NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

SENSOR CONTROLLED CONVEYOR BAND SYSTEM

Graduation Project
EE-400

Student: UĞUR HASDAĞLI (20010529)

Supervisor: Asist. Prof. Dr.
ÖZGÜR C. ÖZERDEM

Lefkoşa - 2007

ACKNOWLEDGEMENT

Firstly I want to thank my father Electrical Engineer YALÇIN HASDAĞLI. With his guidance I learned lots of systems, equipments and their applications in theorically and specially practically from 7 to my age. Also he answered all my questions in my project and every time patiently. His 37 years engineering life, experiences, working and problem solving style lighted my way to engineering gate.

Special thanks to electricians Erhan, Süreyya for their helps and patience during the progress of electronic circuits. And also thanks to Hasan Süren for my conveyor and motor systems.

Thanks to all my friends for 6 magnificent years especially Volkan KAVAKLIOĞLU. Because of him, I never spent my time alone; he was always with me for everything.

Thanks to all my Instructors in engineering Faculty, with their experiences I had good plans about my engineering future.

Finally, lots of thanks to my family. Their efforts which they did for me are priceless. Because of them now I' am here.

ABSTRACT

In today's world electronic devices filled our lives. Technological developments are making every system old by generating new one for old.

For today nearly every industrial companies are using automatic control systems for manufacturing, packaging and etc. Also this project is made for simulation of a working animal feed production system. This system also can be used for every product which must be in an automatic production system.

In this system, we have 2 conveyor band systems for to carry the product from beginning to end of production process. These two bands have 2 sensors. In industrial systems energy saving is very important because of this, I' am using first band's sensor for starting the second band motor. By this way if the first band is empty, second band will not be working. When the product is passed in front of the first sensor the second band will work. Second sensor is used for counting the produced products.

The general system and first band motor is starting by the worker from different switches and products are carrying one by one. When the first sensor is detected the product second band is starting. So, the product is continuing the way. When the product is detected by the second sensor, electronic relay system is adding 1 to digital display panel.

With this system companies can make their energy saving and counting their products easily.

INTRODUCTION

Automation, robotization or industrial automation or numerical control is the use of control systems such as computers to control industrial machinery and processes, replacing human operators. In the scope of industrialization, it is a step beyond mechanization. Whereas mechanization provided human operators with machinery to assist them with the physical requirements of work, automation greatly reduces the need for human sensory and mental requirements as well.

Automation plays an increasingly important role in the global economy and in daily experience. Engineers strive to combine automated devices with mathematical and organizational tools to create complex systems for a rapidly expanding range of applications and human activities.

In this project, mechanization of industrial control system is considered.

The first chapter represents the definition of control system, some examples about motor using and history of control systems and famous creators of James Clerk Maxwell, Edward John Routh, Adolf Hurwitz.

In chapter 2, basic knowledge about electricity, power in electric circuits, resistors, potentiometers, diodes, bridge diodes , dimmers, passive infrared sensors and transformers as electronic parts which are used in project are considered.

In chapter 3 general knowledge about electric motors and its usable types for this kind of projects

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A control system is a device or set of devices to manage, command, direct or regulate the behavior of other devices or systems.

The term "control system" may be applied to the essentially manual controls that allow an operator to, for example, close and open a hydraulic press, band systems, production conveyors where the logic requires that it cannot be moved unless safety guards are in place.

An automatic sequential control system may trigger a series of mechanical actuators in the correct sequence to perform a task. For example various electric and pneumatic transducers may fold and glue a cardboard box, fill it with product and then seal it in an automatic packaging machine.

The electrical motors used commonly in industrial applications are different from each other as structure. The common feature of these motors is converting electrical energy to mechanical energy. Each type of electric motor can not be suitable for position and speed control. So, a motor should be chosen according to controllable magnitude which is preferred. A step motor or servomotor is generally used for necessary applications of position control. Step motors are mostly preferred in the small powered systems and the controls which requires low moment.

Beside of this, the system which has high power, high moment and rapid reaction, servomotors are mostly preferred. However, to make the control of the motor for softly is easy when the motor starting and stopping. Thus, the starting and stopping the motor, load which is connected to the shaft, the damage of the product and the same time the starting current of the motor during starting up are prevented.

Changing the speed of the motor done by adjusting the input voltage of the motor. Mostly semiconductor elements are used to adjust the voltage applied to the motor. These semiconductor elements are controlled by hardware elements such as microprocessor, microcontroller and relevant software. In this study I used a dimmer circuit with high capacity triac to change the input of the transformer. By this way i can control the speed of motors.

1.1 History of Control systems

Although control systems of various types date back to antiquity, a more formal analysis of the field began with a dynamics analysis of the centrifugal governor, conducted by the physicist James Clerk Maxwell in 1868 entitled On Governors. This described and analyzed the phenomenon of "hunting," in which lags in the system can lead to overcompensation and unstable behavior. This generated a flurry of interest in the topic, during which Maxwell's classmate Edward John Routh generalized the results of Maxwell for the general class of linear systems. Independently, Adolf Hurwitz analyzed system stability using differential equations in 1877. This result is called the Routh-Hurwitz Criterion.

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By World War II, control theory was an important part of fire-control systems, guidance systems, and electronics. The Space Race also depended on accurate spacecraft control. However, control theory also saw an increasing use in fields such as economics and sociology.

For a list of active and historical figures who have made a significant contribution to control theory.

2. PART EXPLANATIONS OF PROJECT

2.1 How voltage, current, and resistance relate

An electric circuit is formed when a conductive path is created to allow free electrons to continuously move. This continuous movement of free electrons through the conductors of a circuit is called a current, and it is often referred to in terms of "flow," just like the flow of a liquid through a hollow pipe.

The force motivating electrons to "flow" in a circuit is called voltage. Voltage is a specific measure of potential energy that is always relative between two points. When we speak of a certain amount of voltage being present in a circuit, we are referring to the measurement of how much potential energy exists to move electrons from one particular point in that circuit to another particular point. Without reference to two particular points, the term "voltage" has no meaning.

Free electrons tend to move through conductors with some degree of friction, or opposition to motion. This opposition to motion is more properly called resistance. The amount of current in a circuit depends on the amount of voltage available to motivate the electrons, and also the amount of resistance in the circuit to oppose electron flow. Just like voltage, resistance is a quantity relative between two points. For this reason, the quantities of voltage and resistance are often stated as being "between" or "across" two points in a circuit.

To be able to make meaningful statements about these quantities in circuits, we need to be able to describe their quantities in the same way that we might quantify mass, temperature, volume, length, or any other kind of physical quantity. For mass we might use the units of "pound" or "gram." For temperature we might use degrees Fahrenheit or degrees Celsius. Here are the standard units of measurement for electrical current, voltage, and resistance:

Quantity	Symbol	Unit of Measurement	Unit Abbreviation
Current	I	Ampere ("Amp")	A
Voltage	E *or* V	Volt	V
Resistance	R	Ohm	Ω

Figure :2.1

The "symbol" given for each quantity is the standard alphabetical letter used to represent that quantity in an algebraic equation. Standardized letters like these are common in the disciplines of physics and engineering, and are internationally recognized. The "unit abbreviation" for each quantity represents the alphabetical symbol used as a shorthand notation for its particular unit of measurement. And, yes, that strange-looking "horseshoe" symbol is the capital Greek letter Ω, just a character in a foreign alphabet (apologies to any Greek readers here).

Each unit of measurement is named after a famous experimenter in electricity: The amp after the Frenchman Andre M. Ampere, the volt after the Italian Alessandro Volta, and the ohm after the German Georg Simon Ohm.

The mathematical symbol for each quantity is meaningful as well. The "R" for resistance and the "V" for voltage are both self-explanatory, whereas "I" for current seems a bit weird. The "I" is thought to have been meant to represent "Intensity" (of electron flow), and the other symbol for voltage, "E," stands for "Electromotive force." From what research I've been able to do, there seems to be some dispute over the meaning of "I." The symbols "E" and "V" are interchangeable for the most part, although some texts reserve "E" to represent voltage across a source (such as a battery or generator) and "V" to represent voltage across anything else.

All of these symbols are expressed using capital letters, except in cases where a quantity (especially voltage or current) is described in terms of a brief period of time (called an "instantaneous" value). For example, the voltage of a battery, which is stable over a long period of time, will be symbolized with a capital letter "E," while the voltage peak of a lightning strike at the very instant it hits a power line would most likely be symbolized with a lower-case letter "e" (or lower-case "v") to designate that value as being at a single moment in time. This same lower-case convention holds true for current as well, the lower-case letter "i" representing current at some instant in time. Most direct-current (DC) measurements, however, being stable over time, will be symbolized with capital letters.

One foundational unit of electrical measurement, often taught in the beginnings of electronics courses but used infrequently afterwards, is the unit of the coulomb, which is a measure of electric charge proportional to the number of electrons in an imbalanced state. One coulomb of charge is equal to 6.250.000.000.000.000.000 electrons. The symbol for electric charge quantity is the capital letter "Q," with the unit of coulombs abbreviated by the capital letter "C." It so happens that the unit for electron flow, the amp, is equal to 1 coulomb of electrons passing by a given point in a circuit in 1 second of time. Cast in these terms, current is the rate of electric charge motion through a conductor.

As stated before, voltage is the measure of potential energy per unit charge available to motivate electrons from one point to another. Before we can precisely define what a "volt" is, we must understand how to measure this quantity we call "potential energy." The general metric unit for energy of any kind is the joule, equal to the amount of work performed by a

force of 1 newton exerted through a motion of 1 meter (in the same direction). In British units, this is slightly less than 3/4 pound of force exerted over a distance of 1 foot. Put in common terms, it takes about 1 joule of energy to lift a 3/4 pound weight 1 foot off the ground, or to drag something a distance of 1 foot using a parallel pulling force of 3/4 pound. Defined in these scientific terms, 1 volt is equal to 1 joule of electric potential energy per (divided by) 1 coulomb of charge. Thus, a 9 volt battery releases 9 joules of energy for every coulomb of electrons moved through a circuit.

These units and symbols for electrical quantities will become very important to know as we begin to explore the relationships between them in circuits. The first, and perhaps most important, relationship between current, voltage, and resistance is called Ohm's Law, discovered by Georg Simon Ohm and published in his 1827 paper, The Galvanic Circuit Investigated Mathematically. Ohm's principal discovery was that the amount of electric current through a metal conductor in a circuit is directly proportional to the voltage impressed across it, for any given temperature. Ohm expressed his discovery in the form of a simple equation, describing how voltage, current, and resistance interrelate:

$$E = I R$$

In this algebraic expression, voltage (E) is equal to current (I) multiplied by resistance (R). Using algebra techniques, we can manipulate this equation into two variations, solving for I and for R, respectively:

$$I = \frac{E}{R} \qquad R = \frac{E}{I}$$

Let's see how these equations might work to help us analyze simple circuits:

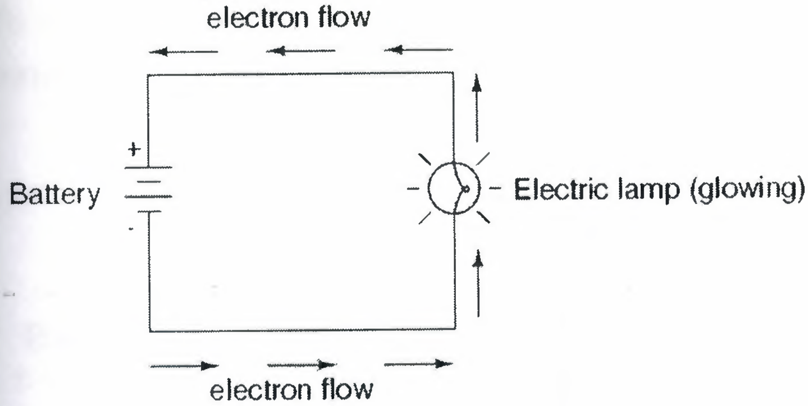


Figure : 2.2

In the above circuit, there is only one source of voltage (the battery, on the left) and only one source of resistance to current (the lamp, on the right). This makes it very easy to apply Ohm's Law. If we know the values of any two of the three quantities (voltage, current, and resistance) in this circuit, we can use Ohm's Law to determine the third.

In this first example, we will calculate the amount of current (I) in a circuit, given values of voltage (E) and resistance (R):

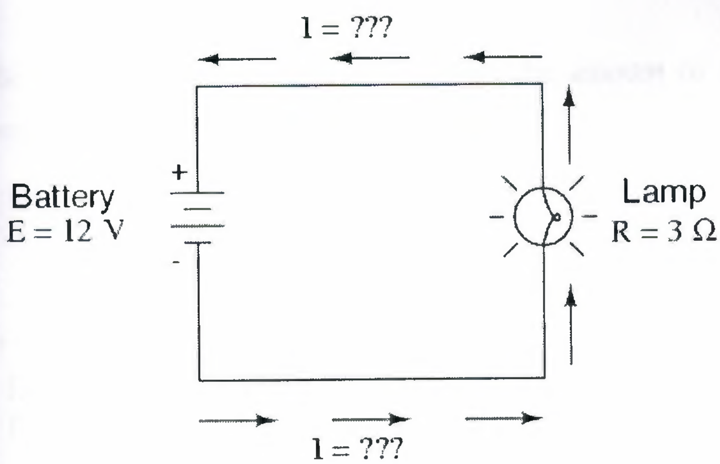


Figure 2.3

What is the amount of current (I) in this circuit?

$$I = \frac{E}{R} = \frac{12\ V}{3\ \Omega} = 4\ A$$

In this second example, we will calculate the amount of resistance (R) in a circuit, given values of voltage (E) and current (I):

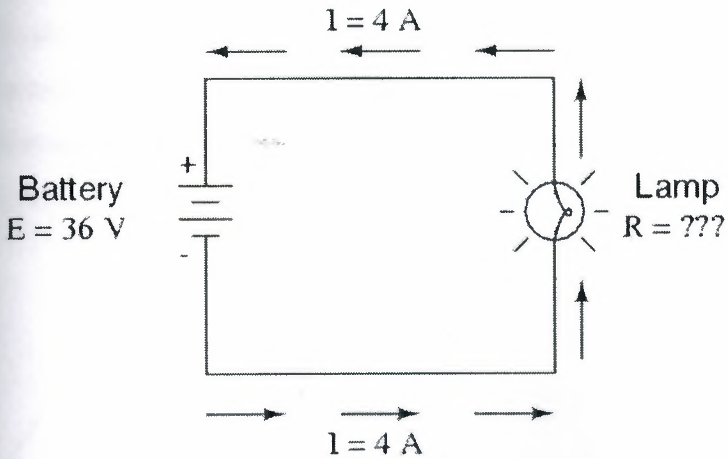


figure :2.4

What is the amount of resistance (R) offered by the lamp?

$$R = \frac{E}{I} = \frac{36\ V}{4\ A} = 9\ \Omega$$

In the last example, we will calculate the amount of voltage supplied by a battery, given values of current (I) and resistance (R):

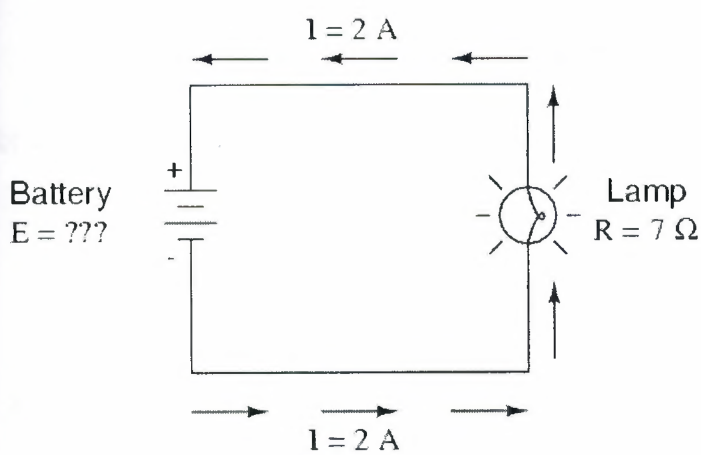


Figure : 2.5

What is the amount of voltage provided by the battery?

$$E = IR = (2\ A)(7\ \Omega) = 14\ V$$

Ohm's Law is a very simple and useful tool for analyzing electric circuits. It is used so often in the study of electricity and electronics that it needs to be committed to memory by the serious student. For those who are not yet comfortable with algebra, there's a trick to remembering how to solve for any one quantity, given the other two. First, arrange the letters E, I, and R in a triangle like this:

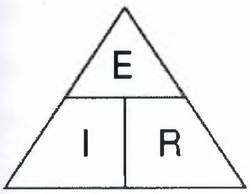
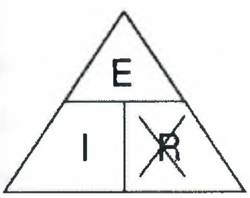


Figure : 2.6

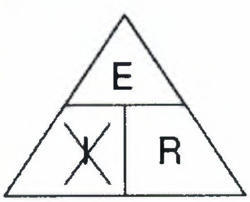
If you know E and I, and wish to determine R, just eliminate R from the picture and see what's left:



$$R = \frac{E}{I}$$

Figure : 2.7

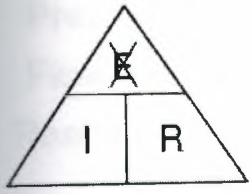
If you know E and R, and wish to determine I, eliminate I and see what's left:



$$I = \frac{E}{R}$$

Figure : 2.8

Lastly, if you know I and R, and wish to determine E, eliminate E and see what's left:



E = I R

Figure 2.9

Eventually, you'll have to be familiar with algebra to seriously study electricity and electronics, but this tip can make your first calculations a little easier to remember. If you are comfortable with algebra, all you need to do is commit E=IR to memory and derive the other two formulae from that when you need them!

Voltage measured in volts, symbolized by the letters "E" or "V". Current measured in amps, symbolized by the letter "I". Resistance measured in ohms, symbolized by the letter "R". Ohm's Law: E = IR ; I = E/R ; R = E/I

2.2 An analogy for Ohm's Law

Ohm's Law also makes intuitive sense if you apply it to the water-and-pipe analogy. If we have a water pump that exerts pressure (voltage) to push water around a "circuit" (current) through a restriction (resistance), we can model how the three variables interrelate. If the resistance to water flow stays the same and the pump pressure increases, the flow rate must also increase.

