right one. Since this is true whether the input is AC or DC, this circuit not only produces DC power when supplied with AC power: it also can provide what is sometimes called "reverse polarity protection". That is, it permits normal functioning when batteries are installed backwards or DC input-power supply wiring "has its wires crossed" (and protects the circuitry it powers against damage that might occur without this circuit in place).

Prior to availability of integrated electronics, such a bridge rectifier was always constructed from discrete components. Since about 1950, a single four-terminal component containing the four diodes connected in the bridge configuration became a standard commercial component and is now available with various voltage and current ratings.

1.5.1 Output smoothing

For many applications, especially with single phase AC where the full-wave bridge serves to convert an AC input into a DC output, the addition of a capacitor may be important because the bridge alone supplies an output voltage of fixed polarity but pulsating magnitude (see photograph above).

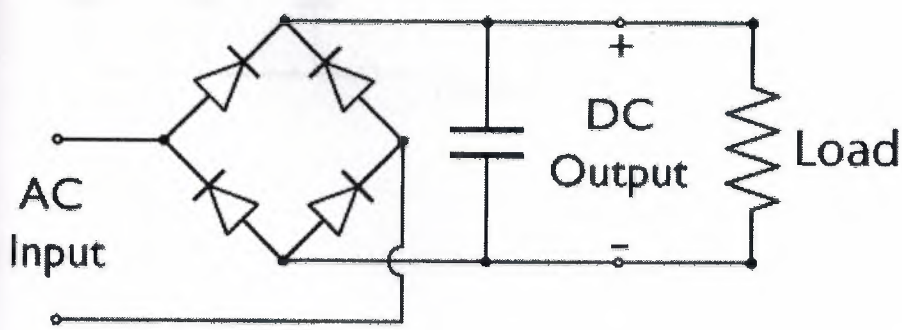


figure 2

The function of this capacitor, known as a 'smoothing capacitor' (see also Filter capacitor) is to lessen the variation in (or 'smooth') the raw output voltage waveform from the bridge. One explanation of 'smoothing' is that the capacitor provides a low impedance path to the AC component of the output, reducing the AC voltage across, and AC current through, the resistive load. In less technical terms, any drop in the output voltage and current of the bridge tends to be cancelled by loss of charge in the capacitor. This charge flows out as additional current through the load. Thus the change of load current and voltage is reduced relative to what would occur without the capacitor. Increases of voltage correspondingly store excess charge in the capacitor, thus moderating the change in output voltage / current.

The capacitor and the load resistance have a typical time constant $\tau = RC$ where C and R are the capacitance and load resistance respectively. As long as the load resistor is large enough so that this time constant is much longer than the time of one ripple cycle, the above configuration will produce a well smoothed DC voltage across the load resistance.

1.5.2 Polyphase diode bridges

This construction can be generalized to rectify polyphase AC inputs. For instance, for three-phase AC, a full wave bridge rectifier consists of six diodes.

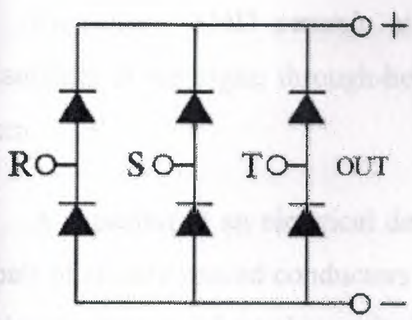


Figure 3

1.6 Capacitors:

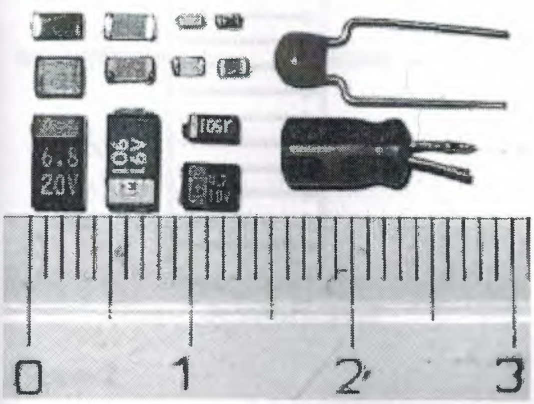


Figure 1

Capacitors: SMD ceramic at top left; SMD tantalum at bottom left; through-hole tantalum at top right; through-hole electrolytic at bottom right. Major scale divisions are cm.

A capacitor is an electrical device that can store energy in the electric field between a pair of closely spaced conductors (called 'plates'). When voltage is applied to the capacitor, electric charges of equal magnitude, but opposite polarity, build up on each plate.

Capacitors are used in electrical circuits as energy-storage devices. They can also be used to differentiate between high-frequency and low-frequency signals and this makes them useful in electronic filters.

Capacitors are occasionally referred to as condensers. This is now considered an antiquated term.

1.6.1 Overview

A capacitor consists of two conductive electrodes, or plates, separated by an insulator.

1.6.2 Capacitance

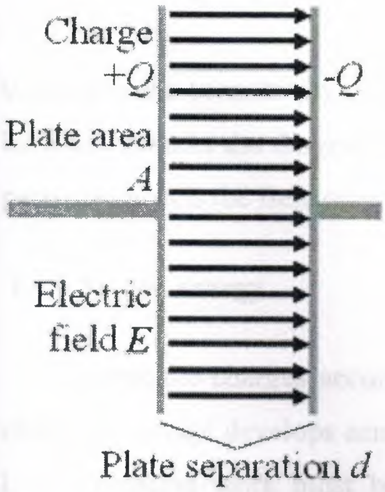


Figure 2

When electric charge accumulates on the plates, an electric field is created in the region between the plates that is proportional to the amount of accumulated charge. This electric field creates a potential difference $V = E \cdot d$ between the plates of this simple parallel-plate capacitor.

The capacitor's capacitance (*C*) is a measure of the amount of charge (*Q*) stored on each plate for a given potential difference or *voltage* (*V*) which appears between the plates:

$$C = \frac{Q}{V}$$ formula 1

In SI units, a capacitor has a capacitance of one farad when one coulomb of charge causes a potential difference of one volt across the plates. Since the farad is a very large unit, values of capacitors are usually expressed in microfarads (µF), nanofarads (nF), or picofarads (pF).

The capacitance is proportional to the surface area of the conducting plate and inversely proportional to the distance between the plates. It is also proportional to the permittivity of the dielectric (that is, non-conducting) substance that separates the plates.

The capacitance of a parallel-plate capacitor is given by:

$$C \approx \frac{\epsilon A}{d}; A \gg d^2$$ formula 2

where ε is the permittivity of the dielectric, *A* is the area of the plates and *d* is the spacing between them.In the diagram, the rotated molecules create an opposing electric field that partially cancels the field created by the plates, a process called dielectric polarization.

1.6.3 Stored energy

As opposite charges accumulate on the plates of a capacitor due to the separation of charge, a voltage develops across the capacitor owing to the electric field of these charges. Ever-increasing work must be done against this ever-increasing electric field as more charge is separated. The energy (measured in joules, in SI) stored in a capacitor is equal to the amount of work required to establish the voltage across the capacitor, and therefore the electric field. The energy stored is given by:

$$E_{\text{stored}} = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}VQ$$

where *V* is the voltage across the capacitor.

The maximum energy that can be (safely) stored in a particular capacitor is limited by the maximum electric field that the dielectric can withstand before it breaks down. Therefore, all capacitors made with the same dielectric have about the same maximum energy density (joules of energy per cubic meter).

1.6.4 Electrical circuits

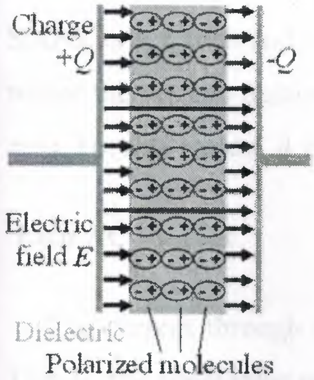


Figure 1

The electrons within dielectric molecules are influenced by the electric field, causing the molecules to rotate slightly from their equilibrium positions. The air gap is shown for clarity; in a real capacitor, the dielectric is in direct contact with the plates. Capacitors also allow AC current to flow and blocks DC current.

1.6.5 DC sources

Electrons cannot easily pass directly across the dielectric from one plate of the capacitor to the other as the dielectric is carefully chosen so that it is a good insulator. When there is a current through a capacitor, electrons accumulate on one plate and electrons are removed from the other plate. This process is commonly called 'charging' the capacitor -- even though the capacitor is at all times electrically neutral. In fact, the current through the capacitor results in the separation of electric charge, rather than the accumulation of electric charge. This separation of charge causes an electric field to develop between the plates of the capacitor giving rise to voltage across the plates. This voltage V is directly proportional to the amount of charge separated Q. Since the current I through the capacitor is the rate at which charge Q is forced through the capacitor (dQ/dt).

For circuits with a constant (DC) voltage source, the voltage across the capacitor cannot exceed the voltage of the source. (Unless the circuit includes a switch and an inductor, as in SMPS, or a switch and some diodes, as in a charge pump). Thus, an equilibrium is reached where the voltage across the capacitor is constant and the current through the capacitor is zero. For this reason, it is commonly said that capacitors block DC.

1.6.6 AC sources

The current through a capacitor due to an AC source reverses direction periodically. That is, the alternating current alternately charges the plates: first in one direction and then the other. With the exception of the instant that the current changes direction, the capacitor current is non-zero at all times during a cycle. For this reason, it is commonly said that capacitors "pass" AC. However, at no time do electrons actually cross between the plates, unless the dielectric breaks down. Such a situation would involve physical damage to the capacitor and likely to the circuit involved as well.

Since the voltage across a capacitor is proportional to the integral of the current, as shown above, with sine waves in AC or signal circuits this results in a phase difference of 90 degrees, the current leading the voltage phase angle. It can be shown that the AC voltage across the capacitor is in quadrature with the alternating current through the capacitor. That is, the voltage and current are 'out-of-phase' by a quarter cycle. The amplitude of the voltage depends on the amplitude of the current divided by the product of the frequency of the current with the capacitance, C.