Pressure =	increase	**Voltage** =	increase
Flow rate =	increase	**Current** =	increase
Resistance=	same	**Resistance**=	same

$$\overset{\uparrow}{E} = \overset{\uparrow}{I}\; R$$

Figure : 2.10

If the pressure stays the same and the resistance increases (making it more difficult for the water to flow), then the flow rate must decrease:

Pressure	= same	**Voltage**	= same
Flow rate	= decrease	**Current**	= decrease
Resistance	= increase	**Resistance**	= increase

$$E = \underset{\downarrow}{I}\ \overset{\uparrow}{R}$$

Figure : 2.11

If the flow rate were to stay the same while the resistance to flow decreased, the required pressure from the pump would necessarily decrease:

Pressure	= decrease	**Voltage**	= decrease
Flow rate	= same	**Current**	= same
Resistance	= decrease	**Resistance**	= decrease

$$\underset{\downarrow}{E} = I\ \underset{\downarrow}{R}$$

Figure : 2.12

As odd as it may seem, the actual mathematical relationship between pressure, flow, and resistance is actually more complex for fluids like water than it is for electrons. If you pursue further studies in physics, you will discover this for yourself. Thankfully for the electronics student, the mathematics of Ohm's Law is very straightforward and simple.

With resistance steady, current follows voltage (an increase in voltage means an increase in current, and vice versa).

With voltage steady, changes in current and resistance are opposite (an increase in current means a decrease in resistance, and vice versa).

With current steady, voltage follows resistance (an increase in resistance means an increase in voltage).

2.2.1 Power in electric circuits

In addition to voltage and current, there is another measure of free electron activity in a circuit: power. First, we need to understand just what power is before we analyze it in any circuits.

Power is a measure of how much work can be performed in a given amount of time. Work is generally defined in terms of the lifting of a weight against the pull of gravity. The heavier the weight and/or the higher it is lifted, the more work has been done. Power is a measure of how rapidly a standard amount of work is done.

For American automobiles, engine power is rated in a unit called "horsepower," invented initially as a way for steam engine manufacturers to quantify the working ability of their machines in terms of the most common power source of their day: horses. One horsepower is defined in British units as 550 ft-lbs of work per second of time. The power of a car's engine won't indicate how tall of a hill it can climb or how much weight it can tow, but it will indicate how fast it can climb a specific hill or tow a specific weight.

The power of a mechanical engine is a function of both the engine's speed and it's torque provided at the output shaft. Speed of an engine's output shaft is measured in revolutions per minute, or RPM. Torque is the amount of twisting force produced by the engine, and it is usually measured in pound-feet, or lb-ft (not to be confused with foot-pounds or ft-lbs, which is the unit for work). Neither speed nor torque alone is a measure of an engine's power.

A 100 horsepower diesel tractor engine will turn relatively slowly, but provide great amounts of torque. A 100 horsepower motorcycle engine will turn very fast, but provide relatively little torque. Both will produce 100 horsepower, but at different speeds and different torques. The equation for shaft horsepower is simple:

$$\text{Horsepower} = \frac{2\,\pi\,S\,T}{33{,}000}$$

Where,

S = shaft speed in r.p.m.

T = shaft torque in lb-ft.

Figure : 2.13

Notice how there are only two variable terms on the right-hand side of the equation, S and T. All the other terms on that side are constant: 2, pi, and 33,000 are all constants (they do not change in value). The horsepower varies only with changes in speed and torque, nothing else. We can re-write the equation to show this relationship:

$$\text{Horsepower} \propto S\,T$$

$\propto$ This symbol means "proportional to"

Figure : 2.14

Because the unit of the "horsepower" doesn't coincide exactly with speed in revolutions per minute multiplied by torque in pound-feet, we can't say that horsepower equals ST. However, they are proportional to one another. As the mathematical product of ST changes, the value for horsepower will change by the same proportion.

In electric circuits, power is a function of both voltage and current. Not surprisingly, this relationship bears striking resemblance to the "proportional" horsepower formula above:

$$P = 1\,E$$

In this case, however, power (P) is exactly equal to current (I) multiplied by voltage (E), rather than merely being proportional to IE. When using this formula, the unit of measurement for power is the watt, abbreviated with the letter "W."

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The "symbol" given for each quantity is the standard alphabetical letter used to represent that quantity in an algebraic equation. Standardized letters like these are common in the disciplines of physics and engineering, and are internationally recognized. The "unit abbreviation" for each quantity represents the alphabetical symbol used as a shorthand notation for its particular unit of measurement. And, yes, that strange-looking "horseshoe" symbol is the capital Greek letter Ω, just a character in a foreign alphabet (apologies to any Greek readers here).

Each unit of measurement is named after a famous experimenter in electricity: The amp after the Frenchman Andre M. Ampere, the volt after the Italian Alessandro Volta, and the ohm after the German Georg Simon Ohm.

The mathematical symbol for each quantity is meaningful as well. The "R" for resistance and the "V" for voltage are both self-explanatory, whereas "I" for current seems a bit weird. The "I" is thought to have been meant to represent "Intensity" (of electron flow), and the other symbol for voltage, "E," stands for "Electromotive force." From what research I've been able to do, there seems to be some dispute over the meaning of "I." The symbols "E" and "V" are interchangeable for the most part, although some texts reserve "E" to represent voltage across a source (such as a battery or generator) and "V" to represent voltage across anything else.

All of these symbols are expressed using capital letters, except in cases where a quantity (especially voltage or current) is described in terms of a brief period of time (called an "instantaneous" value). For example, the voltage of a battery, which is stable over a long period of time, will be symbolized with a capital letter "E," while the voltage peak of a lightning strike at the very instant it hits a power line would most likely be symbolized with a lower-case letter "e" (or lower-case "v") to designate that value as being at a single moment in time. This same lower-case convention holds true for current as well, the lower-case letter "i" representing current at some instant in time. Most direct-current (DC) measurements, however, being stable over time, will be symbolized with capital letters.

One foundational unit of electrical measurement, often taught in the beginnings of electronics courses but used infrequently afterwards, is the unit of the coulomb, which is a measure of electric charge proportional to the number of electrons in an imbalanced state. One coulomb of charge is equal to 6.250.000.000.000.000.000 electrons. The symbol for electric charge quantity is the capital letter "Q," with the unit of coulombs abbreviated by the capital letter "C." It so happens that the unit for electron flow, the amp, is equal to 1 coulomb of electrons passing by a given point in a circuit in 1 second of time. Cast in these terms, current is the rate of electric charge motion through a conductor.

As stated before, voltage is the measure of potential energy per unit charge available to motivate electrons from one point to another. Before we can precisely define what a "volt" is, we must understand how to measure this quantity we call "potential energy." The general metric unit for energy of any kind is the joule, equal to the amount of work performed by a

force of 1 newton exerted through a motion of 1 meter (in the same direction). In British units, this is slightly less than 3/4 pound of force exerted over a distance of 1 foot. Put in common terms, it takes about 1 joule of energy to lift a 3/4 pound weight 1 foot off the ground, or to drag something a distance of 1 foot using a parallel pulling force of 3/4 pound. Defined in these scientific terms, 1 volt is equal to 1 joule of electric potential energy per (divided by) 1 coulomb of charge. Thus, a 9 volt battery releases 9 joules of energy for every coulomb of electrons moved through a circuit.

These units and symbols for electrical quantities will become very important to know as we begin to explore the relationships between them in circuits. The first, and perhaps most important, relationship between current, voltage, and resistance is called Ohm's Law, discovered by Georg Simon Ohm and published in his 1827 paper, The Galvanic Circuit Investigated Mathematically. Ohm's principal discovery was that the amount of electric current through a metal conductor in a circuit is directly proportional to the voltage impressed across it, for any given temperature. Ohm expressed his discovery in the form of a simple equation, describing how voltage, current, and resistance interrelate:

$$E = I R$$

In this algebraic expression, voltage (E) is equal to current (I) multiplied by resistance (R). Using algebra techniques, we can manipulate this equation into two variations, solving for I and for R, respectively:

$$I = \frac{E}{R} \qquad R = \frac{E}{I}$$

Let's see how these equations might work to help us analyze simple circuits:

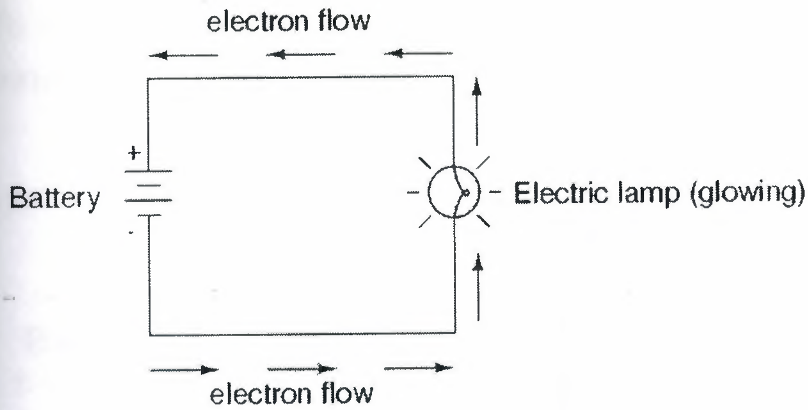


Figure : 2.2

In the above circuit, there is only one source of voltage (the battery, on the left) and only one source of resistance to current (the lamp, on the right). This makes it very easy to apply Ohm's Law. If we know the values of any two of the three quantities (voltage, current, and resistance) in this circuit, we can use Ohm's Law to determine the third.

In this first example, we will calculate the amount of current (I) in a circuit, given values of voltage (E) and resistance (R):

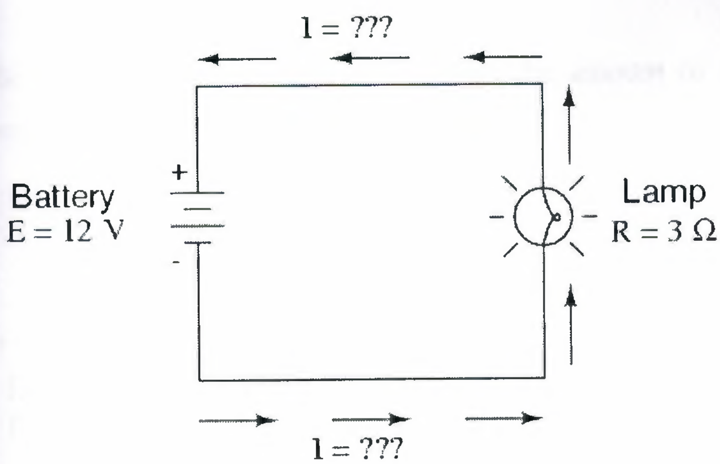


Figure 2.3

What is the amount of current (I) in this circuit?

$$1 = \frac{E}{R} = \frac{12\ V}{3\ \Omega} = 4\ A$$

In this second example, we will calculate the amount of resistance (R) in a circuit, given values of voltage (E) and current (I):

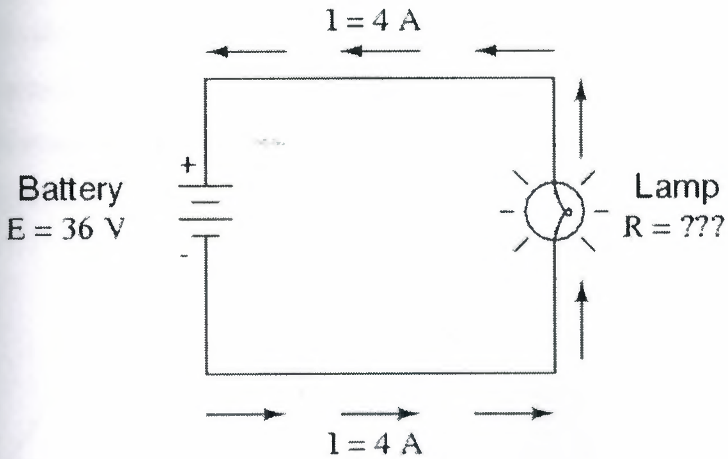


figure :2.4

What is the amount of resistance (R) offered by the lamp?

$$R = \frac{E}{I} = \frac{36\ V}{4\ A} = 9\ \Omega$$

In the last example, we will calculate the amount of voltage supplied by a battery, given values of current (I) and resistance (R):

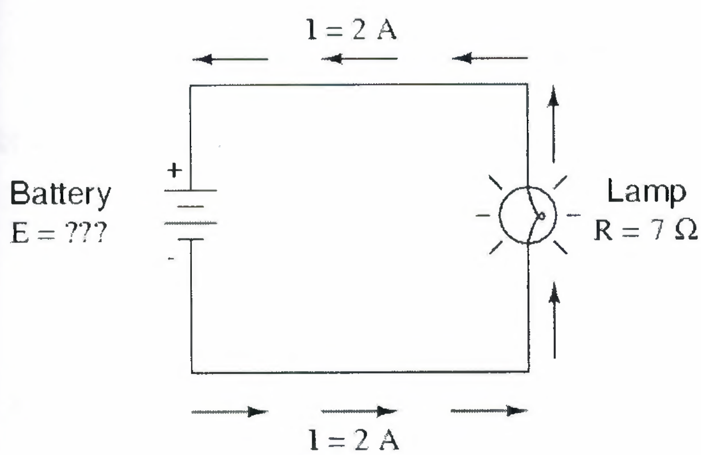


Figure : 2.5

What is the amount of voltage provided by the battery?

$$E = IR = (2\ A)(7\ \Omega) = 14\ V$$

Ohm's Law is a very simple and useful tool for analyzing electric circuits. It is used so often in the study of electricity and electronics that it needs to be committed to memory by the serious student. For those who are not yet comfortable with algebra, there's a trick to remembering how to solve for any one quantity, given the other two. First, arrange the letters E, I, and R in a triangle like this:

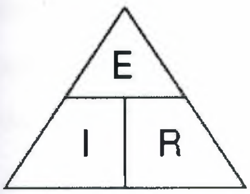
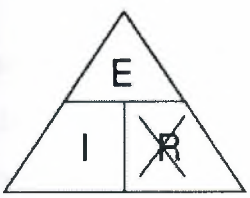


Figure : 2.6

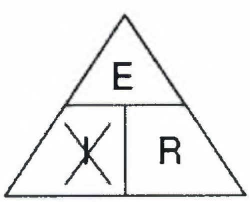
If you know E and I, and wish to determine R, just eliminate R from the picture and see what's left:



$$R = \frac{E}{I}$$

Figure : 2.7

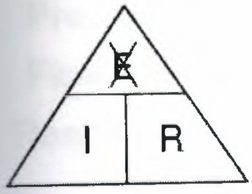
If you know E and R, and wish to determine I, eliminate I and see what's left:



$$I = \frac{E}{R}$$

Figure : 2.8

Lastly, if you know I and R, and wish to determine E, eliminate E and see what's left:



E = I R

Figure 2.9

Eventually, you'll have to be familiar with algebra to seriously study electricity and electronics, but this tip can make your first calculations a little easier to remember. If you are comfortable with algebra, all you need to do is commit E=IR to memory and derive the other two formulae from that when you need them!

Voltage measured in volts, symbolized by the letters "E" or "V". Current measured in amps, symbolized by the letter "I". Resistance measured in ohms, symbolized by the letter "R". Ohm's Law: E = IR ; I = E/R ; R = E/I

2.2 An analogy for Ohm's Law

Ohm's Law also makes intuitive sense if you apply it to the water-and-pipe analogy. If we have a water pump that exerts pressure (voltage) to push water around a "circuit" (current) through a restriction (resistance), we can model how the three variables interrelate. If the resistance to water flow stays the same and the pump pressure increases, the flow rate must also increase.

Pressure =	increase	**Voltage** =	increase
Flow rate =	increase	**Current** =	increase
Resistance=	same	**Resistance**=	same

$$\overset{\uparrow}{E} = \overset{\uparrow}{I}\ R$$

Figure : 2.10

If the pressure stays the same and the resistance increases (making it more difficult for the water to flow), then the flow rate must decrease:

Pressure	= same	**Voltage**	= same
Flow rate	= decrease	**Current**	= decrease
Resistance	= increase	**Resistance**	= increase

$$E = \underset{\downarrow}{I}\ \overset{\uparrow}{R}$$

Figure : 2.11

If the flow rate were to stay the same while the resistance to flow decreased, the required pressure from the pump would necessarily decrease:

Pressure	= decrease	**Voltage**	= decrease
Flow rate	= same	**Current**	= same
Resistance	= decrease	**Resistance**	= decrease

$$\underset{\downarrow}{E} = I\ \underset{\downarrow}{R}$$

Figure : 2.12

As odd as it may seem, the actual mathematical relationship between pressure, flow, and resistance is actually more complex for fluids like water than it is for electrons. If you pursue further studies in physics, you will discover this for yourself. Thankfully for the electronics student, the mathematics of Ohm's Law is very straightforward and simple.

With resistance steady, current follows voltage (an increase in voltage means an increase in current, and vice versa).

With voltage steady, changes in current and resistance are opposite (an increase in current means a decrease in resistance, and vice versa).

With current steady, voltage follows resistance (an increase in resistance means an increase in voltage).

2.2.1 Power in electric circuits

In addition to voltage and current, there is another measure of free electron activity in a circuit: power. First, we need to understand just what power is before we analyze it in any circuits.

Power is a measure of how much work can be performed in a given amount of time. Work is generally defined in terms of the lifting of a weight against the pull of gravity. The heavier the weight and/or the higher it is lifted, the more work has been done. Power is a measure of how rapidly a standard amount of work is done.

For American automobiles, engine power is rated in a unit called "horsepower," invented initially as a way for steam engine manufacturers to quantify the working ability of their machines in terms of the most common power source of their day: horses. One horsepower is defined in British units as 550 ft-lbs of work per second of time. The power of a car's engine won't indicate how tall of a hill it can climb or how much weight it can tow, but it will indicate how fast it can climb a specific hill or tow a specific weight.

The power of a mechanical engine is a function of both the engine's speed and it's torque provided at the output shaft. Speed of an engine's output shaft is measured in revolutions per minute, or RPM. Torque is the amount of twisting force produced by the engine, and it is usually measured in pound-feet, or lb-ft (not to be confused with foot-pounds or ft-lbs, which is the unit for work). Neither speed nor torque alone is a measure of an engine's power.

A 100 horsepower diesel tractor engine will turn relatively slowly, but provide great amounts of torque. A 100 horsepower motorcycle engine will turn very fast, but provide relatively little torque. Both will produce 100 horsepower, but at different speeds and different torques. The equation for shaft horsepower is simple:

$$\text{Horsepower} = \frac{2\,\pi\,S\,T}{33{,}000}$$

Where,

S = shaft speed in r.p.m.

T = shaft torque in lb-ft.