1.6.7 Impedance

The ratio of the phasor voltage across a circuit element to the phasor current through that element is called the impedance *Z*. For a capacitor, the impedance is given by

$$Z_C = \frac{V_C}{I_C} = \frac{-j}{2\pi f C} = -jX_C,$$ formula 1

where

$X_C = \frac{1}{\omega C}$ is the *capacitive reactance*,

$\omega = 2\pi f$ is the angular frequency,

f is the frequency),

C is the capacitance in farads, and

j is the imaginary unit.

While this relation (between the *frequency domain* voltage and current associated with a capacitor) is always true, the ratio of the *time domain* voltage and current *amplitudes* is equal to X_C only for sinusoidal (AC) circuits in steady state.

Hence, capacitive reactance is the negative imaginary component of impedance. The negative sign indicates that the current leads the voltage by 90° for a sinusoidal signal, as opposed to the inductor, where the current lags the voltage by 90°.

The impedance is analogous to the resistance of a resistor. The impedance of a capacitor is inversely proportional to the frequency -- that is, for very high-frequency alternating currents the reactance approaches zero -- so that a capacitor is nearly a short circuit to a very high frequency AC source. Conversely, for very low frequency alternating currents, the reactance increases without bound so that a capacitor is nearly an open circuit to a very low frequency AC source. This frequency dependent behaviour accounts for most uses of the capacitor (see "Applications", below).

Reactance is so called because the capacitor doesn't dissipate power, but merely stores energy. In electrical circuits, as in mechanics, there are two types of load, resistive and reactive. Resistive loads (analogous to an object sliding on a rough surface) dissipate the energy delivered by the circuit, ultimately by electromagnetic emission (see Black body radiation), while reactive loads (analogous to a spring or frictionless moving object) store this energy, ultimately delivering the energy back to the circuit.

Also significant is that the impedance is inversely proportional to the capacitance, unlike resistors and inductors for which impedances are linearly proportional to resistance and inductance respectively. This is why the series and shunt impedance formulae (given below) are the inverse of the resistive case. In series, impedances sum. In parallel, conductances sum.

1.6.8 Laplace equivalent (s-domain)

When using the Laplace transform in circuit analysis, the capacitive impedance is represented in the *s* domain by:

$$Z(s) = \frac{1}{sC}$$

where C is the capacitance, and s ($= \sigma + j\omega$) is the complex frequency.

1.6.9 Series or parallel arrangements

Capacitors in a parallel configuration each have the same potential difference (voltage). Their total capacitance (C_{eq}) is given by:

$$C_{eq} = C_1 + C_2 + \cdots + C_n \quad \text{formula 1}$$

The reason for putting capacitors in parallel is to increase the total amount of charge stored. In other words, increasing the capacitance also increases the amount of energy that can be stored. Its expression is:

$$E_{\text{stored}} = \frac{1}{2}CV^2. \quad \text{formula 2}$$

The current through capacitors in series stays the same, but the voltage across each capacitor can be different. The sum of the potential differences (voltage) is equal to the total voltage. Their total capacitance is given by:

figure 1

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}$$ formula 1

In parallel the effective area of the combined capacitor has increased, increasing the overall capacitance. While in series, the distance between the plates has effectively been increased, reducing the overall capacitance.

In practice capacitors will be placed in series as a means of economically obtaining very high voltage capacitors, for example for smoothing ripples in a high voltage power supply. Three "600 volt maximum" capacitors in series, will increase their overall working voltage to 1800 volts. This is of course offset by the capacitance obtained being only one third of the value of the capacitors used. This can be countered by connecting 3 of these series set-ups in parallel, resulting in a 3x3 matrix of capacitors with the same overall capacitance as an individual capacitor but operable under three times the voltage. In this application, a large resistor would be connected across each capacitor to ensure that the total voltage is divided equally across each capacitor and also to discharge the capacitors for safety when the equipment is not in use.

Another application is for use of polarized capacitors in alternating current circuits; the capacitors are connected in series, in reverse polarity, so that at any given time one of the capacitors is not conducting...

1.6.10 Capacitor/inductor duality

In mathematical terms, the ideal capacitor can be considered as an inverse of the ideal inductor, because the voltage-current equations of the two devices can be transformed into one another by exchanging the voltage and current terms. Just as two or more inductors can be magnetically coupled to make a transformer, two or more charged conductors can be electrostatically coupled to make a capacitor. The mutual capacitance of two conductors is defined as the current that flows in one when the voltage across the other changes by unit voltage in unit time.

1.6.11 Applications

Capacitor symbols

Capacitor	Polarized capacitors	Variable capacitor
		

Table of capacitors have various uses in electronic and electrical systems.

1.6.12 Energy storage

A capacitor can store electric energy when disconnected from its charging circuit, so it can be used like a temporary battery. Capacitors are commonly used in electronic devices to maintain power supply while batteries are being changed. (This prevents loss of information in volatile memory.)

Capacitors are used in power supplies where they smooth the output of a full or half wave rectifier. They can also be used in charge pump circuits as the energy storage element in the generation of higher voltages than the input voltage.

Capacitors are connected in parallel with the power circuits of most electronic devices and larger systems (such as factories) to shunt away and conceal current fluctuations from the primary power source to provide a "clean" power supply for signal or control circuits. Audio equipment, for example, uses several capacitors in this way, to shunt away power line hum before it gets into the signal circuitry. The capacitors act as a local reserve for the

DC power source, and bypass AC currents from the power supply. This is used in car audio applications, when a stiffening capacitor compensates for the inductance and resistance of the leads to the lead-acid car battery.

1.6.13 Power factor correction

Capacitors are used in power factor correction. Such capacitors often come as three capacitors connected as a three phase load. Usually, the values of these capacitors are given not in farads but rather as a reactive power in volt-amperes reactive (VAr). The purpose is to counteract inductive loading from electric motors and fluorescent lighting in order to make the load appear to be mostly resistive.

Tuned circuits

Capacitors and inductors are applied together in tuned circuits to select information in particular frequency bands. For example, radio receivers rely on variable capacitors to tune the station frequency. Speakers use passive analog crossovers, and analog equalizers use capacitors to select different audio bands.

In a tuned circuit such as a radio receiver, the frequency selected is a function of the inductance (L) and the capacitance (C) in series, and is given by:

$$f = \frac{1}{2\pi\sqrt{LC}}$$ formula 1

1.6.14 Other applications

1.6.14.1 Sensing

Most capacitors are designed to maintain a fixed physical structure. However, various things can change the structure of the capacitor — the resulting change in capacitance can be used to sense those things.

Changing the dielectric: the effects of varying the physical and/or electrical characteristics of the dielectric can also be of use. Capacitors with an exposed and porous dielectric can be used to measure humidity in air.

Changing the distance between the plates: Capacitors are used to accurately measure the fuel level in airplanes. Capacitors with a flexible plate can be used to measure strain or pressure. Capacitors are used as the sensor in condenser microphones, where one plate is moved by air pressure, relative to the fixed position of the other plate. Some accelerometers use MEMS capacitors etched on a chip to measure the magnitude and direction of the acceleration vector. They are used to detect changes in acceleration, eg. as tilt sensors or to detect free fall, as sensors triggering airbag deployment, and in many other applications. Also some fingerprint sensors.

1.6.14.2 Hazards and safety

Capacitors may retain a charge long after power is removed from a circuit; this charge can cause shocks (sometimes fatal) or damage to connected equipment. For example, even a seemingly innocuous device such as a disposable camera flash unit powered by a 1.5 volt AA battery contains a capacitor which may be charged to over 300 volts. This is easily capable of delivering an extremely painful, and possibly lethal shock.

Care must be taken to ensure that any large or high-voltage capacitor is properly discharged before servicing the containing equipment. For safety purposes, all large capacitors should be discharged before handling. For board-level capacitors, this is done by placing a bleeder resistor across the terminals, whose resistance is large enough that the leakage current will not affect the circuit, but small enough to discharge the capacitor shortly after power is removed. High-voltage capacitors should be stored with the terminals shorted, since temporarily discharged capacitors can develop potentially dangerous voltages when the terminals are left open-circuited.

Large oil-filled old capacitors must be disposed of properly as some contain polychlorinated biphenyls (PCBs). It is known that waste PCBs can leak into groundwater under landfills. If consumed by drinking contaminated water, PCBs are carcinogenic, even in very tiny amounts. If the capacitor is physically large it is more likely to be dangerous and may require precautions in addition to those described above. New electrical components are no longer produced with PCBs. ("PCB" in electronics usually means printed circuit board, but the above usage is an exception.) Capacitors containing PCB were labelled as containing "Askarel" and several other trade names.

1.6.14.3 High-voltage

Above and beyond usual hazards associated with working with high voltage, high energy circuits, there are a number of dangers that are specific to high voltage capacitors. High voltage capacitors may catastrophically fail when subjected to voltages or currents beyond their rating, or as they reach their normal end of life. Dielectric or metal interconnection failures may create arcing within oil-filled units that vaporizes dielectric fluid, resulting in case bulging, rupture, or even an explosion that disperses flammable oil, starts fires, and damages nearby equipment. Rigid cased cylindrical glass or plastic cases are more prone to explosive rupture than rectangular cases due to an inability to easily expand under pressure. Capacitors used in RF or sustained high current applications can overheat, especially in the center of the capacitor rolls. The trapped heat may cause rapid interior heating and destruction, even though the outer case remains relatively cool. Capacitors used within high energy capacitor banks can violently explode when a fault in one capacitor causes sudden dumping of energy stored in the rest of the bank into the failing unit. And, high voltage vacuum capacitors can generate soft X-rays even during normal operation. Proper containment, fusing, and preventative maintenance can help to minimize these hazards.

High voltage capacitors can benefit from a pre-charge to limit in-rush currents at power-up of HVDC circuits. This will extend the life of the component and may mitigate high voltage hazards.

1.6.14.4 History

figure 1

Various types of capacitors. From left: multilayer ceramic, ceramic disc, multilayer polyester film, tubular ceramic, polystyrene (twice: axial and radial), electrolytic. Major scale divisions are cm.

figure 2

Various Capacitors

In October 1745, Ewald Georg von Kleist of Pomerania invented the first recorded capacitor: a glass jar coated inside and out with metal. The inner coating was connected to a rod that passed through the lid and ended in a metal sphere. By having this thin layer of glass insulation (a dielectric) between two large, closely spaced plates, von Kleist found the energy density could be increased dramatically compared with the situation with no insulator.