Figure : 2.13

Notice how there are only two variable terms on the right-hand side of the equation, S and T. All the other terms on that side are constant: 2, pi, and 33,000 are all constants (they do not change in value). The horsepower varies only with changes in speed and torque, nothing else. We can re-write the equation to show this relationship:

$$\text{Horsepower} \propto S\,T$$

$\propto$ This symbol means "proportional to"

Figure : 2.14

Because the unit of the "horsepower" doesn't coincide exactly with speed in revolutions per minute multiplied by torque in pound-feet, we can't say that horsepower equals ST. However, they are proportional to one another. As the mathematical product of ST changes, the value for horsepower will change by the same proportion.

In electric circuits, power is a function of both voltage and current. Not surprisingly, this relationship bears striking resemblance to the "proportional" horsepower formula above:

$$P = 1\,E$$

In this case, however, power (P) is exactly equal to current (I) multiplied by voltage (E), rather than merely being proportional to IE. When using this formula, the unit of measurement for power is the watt, abbreviated with the letter "W."

It must be understood that neither voltage nor current by themselves constitute power. Rather, power is the combination of both voltage and current in a circuit. Remember that voltage is the specific work (or potential energy) per unit charge, while current is the rate at which electric charges move through a conductor. Voltage (specific work) is analogous to the work done in lifting a weight against the pull of gravity. Current (rate) is analogous to the speed at which that weight is lifted. Together as a product (multiplication), voltage (work) and current (rate) constitute power.

Just as in the case of the diesel tractor engine and the motorcycle engine, a circuit with high voltage and low current may be dissipating the same amount of power as a circuit with low voltage and high current. Neither the amount of voltage alone nor the amount of current alone indicates the amount of power in an electric circuit.

In an open circuit, where voltage is present between the terminals of the source and there is zero current, there is zero power dissipated, no matter how great that voltage may be. Since P=IE and I=0 and anything multiplied by zero is zero, the power dissipated in any open circuit must be zero. Likewise, if we were to have a short circuit constructed of a loop of superconducting wire (absolutely zero resistance), we could have a condition of current in the loop with zero voltage, and likewise no power would be dissipated. Since P=IE and E=0 and anything multiplied by zero is zero, the power dissipated in a superconducting loop must be zero. (We'll be exploring the topic of superconductivity in a later chapter).

Whether we measure power in the unit of "horsepower" or the unit of "watt," we're still talking about the same thing: how much work can be done in a given amount of time. The two units are not numerically equal, but they express the same kind of thing. In fact, European automobile manufacturers typically advertise their engine power in terms of kilowatts (kW), or thousands of watts, instead of horsepower! These two units of power are related to each other by a simple conversion formula:

$$1 \text{ Horsepower} = 745.7 \text{ Watts}$$

So, our 100 horsepower diesel and motorcycle engines could also be rated as "74570 watt" engines, or more properly, as "74.57 kilowatt" engines. In European engineering specifications, this rating would be the norm rather than the exception.

Power is the measure of how much work can be done in a given amount of time.

Mechanical power is commonly measured (in America) in "horsepower."

Electrical power is almost always measured in "watts," and it can be calculated by the formula P = IE.

Electrical power is a product of both voltage and current, not either one separately.

Horsepower and watts are merely two different units for describing the same kind of physical measurement, with 1 horsepower equaling 745.7 watts.

2.2.2 Calculating electric power

We've seen the formula for determining the power in an electric circuit: by multiplying the voltage in "volts" by the current in "amps" we arrive at an answer in "watts." Let's apply this to a circuit example:

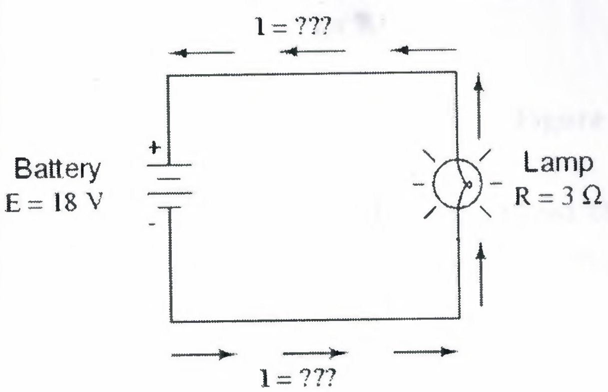


Figure : 2.15

In the above circuit, we know we have a battery voltage of 18 volts and a lamp resistance of 3 Ω. Using Ohm's Law to determine current, we get:

$$I = \frac{E}{R} = \frac{18\ V}{3\ \Omega} = 6\ A$$

Now that we know the current, we can take that value and multiply it by the voltage to determine power:

$P = I\,E = (6\text{ A})(18\text{ V}) = 108\text{ W}$

Answer: the lamp is dissipating (releasing) 108 watts of power, most likely in the form of both light and heat.

Let's try taking that same circuit and increasing the battery voltage to see what happens. Intuition should tell us that the circuit current will increase as the voltage increases and the lamp resistance stays the same. Likewise, the power will increase as well:

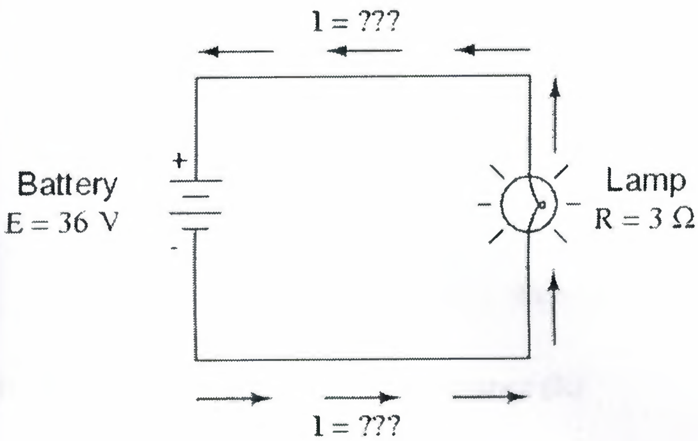


Figure : 2.16

Now, the battery voltage is 36 volts instead of 18 volts. The lamp is still providing 3 Ω of electrical resistance to the flow of electrons. The current is now:

$$I = \frac{E}{R} = \frac{36\text{ V}}{3\ \Omega} = 12\text{ A}$$

This stands to reason: if I = E/R, and we double E while R stays the same, the current should double. Indeed, it has: we now have 12 amps of current instead of 6. Now, what about power?

$P = I\,E = (12\text{ A})(36\text{ V}) = 432\text{ W}$

Notice that the power has increased just as we might have suspected, but it increased quite a bit more than the current. Why is this? Because power is a function of voltage multiplied by current, and both voltage and current doubled from their previous values, the power will increase by a factor of 2 x 2, or 4. You can check this by dividing 432 watts by 108 watts and seeing that the ratio between them is indeed 4.

Using algebra again to manipulate the formulae, we can take our original power formula and modify it for applications where we don't know both voltage and current:

If we only know voltage (E) and resistance (R):

If, $I = \dfrac{E}{R}$ *and* $P = I\,E$

Then, $P = \dfrac{E}{R}\,E$ *or* $\mathbf{P = \dfrac{E^2}{R}}$

Figure : 2.17

If we only know current (I) and resistance (R):

If, $E = I\,R$ *and* $P = I\,E$

Then, $P = I(I\,R)$ *or* $\mathbf{P = I^2 R}$

Figure : 2.18

An historical note: it was James Prescott Joule, not Georg Simon Ohm, who first discovered the mathematical relationship between power dissipation and current through a resistance. This discovery, published in 1841, followed the form of the last equation ($P = I^2R$), and is properly known as Joule's Law. However, these power equations are so commonly associated with the Ohm's Law equations relating voltage, current, and resistance (E=IR ; I=E/R ; and R=E/I) that they are frequently credited to Ohm.

Power equations

$P = IE$ $\quad P = \dfrac{E^2}{R}$ $\quad P = I^2R$

Power measured in watts, symbolized by the letter "W".

Joule's Law: $P = I^2R$; $P = IE$; $P = E^2/R$

2.3 RESISTORS

The resistor's function is to reduce the flow of electric current. This symbol —\/\/\/— is used to indicate a resistor in a circuit diagram, known as a schematic. Resistance value is designated in units called the "Ohm." A 1000 Ohm resistor is typically shown as 1K-Ohm (kilo Ohm), and 1000 K-Ohms is written as 1M-Ohm (megohm).

There are two classes of resistors; fixed resistors and the variable resistors. They are also classified according to the material from which they are made. The typical resistor is made of either carbon film or metal film. There are other types as well, but these are the most common.

The resistance value of the resistor is not the only thing to consider when selecting a resistor for use in a circuit. The "tolerance" and the electric power ratings of the resistor are also important.

The tolerance of a resistor denotes how close it is to the actual rated resistence value. For example, a ±5% tolerance would indicate a resistor that is within ±5% of the specified resistance value.

The power rating indicates how much power the resistor can safely tolerate. Just like you wouldn't use a 6 volt flashlight lamp to replace a burned out light in your house, you wouldn't use a 1/8 watt resistor when you should be using a 1/2 watt resistor.

The maximum rated power of the resistor is specified in Watts. Power is calculated using the square of the current (I^2) x the resistance value (R) of the resistor. If the maximum rating of the resistor is exceeded, it will become extremely hot, and even burn.

Resistors in electronic circuits are typicaly rated 1/8W, 1/4W, and 1/2W. 1/8W is almost always used in signal circuit applications.

When powering a light emitting diode, a comparatively large current flows through the resistor, so you need to consider the power rating of the resistor you choose.

2.3.1 Rating electric power

For example, to power a 5V circuit using a 12V supply, a three-terminal voltage regulator is usually used. However, if you try to drop the voltage from 12V to 5V using only a resistor, then you need to calculate the power rating of the resistor as well as the resistance value.

At this time, the current consumed by the 5V circuit needs to be known. Here are a few ways to find out how much current the circuit demands. Assemble the circuit and measure the actual current used with a multi-meter. Check the component's current use against a standard table. Assume the current consumed is 100 mA (milliamps) in the following example. 7V must be dropped with the resistor. The resistance value of the resistor becomes 7V / 0.1A = 70(ohm). The consumption of electric power for this resistor becomes
0.1A x 0.1A x 70 ohm = 0.7W.
Generally, it's safe to choose a resistor which has a power rating of about twice the power consumption needed.

2.3.2 Resistance value

As for the standard resistance value, the values used can be divided like a logarithm. For example, in the case of E3, The values [1], [2.2], [4.7] and [10] are used. They divide 10 into three, like a logarithm.
In the case of E6 : [1], [1.5], [2.2], [3.3], [4.7], [6.8], [10].
In the case of E12 : [1], [1.2], [1.5], [1.8], [2.2], [2.7], [3.3], [3.9], [4.7], [5.6], [6.8], [8.2], [10].
It is because of this that the resistance value is seen at a glance to be a discrete value. The resistance value is displayed using the color code(the colored bars/the colored stripes), because the average resistor is too small to have the value printed on it with numbers. You had better learn the color code, because almost all resistors of 1/2W or less use the color code to display the resistance value.

2.3.3 Types of resistors

2.3.3.1 Fixed Resistors

A fixed resistor is one in which the value of its resistance cannot change.

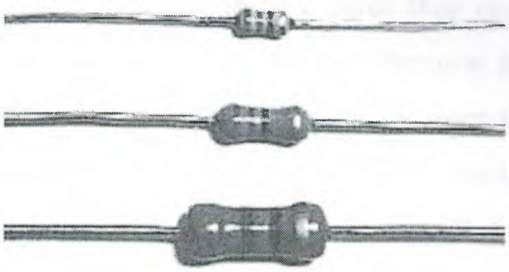
2.3.3.2 Carbon film resistors

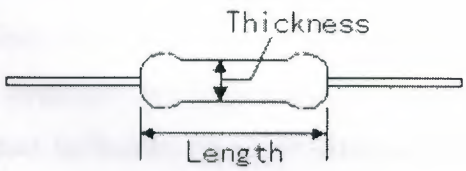
This is the most general purpose, cheap resistor. Usually the tolerance of the resistance value is ±5%. Power ratings of 1/8W, 1/4W and 1/2W are frequently used.

Figure:2.19

Carbon film resistors have a disadvantage; they tend to be electrically noisy. Metal film resistors are recommended for use in analog circuits. However, I have never experienced any problems with this noise.

The physical size of the different resistors are as follows.





From the top of the photograph
1/8W
1/4W
1/2W

Rough size

Rating power (W)	Thickness (mm)	Length (mm)
1/8	2	3
1/4	2	6
1/2	3	9

Figure : 2.20

This resistor is called a Single-In-Line(SIL) resistor network. It is made with many resistors of the same value, all in one package. One side of each resistor is connected with one side of all the other resistors inside. One example of its use would be to control the current in a circuit powering many light emitting diodes (LEDs).

In the photograph on the left, 8 resistors are housed in the package. Each of the leads on the package is one resistor. The ninth lead on the left side is the common lead. The face value of the resistance is printed. (It depends on the supplier.)

Some resistor networks have a "4S" printed on the top of the resistor network. The 4S indicates that the package contains 4 independent resistors that are not wired together inside. The housing has eight leads instead of nine. The internal wiring of these typical resistor networks has been illustrated below. The size (black part) of the resistor network which I have is as follows: For the type with 9 leads, the thickness is 1.8 mm, the height 5mm, and the width 23 mm. For the types with 8 component leads, the thickness is 1.8 mm, the height 5 mm, and the width 20 mm.

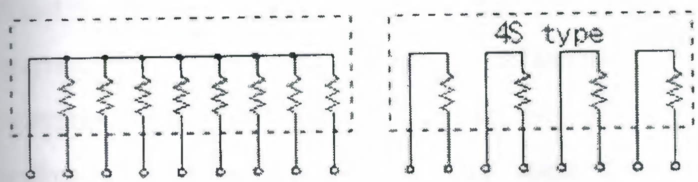
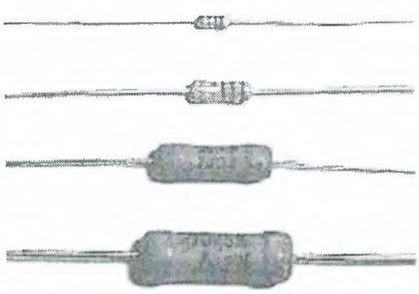
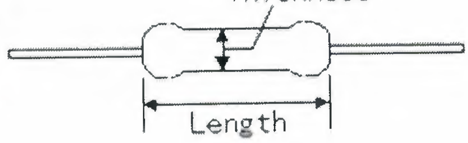


Figure : 2.21

2.3.3.3 Metal film resistors

Metal film resistors are used when a higher tolerance (more accurate value) is needed. They are much more accurate in value than carbon film resistors. They have about ±0.05% tolerance. They have about ±0.05% tolerance. I don't use any high tolerance resistors in my circuits. Resistors that are about ±1% are more than sufficient. Ni-Cr (Nichrome) seems to be circuits. Resistors that are about ±1% are more than sufficient. Ni-Cr (Nichrome) seems to be used for the material of resistor. The metal film resistor is used for bridge circuits, filter circuits, and low-noise analog signal circuits.





From the top of the photograph
1/8W (tolerance ±1%)
1/4W (tolerance ±1%)
1W (tolerance ±5%)
2W (tolerance ±5%)

Rough size

Rating power (W)	**Thickness (mm)**	**Length (mm)**
1/8	2	3
1/4	2	6
1	3.5	12
2	5	15

Figure:2.22

2.3.3.4 Variable Resistors

There are two general ways in which variable resistors are used. One is the variable resistor which value is easily changed, like the volume adjustment of Radio. The other is semi-fixed resistor that is not meant to be adjusted by anyone but a technician. It is used to adjust the operating condition of the circuit by the technician. Semi-fixed resistors are used to compensate for the inaccuracies of the resistors, and to fine-tune a circuit. The rotation angle of the variable resistor is usually about 300 degrees. Some variable resistors must be turned many times to use the whole range of resistance they offer. This allows for very precise adjustments of their value. These are called "Potentiometers" or "Trimmer Potentiometers."

figure : 2.23

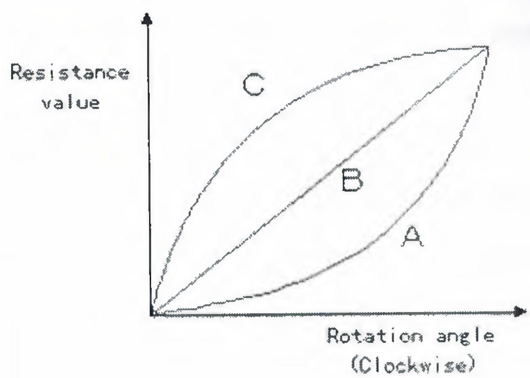


Figure : 2.24

In the photograph to the left, the variable resistor typically used for volume controls can be seen on the far right. Its value is very easy to adjust. The four resistors at the center of the photograph are the semi-fixed type. These ones are mounted on the printed circuit board. The two resistors on the left are the trimmer potentiometers.

This symbol  is used to indicate a variable resistor in a circuit diagram.

There are three ways in which a variable resistor's value can change according to the rotation angle of its axis.
When type "A" rotates clockwise, at first, the resistance value changes slowly and then in the second half of its axis, it changes very quickly.
The "A" type variable resistor is typically used for the volume control of a radio, for example. It is well suited to adjust a low sound subtly. It suits the characteristics of the ear. The ear hears low sound changes well, but isn't as sensitive to small changes in loud sounds. A larger change is needed as the volume is increased. These "A" type variable resistors are sometimes called "audio taper" potentiometers.
As for type "B", the rotation of the axis and the change of the resistance value are directly related. The rate of change is the same, or linear, throughout the sweep of the axis. This type suits a resistance value adjustment in a circuit, a balance circuit and so on.
They are sometimes called "linear taper" potentiometers.
Type "C" changes exactly the opposite way to type "A". In the early stages of the rotation of the axis, the resistance value changes rapidly, and in the second half, the change occurs more slowly. This type isn't too much used. It is a special use.
As for the variable resistor, most are type "A" or type "B".

2.3.3.5 CDS Elements

Some components can change resistance value by changes in the amount of light hitting them. One type is the Cadmium Sulfide Photocell. (Cd) The more light that hits it, the smaller its resistance value becomes.
There are many types of these devices. They vary according to light sensitivity, size, resistance value etc.

Figure : 2.25

Pictured at the left is a typical CDS photocell. Its diameter is 8 mm, 4 mm high, with a cylinder form. When bright light is hitting it, the value is about 200 ohms, and when in the dark, the resistance value is about 2M ohms.
This device is using for the head lamp illumination confirmation device of the car, for example.

2.3.3.6 Other Resistors

There is another type of resistor other than the carbon-film type and the metal film resistors.

It is the wirewound resistor.A wirewound resistor is made of metal resistance wire, and because of this, they can be manufactured to precise values. Also, high-wattage resistors can be made by using a thick wire material. Wirewound resistors cannot be used for high-frequency circuits. Coils are used in high frequency circuits. Since a wirewound resistor is a wire wrapped around an insulator, it is also a coil, in a manner of speaking. Using one could change the behavior of the circuit. Still another type of resistor is the Ceramic resistor. These are wirewound resistors in a ceramic case, strengthened with a special cement. They have very high power ratings, from 1 or 2 watts to dozens of watts. These resistors can become extremely hot when used for high power applications, and this must be taken into account when designing the circuit. These devices can easily get hot enough to burn you if you touch one.

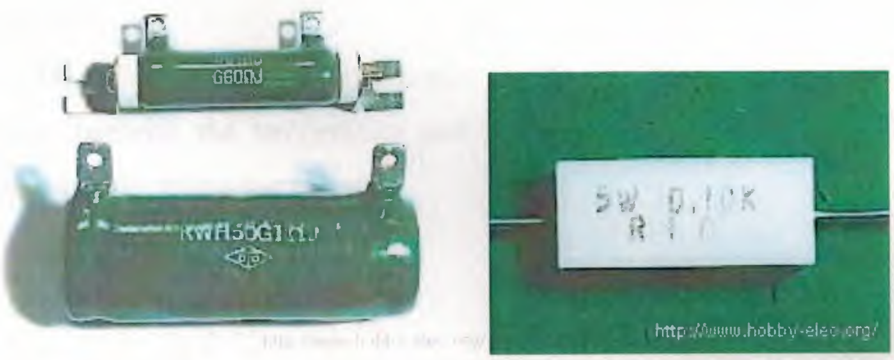


Figure : 2.26

The photograph on the left is of wirewound resistors. The upper one is 10W and is the length of 45 mm, 13 mm thickness. The lower one is 50W and is the length of 75 mm, 29 mm thickness. The upper one is has metal fittings attached. These devices are insulated with a ceramic coating.

Figure : 2.27

The photograph on above is a ceramic (or cement) resistor of 5W and is the height of 9 mm, 9 mm depth, 22 mm width.

Thermistor (Thermally sensitive resistor)

The resistance value of the thermistor changes according to temperature. This part is used as a temperature sensor.There are mainly three types of thermistor.

NTC(Negative Temperature Coefficient Thermistor) :

With this type, the resistance value decreases continuously as the temperature rises.

PTC(Positive Temperature Coefficient Thermistor) :

With this type, the resistance value increases suddenly when the temperature rises above a specific point.

CTR(Critical Temperature Resister Thermistor) :

With this type, the resistance value decreases suddenly when the temperature rises above a specific point.

The NTC type is used for the temperature control.

The relation between the temperature and the resistance value of the NTC type can be calculated using the following formula.

$$R = R_0 \cdot \exp^{B\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

Figure : 2.28

R : The resistance value at the temperature T

T : The temperature [K]

R_0 : The resistance value at the reference temperature T_0

T_0 : The reference temperature [K]

B : The coefficient

Figure : 2.29

As the reference temperature, typically, 25°C is used.

The unit with the temperature is the absolute temperature(Value of which 0 was -273°C) in K(Kelvin).

25°C are the 298 kelvins.

2.3.3.7 Resistor color code

Example 1

(Brown=1),(Black=0),(Orange=3)

10 x 10^3 = 10k ohm

Tolerance(Gold) = ±5%

Example 2

(Yellow=4),(Violet=7),(Black=0),(Red=2)

470 x 10^2 = 47k ohm

Tolerance(Brown) = ±1%

Color	Value	Multiplier	Tolerance (%)
Black	0	0	-
Brown	1	1	±1
Red	2	2	±2
Orange	3	3	±0.05
Yellow	4	4	-
Green	5	5	±0.5
Blue	6	6	±0.25
Violet	7	7	±0.1
Gray	8	8	-
White	9	9	-
Gold	-	-1	±5
Silver	-	-2	±10
None	-	-	±20

Figure : 2.30

2.4 POTENTIOMETERS

A potentiometer is a variable resistor that can be used as a voltage divider.

Originally a potentiometer was an instrument to measure the potential (or voltage) in a circuit by tapping off a fraction of a known voltage from a resistive slide wire and comparing it with the unknown voltage by means of a galvanometer.

The present popular usage of the term potentiometer (or 'pot' for short) describes an electrical device which has a user-adjustable resistance. Usually, this is a three-terminal resistor with a sliding contact in the center (the wiper). If all three terminals are used, it can act as a variable voltage divider. If only two terminals are used (one side and the wiper), it acts as a variable resistor. Its shortcoming is that of corrosion or wearing of the sliding contact, especially if it is kept in one position.

2.4.1 Potentiometer as electronic component

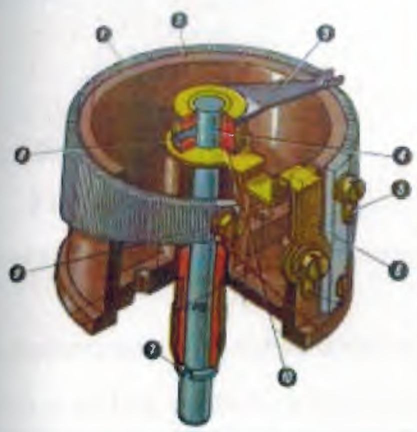


Figure : 2.31

Construction of a wire-wound circular potentiometer. The resistive element (1) of the shown device is trapezoidal, giving a non-linear relationship between resistance and turn angle. The wiper (3) rotates with the axis (4), providing the changeable resistance between the wiper contact (6) and the fixed contacts (5) and (9). The vertical position of the axis is fixed in the body (2) with the ring (7) (below) and the bolt (8) (above).

In modern usage, a potentiometer is a potential divider, a three terminal resistor where the position of the sliding connection is user adjustable via a knob or slider. Potentiometers are sometimes provided with one or more switches mounted on the same shaft. For instance, when attached to a volume control, the knob can also function as an on/off switch at the lowest volume.

Ordinary potentiometers are rarely used to control anything of significant power (even lighting) directly due to resistive losses, but they are frequently used to adjust the level of analog signals (e.g. volume controls on audio equipment) and as control inputs for electronic circuits (e.g. a typical domestic light dimmer uses a potentiometer to set the point in the cycle at which the triac turns on). Potentiometers used to control high power are normally called rheostats.

2.4.2 Types of potentiometers

2.4.2.1 Low-power types

Figure : 2.32

A typical single turn potentiometer

A potentiometer is constructed using a flat graphite annulus (ring) as the resistive element, with a sliding contact (wiper) sliding around this annulus. The wiper is connected to an axle and, via another rotating contact, is brought out as the third terminal. On panel pots, the wiper is usually the centre terminal. For single turn pots, this wiper typically travels just under one revolution around the contact. 'Multiturn' potentiometers also exist, where the resistor element may be helical and the wiper may move 10, 20, or more complete revolutions. In addition to graphite, other materials may be used for the resistive element. These may be resistance wire or carbon particles in plastic or a ceramic/metal mixture. One popular form of rotary potentiometer is called a string pot. It is a multi-turn potentiometer with an attached reel of wire turning against a spring. It's very convenient for measuring movement and therefore acts as a position transducer. In a linear slider pot, a sliding control is provided instead of a dial control. The word linear also describes the geometry of the resistive element which is a rectangular strip, (not an annulus as in a rotary potentiometer). Because of their construction, this type of pot has a greater potential for getting contaminated. Potentiometers can be obtained with either linear or logarithmic laws (or "tapers").

Figure : 2.33

PCB mount trimmer potentiometers, or "trimpots", intended for infrequent adjustment.

2.4.2.2 Linear potentiometers

A linear pot has a resistive element of constant cross-section, resulting in a device where the resistance between the contact (wiper) and one end terminal is proportional to the distance between them. Linear describes the electrical 'law' of the device, not the geometry of the resistive element.

2.4.2.3 Logarithmic potentiometers

A log pot has a resistive element that either 'tapers' in from one end to the other, or is made from a material whose resistivity varies from one end to the other. This results in a device where output voltage is a logarithmic (or inverse logarithmic depending on type) function of the mechanical angle of the pot.

Most (cheaper) "log" pots are actually not logarithmic, but use two regions of different, but constant, resistivity to approximate a logarithmic law. A log pot can also be simulated with a linear pot and an external resistor. True log pots are significantly more expensive.

2.4.2.4 High-power types

Figure : 2.34

A high power toroidal wirewound rheostat.

A rheostat is essentially a potentiometer, but is usually much larger, designed to handle much higher voltage and current. Typically these are constructed as a resistive wire wrapped to form a toroid coil (or most of one) with the wiper moving over the upper surface of the toroid, sliding from one turn of the wire to the next. Sometimes a rheostat is made from resistance wire wound on a heat resisting cylinder with the slider made from a number of metal fingers that grip lightly onto a small portion of the turns of resistance wire. The 'fingers' can be moved along the coil of resistance wire by a sliding knob thus changing the 'tapping' point. They are usually used as variable resistors rather than variable potential dividers.

2.4.2.5 Digital control

Digitally Controlled Potentiometers (DCPs) can be used in analogue signal processing circuits to replace potentiometers. They allow small adjustments to be made to the circuit by software, instead of a mechanical adjustment. Because this type of control is updated only infrequently, it often has a slow serial interface, like I^2C. Some types have non-volatile memory to enable them to remember their last settings when the power is switched off.

The same idea can be used to create Digital Volume Controls, attenuators, or other controls under digital control. Usually such devices feature quite a high degree of accuracy, and find applications in instrumention, mixing desks and other precision systems.

The DCP should not be confused with the digital to analogue converter (DAC) which actually creates an analogue signal from a digital one. A DCP only controls an existing analogue signal digitally. However, some DACs using resistive R-2R architecture have been functionally used as DCPs where the (varying) analogue signal is input to the reference voltage pin of the DAC and the digitally-controlled attenuated output is taken from the output of the DAC.

2.4.3 Applications of potentiometers

2.4.3.1 Transducers

Potentiometers are also very widely used as a part of displacement transducers because of the simplicity of construction and because they can give a large output signal.

2.4.3.2 Audio control

Figure : 2.35

Sliding potentiometers ("faders")

One of the most common uses for modern low-power potentiometers is as audio control devices. Both sliding pots (also known as faders) and rotary potentiometers (commonly called knobs) are regularly used to adjust loudness, frequency attenuation and other characteristics of audio signals.

The 'log pot' is used as the volume control in audio amplifiers, where it is also called an "audio taper pot", because the amplitude response of the human ear is also logarithmic. It ensures that, on a volume control marked 0 to 10, for example, a setting of 5 sounds half as loud as a setting of 10. There is also an anti-log pot or reverse audio taper which is simply the reverse of a log pot. It is almost always used in a ganged configuration with a log pot, for instance, in an audio balance control.

A potentiometer used in combination with an inductor or capacitor acts as a "tone" control.

2.4.4 Theory of operation

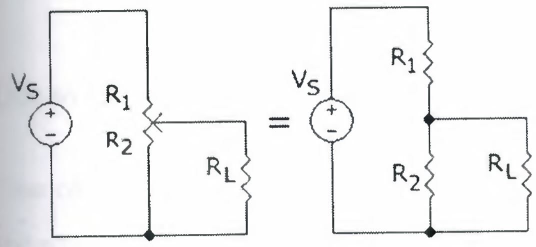


Figure : 2.36

A potentiometer with a resistive load, showing equivalent fixed resistors for clarity.

The 'modern' potentiometer can be used as a potential divider (or voltage divider) to obtain a manually adjustable output voltage at the slider (wiper) from a fixed input voltage applied across the two ends of the pot. This is the most common use of pots.

The voltage across R_L is determined by the formula:

$$V_L = \frac{R_2 \| R_L}{R_1 + R_2 \| R_L} \cdot V_s$$

The parallel lines indicate components in parallel. Expanded fully, the equation becomes:

$$V_L = \frac{R_2 R_L}{R_1 R_L + R_2 R_L + R_1 R_2} \cdot V_s$$

Although it is not always the case, if R_L is large compared to the other resistances (like the input to an operational amplifier), the output voltage can be approximated by the simpler equation:

$$V_L = \frac{R_2}{R_1 + R_2} \cdot V_s$$

As an example, assume

$V_S = 10\ \mathrm{V}$, $R_1 = 1\ \mathrm{k\Omega}$, $R_2 = 2\ \mathrm{k\Omega}$, and $R_L = 100\ \mathrm{k\Omega}$.

Since the load resistance is large compared to the other resistances, the output voltage V_L will be approximately:

$$\frac{2\ \mathrm{k}\Omega}{1\ \mathrm{k}\Omega + 2\ \mathrm{k}\Omega} \cdot 10\ \mathrm{V} = \frac{2}{3} \cdot 10\ \mathrm{V} \approx 6.667\ \mathrm{V}$$

Due to the load resistance, however, it will actually be slightly lower: ≈ 6.623 V.

One of the advantages of the potential divider compared to a variable resistor in series with the source is that, while variable resistors have a maximum resistance where some current will always flow, dividers are able to vary the output voltage from maximum (V_S) to ground (zero volts) as the wiper moves from one end of the pot to the other. There is, however, always a small amount of contact resistance.

In addition, the load resistance is often not known and therefore simply placing a variable resistor in series with the load could have a negligible effect or an excessive effect, depending on the load.

2.5 DIODES

A diode is a semiconductor device which allows current to flow through it in only one direction. Although a transistor is also a semiconductor device, it does not operate the way a diode does. A diode is specifically made to allow current to flow through it in only one direction.

Some ways in which the diode can be used are listed here.
A diode can be used as a rectifier that converts AC (Alternating Current) to DC (Direct Current) for a power supply device.
Diodes can be used to separate the signal from radio frequencies.
Diodes can be used as an on/off switch that controls current.
This symbol —▶|— is used to indicate a diode in a circuit diagram.

The meaning of the symbol is (Anode)—▶|—(Cathode).
Current flows from the anode side to the cathode side.

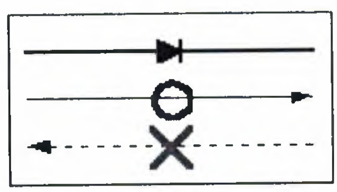


Figure : 2.37

Although all diodes operate with the same general principle, there are different types suited to different applications. For example, the following devices are best used for the applications noted.

2.5.1 Types Of Diodes

2.5.1.1 Voltage regulation diode (Zener Diode)

The circuit symbol is .

It is used to regulate voltage, by taking advantage of the fact that Zener diodes tend to stabilize at a certain voltage when that voltage is applied in the opposite direction.

2.5.1.2 Light emitting diode

The circuit symbol is .

This type of diode emits light when current flows through it in the forward direction. (Forward biased.)

2.5.1.3 Variable capacitance diode

The circuit symbol is .

The current does not flow when applying the voltage of the opposite direction to the diode. In this condition, the diode has a capacitance like the capacitor. It is a very small capacitance. The capacitance of the diode changes when changing voltage. With the change of this capacitance, the frequency of the oscillator can be changed.The graph on the right shows the electrical characteristics of a typical diode.

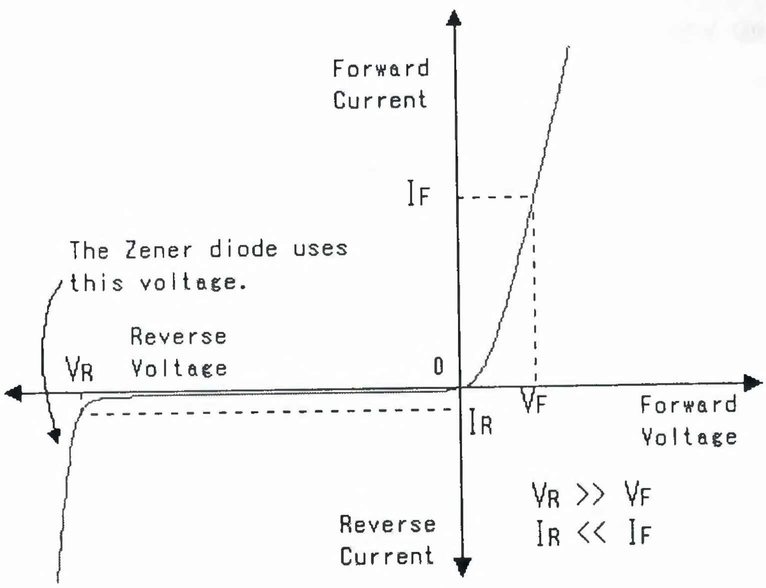


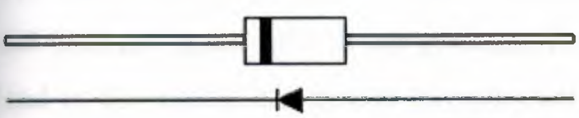
Figure : 2.38

When a small voltage is applied to the diode in the forward direction, current flows easily. Because the diode has a certain amount of resistance, the voltage will drop slightly as current flows through the diode. A typical diode causes a voltage drop of about 0.6 - 1V (V_F) (In the case of silicon diode, almost 0.6V)
This voltage drop needs to be taken into consideration in a circuit which uses many diodes in series. Also, the amount of current passing through the diodes must be considered.

When voltage is applied in the reverse direction through a diode, the diode will have a great resistance to current flow.
Different diodes have different characteristics when reverse-biased. A given diode should be selected depending on how it will be used in the circuit.
The current that will flow through a diode biased in the reverse direction will vary from several mA to just µA, which is very small.

The limiting voltages and currents permissible must be considered on a case by case basis. For example, when using diodes for rectification, part of the time they will be required to withstand a reverse voltage. If the diodes are not chosen carefully, they will break down.

2.5.1.4 Rectification / Switching / Regulation diode



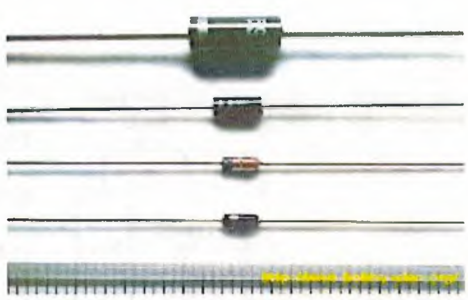


Figure : 2.39

The stripe stamped on one end of the diode shows indicates the polarity of the diode.
The stripe shows the cathode side.
The top two devices shown in the picture are diodes used for rectification. They are made to handle relatively high currents. The device on top can handle as high as 6A, and the one below it can safely handle up to 1A.

However, it is best used at about 70% of its rating because this current value is a maximum rating.