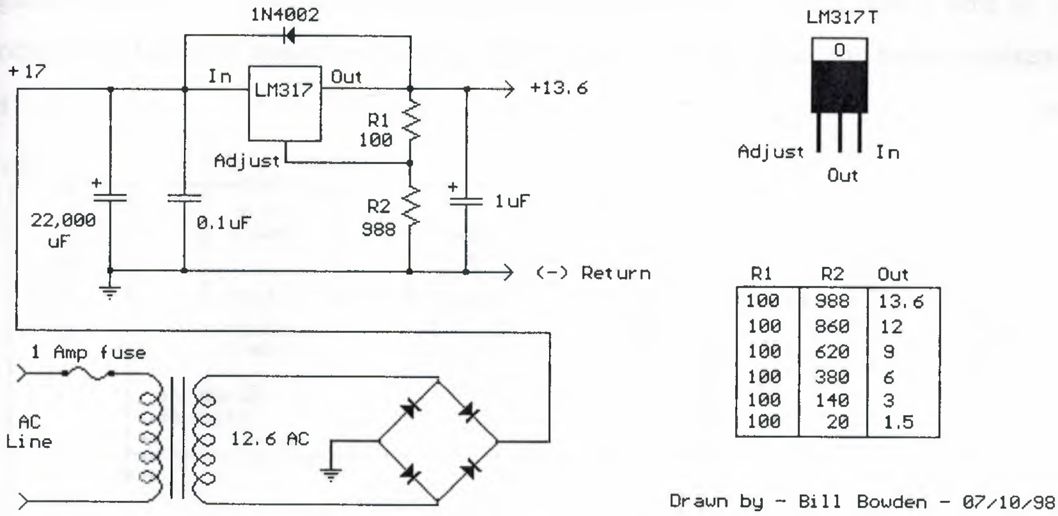
In January 1746, before Kleist's discovery became widely known, a Dutch physicist Pieter van Musschenbroek independently invented a very similar capacitor. It was named the Leyden jar, after the University of Leyden where van Musschenbroek worked. Daniel Gralath was the first to combine several jars in parallel into a "battery" to increase the total possible stored charge.

1.7 LM 317 VARİABLE VOLTAGE REGULATOR

The LM317T is a adjustable 3 terminal positive voltage regulator capable of supplying in excess of 1.5 amps over an output range of 1.25 to 37 volts. The device also has built in current limiting and thermal shutdown which makes it essentially blow-out proof.

Output voltage is set by two resistors R1 and R2 connected as shown below. The voltage across R1 is a constant 1.25 volts and the adjustment terminal current is less than 100uA. The output voltage can be closely approximated from Vout=1.25 * (1+(R2/R1)) which ignores the adjustment terminal current but will be close if the current through R1 and R2 is many times greater. A minimum load of about 10mA is required, so the value for R1 can be selected to drop 1.25 volts at 10mA or 120 ohms. Something less than 120 ohms can be used to insure the minimum current is greater than 10mA. The example below shows a LM317 used as 13.6 volt regulator. The 988 ohm resistor for R2 can be obtained with a standard 910 and 75 ohm in series.

When power is shut off to the regulator the output voltage should fall faster than the input. In case it doesn't, a diode can be connected across the input/output terminals to protect the regulator from possible reverse voltages. A 1uF tantalum or 25uF electrolytic capacitor across the output improves transient response and a small 0.1uF tantalum capacitor is recommended across the input if the regulator is located an appreciable distance from the power supply filter. The power transformer should be large enough so that the regulator input voltage remains 3 volts above the output at full load, or 16.6 volts for a 13.6 volt output.



R1	R2	Out
100	988	13.6
100	860	12
100	620	9
100	380	6
100	140	3
100	20	1.5

Figure 1

1.7.1 LM317T Voltage Regulator with Pass Transistor

The LM317T output current can be increased by using an additional power transistor to share a portion of the total current. The amount of current sharing is established with a resistor placed in series with the 317 input and a resistor placed in series with the emitter of the pass transistor. In the figure below, the pass transistor will start conducting when the LM317 current reaches about 1 amp, due to the voltage drop across the 0.7 ohm resistor. Current limiting occurs at about 2 amps for the LM317 which will drop about 1.4 volts across the 0.7 ohm resistor and produce a 700 millivolt drop across the 0.3 ohm emitter resistor. Thus the total current is limited to about 2+ (.7/.3) = 4.3 amps. The input voltage will need to be about 5.5 volts greater than the output at full load and heat dissipation at full load would be about 23 watts, so a fairly large heat sink may be needed for both the regulator and pass transistor. The filter capacitor size can be approximated from C=IT/E where I is the current, T is the half cycle time (8.33 mS at 60 Hertz), and E is the fall in voltage that will occur during one half cycle. To keep the ripple voltage below 1 volt at 4.3 amps, a 36,000 uF or greater filter capacitor is needed. The power transformer should be large enough so that the peak input voltage to the regulator remains 5.5 volts above the output at full load, or 17.5 volts for a 12 volt output. This allows for a 3 volt drop across the regulator, plus a 1.5 volt drop across the series resistor (0.7 ohm), and 1 volt of ripple produced by the filter capacitor. A larger filter capacitor will reduce the input requirements, but not much.

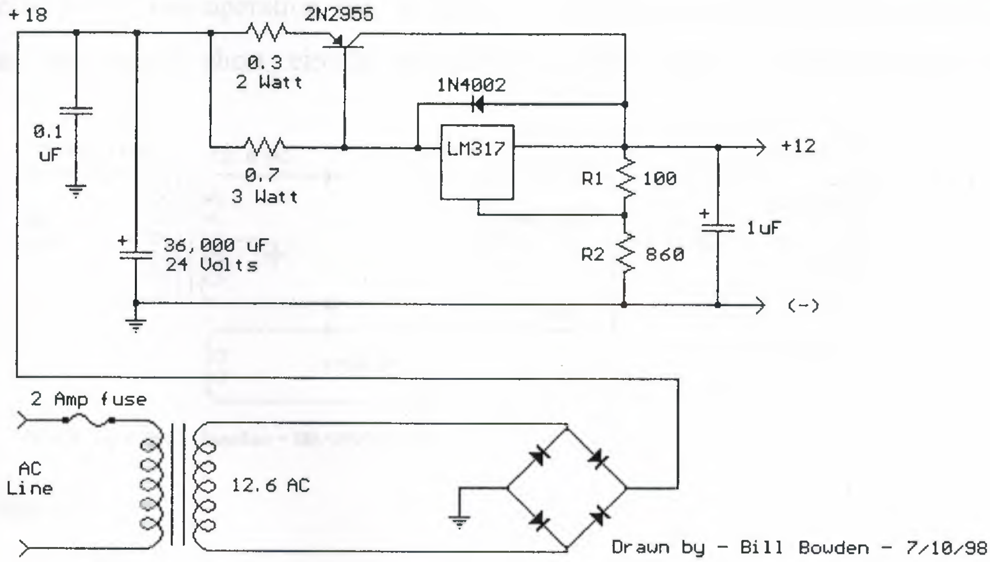


Figure 2

1.7.2 High Current Regulated Supply

The high current regulator below uses an additional winding or a separate transformer to supply power for the LM317 regulator so that the pass transistors can operate closer to saturation and improve efficiency. For good efficiency the voltage at the collectors of the two parallel 2N3055 pass transistors should be close to the output voltage. The LM317 requires a couple extra volts on the input side, plus the emitter/base drop of the 3055s, plus whatever is lost across the (0.1 ohm) equalizing resistors (1volt at 10 amps), so a separate transformer and rectifier/filter circuit is used that is a few volts higher than the output voltage. The LM317 will provide over 1 amp of current to drive the bases of the pass transistors and assumming a gain of 10 the combination should deliver 15 amps or more. The LM317 always operates with a voltage difference of 1.2 between the output terminal and adjustment terminal and requires a minimum load of 10mA, so a 75 ohm resistor was chosen which will draw (1.2/75 = 16mA). This same current flows through the emitter resistor of the 2N3904 which produces about a 1 volt drop across the 62 ohm resistor and 1.7 volts at the base. The output voltage is set with the voltage divider (1K/560) so that 1.7 volts is applied to the 3904 base when the output is 5 volts. For 13 volt operation, the 1K resistor could be adjusted to around 3.6K. The regulator has no output short circuit protection so the output probably should be fused.

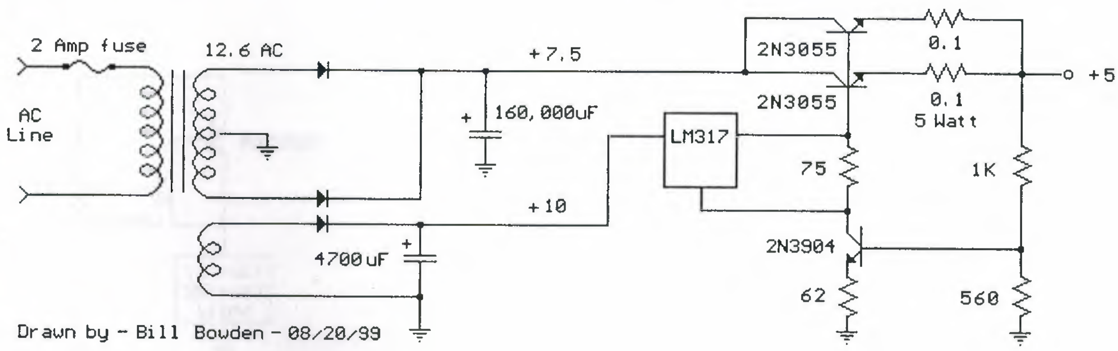


Figure 3

1.7.3 Simple Adjustable Voltage Source

A simple but less efficient methode of controlling a DC voltage is to use a voltage divider and transistor emitter follower configuration. The figure below illustrates using a 1K pot to set the base voltage of a medium power NPN transistor. The collector of the NPN feeds the base of a larger PNP power transistor which supplies most of the current to the load. The output voltage will be about 0.7 volts below the voltage of the wiper of the 1K pot so the output can be adjusted from 0 to the full supply voltage minus 0.7 volts. Using two transistors provides a current gain of around 1000 or more so that only a couple milliamps of current is drawn from the voltage divider to supply a couple amps of current at the output. Note that this circuit is much less efficient than the 555 timer dimmer circuit using a variabe duty cycle switching approach. In the

figure below, the 25 watt/ 12 volt lamp draws about 2 amps at 12 volts and 1 amp at 3 volts so that the power lost when the lamp is dim is around (12-3 volts * 1 amp) = 9 watts. A fairly large heat sink is required to prevent the PNP power transistor from overheating. The power consumed by the lamp will be only (3 volts * 1 amp) = 3 watts which gives us an efficiency factor of only 25% when the lamp is dimmed. The advantage of the circuit is simplicity, and also that it doesn't generate any RF interference as a switching regulator does. The circuit can be used as a voltage regulator if the input voltage remains constant, but it will not compensate for changes at the input as the LM317 does.