The third device from the top (red color) has a part number of 1S1588. This diode is used for switching, because it can switch on and off at very high speed. However, the maximum current it can handle is 120 mA. This makes it well suited to use within digital circuits. The maximum reverse voltage (reverse bias) this diode can handle is 30V.
The device at the bottom of the picture is a voltage regulation diode with a rating of 6V. When this type of diode is reverse biased, it will resist changes in voltage. If the input voltage is increased, the output voltage will not change. (Or any change will be an insignificant amount.) While the output voltage does not increase with an increase in input voltage, the output current will.
This requires some thought for a protection circuit so that too much current does not flow. The rated current limit for the device is 30 mA.
Generally, a 3-terminal voltage regulator is used for the stabilization of a power supply. Therefore, this diode is typically used to protect the circuit from momentary voltage spikes. 3 terminal regulators use voltage regulation diodes inside.

2.5.1.5 Light Emitting Diode (LED)

Light emitting diodes must be choosen according to how they will be used, because there are various kinds.
The diodes are available in several colors. The most common colors are red and green, but there are even blue ones.

The device on the far right in the photograph combines a red LED and green LED in one package. The component lead in the middle is common to both LEDs. As for the remaing two leads, one side is for the green, the other for the red LED. When both are turned on simultaneously, it becomes orange.

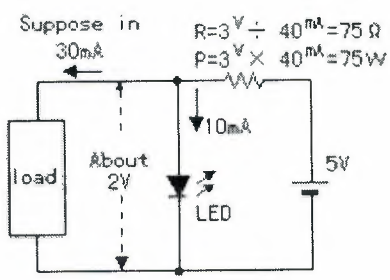


Figure : 2.40

When an LED is new out of the package, the polarity of the device can be determined by looking at the leads. The longer lead is the Anode side, and the short one is the Cathode side.

The polarity of an LED can also be determined using a resistance meter, or even a 1.5 V battery.

When using a test meter to determine polarity, set the meter to a low resistance measurement range. Connect the probes of the meter to the LED. If the polarity is correct, the LED will glow. If the LED does not glow, switch the meter probes to the opposite leads on the LED. In either case, the side of the diode which is connected to the black meter probe when the LED glows, is the Anode side. Positive voltage flows out of the black probe when the meter is set to measure resistance.

It is possible to use an LED to obtain a fixed voltage. The voltage drop (forward voltage, or V_F) of an LED is comparatively stable at just about 2V.

Figure : 2.41

2.5.1.6 Shottky barrier diyote

Diodes are used to rectify alternating current into direct current. However, rectification will not occur when the frequency of the alternating current is too high. This is due to what is known as the "reverse recovery characteristic."

The reverse recovery characteristic can be explained as follows:

IF the opposite voltage is suddenly applied to a forward-biased diode, current will continue to flow in the forward direction for a brief moment. This time until the current stops flowing is called the Reverse Recovery Time. The current is considered to be stopped when it falls to about 10% of the value of the peak reverse current.

The Shottky barrier diode has a short reverse recovery time, which makes it ideally suited to use in high frequency rectification.

The shottky barrier diode has the following characteristics.The voltage drop in the forward direction is low.The reverse recovery time is short. However, it has the following disadvantages.The diode can have relatively high leakage current.The surge resistance is low.

Because the reverse recovery time is short, this diode is often used for the switching regulator in a high frequency circuit.

2.5.2 Semiconductor diodes

Figure : 2.42

Diode schematic symbol. Conventional current can flow from the anode to the cathode, but not the other way around.

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 cannot flow 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.

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 (see also signal processing).

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.

2.5.2.1 Types of semiconductor diode

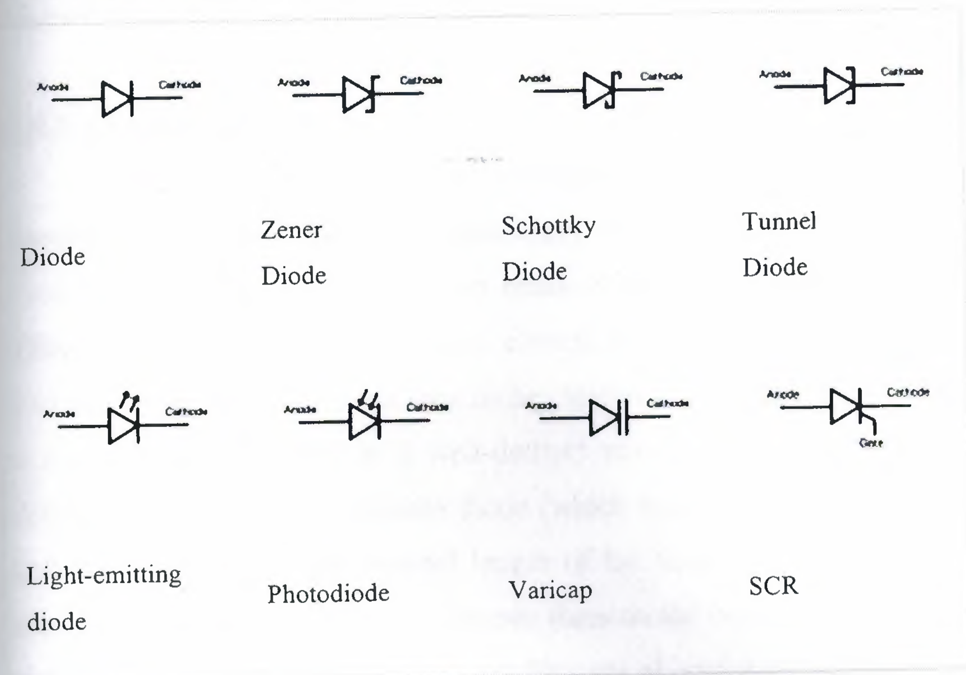


Figure : 2.43 Some diode symbols

There are several types of semiconductor junction diodes:

2.5.2.2 Normal (p-n) diodes

which operate as described above. 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.

2.5.2.3 Zener diodes

Zener 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.

2.5.2.4 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.

2.5.2.5 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.

2.6 Diode Bridge

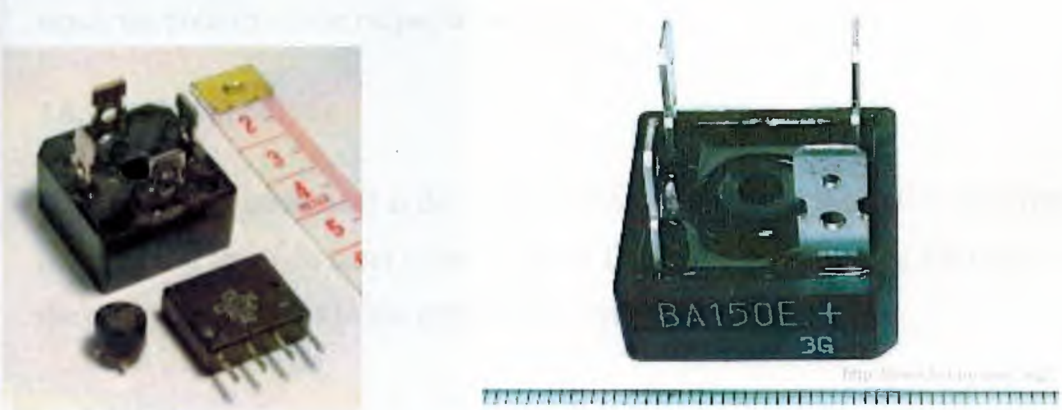


Figure : 2.44

Three bridge rectifiers. The size is generally related to the current handling capability.

A diode bridge or bridge rectifier 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.

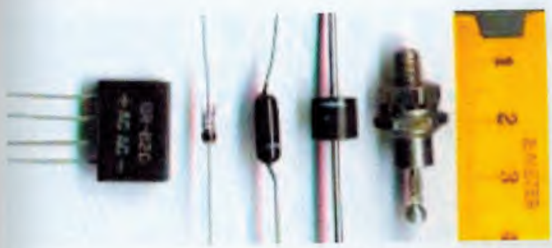


Figure : 2.45

Diodes; the one on the left is a diode bridge

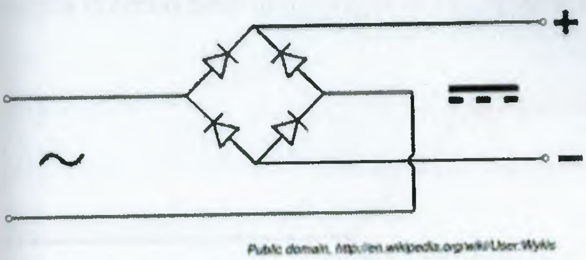


Figure : 2.46

Schematic of a diode bridge

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.

2.6.1 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.

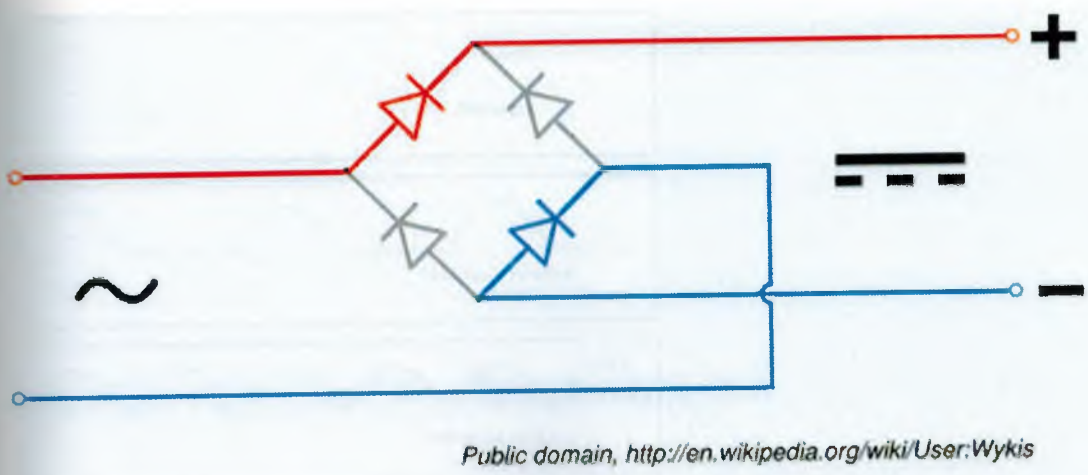


Figure : 2.47

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.

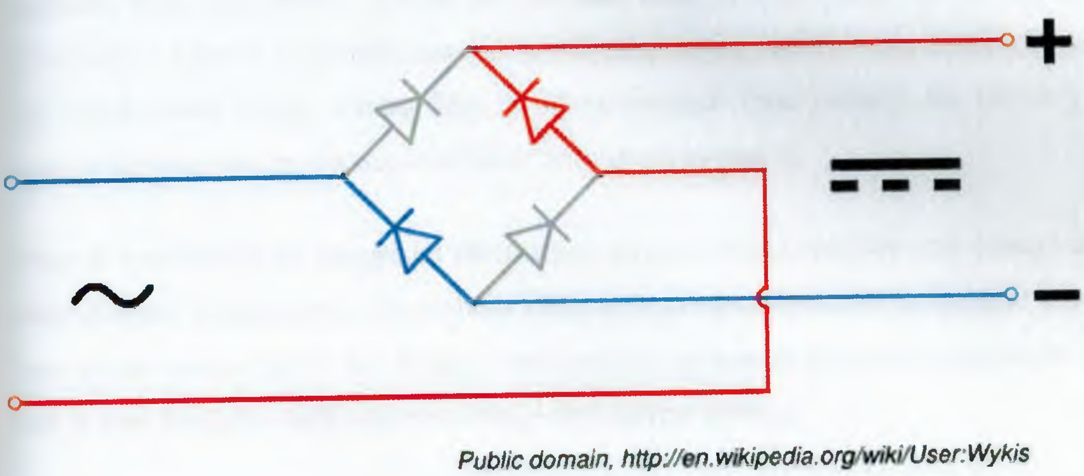


Figure : 2.48

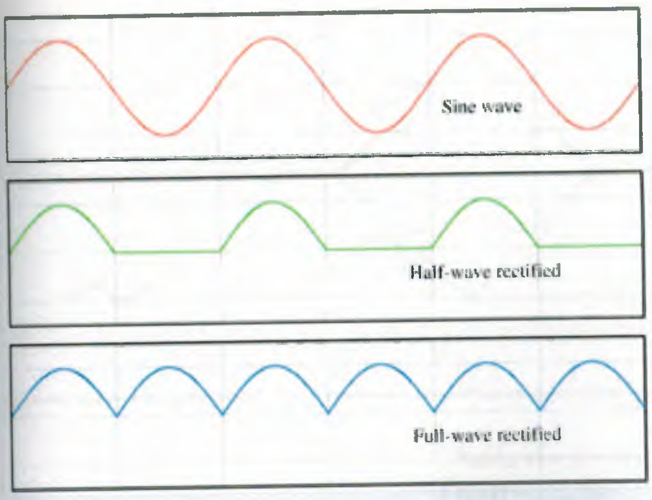


Figure : 2.49

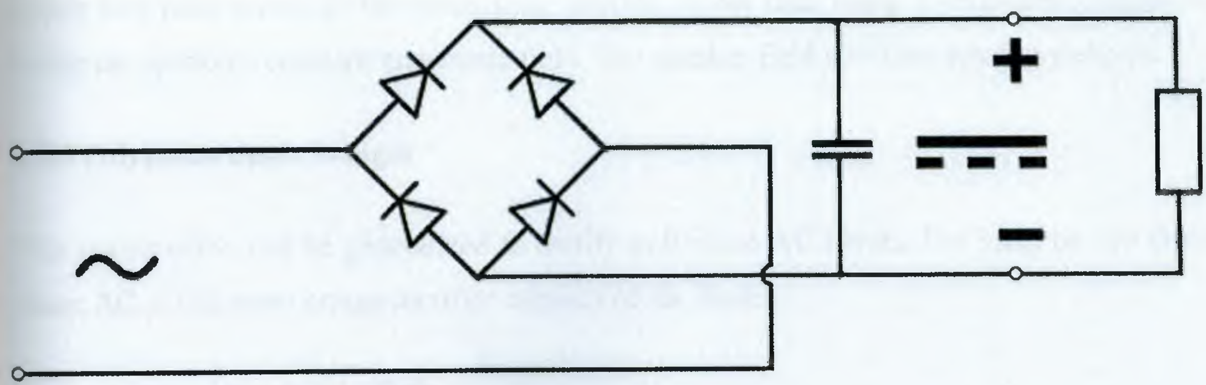
AC, half-wave and full wave rectified signals

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.

2.6.2 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).



Public domain, http://en.wikipedia.org/wiki/User:Wykis

Figure : 2.50

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. In some designs, a series resistor at the load side of the capacitor is added. The smoothing can then be improved by adding additional stages of capacitor–resistor pairs, often done only for sub-supplies to critical high-gain circuits that tend to be sensitive to supply voltage noise.

Output can also be smoothed using a choke, a coil of conductor enclosed by an iron frame (similar to a transformer in construction). This tends to keep the current (rather than the voltage) constant. Due to the relatively high cost of an effective choke compared to a resistor and capacitor this is not employed in modern equipment. Some early console radios created the speaker's constant field with the current from the high voltage ("B +") power supply, which was then routed to the consuming circuits, rather than using a permanent magnet to create the speaker's constant magenetic field. The speaker field coil thus acted as a choke.

2.6.3 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.

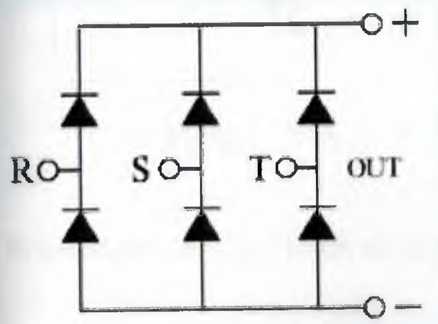


Figure : 2.51

Three Phase Bridge Rectifier for a wind turbine.

Figure : 2.52

Three Phase Bridge Rectifier for wind turbine.

Retrieved from "http://en.wikipedia.org/wiki/Diode_bridge"

2.6.4 Wheatstone bridge

A Wheatstone bridge is a measuring instrument invented by Samuel Hunter Christie in 1833 and improved and popularized by Sir Charles Wheatstone in 1843. It is used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component. Its operation is similar to the original potentiometer except that in potentiometer circuits the meter used is a sensitive galvanometer.

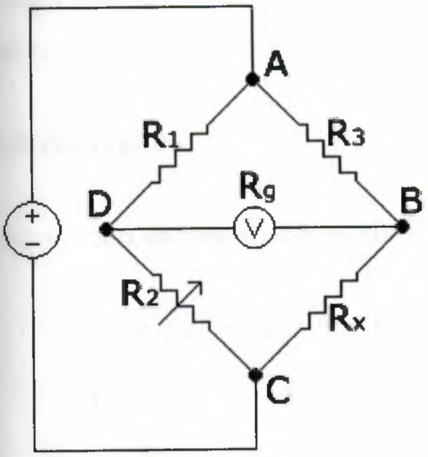


Figure : 2.53

Wheatstone's bridge circuit diagram.

In the circuit at right, R_x is the unknown resistance to be measured; R_1, R_2 and R_3 are resistors of known resistance and the resistance of R_2 is adjustable. If the ratio of the two resistances in the known leg (R_2 / R_1) is equal to the ratio of the two in the unknown leg (R_x / R_3), then the voltage between the two midpoints will be zero and no current will flow between the midpoints. R_2 is varied until this condition is reached. The current direction indicates if R_2 is too high or too low.

Detecting zero current can be done to extremely high accuracy (see Galvanometer). Therefore, if R_1, R_2 and R_3 are known to high precision, then R_x can be measured to high precision. Very small changes in R_x disrupt the balance and are readily detected.

If the bridge is balanced, which means that the current through the galvanometer R_g is equal to zero, the equivalent resistance of the circuit between the source voltage terminals is:

$R_1 + R_2$ in parallel with $R_3 + R_x$

$$R_E = \frac{(R_1 + R_2) \cdot (R_3 + R_x)}{R_1 + R_2 + R_3 + R_x}$$

Alternatively, if R_1, R_2, and R_3 are known, but R_2 is not adjustable, the voltage or current flow through the meter can be used to calculate the value of R_x, using Kirchhoff's circuit laws (also known as Kirchhoff's rules). This setup is frequently used in strain gauge and Resistance

Temperature Detector measurements, as it is usually faster to read a voltage level off a meter than to adjust a resistance to zero the voltage.