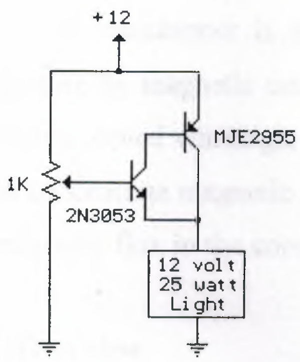


Figure 4

Chapter 2

Transformer

A transformer is an electrical device that transfers energy from one circuit to another by magnetic coupling with no moving parts. A transformer comprises two or more coupled windings, or a single tapped winding and, in most cases, a magnetic core to concentrate magnetic flux. A changing current in one winding creates a time-varying magnetic flux in the core, which induces a voltage in the other windings.

2.1. Overview

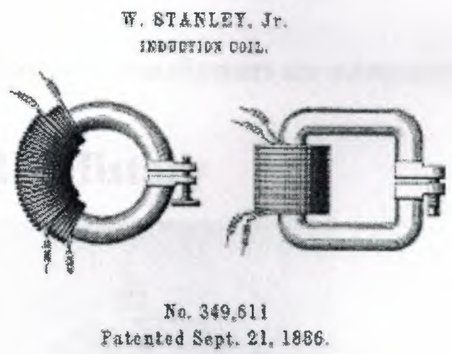


Figure of A historical Stanley transformer.

The transformer is one of the simplest of electrical devices, yet transformer designs and materials continue to be improved. Transformers are essential for high voltage power transmission, which makes long distance transmission economically practical. This advantage was the principal factor in the selection of alternating current power transmission in the "War of Currents" in the late 1880s.

Audio frequency transformers (at the time called repeating coils) were used by the earliest experimenters in the development of the telephone. While new technologies have made some transformers in electronics applications obsolete, transformers are still found in many electronic devices.

Transformers come in a range of sizes from a thumbnail-sized coupling transformer hidden inside a stage microphone to huge gigawatt units used to interconnect large portions of national power grids. All operate with the same basic principles and with many similarities in their parts.

Transformers alone cannot do the following:

Convert DC to AC or vice versa

Change the voltage or current of DC

Change the AC supply frequency.

However, transformers are components of the systems that perform all these functions.

2.2.History

Figure of single phase pole-mounted step-down transformer

Michael Faraday built the first transformer, although he used it only to demonstrate the principle of electromagnetic induction and did not foresee the use to which it would eventually be put.

Lucien Gaulard and John Dixon Gibbs, who first exhibited a device called a 'secondary generator' in London in 1881 and then sold the idea to American company Westinghouse. This may have been the first practical power transformer. They also exhibited the invention in Turin in 1884, where it was adopted for an electric lighting system. Their early devices used an open iron core, which was soon abandoned in favour of a more efficient circular core with a closed magnetic path.

Russian engineer Pavel Yablochkov in 1876 invented a lighting system based on a set of induction coils, where primary windings were connected to a source of alternating current and secondary windings could be connected to several "electric candles". As the patent said such a system "allows to provide separate supply to several lighting fixtures with different luminous intensities from a single source of electric power". Evidently the induction coil in this system operated as a transformer.

William Stanley, an engineer for Westinghouse, who built the first practical device in 1885 after George Westinghouse bought Gaulard and Gibbs' patents. The core was made from interlocking E-shaped iron plates. This design was first used commercially in 1886.

Hungarian engineers Károly Zipernowsky, Ottó Bláthy and Miksa Déri at the Ganz company in Budapest in 1885, who created the efficient "ZBD" model based on the design by Gaulard and Gibbs.

Russian engineer Mikhail Dolivo-Dobrovolsky in 1889 developed the first three-phase transformer.

Nikola Tesla in 1891 invented the Tesla coil, which is a high-voltage, air-core, dual-tuned resonant transformer for generating very high voltages at high frequency.

Many others have patents on transformers.

2.2.1 An analogy

The transformer may be considered as a simple two-wheel 'gearbox' for electrical voltage and current. The primary winding is analogous to the input shaft and the secondary winding to the output shaft. In this analogy, current is equivalent to shaft speed, voltage to shaft torque. In a gearbox, mechanical power (torque multiplied by speed) is constant (neglecting losses) and is equivalent to electrical power (voltage multiplied by current) which is also constant.

The gear ratio is equivalent to the transformer step-up or step-down ratio. A step-up transformer acts analogously to a reduction gear (in which mechanical power is transferred from a small, rapidly rotating gear to a large, slowly rotating gear): it trades current (speed) for voltage (torque), by transferring power from a primary coil to a secondary coil having more turns. A step-down transformer acts analogously to a multiplier gear (in which mechanical power is transferred from a large gear to a small gear): it trades voltage (torque) for current (speed), by transferring power from a primary coil to a secondary coil having fewer turns.

2.3. Basic principles

2.3.1 Coupling by mutual induction

A simple transformer consists of two electrical conductors called the primary winding and the secondary winding. Energy is coupled between the windings by the time-varying magnetic flux that passes through (links) both primary and secondary windings. When the current in a coil is switched on or off or changed, a voltage is induced in a neighboring coil. The effect, called mutual inductance, is an example of electromagnetic induction.

2.3.2 Simplified analysis

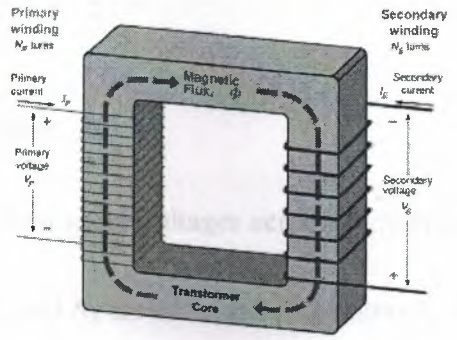


Figure of a practical step-down transformer showing magnetising flux in the core

If a time-varying voltage v_P is applied to the primary winding of N_P turns, a current will flow in it producing a magnetomotive force (MMF). Just as an electromotive force (EMF) drives current around an electric circuit, so MMF tries to drive magnetic flux through a magnetic circuit. The primary MMF produces a varying magnetic flux Φ_P in the core, and, with an open circuit secondary winding, induces a back electromotive force (EMF) in opposition to v_P. In accordance with Faraday's law of induction, the voltage induced across the primary winding is proportional to the rate of change of flux:

$$v_P = N_P \frac{d\Phi_P}{dt} \quad \text{and} \quad v_S = N_S \frac{d\Phi_S}{dt}$$

where

v_P and v_S are the voltages across the primary winding and secondary winding,

N_P and N_S are the numbers of turns in the primary winding and secondary winding,

$d\Phi_P / dt$ and $d\Phi_S / dt$ are the derivatives of the flux with respect to time of the primary and secondary windings.

Saying that the primary and secondary windings are perfectly coupled is equivalent to saying that $\Phi_P = \Phi_S$. Substituting and solving for the voltages shows that:

$$\frac{v_P}{v_S} = \frac{N_P}{N_S}$$

where

v_p and v_s are voltages across primary and secondary,

N_p and N_s are the numbers of turns in the primary and secondary, respectively.

Hence in an ideal transformer, the ratio of the primary and secondary voltages is equal to the ratio of the number of turns in their windings, or alternatively, the voltage per turn is the same for both windings. The ratio of the currents in the primary and secondary circuits is inversely proportional to the turns ratio. This leads to the most common use of the transformer: to convert electrical energy at one voltage to energy at a different voltage by means of windings with different numbers of turns. In a practical transformer, the higher-voltage winding will have more turns, of smaller conductor cross-section, than the lower-voltage windings.

The EMF in the secondary winding, if connected to an electrical circuit, will cause current to flow in the secondary circuit. The MMF produced by current in the secondary opposes the MMF of the primary and so tends to cancel the flux in the core. Since the reduced flux reduces the EMF induced in the primary winding, increased current flows in the primary circuit. The resulting increase in MMF due to the primary current offsets the effect of the opposing secondary MMF. In this way, the electrical energy fed into the primary winding is delivered to the secondary winding. Also because of this, the flux density will always stay the same as long as the primary voltage is steady.

For example, suppose a power of 50 watts is supplied to a resistive load from a transformer with a turns ratio of 25:2.

$P = EI$ (power = electromotive force × current)

50 W = 2 V × 25 A in the primary circuit if the load is a resistive load. (See note 1)

Now with transformer change:

50 W = 25 V × 2 A in the secondary circuit.

2.3.3 Analysis of the ideal transformer

This treats the windings as a pair of mutually coupled coils with both primary and secondary windings passing currents and with each coil linked with the same magnetic flux. In an *ideal* transformer the core requires no MMF. The primary and secondary MMFs, acting in opposite directions, are exactly balancing each other and hence, there is no overall resultant MMF acting on the core. There is, however, no need for any MMF acting on the core of an ideal transformer to create a magnetic flux. The flux in the core is unambiguously determined by the applied primary voltage in accordance with Faraday's law of induction, or rather by an integration of the aforesaid law.

In the ideal transformer at no load, i.e. with the secondary load removed, the voltage applied to the primary winding is opposed by an induced EMF in the winding equal to the applied voltage in accordance with Faraday's law of induction. No current will flow in the winding since no MMF is required by the core. One might also say that the inductance of the primary winding at no load is infinitely large.

Further on, the balance of the primary and secondary MMFs i.e. $N_P i_P = N_S i_S$, gives the ratio of the secondary and primary currents as:

$$\frac{i_P}{i_S} = \frac{N_S}{N_P}$$ formula 1

That is, the ratio between the primary and secondary currents is the inverse of the ratio between the corresponding voltages.

2.3.4 DC voltages and currents

A real (non-ideal) transformer cannot pass a steady DC voltage. DC applied to a winding of an ideal transformer will cause a DC voltage to be induced in the other winding; this is because any voltage applied will create a changing flux. However, using a transformer with DC voltages would require the magnetic flux in the core (and current supplied by the DC voltage source) to increase without bound, limited only by the series resistance of the windings. Once the flux stops changing, no voltage is induced in the other winding. If the core is made of anything other than air (e.g. iron) it will also saturate. Saturation will drastically reduce the amount of power that can be transferred, as well as causing the current to rise even more steeply. For these reasons it is very important to avoid having any DC component in the voltages being applied to a transformer. The amount of power being dissipated in the winding will be limited solely by the winding resistance.

It is possible to draw DC current from a transformer, as a DC current merely represents a constant offset to the flux in the core. DC currents are caused by some non-linear loads (e.g. a half-wave rectifier). Most transformers are designed to be driven to near saturation without any DC current components, so having a DC current will make the transformer saturate more easily. Full-wave rectifiers do not have this issue, since the current they draw has no DC component.

2.3.5 The universal EMF equation

If the flux in the core is sinusoidal, the relationship for either winding between its number of turns, voltage, magnetic flux density and core cross-sectional area is given by the universal emf equation (from Faraday's law):

$$E = \frac{2\pi f N a B}{\sqrt{2}} = 4.44 f N a B$$

where

E is the sinusoidal rms or root mean square voltage of the winding,

f is the frequency in hertz,

N is the number of turns of wire on the winding,

a is the cross-sectional area of the core in square metres

B is the peak magnetic flux density in teslas,

Other consistent systems of units can be used with the appropriate conversions in the equation.

2.4. Practical considerations

2.4.1 Classifications

Transformers are adapted to numerous engineering applications and may be classified in many ways:

By power level (from fraction of a volt-ampere(VA) to over a thousand MVA),

By application (power supply, impedance matching, circuit isolation),

By frequency range (power, audio, radio frequency(RF))

By voltage class (a few volts to about 750 kilovolts)

By cooling type (air cooled, oil filled, fan cooled, water cooled, etc.)

By purpose (distribution, rectifier, arc furnace, amplifier output, etc.).

By ratio of the number of turns in the coils

Step-up

The secondary has more turns than the primary.

Step-down

The secondary has fewer turns than the primary.

Isolating

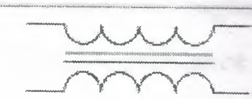
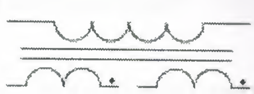
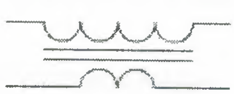
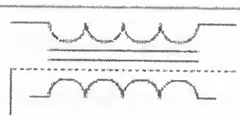
Intended to transform from one voltage to the same voltage. The two coils have approximately equal numbers of turns, although often there is a slight difference in the number of turns, in order to compensate for losses (otherwise the output voltage would be a little less than, rather than the same as, the input voltage).

Variable

The primary and secondary have an adjustable number of turns which can be selected without reconnecting the transformer.

2.4.2 Circuit symbols

Table of Standard symbols

	Transformer with two windings and iron core.
	Transformer with three windings. The dots show the relative winding configuration of the windings.
	Step-down or step-up transformer. The symbol shows which winding has more turns, but does not usually show the exact ratio.
	Transformer with electrostatic screen, which prevents capacitive coupling between the windings.

2.4.3 Losses

An ideal transformer would have no losses, and would therefore be 100% efficient. In practice, energy is dissipated due both to the resistance of the windings known as copper loss or I^2 R loss, and to magnetic effects primarily attributable to the core (known as *iron loss* measured in watts per pound). Transformers are, in general, highly efficient. Large power transformers (over 50 MVA) may attain an efficiency as high as 99.75%. Small transformers, such as a plug-in "power brick" used to power small consumer electronics, may be less than 85% efficient.

Transformer losses arise from:

Winding resistance

Current flowing through the windings causes resistive heating of the conductors (I^2 R loss). At higher frequencies, skin effect and proximity effect create additional winding resistance and losses.

Eddy currents

Induced eddy currents circulate within the core, causing resistive heating. Silicon is added to the steel to help in controlling eddy currents. Adding silicon also has the advantage of stopping aging of the electrical steel that was a problem years ago.

Hysteresis losses

Each time the magnetic field is reversed, a small amount of energy is lost to hysteresis within the magnetic core. The amount of hysteresis is a function of the particular core material.

Magnetostriction

Magnetic flux in the core causes it to physically expand and contract slightly with the alternating magnetic field, an effect known as magnetostriction. This in turn causes losses due to frictional heating in susceptible ferromagnetic cores.

Mechanical losses

In addition to magnetostriction, the alternating magnetic field causes fluctuating electromagnetic forces between the primary and secondary windings. These incite vibrations within nearby metalwork, creating a familiar humming or buzzing noise, and consuming a small amount of power.

Stray losses

Not all the magnetic field produced by the primary is intercepted by the secondary. A portion of the leakage flux may induce eddy currents within nearby conductive objects, such as the transformer's support structure, and be converted to heat.

Cooling system

Large power transformers may be equipped with cooling fans, oil pumps or water-cooled heat exchangers designed to remove the heat caused by copper and iron losses. The power used to operate the cooling system is typically considered part of the losses of the transformer.

2.4.4 Operation at different frequencies

The equation shows that the EMF of a transformer at a given flux density increases with frequency. By operating at higher frequencies, transformers can be physically more compact without reaching saturation, and a given core is able to transfer more power. However, other properties of the transformer, such as losses within the core and skin-effect, also increase with frequency. Generally, operation of a transformer at its designed voltage but at a higher frequency than intended will lead to reduced magnetising (no load primary) current. At a frequency lower than the design value, with the rated voltage applied, the magnetising current may increase to an excessive level.

Steel cores develop a larger hysteresis loss due to eddy currents as the operating frequency is increased. Ferrite, or thinner steel laminations for the core are typically used for frequencies above 1kHz. The thinner steel laminations serve to reduce the eddy currents. Some types of very thin steel laminations can operate at up to 10 kHz or higher. Ferrite is used in higher frequency applications, extending to the VHF band and beyond. Aircraft traditionally use 400 Hz power systems since the slight increase in thermal losses is more than offset by the reduction in core and winding weight. Military gear includes 400 Hz (and other frequencies) to supply power for radar or servomechanisms.

Flyback transformers are built using ferrite cores. They supply high voltage to the CRTs at the frequency of the horizontal oscillator. In the case of television sets, this is about 15.7kHz. It may be as high as 75 - 120kHz for high-resolution computer monitors.

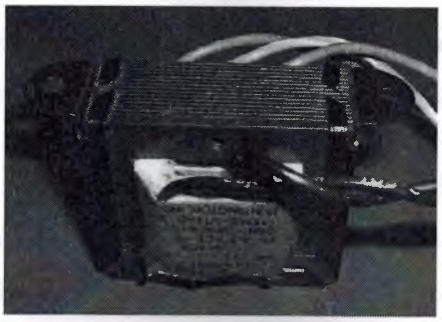
Switching power supply transformers usually operate between 30-1000 kHz. The tiny cores found in wristwatch backlight power supplies produce audible sound (about 1 kHz).

Operation of a power transformer at other than its design frequency may require assessment of voltages, losses, and cooling to establish if safe operation is practical. For example, transformers at hydroelectric generating stations may be equipped with over-excitation protection, so-called "volts per hertz" protection relays, to protect the transformer from overvoltage at higher-than-rated frequency which may occur if a generator loses its connected load.

2.5. Construction

2.5.1 Cores

Figure 1



2.5.1.1 Steel cores

Laminated core transformer showing edge of laminations at top of unit.

Transformers for use at power or audio frequencies have cores made of many thin laminations of silicon steel. By concentrating the magnetic flux, more of it is usefully linked by both primary and secondary windings. Since the steel core is conductive, it, too, has currents induced in it by the changing magnetic flux. Each layer is insulated from the adjacent layer to reduce the energy lost to eddy current heating of the core. The thin laminations are used to reduce the eddy currents, and the insulation is used to keep the laminations from acting as a solid piece of steel. The thinner the laminations, the lower the eddy currents, and the lower the losses. Very thin laminations are generally used on high frequency transformers. The cost goes up when using thinner laminations mainly over the labor in stacking them.

A typical laminated core is made from E-shaped and I-shaped pieces, leading to the name "EI transformer". In the EI transformer, the laminations are stacked in what is known as an interleaved fashion. Due to this interleaving a second gap in parallel (in an analogy to electronic circuits) to the gap between E and I is formed between the E-pieces. The E-pieces are pressed together to reduce the gap width to that of the insulation. The gap area is very large, so that the effective gap width is very small (in analogy to a capacitor). For this to work the flux has to gradually flow from one E to the other. That means that on one end all flux is only on every second E. That means saturation occurs at half the flux density. Using a longer E and wedging it with two small Is will increase the overlap and additionally make the grains more parallel to the flux (think of a wooden frame for a window). If an air gap is needed (which is unlikely considering the low remanence available for steel), all the E's are stacked on one side, and all the I's on the other creating a gap.

The cut core or C-core is made by winding a silicon steel strip around a rectangular form. After the required thickness is achieved, it is removed from the form and the laminations are bonded together. It is then cut in two forming two C shapes. The faces of the cuts are then ground smooth so they fit very tight with a very small gap to reduce losses. The core is then assembled by placing the two C halves together, and holding them closed by a steel strap. Usually two C-cores are used to shorten the return path for the magnetic flux resulting in a form similar to the EI. More cores would necessitate a triangular cross-section. Like toroidal cores they have the advantage, that the flux is always in the oriented parallel the grains. Due to the bending of the core some area is lost for a rectangular winging.