2.6.5 Derivation

First, we can use the first Kirchhoff rule to find the currents in junctions **B** and **D**:

$$\begin{aligned} I_3 - I_x - I_g &= 0 \\ I_1 + I_g - I_2 &= 0 \end{aligned}$$

Then, we use Kirchhoff's second rule for finding the voltage in the loops **ABD** and **BCD**:

$$\begin{aligned} I_3 \cdot R_3 + I_g \cdot R_g - I_1 \cdot R_1 = 0 \\ I_x \cdot R_x - I_2 \cdot R_2 - I_g \cdot R_g = 0 \end{aligned}$$

The bridge is balanced and $I_g = 0$, so we can rewrite the second set of equations:

$$\begin{aligned} I_3 \cdot R_3 = I_1 \cdot R_1 \\ I_x \cdot R_x = I_2 \cdot R_2 \end{aligned}$$

Then, we divide the equations and rearrange them, giving:

$$R_x = \frac{R_2 \cdot I_2 \cdot I_3 \cdot R_3}{R_1 \cdot I_1 \cdot I_x}$$

From the first rule, we know that $I_3 = I_x$ and $I_1 = I_2$. The desired value of R_x is now known to be given as:

$$R_x = \frac{R_3 \cdot R_2}{R_1}$$

If all four resistor values and the supply voltage (V_s) are known, the voltage across the bridge (V) can be found by working out the voltage from each potential divider and subtracting one from the other. The equation for this is:

$$V = \frac{R_x}{R_3 + R_x} V_s - \frac{R_2}{R_1 + R_2} V_s$$

This can be simplified to:

$$V = \left(\frac{R_x}{R_3 + R_x} - \frac{R_2}{R_1 + R_2}\right) V_s$$

The Wheatstone bridge illustrates the concept of a difference measurement, which can be extremely accurate. Variations on the Wheatstone bridge can be used to measure capacitance, inductance, impedance and other quantities, such as the amount of combustible gases in a sample, with an explosimeter. The **Kelvin Double bridge** was one specially adapted for measuring very low resistances. This was invented in 1861 by William Thomson, Lord Kelvin.

The concept was extended to alternating current measurements by James Clerk Maxwell in 1865 and further improved by Alan Blumlein in about 1926.

2.7 TRIAC

A TRIAC, or TRIode for Alternating Current is an electronic component approximately equivalent to two silicon-controlled rectifiers (SCRs/thyristors) joined in inverse parallel (paralleled but with the polarity reversed) and with their gates connected together. This results in a bidirectional electronic switch which can conduct current in either direction when it is triggered (turned on). It can be triggered by either a positive or a negative voltage being applied to its gate electrode. Once triggered, the device continues to conduct until the current through it drops below a certain threshold value, such as at the end of a half-cycle of alternating current (AC) mains power. This makes the TRIAC a very convenient switch for AC circuits, allowing the control of very large power flows with milliampere-scale control currents. In addition, applying a trigger pulse at a controllable point in an AC cycle allows one to control the percentage of current that flows through the TRIAC to the load (so-called phase control).

Low power TRIACs are used in many applications such as light dimmers, speed controls for electric fans and other electric motors, and in the modern computerized control circuits of many household small and major appliances. However, when used with inductive loads such as electric fans, care must be taken to assure that the TRIAC will turn off correctly at the end of each half-cycle of the ac power.

2.8 DIMMER

Analog Circuit Design, Art, Science, and Personalities", edited by Jim Williams, 1991, Butterword HeinemannDimmer

Figure : 2.54

Another dimmer by Colortran

Dimmers are devices used to vary the brightness of a light. By decreasing or increasing the RMS voltage and hence the mean power to the lamp it is possible to vary the intensity of the light output. Although variable-voltage devices are used for various purposes, the term dimmer is generally reserved for those intended to control lighting.

Dimmers range in size from small units the size of a normal lightswitch used for domestic lighting to high power units used in large theatre or architectural lighting installations. Small domestic dimmers are generally directly controlled, although remote control systems (such as X10) are available. Modern professional dimmers are generally controlled by a digital control system like DMX.

In the professional lighting industry changes in intensity are called "fades" and can be "fades up" or "fades down". Dimmers with direct manual control had a limit on the speed they could be varied at but this issue is pretty much gone with modern digital units (although very fast changes in brightness may still be avoided for other reasons like bulb life).

They are used instead of variable resistors because they have higher efficiency. A variable resistor would dissipate power by heat (efficiency as low as 0.5). By switching on and off, theoretically a dimmer does not heat up (efficiency close to 1.0).

2.8.1 History

Some of the earliest records of dimmers were of Granville Woods "Safety Dimmer" in 1890; dimmers before that were liable to cause fires.

Early dimmers were directly controlled through the manual manipulation of large dimmer panels, but this meant that all power had to come through the lighting control location, which could be inconvenient and potentially dangerous, especially with systems that had a large number of channels, high power lights or both (such as a stage disco or other similar venues).

When thyristor dimmers came into use, analog remote control systems (often 0-10V lighting control systems) became feasible. The wire for the control systems was much smaller (with low current and lower danger) than the heavy power cables of previous lighting systems. Each dimmer had its own control wires which meant a huge number of wires leaving the lighting control location and running to each individual dimmer. Modern systems use a digital control protocol such as DMX to control a large number of dimmers (and other stage equipment) through a single cable.

In 1961 Joel Spira, founder of Lutron Electronics, invented the first solid state dimmer, which switches the current on and off 120 times per second, saving energy and allowing the dimmer to be installed in a standard electrical wallbox.

2.8.2 Types of dimmer

Early examples of a dimmer include a salt water dimmer. In a salt water dimmer, there were two metal contacts in a glass beaker. One contact was on the bottom, while the other was able to move up and down. The closer the contacts to each other, the higher the level of the light. Using salt water dimmers was a tedious and precarious task that included filling the beakers with water, checking the concentration of the salt, and raising or lowering the top contact. Salt water dimmers were not efficient due to the evaporation of water and the corrosion of the many metal pieces. These dimmers were colloquially known as "piss pots", for obvious reasons. Many old theatre electricians still recount stories of how they were initiated into the art by being requested to "top up a pot" and receiving a shock, as unbeknownst to them the pot was live...

Figure : 2.55

Two 6000 watt motor driven autotransformer dimmers, used for house lighting

Dimmers were also often based on rheostats. These were inefficient; when set to the middle brightness levels, they could dissipate as heat a significant portion of the power rating of the load (up to 25% for resistive loads, more for temperature dependent loads like lamps) so they were physically large and required plenty of cooling air. Also, because their dimming effect depended a great deal on the total load applied to each rheostat, the load needed to be matched fairly carefully to the power rating of the rheostat. Finally, as they relied on mechanical control they were slow and it was difficult to change many channels at a time.

Variable autotransformers (often referred to as variacs) were then introduced. While they were still nearly as large as rheostat dimmers, they were highly efficient devices and their dimming effect was independent of the load applied so it was far easier to design the lighting that would be attached to each autotransformer channel. Remote control of the dimmers was still impractical, although some dimmers (typically, for "house light" use) were equipped with motor drives that could slowly and steadily reduce or increase the brightness of the attached lamps. Whilst variacs have fallen out of use for lighting they are still used in other applications such as under/overvoltage testing of equipment due to the fact they deliver a reasonably pure sine wave output and produce no radio frequency noise.

Figure : 2.56

A Strand CD80 thyristor dimmer rack

Thyristor (and briefly, thyratron) dimmers were introduced to solve some of these problems. Because they use switching techniques instead of potential division there is almost no wasted power, dimming can be almost instantanious and is easily controlled by remote electronics. Triacs are used instead of SCR thyristors in lower cost designs, but do not have the surge handling capacity of back-to-back SCR's, and are only suitable for loads less than about 20 Amps. The switches generate some heat during switching, and can cause interference. Large inductors are used as part of the circuitry to suppress this interference. When the dimmer is at 50% power the switches are switching their highest voltage (>300 V in Europe) and the sudden surge of power causes the coils on the inductor to move, creating buzzing sound associated with some types of dimmer; this same effect can be heard in the filaments of the incandescent lamps as "singing". The suppression circuitry adds a lot of weight to the dimmer, and is often insufficient to prevent buzzing to be heard on audio systems that share the mains supply with the lighting loads. This development also made it possible to make dimmers small enough to be used in place of normal domestic light switches. European dimmers must comply with relevant EMC legislation requirements; this involves suppressing the emissions described above to limits described in EN55104.

An alternative to the leading-edge dimming that is typically used with SCRs is trailing edge dimming, where the falling part of the waveform is cut rather than the rising part. This is most often used in devices that use a switched-mode power supplies that need the front of the waveform complete so that it may cut itself.

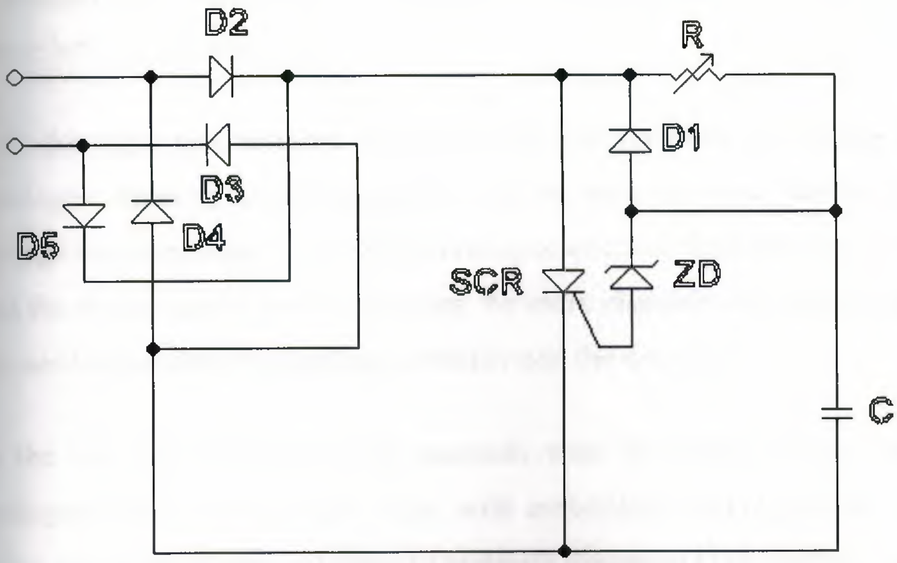


Figure : 2.57

A typical SCR based light dimmer which dims the light through phase angle control. This unit is wired in series with the load. Diodes (D_2, D_3, D_4 and D_5) form a bridge which generates DC with lots of ripple. R and C form a circuit with a time constant, as the voltage increases from zero (at the start of every halfwave) C will charge up, when C is able to make ZD conduct and inject current into the SCR the SCR will fire. When the SCR conducts then D_1 will discharge C via the SCR. The SCR will shut off when the current falls to zero when the supply voltage drops at the end of the half cycle, ready for the circuit to start work on the next half cycle.

Sine-wave dimming promises to solve the weight and interference issues that afflict thyristor dimmers. These are effectively high power switched-mode power supplies. They rely on a new generation of insulated gate bipolar transistors (IGBTs) which are still relatively expensive.

2.8.3 Control

Figure : 2.58

A dimmer rack containing 192 dimmers, with one dimmer per circuit. The black box at the upper left is a demultiplexer.

Non domestic dimmers are usually controlled remotely by means of various protocols. Analogue dimmers usually require a separate wire for each channel of dimming carrying a voltage between 0 and 10 V. Some analogue circuitry then derives a control signal from this and the mains supply for the switches. As more channels are added to the system more wires are needed between the lighting controller and the dimmers.

In the late 70s serial analogue protocols were developed. These multiplexed a series of analogue levels onto a single wire, with embedded clocking signal similar to a composite video signal (in the case of Strand Lighting's European D54 standard, handling 384 dimmers) or separate clocking signal (in the case of the US standard AMX192).

Digital protocols, such as DMX512 have proved to be the answer since the late 80s. In early implementations a digital signal was sent from the controller to a demultiplexer, which sat next to the dimmers. This converted the digital signal into a collection of 0 to +10 V or 0 to -10 V signals which could be connected to the individual analogue control circuits.

Modern dimmer designs use microprocessors to convert the digital signal directly into a control signal for the switches. This has many advantages, giving closer control over the dimming, and giving the opportunity for diagnostic feedback to be sent digitally back to the lighting controller.

2.8.4 Dimming curves

The design of most analogue dimmers meant that the output of the dimmer was not directly proportional to the input. Instead, as the operator brought up a fader the dimmer would dim slowly at first, then quickly in the middle, then quickly at the top. The shape of the curve resembled that of the third quarter of a sine wave. Different dimmers produced different dimmer curves, and different applications typically demanded different responses.

Television often uses a "Square" law, providing finer control in top part of the curve, essential to allow accurate trimming of the colour temperature of TV lighting. Theatrical dimmers tend to use a softer "S curve" or linear curve. Digital dimmers can be made to have whatever curve the manufacturer desires and may have a choice between a linear relationship and selection of different curves, so that they can be matched with older analogue dimmers. Sophisticated systems provide user-programmable or non-standard curves, and a common use of a non-standard curve it to turn a dimmer into a "non-dim", switching on at a user defined control level.

Example dimmer curves

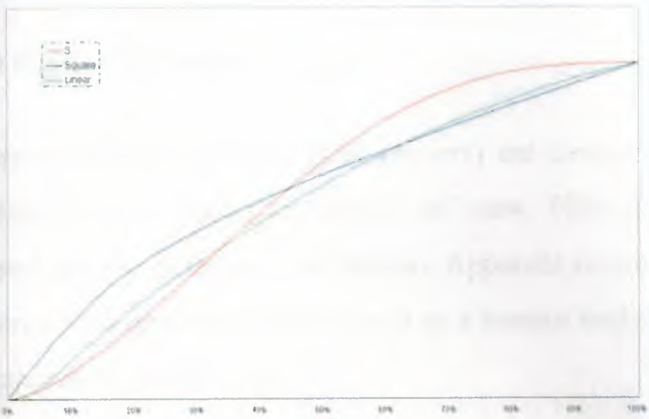


Figure : 2.59

2.8.5 Rise time

One measure of the quality of the dimmer is the "rise time". The rise time in this context is the amount of time it takes within the cut part of the waveform to get from the zero-point crossover to the start of the uncut part of the waveform. A longer rise time reduces the noise of the dimmer and the lamp as well as extending the life of the map. Unsurprisingly, a longer rise time is more expensive to implement than a short one, this is because the size of choke has to be increased.

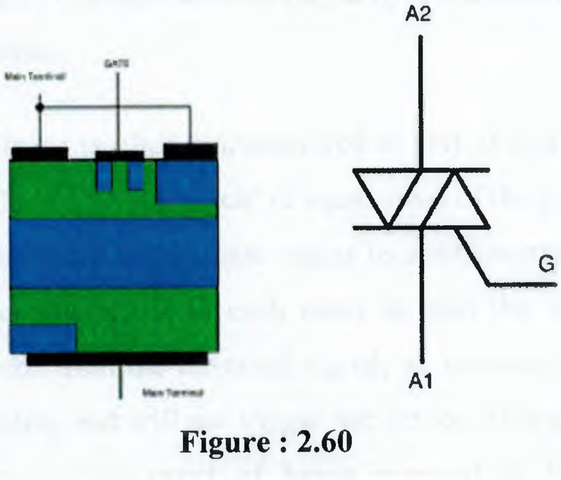


Figure : 2.60

NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

SENSOR CONTROLLED CONVEYOR BAND SYSTEM

Graduation Project
EE-400

Student: UĞUR HASDAĞLI (20010529)

Supervisor: Asist. Prof. Dr.
ÖZGÜR C. ÖZERDEM

Lefkoşa - 2007

ACKNOWLEDGEMENT

Firstly I want to thank my father Electrical Engineer YALÇIN HASDAĞLI. With his guidance I learned lots of systems, equipments and their applications in theorically and specially practically from 7 to my age. Also he answered all my questions in my project and every time patiently. His 37 years engineering life, experiences, working and problem solving style lighted my way to engineering gate.

Special thanks to electricians Erhan, Süreyya for their helps and patience during the progress of electronic circuits. And also thanks to Hasan Süren for my conveyor and motor systems.

Thanks to all my friends for 6 magnificent years especially Volkan KAVAKLIOĞLU. Because of him, I never spent my time alone; he was always with me for everything.

Thanks to all my Instructors in engineering Faculty, with their experiences I had good plans about my engineering future.

Finally, lots of thanks to my family. Their efforts which they did for me are priceless. Because of them now I' am here.

ABSTRACT

In today's world electronic devices filled our lives. Technological developments are making every system old by generating new one for old.

For today nearly every industrial companies are using automatic control systems for manufacturing, packaging and etc. Also this project is made for simulation of a working animal feed production system. This system also can be used for every product which must be in an automatic production system.

In this system, we have 2 conveyor band systems for to carry the product from beginning to end of production process. These two bands have 2 sensors. In industrial systems energy saving is very important because of this, I' am using first band's sensor for starting the second band motor. By this way if the first band is empty, second band will not be working. When the product is passed in front of the first sensor the second band will work. Second sensor is used for counting the produced products.

The general system and first band motor is starting by the worker from different switches and products are carrying one by one. When the first sensor is detected the product second band is starting. So, the product is continuing the way. When the product is detected by the second sensor, electronic relay system is adding 1 to digital display panel.

With this system companies can make their energy saving and counting their products easily.

INTRODUCTION

Automation, robotization or industrial automation or numerical control is the use of control systems such as computers to control industrial machinery and processes, replacing human operators. In the scope of industrialization, it is a step beyond mechanization. Whereas mechanization provided human operators with machinery to assist them with the physical requirements of work, automation greatly reduces the need for human sensory and mental requirements as well.

Automation plays an increasingly important role in the global economy and in daily experience. Engineers strive to combine automated devices with mathematical and organizational tools to create complex systems for a rapidly expanding range of applications and human activities.

In this project, mechanization of industrial control system is considered.

The first chapter represents the definition of control system, some examples about motor using and history of control systems and famous creators of James Clerk Maxwell, Edward John Routh, Adolf Hurwitz.

In chapter 2, basic knowledge about electricity, power in electric circuits, resistors, potentiometers, diodes, bridge diodes , dimmers, passive infrared sensors and transformers as electronic parts which are used in project are considered.

In chapter 3 general knowledge about electric motors and its usable types for this kind of projects

TABLE OF CONTENTS

1. Definition of Control systems

A control system is a device or set of devices to manage, command, direct or regulate the behavior of other devices or systems.

The term "control system" may be applied to the essentially manual controls that allow an operator to, for example, close and open a hydraulic press, band systems, production conveyors where the logic requires that it cannot be moved unless safety guards are in place.