A steel core's remanence means that it retains a static magnetic field when power is removed. When power is then reapplied, the residual field will cause a high inrush current until the effect of the remanent magnetism is reduced, usually after a few cycles of the applied alternating current. Overcurrent protection devices such as fuses must be selected to allow this harmless inrush to pass. On transformers connected to long overhead power transmission lines, induced currents due to geomagnetic disturbances during solar storms can cause saturation of the core, and false operation of transformer protection devices.

Distribution transformers can achieve low off-load losses by using cores made with low loss high permeability silicon steel and amorphous (non-crystalline) steel, so-called "metal glasses" — the high cost of the core material is offset by the lower losses incurred at light load, over the life of the transformer. In order to maintain good voltage regulation, distribution transformers are designed to have very low leakage inductance.

Certain special purpose transformers use long magnetic paths, insert air gaps, or add magnetic shunts (which bypass a portion of magnetic flux that would otherwise link the primary and secondary windings) in order to intentionally add leakage inductance. The additional leakage inductance limits the secondary winding's short circuit current to a safe, or a controlled, level. This technique is used to stabilize the output current for loads that exhibit negative resistance such as electric arcs, mercury vapor lamps, and neon signs, or safely handle loads that may become periodically short-circuited such as electric arc welders. Gaps are also used to keep a transformer from saturating, especially audio transformers which have a DC component added.

2.5.1.2 Solid cores

Powdered iron cores are used in circuits (such as switch-mode power supplies) that operate above mains frequencies and up to a few tens of kilohertz. These materials combine high magnetic permeability with high bulk electrical resistivity.

At even higher, radio-frequencies (RF), other types of cores made from non-conductive magnetic ceramic materials, called *ferrites*, are common. Some RF transformers also have moveable cores (sometimes called slugs) which allow adjustment of the coupling coefficient (and bandwidth) of tuned radio-frequency circuits.

These shapes are available as magnetic cores and steel cores: Toroid cores, E-cores, C-cores. No pot-cores are not manufactureable out of laminate.

2.5.1.3 Air cores

High-frequency transformers may also use air cores. These eliminate the loss due to hysteresis in the core material. Such transformers maintain high coupling efficiency (low stray field loss) by overlapping the primary and secondary windings.

2.5.1.4 Toroidal cores

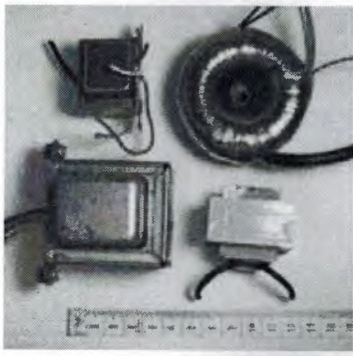


Figure 2

Various transformers. The top right is toroidal. The bottom right is from a 12 VAC wall wart supply.

Toroidal transformers are built around a ring-shaped core, which is made from a long strip of silicon steel or permalloy wound into a coil, from powdered iron, or ferrite, depending on operating frequency. The strip construction ensures that the grain boundaries are optimally aligned, improving the transformer's efficiency by reducing the core's reluctance. The closed ring shape eliminates air gaps inherent in the construction of an EI core. The cross-section of the ring is usually square or rectangular, but more expensive cores with circular cross-sections are also available. The primary and secondary coils are often wound concentrically to cover the entire surface of the core. This minimises the length of wire needed, and also provides screening to minimize the core's magnetic field from generating electromagnetic interference.

Ferrite toroid cores are used at higher frequencies, typically between a few tens of kilohertz to a megahertz, to reduce losses, physical size, and weight of switch-mode power supplies.

Toroidal transformers are more efficient than the cheaper laminated EI types of similar power level. Other advantages, compared to EI types, include smaller size (about half), lower weight (about half), less mechanical hum (making them superior in audio amplifiers), lower exterior magnetic field (about one tenth), low off-load losses (making them more efficient in standby circuits), single-bolt mounting, and more choice of shapes. This last point means that, for a given power output, either a wide, flat toroid or a tall, narrow one with the same electrical properties can be chosen, depending on the space available. The main disadvantages are higher cost and limited size.

A drawback of toroidal transformer construction is the higher cost of windings. As a consequence, toroidal transformers are uncommon above ratings of a few kVA. Small distribution transformers may achieve some of the benefits of a toroidal core by splitting it and forcing it open, then inserting a bobbin containing primary and secondary windings.

When fitting a toroidal transformer, it is important to avoid making an unintentional short-circuit through the core.

2.5.2 Windings

The wire of the adjacent turns in a coil, and in the different windings, must be electrically insulated from each other. The wire used is generally magnet wire. Magnet wire is a copper wire with a coating of varnish or some other synthetic coating. Transformers for years have used Formvar wire which is a varnished type of magnet wire.

The conducting material used for the winding depends upon the application. Small power and signal transformers are wound with solid copper wire, insulated usually with enamel, and sometimes additional insulation. Larger power transformers may be wound with wire, copper, or aluminum rectangular conductors. Strip conductors are used for very heavy currents. High frequency transformers operating in the tens to hundreds of kilohertz will have windings made of Litz wire to minimize the skin effect losses in the conductors. Large power transformers use multiple-stranded conductors as well, since even at low power frequencies non-uniform distribution of current would otherwise exist in high-current windings. Each strand is insulated from the other, and the strands are arranged so that at certain points in the winding, or throughout the whole winding, each portion occupies different relative positions in the complete conductor. This "transposition" equalizes the current flowing in each strand of the conductor, and reduces eddy current losses in the winding itself. The stranded conductor is also more flexible than a solid conductor of similar size. (see reference (1) below)

For signal transformers, the windings may be arranged in a way to minimise leakage inductance and stray capacitance to improve high-frequency response. This can be done by splitting up each coil into sections, and those sections placed in layers between the sections of the other winding. This is known as a stacked type or interleaved winding.

Windings on both the primary and secondary of power transformers may have external connections (called taps) to intermediate points on the winding to allow adjustment of the voltage ratio. Taps may be connected to an automatic, on-load tap changer type of switchgear for voltage regulation of distribution circuits. Audio-frequency transformers, used for the distribution of audio to public address loudspeakers, have taps to allow adjustment of impedance to each speaker. A center-tapped transformer is often used in the output stage of an audio power amplifier in a push-pull type circuit. Modulation transformers in AM transmitters are very similar. Tapped transformers are also used as components of amplifiers, oscillators, and for feedback linearization of amplifier circuits.

2.5.3 Insulation

The turns of the windings must be insulated from each other to ensure that the current travels through the entire winding. The potential difference between adjacent turns is usually small, so that enamel insulation is usually sufficient for small power transformers. Supplemental sheet or tape insulation is usually employed between winding layers in larger transformers.

The transformer may also be immersed in transformer oil that provides further insulation. Although the oil is primarily used to cool the transformer, it also helps to reduce the formation of corona discharge within high voltage transformers. By cooling the windings, the insulation will not break down as easily due to heat. To ensure that the insulating capability of the transformer oil does not deteriorate, the transformer casing is completely sealed against moisture ingress. Thus the oil serves as both a cooling medium to remove heat from the core and coil, and as part of the insulation system.

Certain power transformers have the windings protected by epoxy resin. By impregnating the transformer with epoxy under a vacuum, air spaces within the windings are replaced with epoxy, thereby sealing the windings and helping to prevent the possible formation of corona and absorption of dirt or water.

2.5.4 Shielding

Where transformers are intended for minimum electrostatic coupling between primary and secondary circuits, an electrostatic shield can be placed between windings to reduce the capacitance between primary and secondary windings. The shield may be a single layer of metal foil, insulated where it overlaps to prevent it acting as a shorted turn, or a single layer winding between primary and secondary. The shield is connected to earth ground.

Transformers may also be enclosed by magnetic shields, electrostatic shields, or both to prevent outside interference from affecting the operation of the transformer, or to prevent the transformer from affecting the operation of nearby devices that may be sensitive to stray fields such as CRTs.

2.5.5 Coolant

Figure 3

Three phase dry-type transformer with cover removed; rated about 200 KVA, 480 V.

Small signal transformers do not generate significant amounts of heat. Power transformers rated up to a few kilowatts rely on natural convective air cooling. Specific provision must be made for cooling of high-power transformers. Transformers handling higher power, or having a high duty cycle can be fan-cooled.

Some dry transformers are enclosed in pressurized tanks and are cooled by nitrogen or sulfur hexafluoride gas.

The windings of high-power or high-voltage transformers are immersed in transformer oil — a highly-refined mineral oil, that is stable at high temperatures. Large transformers to be used indoors must use a non-flammable liquid. Formerly, polychlorinated biphenyl (PCB) was used as it was not a fire hazard in indoor power transformers and it is highly stable. Due to the stability and toxic effects of PCB byproducts, and its accumulation in the environment, it is no longer permitted in new equipment. Old transformers which still contain PCB should be examined on a weekly basis for leakage. If found to be leaking, it should be changed out, and professionally decontaminated or scrapped in an environmentally safe manner. Today, nontoxic, stable silicone-based oils, or fluorinated hydrocarbons may be used where the expense of a fire-resistant liquid offsets additional building cost for a transformer vault. Other less-flammable fluids such as canola oil may be used but all fire resistant fluids have some drawbacks in performance, cost, or toxicity compared with mineral oil.

The oil cools the transformer, and provides part of the electrical insulation between internal live parts. It has to be stable at high temperatures so that a small short or arc will not cause a breakdown or fire. The oil-filled tank may have radiators through which the oil circulates by natural convection. Very large or high-power transformers (with capacities of millions of watts) may have cooling fans, oil pumps and even oil to water heat exchangers. Oil-filled transformers undergo prolonged drying processes, using vapor-phase heat transfer, electrical self-heating, the application of a vacuum, or combinations of these, to ensure that the transformer is completely free of water vapor before the cooling oil is introduced. This helps prevent electrical breakdown under load.

Oil-filled power transformers may be equipped with Buchholz relays which are safety devices that sense gas build-up inside the transformer (a side effect of an electric arc inside the windings), and thus switches off the transformer.

Experimental power transformers in the 2 MVA range have been built with superconducting windings which eliminates the copper losses, but not the core steel loss. These are cooled by liquid nitrogen or helium.

2.5.6 Terminals

Very small transformers will have wire leads connected directly to the ends of the coils, and brought out to the base of the unit for circuit connections. Larger transformers may have heavy bolted terminals, bus bars or high-voltage insulated bushings made of polymers or porcelain. A large bushing can be a complex structure since it must provide electrical insulation without letting the transformer leak oil.

2.5.7 Enclosure

Small transformers often have no enclosure. Transformers may have a shield enclosure, as described above. Larger units may be enclosed to prevent contact with live parts, and to contain the cooling medium (oil or pressurized gas).

2.6. Transformer types

2.6.1 Autotransformers

An autotransformer has only a single winding, which is tapped at some point along the winding. AC or pulsed voltage is applied across a portion of the winding, and a higher (or lower) voltage is produced across another portion of the same winding. While theoretically separate parts of the winding can be used for input and output, in practice the higher voltage will be connected to the ends of the winding, and the lower voltage from one end to a tap. For example, a transformer with a tap at the center of the winding can be used with 230 volts across the entire winding, and 115 volts between one end and the tap. It can be connected to a 230 volt supply to drive 115 volt equipment, or reversed to drive 230 volt equipment from 115 volts. As the same winding is used for input and output, the flux in the core is partially cancelled, and a smaller core can be used. For voltage ratios not exceeding about 3:1, an autotransformer is cheaper, lighter, smaller and more efficient than a true (two-winding) transformer of the same rating.

In practice, transformer losses mean that autotransformers are not perfectly reversible; one designed for stepping down a voltage will deliver slightly less voltage than required if used to step up. The difference is usually slight enough to allow reversal where the actual voltage level is not critical.

By exposing part of the winding coils and making the secondary connection through a sliding brush, an autotransformer with a near-continuously variable turns ratio can be obtained, allowing for very small increments of voltage.

2.6.2 Polyphase transformers

For three-phase power, three separate single-phase transformers can be used, or all three phases can be connected to a single polyphase transformer. The three primary windings are connected together and the three secondary windings are connected together. The most common connections are Y-Δ, Δ-Y, Δ-Δ and Y-Y. A vector group indicates the configuration of the windings and the phase angle difference between them. If a winding is connected to earth (grounded), the earth connection point is usually the center point of a Y winding. If the secondary is a Δ winding, the ground may be connected to a center tap on one winding (high leg delta) or one phase may be grounded (corner grounded delta). There are many possible configurations that may involve more or fewer than six windings and various tap connections.

2.6.3 Resonant transformers

A resonant transformer operates at the resonant frequency of one or more of its coils and (usually) an external capacitor. The resonant coil, usually the secondary, acts as an inductor, and is connected in series with a capacitor. When the primary coil is driven by a periodic source of alternating current, such as a square or Sawtooth wave at the resonant frequency, each pulse of current helps to build up an oscillation in the secondary coil. Due to resonance, a very high voltage can develop across the secondary, until it is limited by some process such as electrical breakdown. These devices are used to generate high alternating voltages, and the current available can be much larger than that from electrostatic machines such as the Van de Graaff generator or Wimshurst machine.

Tesla coil

Oudin coil (or Oudin resonator; named after its inventor Paul Oudin)

D'Arsonval apparatus

Ignition coil or induction coil used in the ignition system of a petrol engine

Flyback transformer of a CRT television set or video monitor.

Electrical breakdown and insulation testing of high voltage equipment and cables. In the latter case, the transformer's secondary is resonated with the cable's capacitance.

Other applications of resonant transformers are as coupling between stages of a superheterodyne receiver, where the selectivity of the receiver is provided by the tuned transformers of the intermediate-frequency amplifiers.

A voltage regulating transformer uses a resonant winding and allows part of the core to go into saturation on each half-cycle of the alternating current. This effect stabilizes the output of the regulating transformer, which can be used for equipment that is sensitive to variations of the supply voltage. Saturating transformers provide a simple rugged method to stabilize an AC power supply. However, due to the hysteresis losses accompanying this type of operation, efficiency is low.

2.6.4 Instrument transformers

2.6.4.1 Current transformers

Figure 4

A current transformer is a type of "instrument transformer" that is designed to provide a current in its secondary which is accurately proportional to the current flowing in its primary. This accuracy is directly related to a number of factors including the following:

burden,

rating factor,

load,

external electromagnetic fields,

temperature and

physical CT configuration.

The burden in a CT metering circuit is essentially the amount of impedance (largely resistive) present. Typical burden ratings for CTs are B-0.1, B-0.2, B-0.5, B-1.0, B-2.0 and B-4.0. This means a CT with a burden rating of B-0.2 can tolerate up to 0.2Ω of impedance in the metering circuit before its output current is no longer a fixed ratio to the primary current. Items that contribute to the burden of a current measurement circuit are switch blocks meters and intermediate conductors. The most common source of excess burden in a current measurement circuit is the conductor between the meter and the CT. Often times, substation meters are located significant distances from the meter cabinets and the excessive length of small gauge conductor creates a large resistance.

Rating factor is a factor by which the nominal full load current of a CT can be multiplied to determine its absolute maximum measurable primary current. Conversely, the minimum primary current a CT can accurately measure is "light load," or 10% of the nominal current. The rating factor of a CT is largely dependent upon ambient temperature. Most CTs have rating factors for 35 degrees Celsius and 55 degrees Celsius. A CT usually demonstrates reduced capacity to maintain accuracy with rising ambient temperature. It is important to be mindful of ambient temperatures and resultant rating factors when CTs are installed inside pad-mounted transformers or poorly ventilated mechanical rooms. Recently, manufacturers have been moving towards lower nominal primary currents with greater rating factors. This is made possible by the development of more efficient ferrites and their corresponding hysteresis curves. This is a distinct advantage over previous CTs because it increases their range of accuracy. For example, a 200:5 CT with a rating factor of 4.0 is most accurate between 20A (light load)and 800A (4.0 times the nominal rating, or "full load," of the CT) of primary current. While previous revisions of CTs were on the order of 500:5 with a rating factor of 1.5 yielding an effective range of 50A to 750A. This is an 11% increase in effective range for two CTs that would be used at similar services. Not to mention, the relative cost of a 500:5 CT is significantly greater than that of a 200:5.

Physical CT configuration is another important factor in reliable CT accuracy. While all electrical engineers are quite comfortable with Gauss' Law, there are some issues when attempting to apply theory to the real world. When conductors passing through a CT are not centered in the circular (or oval) void, slight inaccuracies may occur. It is important to center primary conductors as they pass through CTs to promote the greatest level of CT accuracy. Afterall, in an electric metering circuit, the most inaccurate component is the CT.

Current transformers (CTs) are commonly used in metering and protective relaying in the electrical power industry where they facilitate the safe measurement of large currents, often in the presence of high voltages. The current transformer safely isolates measurement and control circuitry from the high voltages typically present on the circuit being measured.

Current transformers are often constructed by passing a single primary turn (either an insulated cable or an uninsulated bus bar) through a well-insulated toroidal core wrapped with many turns of wire. Current transformers are used extensively for measuring current and monitoring the operation of the power grid. The CT is typically described by its current ratio from primary to secondary. Common secondaries are 1 or 5 amperes. For example, a 4000:5 CT would provide an output current of 5 amperes when the primary was passing 4000 amperes. The secondary winding can be single ratio or multi ratio, with five taps being common for multi ratio CTs. Typically, the secondary connection points are labeled as 1s1, 1s2, 2s1, 2s2 and so on. The multi ratio CTs are typically used for current matching in current differential protective relaying applications. Often, multiple CTs will be installed as a "stack" for various uses (for example, protection devices and revenue metering may use separate CTs). For a three-stacked CT application, the secondary winding connection points are typically labeled Xn, Yn, Zn. Care must be taken that the secondary of a current transformer is not disconnected from its load while current is flowing in the primary, as this will produce a dangerously high voltage across the open secondary.

Specially constructed *wideband current transformers* are also used (usually with an oscilloscope) to measure waveforms of high frequency or pulsed currents within pulsed power systems. One type of specially constructed wideband transformer provides a voltage output that is proportional to the measured current. Another type (called a Rogowski coil) requires an external integrator in order to provide a voltage output that is proportional to the measured current. Unlike CTs used for power circuitry, wideband CT's are rated in output volts per ampere of primary current.

2.6.4.2 Voltage transformers

Voltage transformers (VTs) or potential transformers (PTs) are another type of instrument transformer, used for metering and protection in high-voltage circuits. They are designed to present negligible load to the supply being measured and to have a precise voltage ratio to accurately step down high voltages so that metering and protective relay equipment can be operated at a lower potential. Typically the secondary of a voltage transformer is rated for 69 or 120 Volts at rated primary voltage, to match the input ratings of protection relays.

The transformer winding high-voltage connection points are typically labelled as H1, H2 (sometimes H0 if it is internally grounded) and X1, X2, and sometimes an X3 tap may be present. Sometimes a second isolated winding (Y1, Y2, Y3) may also be available on the same voltage transformer. The high side (primary) may be connected phase to ground or phase to phase. The low side (secondary) is usually phase to ground.

The terminal identifications (H1, X1, Y1, etc.) are often referred to as polarity. This applies to current transformers as well. At any instant terminals with the same suffix numeral have the same polarity and phase. Correct identification of terminals and wiring is essential for proper operation of metering and protection relays.

While VTs were formerly used for all voltages greater than 240V primary, modern meters eliminate the need VTs for most secondary service voltages.

2.6.5 Pulse transformers

A pulse transformer is a transformer that is optimised for transmitting rectangular electrical pulses (that is, pulses with fast rise and fall times and a constant amplitude). Small versions called *signal* types are used in digital logic and telecommunications circuits, often for matching logic drivers to transmission lines. Medium-sized *power* versions are used in power-control circuits such as camera flash controllers. Larger *power* versions are used in the electrical power distribution industry to interface low-voltage control circuitry to the high-voltage gates of power semiconductors. Special high voltage pulse transformers are also used to generate high power pulses for radar, particle accelerators, or other high energy pulsed power applications.