An automatic sequential control system may trigger a series of mechanical actuators in the correct sequence to perform a task. For example various electric and pneumatic transducers may fold and glue a cardboard box, fill it with product and then seal it in an automatic packaging machine.

The electrical motors used commonly in industrial applications are different from each other as structure. The common feature of these motors is converting electrical energy to mechanical energy. Each type of electric motor can not be suitable for position and speed control. So, a motor should be chosen according to controllable magnitude which is preferred. A step motor or servomotor is generally used for necessary applications of position control. Step motors are mostly preferred in the small powered systems and the controls which requires low moment.

Beside of this, the system which has high power, high moment and rapid reaction, servomotors are mostly preferred. However, to make the control of the motor for softly is easy when the motor starting and stopping. Thus, the starting and stopping the motor, load which is connected to the shaft, the damage of the product and the same time the starting current of the motor during starting up are prevented.

Changing the speed of the motor done by adjusting the input voltage of the motor. Mostly semiconductor elements are used to adjust the voltage applied to the motor. These semiconductor elements are controlled by hardware elements such as microprocessor, microcontroller and relevant software. In this study I used a dimmer circuit with high capacity triac to change the input of the transformer. By this way i can control the speed of motors.

1.1 History of Control systems

Although control systems of various types date back to antiquity, a more formal analysis of the field began with a dynamics analysis of the centrifugal governor, conducted by the physicist James Clerk Maxwell in 1868 entitled On Governors. This described and analyzed the phenomenon of "hunting," in which lags in the system can lead to overcompensation and unstable behavior. This generated a flurry of interest in the topic, during which Maxwell's classmate Edward John Routh generalized the results of Maxwell for the general class of linear systems. Independently, Adolf Hurwitz analyzed system stability using differential equations in 1877. This result is called the Routh-Hurwitz Criterion.

A notable application of dynamic control was in the area of manned flight. The Wright Brothers made their first successful test flights on December 17, 1903 and were distinguished by their ability to control their flights for substantial periods (more so than the ability to produce lift from an airfoil, which was known). Control of the airplane was necessary for safe flight.

By World War II, control theory was an important part of fire-control systems, guidance systems, and electronics. The Space Race also depended on accurate spacecraft control. However, control theory also saw an increasing use in fields such as economics and sociology.

For a list of active and historical figures who have made a significant contribution to control theory.

2. PART EXPLANATIONS OF PROJECT

2.1 How voltage, current, and resistance relate

An electric circuit is formed when a conductive path is created to allow free electrons to continuously move. This continuous movement of free electrons through the conductors of a circuit is called a current, and it is often referred to in terms of "flow," just like the flow of a liquid through a hollow pipe.

The force motivating electrons to "flow" in a circuit is called voltage. Voltage is a specific measure of potential energy that is always relative between two points. When we speak of a certain amount of voltage being present in a circuit, we are referring to the measurement of how much potential energy exists to move electrons from one particular point in that circuit to another particular point. Without reference to two particular points, the term "voltage" has no meaning.

Free electrons tend to move through conductors with some degree of friction, or opposition to motion. This opposition to motion is more properly called resistance. The amount of current in a circuit depends on the amount of voltage available to motivate the electrons, and also the amount of resistance in the circuit to oppose electron flow. Just like voltage, resistance is a quantity relative between two points. For this reason, the quantities of voltage and resistance are often stated as being "between" or "across" two points in a circuit.

To be able to make meaningful statements about these quantities in circuits, we need to be able to describe their quantities in the same way that we might quantify mass, temperature, volume, length, or any other kind of physical quantity. For mass we might use the units of "pound" or "gram." For temperature we might use degrees Fahrenheit or degrees Celsius. Here are the standard units of measurement for electrical current, voltage, and resistance:

Quantity	Symbol	Unit of Measurement	Unit Abbreviation
Current	I	Ampere ("Amp")	A
Voltage	E *or* V	Volt	V
Resistance	R	Ohm	Ω

Figure :2.1

The "symbol" given for each quantity is the standard alphabetical letter used to represent that quantity in an algebraic equation. Standardized letters like these are common in the disciplines of physics and engineering, and are internationally recognized. The "unit abbreviation" for each quantity represents the alphabetical symbol used as a shorthand notation for its particular unit of measurement. And, yes, that strange-looking "horseshoe" symbol is the capital Greek letter Ω, just a character in a foreign alphabet (apologies to any Greek readers here).

Each unit of measurement is named after a famous experimenter in electricity: The amp after the Frenchman Andre M. Ampere, the volt after the Italian Alessandro Volta, and the ohm after the German Georg Simon Ohm.

The mathematical symbol for each quantity is meaningful as well. The "R" for resistance and the "V" for voltage are both self-explanatory, whereas "I" for current seems a bit weird. The "I" is thought to have been meant to represent "Intensity" (of electron flow), and the other symbol for voltage, "E," stands for "Electromotive force." From what research I've been able to do, there seems to be some dispute over the meaning of "I." The symbols "E" and "V" are interchangeable for the most part, although some texts reserve "E" to represent voltage across a source (such as a battery or generator) and "V" to represent voltage across anything else.

All of these symbols are expressed using capital letters, except in cases where a quantity (especially voltage or current) is described in terms of a brief period of time (called an "instantaneous" value). For example, the voltage of a battery, which is stable over a long period of time, will be symbolized with a capital letter "E," while the voltage peak of a lightning strike at the very instant it hits a power line would most likely be symbolized with a lower-case letter "e" (or lower-case "v") to designate that value as being at a single moment in time. This same lower-case convention holds true for current as well, the lower-case letter "i" representing current at some instant in time. Most direct-current (DC) measurements, however, being stable over time, will be symbolized with capital letters.

One foundational unit of electrical measurement, often taught in the beginnings of electronics courses but used infrequently afterwards, is the unit of the coulomb, which is a measure of electric charge proportional to the number of electrons in an imbalanced state. One coulomb of charge is equal to 6.250.000.000.000.000.000 electrons. The symbol for electric charge quantity is the capital letter "Q," with the unit of coulombs abbreviated by the capital letter "C." It so happens that the unit for electron flow, the amp, is equal to 1 coulomb of electrons passing by a given point in a circuit in 1 second of time. Cast in these terms, current is the rate of electric charge motion through a conductor.

As stated before, voltage is the measure of potential energy per unit charge available to motivate electrons from one point to another. Before we can precisely define what a "volt" is, we must understand how to measure this quantity we call "potential energy." The general metric unit for energy of any kind is the joule, equal to the amount of work performed by a

force of 1 newton exerted through a motion of 1 meter (in the same direction). In British units, this is slightly less than 3/4 pound of force exerted over a distance of 1 foot. Put in common terms, it takes about 1 joule of energy to lift a 3/4 pound weight 1 foot off the ground, or to drag something a distance of 1 foot using a parallel pulling force of 3/4 pound. Defined in these scientific terms, 1 volt is equal to 1 joule of electric potential energy per (divided by) 1 coulomb of charge. Thus, a 9 volt battery releases 9 joules of energy for every coulomb of electrons moved through a circuit.

These units and symbols for electrical quantities will become very important to know as we begin to explore the relationships between them in circuits. The first, and perhaps most important, relationship between current, voltage, and resistance is called Ohm's Law, discovered by Georg Simon Ohm and published in his 1827 paper, The Galvanic Circuit Investigated Mathematically. Ohm's principal discovery was that the amount of electric current through a metal conductor in a circuit is directly proportional to the voltage impressed across it, for any given temperature. Ohm expressed his discovery in the form of a simple equation, describing how voltage, current, and resistance interrelate:

$$E = I R$$

In this algebraic expression, voltage (E) is equal to current (I) multiplied by resistance (R). Using algebra techniques, we can manipulate this equation into two variations, solving for I and for R, respectively:

$$I = \frac{E}{R} \qquad R = \frac{E}{I}$$

Let's see how these equations might work to help us analyze simple circuits:

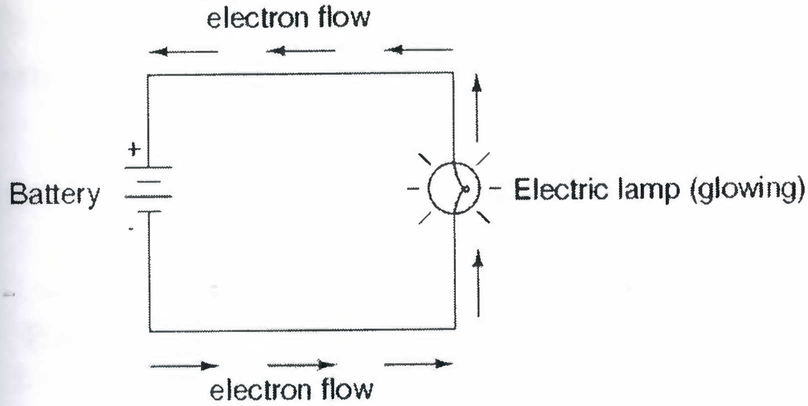


Figure : 2.2

In the above circuit, there is only one source of voltage (the battery, on the left) and only one source of resistance to current (the lamp, on the right). This makes it very easy to apply Ohm's Law. If we know the values of any two of the three quantities (voltage, current, and resistance) in this circuit, we can use Ohm's Law to determine the third.

In this first example, we will calculate the amount of current (I) in a circuit, given values of voltage (E) and resistance (R):

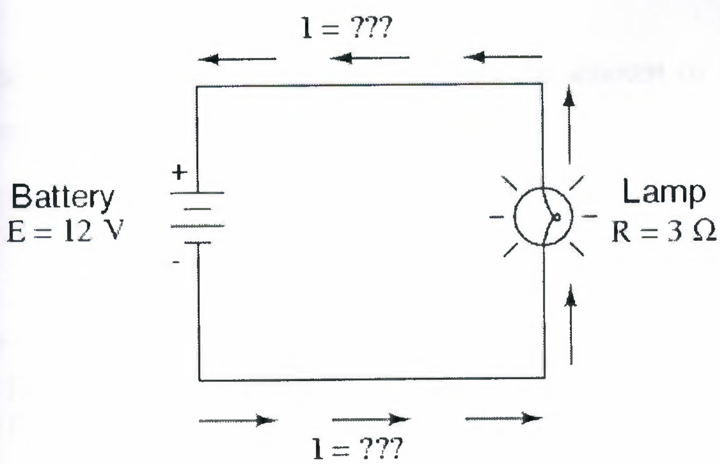


Figure 2.3

What is the amount of current (I) in this circuit?

$$I = \frac{E}{R} = \frac{12\ V}{3\ \Omega} = 4\ A$$

In this second example, we will calculate the amount of resistance (R) in a circuit, given values of voltage (E) and current (I):

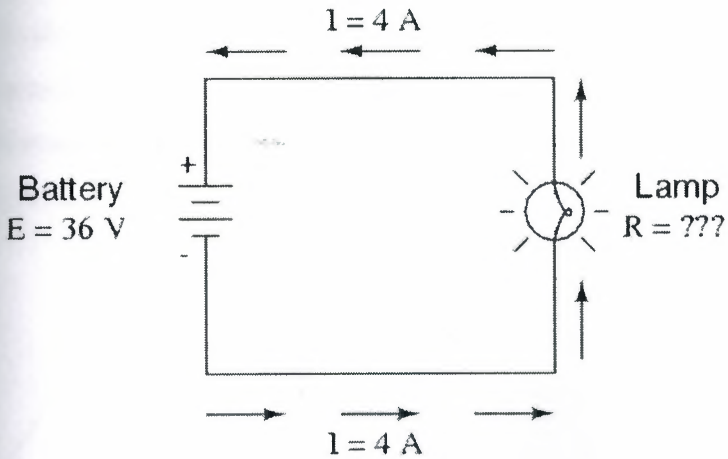


figure :2.4

What is the amount of resistance (R) offered by the lamp?

$$R = \frac{E}{I} = \frac{36\ V}{4\ A} = 9\ \Omega$$

In the last example, we will calculate the amount of voltage supplied by a battery, given values of current (I) and resistance (R):

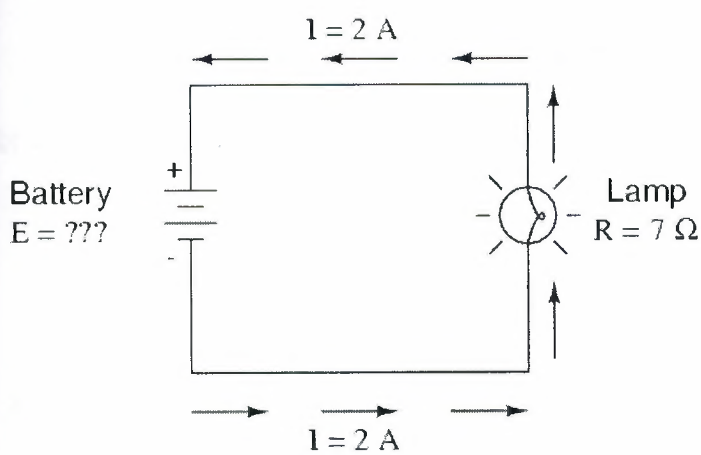


Figure : 2.5

What is the amount of voltage provided by the battery?

$E = IR = (2\ A)(7\ \Omega) = 14\ V$

Ohm's Law is a very simple and useful tool for analyzing electric circuits. It is used so often in the study of electricity and electronics that it needs to be committed to memory by the serious student. For those who are not yet comfortable with algebra, there's a trick to remembering how to solve for any one quantity, given the other two. First, arrange the letters E, I, and R in a triangle like this:

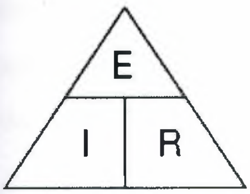
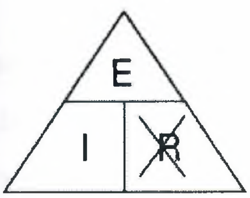


Figure : 2.6

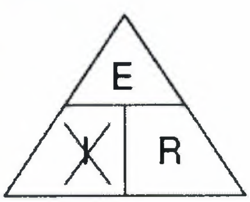
If you know E and I, and wish to determine R, just eliminate R from the picture and see what's left:



$$R = \frac{E}{I}$$

Figure : 2.7

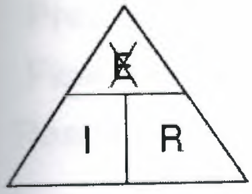
If you know E and R, and wish to determine I, eliminate I and see what's left:



$$I = \frac{E}{R}$$

Figure : 2.8

Lastly, if you know I and R, and wish to determine E, eliminate E and see what's left:



E = I R

Figure 2.9

Eventually, you'll have to be familiar with algebra to seriously study electricity and electronics, but this tip can make your first calculations a little easier to remember. If you are comfortable with algebra, all you need to do is commit E=IR to memory and derive the other two formulae from that when you need them!

Voltage measured in volts, symbolized by the letters "E" or "V". Current measured in amps, symbolized by the letter "I". Resistance measured in ohms, symbolized by the letter "R". Ohm's Law: E = IR ; I = E/R ; R = E/I

2.2 An analogy for Ohm's Law

Ohm's Law also makes intuitive sense if you apply it to the water-and-pipe analogy. If we have a water pump that exerts pressure (voltage) to push water around a "circuit" (current) through a restriction (resistance), we can model how the three variables interrelate. If the resistance to water flow stays the same and the pump pressure increases, the flow rate must also increase.

Pressure =	increase	**Voltage** =	increase
Flow rate =	increase	**Current** =	increase
Resistance=	same	**Resistance**=	same

$$\overset{\uparrow}{E} = \overset{\uparrow}{I}\ R$$

Figure : 2.10

If the pressure stays the same and the resistance increases (making it more difficult for the water to flow), then the flow rate must decrease:

Pressure	= same	**Voltage**	= same
Flow rate	= decrease	**Current**	= decrease
Resistance	= increase	**Resistance**	= increase

$$E = \underset{\downarrow}{I}\ \overset{\uparrow}{R}$$

Figure : 2.11

If the flow rate were to stay the same while the resistance to flow decreased, the required pressure from the pump would necessarily decrease:

Pressure	= decrease	**Voltage**	= decrease
Flow rate	= same	**Current**	= same
Resistance	= decrease	**Resistance**	= decrease

$$\underset{\downarrow}{E} = I\ \underset{\downarrow}{R}$$

Figure : 2.12

As odd as it may seem, the actual mathematical relationship between pressure, flow, and resistance is actually more complex for fluids like water than it is for electrons. If you pursue further studies in physics, you will discover this for yourself. Thankfully for the electronics student, the mathematics of Ohm's Law is very straightforward and simple.

With resistance steady, current follows voltage (an increase in voltage means an increase in current, and vice versa).

With voltage steady, changes in current and resistance are opposite (an increase in current means a decrease in resistance, and vice versa).

With current steady, voltage follows resistance (an increase in resistance means an increase in voltage).

2.2.1 Power in electric circuits

In addition to voltage and current, there is another measure of free electron activity in a circuit: power. First, we need to understand just what power is before we analyze it in any circuits.

Power is a measure of how much work can be performed in a given amount of time. Work is generally defined in terms of the lifting of a weight against the pull of gravity. The heavier the weight and/or the higher it is lifted, the more work has been done. Power is a measure of how rapidly a standard amount of work is done.

For American automobiles, engine power is rated in a unit called "horsepower," invented initially as a way for steam engine manufacturers to quantify the working ability of their machines in terms of the most common power source of their day: horses. One horsepower is defined in British units as 550 ft-lbs of work per second of time. The power of a car's engine won't indicate how tall of a hill it can climb or how much weight it can tow, but it will indicate how fast it can climb a specific hill or tow a specific weight.

The power of a mechanical engine is a function of both the engine's speed and it's torque provided at the output shaft. Speed of an engine's output shaft is measured in revolutions per minute, or RPM. Torque is the amount of twisting force produced by the engine, and it is usually measured in pound-feet, or lb-ft (not to be confused with foot-pounds or ft-lbs, which is the unit for work). Neither speed nor torque alone is a measure of an engine's power.

A 100 horsepower diesel tractor engine will turn relatively slowly, but provide great amounts of torque. A 100 horsepower motorcycle engine will turn very fast, but provide relatively little torque. Both will produce 100 horsepower, but at different speeds and different torques. The equation for shaft horsepower is simple:

$$\text{Horsepower} = \frac{2 \pi S T}{33{,}000}$$

Where,

S = shaft speed in r.p.m.

T = shaft torque in lb-ft.