To minimise distortion of the pulse shape, a pulse transformer needs to have low values of leakage inductance and distributed capacitance, and a high open-circuit inductance. In power-type pulse transformers, a low coupling capacitance (between the primary and secondary) is important to protect the circuitry on the primary side from high-powered transients created by the load. For the same reason, high insulation resistance and high breakdown voltage are required. A good transient response is necessary to maintain the rectangular pulse shape at the secondary, because a pulse with slow edges would create switching losses in the power semiconductors.

The product of the peak pulse voltage and the duration of the pulse (or more accurately, the voltage-time integral) is often used to characterise pulse transformers. Generally speaking, the larger this product, the larger and more expensive the transformer.

2.6.6 RF transformers (transmission line transformers)

For radio frequency use, transformers are sometimes made from configurations of transmission line, sometimes bifilar or coaxial cable, wound around ferrite or other types of core. This style of transformer gives an extremely wide bandwidth but only a limited number of ratios (such as 1:9, 1:4 or 1:2) can be achieved with this technique.

The core material increases the inductance dramatically, thereby raising its Q factor. The cores of such transformers help improve performance at the lower frequency end of the band. RF transformers sometimes used a third coil (called a tickler winding) to inject feedback into an earlier (detector) stage in antique regenerative radio receivers.

2.6.6.1 Baluns

Baluns are transformers designed specifially to connect between balanced and unbalanced circuits. These are sometimes made from configurations of transmission line and sometimes bifilar or coaxial cable and are similar to transmission line transformers in construction and operation.

2.6.7 Audio transformers

Figure 5

Transformers in a tube amplifier. Output transformers are on the left. The power supply toroidal transformer is on right.

Audio transformers are usually the factor which limit sound quality; electronic circuits with wide frequency response and low distortion are relatively simple to design.

Transformers are also used in DI boxes to convert impedance from high-impedance instruments (for example, bass guitars) to enable them to be connected to a microphone input on the mixing console.

A particularly critical component is the output transformer of an audio power amplifier. Valve circuits for quality reproduction have long been produced with no other (inter-stage) audio transformers, but an output transformer is needed to couple the relatively high impedance (up to a few hundred ohms depending upon configuration) of the output valve(s) to the low impedance of a loudspeaker. (The valves can deliver a low current at a high voltage; the speakers require high current at low voltage.) Solid-state power amplifiers may need no output transformer at all.

For good low-frequency response a relatively large iron core is required; high power handling increases the required core size. Good high-frequency response requires carefully designed and implemented windings without excessive leakage inductance or stray capacitance. All this makes for an expensive component.

Early transistor audio power amplifiers often had output transformers, but they were eliminated as designers discovered how to design amplifiers without them.

2.6.7.1 Speaker transformers

In the same way that transformers are used to create high voltage power transmission circuits that minimize transmission losses, speaker transformers allow many individual loudspeakers to be powered from a single audio circuit operated at higher-than normal speaker voltages. This application is common in public address (e.g., Tannoy) applications. Such circuits are commonly referred to as

constant voltage or *70 volt* speaker circuits although the audio waveform is obviously a constantly changing voltage.

At the audio amplifier, a large audio transformer may be used to step-up the low impedance, low-voltage output of the amplifier to the designed line voltage of the speaker circuit. Then, a smaller transformer at each speaker returns the voltage and impedance to ordinary speaker levels. The speaker transformers commonly have multiple primary taps, allowing the volume at each speaker to be adjusted in a number of discrete steps.

Use of a constant-voltage speaker circuit means that there is no need to worry about the impedance presented to the amplifier output (which would clearly be too low if all of the speakers were arranged in parallel and would be too complex a design problem if the speakers were arranged in series-parallel). The use of higher transmission voltage and impedance means that power lost in the connecting wire is minimized, even with the use of small-gauge conductors (and leads to the term *constant voltage* as the line voltage doesn't change much as additional speakers are added to the system). Also, the ability to adjust, locally, the volume of each speaker (without the complexity and power loss of an L pad) is a useful feature.

2.6.7.2 Small Signal transformers

Moving coil phonograph cartridges produce a very small voltage. In order for this to be amplified with a reasonable signal-noise ratio, a transformer is usually used to convert the voltage to the range of the more common moving-magnet cartridges.

2.6.7.3 'Interstage' and coupling transformers

A use for interstage transformers is in the case of push-pull amplifiers where an inverted signal is required. Here two secondary windings wired in opposite polarities may be used to drive the output devices.

2.7. Uses of transformers

For supplying power from an alternating current power grid to equipment which uses a different voltage.

Electric power transmission over long distances.

Large, specially constructed power transformers are used for electric arc furnaces used in steelmaking.

Rotating transformers are designed so that one winding turns while the other remains stationary. A common use was the video head system as used in VHS and Beta video tape players. These can pass power or radio signals from a stationary mounting to a rotating mechanism, or radar antenna.

Sliding transformers can pass power or signals from a stationary mounting to a moving part such as a machine tool head.

A transformer-like device is used for position measurement. See linear variable differential transformer.

Some rotary transformers are used to couple signals between two parts which rotate in relation to each other.

Other rotary transformers are precisely constructed in order to measure distances or angles. Usually they have a single primary and two or more secondaries, and electronic circuits measure the different amplitudes of the currents in the secondaries. See synchro and resolver.

Small transformers are often used internally to couple different stages of radio receivers and audio amplifiers.

Transformers may be used as external accessories for impedance matching; for example to match a microphone to an amplifier.

Balanced-to-unbalanced conversion. A special type of transformer called a balun is used in radio and audio circuits to convert between balanced linecircuits and unbalanced transmission lines such as antenna downleads.

Chapter 3

Description of my project

3.1 How it works

My project of power supply starts with transformer, which reduces the 220V ac from the line to a safe and convenient nomuinal 30 V ac sine wave voltage with only moderate loss of power.

Next comes a full-wave bridge rectifier consisting of four half-wave rectifiers that act as diodes. A half-wave rectifier allows current to flow through it in only one direction, Half-wave rectifier If an alternating sine-wave voltage is applied to a rectifier, it transmits only the positive half-waves . Rectifier sine wave after passing through half-wave rectifier Four half-wave rectifiers connected form a bridge rectifier.

The four half-wave rectifiers act as switches that connect the upper or lower lead on the left, when either is positive, to the right-hand output lead, and to the left-hand output lead when either is negative . Bridge rectifier in action In this way the wiggly ac is made to flow in only one direction, it is straightened out or rectified. Voltage output from the bridge rectifier.

And then I use capacitors.This components can do many things in both ac circuits and dc circuits.Capacitors store energy and when coupled with resistors can delay voltage changeş .Sometimes it can be used to filter unwanted frequency signalş.Capacitors and resistors can be combined to make frequency dependent and independent voltage dividers

Next comes I use the LM317T three-terminal integrated circuit (IC),it is containing 26 transistors and various resistors and capacitors. It keeps the output voltage constant with respect to an internal reference voltage, using feedback, it is a 'voltage regulator'.

3.2 Construction:

First lets place the parts according to the top view of perfboard. Bend the white socket's short leads carefully while installing. The black regulator's three leads will fit into the socket. You will only solder the socket's leads so that the regulator can be easily removed. Identify on your perfboard which socket leads will correspond to the ADJ, OUT, and IN leads of the regulator.Bend the leads of the rectifier, capacitors, and resistors as shown on the bottom view of perfboard. Measure, cut, and solder a piece of the bare wire to the minus lead (-) of the rectifier. Extend this wire across the board, and then form a loop on the top side. This will be the minus (-) output loop.

Loop the end of the minus lead (-) of the large capacitor (the band points to the minus lead) through the perfboard at the bare wire from step.Solder the pot lead nearest the edge of the perfboard to the bare wire. Be sure the pot is oriented as shown in the top view. Solder the minus lead (-) of the small capacitor (the band points to the minus lead) the bare wire. Solder the plus lead (+) of the rectifier to the plus lead (+) of the large capacitorExtend this wire across the perfboard, and then form a loop on the top side. This will be the plus (+) output loop Solder the plus lead (+) of the small capacitor to the bare wire of the previous .Solder one lead of the resistor to the bare wire of step Solder the other lead of the resistor to the two other leads of the pot, thus connecting those two leads of the pot together.Remove the insulation from two different lengths, 50 mm and 100 mm (2in and 4 in) of black stranded wire. Tin all four ends and solder one length to each of the ac leads of the rectifier

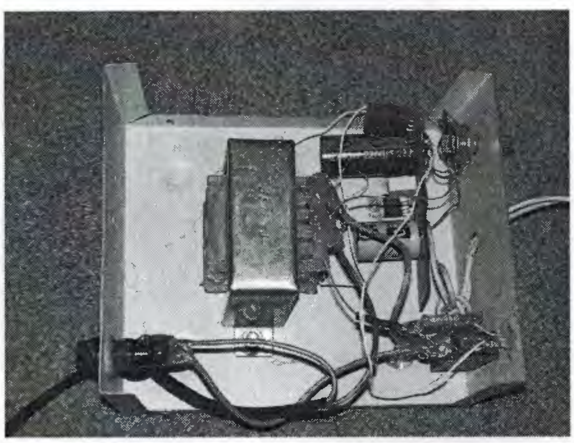


Figure of my project

CONCLUSION

In this project we have seen the functions of power supply.Structures and importance of the power supply in the industry.

There are many types of power supply in industry so this technology always improve.This project will be efective on my career.

The materials used in the circuit make me look at the these kind of projects with another wievpoint.

Also I have learned how to construct a circuit,solder the elements and trained my mathematical calculation skill.

By the way I wanted to inform you about power electrics,general information about electrical devices,as practical as possible.

As a result I'm very glad to prepare such a project and to take the chance of improving myself.

Also I thank to my supervisor Assoc. Prof. Dr. Özgür C. Özerdem for helping to prepare my project.

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