Figure : 2.13

Notice how there are only two variable terms on the right-hand side of the equation, S and T. All the other terms on that side are constant: 2, pi, and 33,000 are all constants (they do not change in value). The horsepower varies only with changes in speed and torque, nothing else. We can re-write the equation to show this relationship:

$$\text{Horsepower} \propto S\,T$$

$\propto$ This symbol means "proportional to"

Figure : 2.14

Because the unit of the "horsepower" doesn't coincide exactly with speed in revolutions per minute multiplied by torque in pound-feet, we can't say that horsepower equals ST. However, they are proportional to one another. As the mathematical product of ST changes, the value for horsepower will change by the same proportion.

In electric circuits, power is a function of both voltage and current. Not surprisingly, this relationship bears striking resemblance to the "proportional" horsepower formula above:

$$P = 1\,E$$

In this case, however, power (P) is exactly equal to current (I) multiplied by voltage (E), rather than merely being proportional to IE. When using this formula, the unit of measurement for power is the watt, abbreviated with the letter "W."

It must be understood that neither voltage nor current by themselves constitute power. Rather, power is the combination of both voltage and current in a circuit. Remember that voltage is the specific work (or potential energy) per unit charge, while current is the rate at which electric charges move through a conductor. Voltage (specific work) is analogous to the work done in lifting a weight against the pull of gravity. Current (rate) is analogous to the speed at which that weight is lifted. Together as a product (multiplication), voltage (work) and current (rate) constitute power.

Just as in the case of the diesel tractor engine and the motorcycle engine, a circuit with high voltage and low current may be dissipating the same amount of power as a circuit with low voltage and high current. Neither the amount of voltage alone nor the amount of current alone indicates the amount of power in an electric circuit.

In an open circuit, where voltage is present between the terminals of the source and there is zero current, there is zero power dissipated, no matter how great that voltage may be. Since $P=IE$ and $I=0$ and anything multiplied by zero is zero, the power dissipated in any open circuit must be zero. Likewise, if we were to have a short circuit constructed of a loop of superconducting wire (absolutely zero resistance), we could have a condition of current in the loop with zero voltage, and likewise no power would be dissipated. Since $P=IE$ and $E=0$ and anything multiplied by zero is zero, the power dissipated in a superconducting loop must be zero. (We'll be exploring the topic of superconductivity in a later chapter).

Whether we measure power in the unit of "horsepower" or the unit of "watt," we're still talking about the same thing: how much work can be done in a given amount of time. The two units are not numerically equal, but they express the same kind of thing. In fact, European automobile manufacturers typically advertise their engine power in terms of kilowatts (kW), or thousands of watts, instead of horsepower! These two units of power are related to each other by a simple conversion formula:

$$1 \text{ Horsepower} = 745.7 \text{ Watts}$$

So, our 100 horsepower diesel and motorcycle engines could also be rated as "74570 watt" engines, or more properly, as "74.57 kilowatt" engines. In European engineering specifications, this rating would be the norm rather than the exception.

Power is the measure of how much work can be done in a given amount of time.

Mechanical power is commonly measured (in America) in "horsepower."

Electrical power is almost always measured in "watts," and it can be calculated by the formula $P = IE$.

Electrical power is a product of both voltage and current, not either one separately.

Horsepower and watts are merely two different units for describing the same kind of physical measurement, with 1 horsepower equaling 745.7 watts.

2.2.2 Calculating electric power

We've seen the formula for determining the power in an electric circuit: by multiplying the voltage in "volts" by the current in "amps" we arrive at an answer in "watts." Let's apply this to a circuit example:

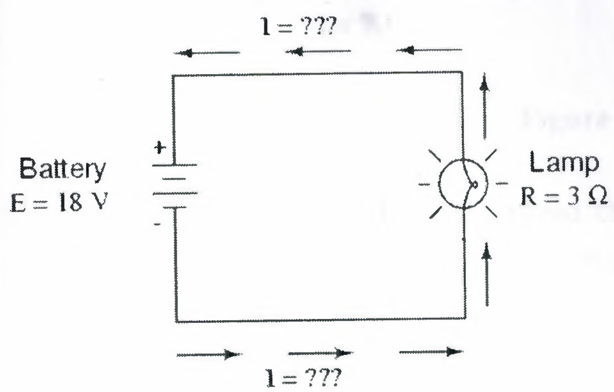


Figure : 2.15

In the above circuit, we know we have a battery voltage of 18 volts and a lamp resistance of 3 Ω. Using Ohm's Law to determine current, we get:

$$I = \frac{E}{R} = \frac{18\ V}{3\ \Omega} = 6\ A$$

Now that we know the current, we can take that value and multiply it by the voltage to determine power:

$P = I\,E = (6\ A)(18\ V) = 108\ W$

Answer: the lamp is dissipating (releasing) 108 watts of power, most likely in the form of both light and heat.

Let's try taking that same circuit and increasing the battery voltage to see what happens. Intuition should tell us that the circuit current will increase as the voltage increases and the lamp resistance stays the same. Likewise, the power will increase as well:

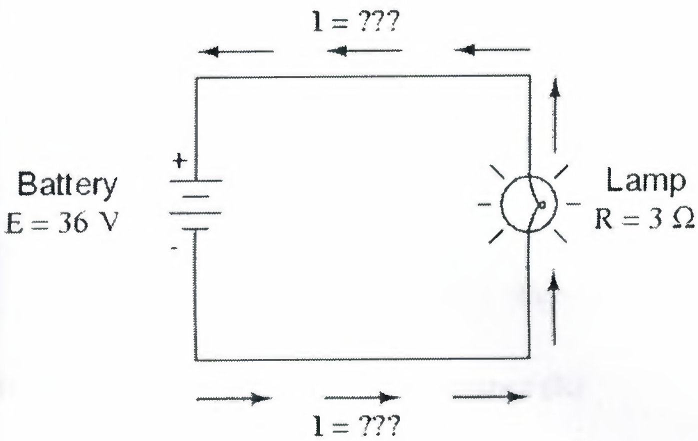


Figure : 2.16

Now, the battery voltage is 36 volts instead of 18 volts. The lamp is still providing 3 Ω of electrical resistance to the flow of electrons. The current is now:

$$I = \frac{E}{R} = \frac{36\ V}{3\ \Omega} = 12\ A$$

This stands to reason: if I = E/R, and we double E while R stays the same, the current should double. Indeed, it has: we now have 12 amps of current instead of 6. Now, what about power?

$P = I\,E = (12\ A)(36\ V) = 432\ W$

Notice that the power has increased just as we might have suspected, but it increased quite a bit more than the current. Why is this? Because power is a function of voltage multiplied by current, and both voltage and current doubled from their previous values, the power will increase by a factor of 2 x 2, or 4. You can check this by dividing 432 watts by 108 watts and seeing that the ratio between them is indeed 4.

Using algebra again to manipulate the formulae, we can take our original power formula and modify it for applications where we don't know both voltage and current:

If we only know voltage (E) and resistance (R):

$$\textit{If,}\quad I = \frac{E}{R} \quad \textit{and} \quad P = I\,E$$

$$\textit{Then,}\quad P = \frac{E}{R}\,E \quad \textit{or} \quad \mathbf{P = \frac{E^2}{R}}$$

Figure : 2.17

If we only know current (I) and resistance (R):

$$\textit{If,}\quad E = I\,R \quad \textit{and} \quad P = I\,E$$

$$\textit{Then,}\quad P = I(I\,R) \quad \textit{or} \quad \mathbf{P = I^2 R}$$

Figure : 2.18

An historical note: it was James Prescott Joule, not Georg Simon Ohm, who first discovered the mathematical relationship between power dissipation and current through a resistance. This discovery, published in 1841, followed the form of the last equation ($P = I^2R$), and is properly known as Joule's Law. However, these power equations are so commonly associated with the Ohm's Law equations relating voltage, current, and resistance (E=IR ; I=E/R ; and R=E/I) that they are frequently credited to Ohm.

Power equations

$$P = IE \qquad P = \frac{E^2}{R} \qquad P = I^2R$$

Power measured in watts, symbolized by the letter "W".

Joule's Law: $P = I^2R$; $P = IE$; $P = E^2/R$

2.3 RESISTORS

The resistor's function is to reduce the flow of electric current. This symbol —^^^—is used to indicate a resistor in a circuit diagram, known as a schematic. Resistance value is designated in units called the "Ohm." A 1000 Ohm resistor is typically shown as 1K-Ohm (kilo Ohm), and 1000 K-Ohms is written as 1M-Ohm (megohm).

There are two classes of resistors; fixed resistors and the variable resistors. They are also classified according to the material from which they are made. The typical resistor is made of either carbon film or metal film. There are other types as well, but these are the most common.

The resistance value of the resistor is not the only thing to consider when selecting a resistor for use in a circuit. The "tolerance" and the electric power ratings of the resistor are also important.

The tolerance of a resistor denotes how close it is to the actual rated resistence value. For example, a ±5% tolerance would indicate a resistor that is within ±5% of the specified resistance value.

The power rating indicates how much power the resistor can safely tolerate. Just like you wouldn't use a 6 volt flashlight lamp to replace a burned out light in your house, you wouldn't use a 1/8 watt resistor when you should be using a 1/2 watt resistor.

The maximum rated power of the resistor is specified in Watts. Power is calculated using the square of the current (I^2) x the resistance value (R) of the resistor. If the maximum rating of the resistor is exceeded, it will become extremely hot, and even burn.

Resistors in electronic circuits are typicaly rated 1/8W, 1/4W, and 1/2W. 1/8W is almost always used in signal circuit applications.

When powering a light emitting diode, a comparatively large current flows through the resistor, so you need to consider the power rating of the resistor you choose.

2.3.1 Rating electric power

For example, to power a 5V circuit using a 12V supply, a three-terminal voltage regulator is usually used. However, if you try to drop the voltage from 12V to 5V using only a resistor, then you need to calculate the power rating of the resistor as well as the resistance value.

At this time, the current consumed by the 5V circuit needs to be known. Here are a few ways to find out how much current the circuit demands. Assemble the circuit and measure the actual current used with a multi-meter. Check the component's current use against a standard table. Assume the current consumed is 100 mA (milliamps) in the following example. 7V must be dropped with the resistor. The resistance value of the resistor becomes 7V / 0.1A = 70(ohm). The consumption of electric power for this resistor becomes
0.1A x 0.1A x 70 ohm = 0.7W.
Generally, it's safe to choose a resistor which has a power rating of about twice the power consumption needed.

2.3.2 Resistance value

As for the standard resistance value, the values used can be divided like a logarithm. For example, in the case of E3, The values [1], [2.2], [4.7] and [10] are used. They divide 10 into three, like a logarithm.
In the case of E6 : [1], [1.5], [2.2], [3.3], [4.7], [6.8], [10].
In the case of E12 : [1], [1.2], [1.5], [1.8], [2.2], [2.7], [3.3], [3.9], [4.7], [5.6], [6.8], [8.2], [10].
It is because of this that the resistance value is seen at a glance to be a discrete value. The resistance value is displayed using the color code(the colored bars/the colored stripes), because the average resistor is too small to have the value printed on it with numbers. You had better learn the color code, because almost all resistors of 1/2W or less use the color code to display the resistance value.

2.3.3 Types of resistors

2.3.3.1 Fixed Resistors

A fixed resistor is one in which the value of its resistance cannot change.

2.3.3.2 Carbon film resistors

This is the most general purpose, cheap resistor. Usually the tolerance of the resistance value is ±5%. Power ratings of 1/8W, 1/4W and 1/2W are frequently used.

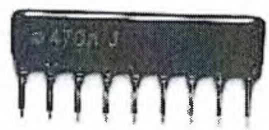
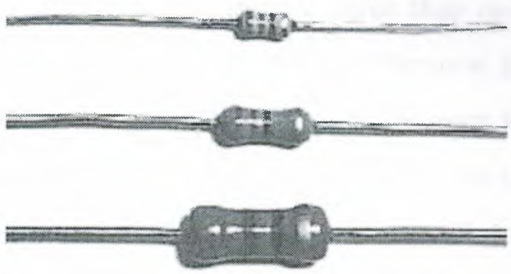
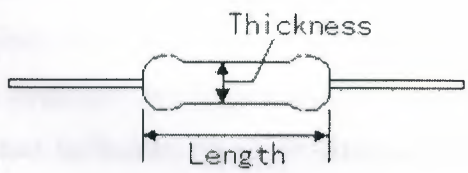


Figure:2.19

Carbon film resistors have a disadvantage; they tend to be electrically noisy. Metal film resistors are recommended for use in analog circuits. However, I have never experienced any problems with this noise.

The physical size of the different resistors are as follows.





From the top of the photograph
1/8W
1/4W
1/2W

Rough size

Rating power (W)	**Thickness (mm)**	**Length (mm)**
1/8	2	3
1/4	2	6
1/2	3	9

Figure : 2.20

This resistor is called a Single-In-Line(SIL) resistor network. It is made with many resistors of the same value, all in one package. One side of each resistor is connected with one side of all the other resistors inside. One example of its use would be to control the current in a circuit powering many light emitting diodes (LEDs).

In the photograph on the left, 8 resistors are housed in the package. Each of the leads on the package is one resistor. The ninth lead on the left side is the common lead. The face value of the resistance is printed. (It depends on the supplier.)

Some resistor networks have a "4S" printed on the top of the resistor network. The 4S indicates that the package contains 4 independent resistors that are not wired together inside. The housing has eight leads instead of nine. The internal wiring of these typical resistor networks has been illustrated below. The size (black part) of the resistor network which I have is as follows: For the type with 9 leads, the thickness is 1.8 mm, the height 5mm, and the width 23 mm. For the types with 8 component leads, the thickness is 1.8 mm, the height 5 mm, and the width 20 mm.

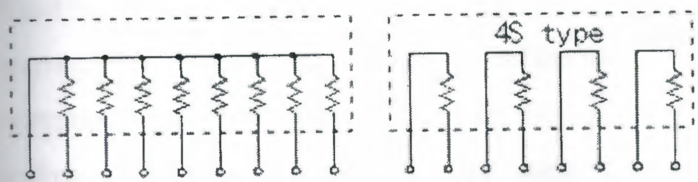
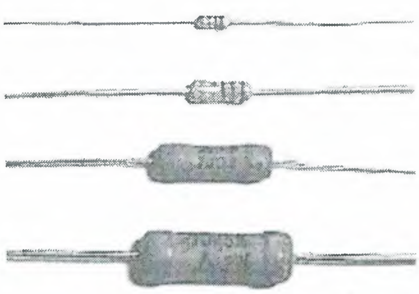
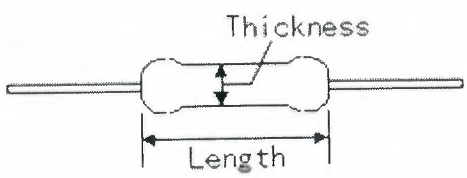


Figure : 2.21

2.3.3.3 Metal film resistors

Metal film resistors are used when a higher tolerance (more accurate value) is needed. They are much more accurate in value than carbon film resistors. They have about ±0.05% tolerance. They have about ±0.05% tolerance. I don't use any high tolerance resistors in my circuits. Resistors that are about ±1% are more than sufficient. Ni-Cr (Nichrome) seems to be circuits. Resistors that are about ±1% are more than sufficient. Ni-Cr (Nichrome) seems to be used for the material of resistor. The metal film resistor is used for bridge circuits, filter circuits, and low-noise analog signal circuits.





From the top of the photograph
1/8W (tolerance ±1%)
1/4W (tolerance ±1%)
1W (tolerance ±5%)
2W (tolerance ±5%)

Rough size

Rating power (W)	**Thickness (mm)**	**Length (mm)**
1/8	2	3
1/4	2	6
1	3.5	12
2	5	15

Figure:2.22

2.3.3.4 Variable Resistors

There are two general ways in which variable resistors are used. One is the variable resistor which value is easily changed, like the volume adjustment of Radio. The other is semi-fixed resistor that is not meant to be adjusted by anyone but a technician. It is used to adjust the operating condition of the circuit by the technician. Semi-fixed resistors are used to compensate for the inaccuracies of the resistors, and to fine-tune a circuit. The rotation angle of the variable resistor is usually about 300 degrees. Some variable resistors must be turned many times to use the whole range of resistance they offer. This allows for very precise adjustments of their value. These are called "Potentiometers" or "Trimmer Potentiometers."

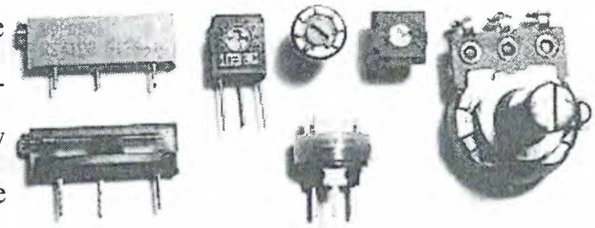


figure : 2.23

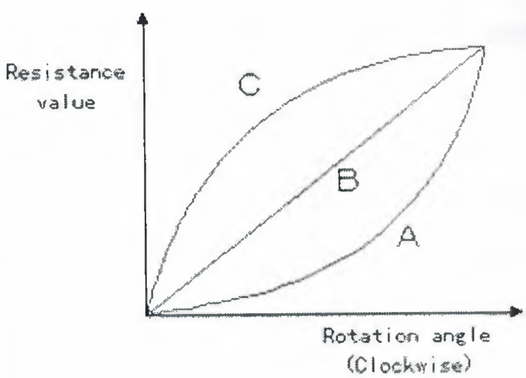


Figure : 2.24

In the photograph to the left, the variable resistor typically used for volume controls can be seen on the far right. Its value is very easy to adjust. The four resistors at the center of the photograph are the semi-fixed type. These ones are mounted on the printed circuit board. The two resistors on the left are the trimmer potentiometers.

This symbol  is used to indicate a variable resistor in a circuit diagram.

There are three ways in which a variable resistor's value can change according to the rotation angle of its axis.

When type "A" rotates clockwise, at first, the resistance value changes slowly and then in the second half of its axis, it changes very quickly.

The "A" type variable resistor is typically used for the volume control of a radio, for example. It is well suited to adjust a low sound subtly. It suits the characteristics of the ear. The ear hears low sound changes well, but isn't as sensitive to small changes in loud sounds. A larger change is needed as the volume is increased. These "A" type variable resistors are sometimes called "audio taper" potentiometers.

As for type "B", the rotation of the axis and the change of the resistance value are directly related. The rate of change is the same, or linear, throughout the sweep of the axis. This type suits a resistance value adjustment in a circuit, a balance circuit and so on.

They are sometimes called "linear taper" potentiometers.

Type "C" changes exactly the opposite way to type "A". In the early stages of the rotation of the axis, the resistance value changes rapidly, and in the second half, the change occurs more slowly. This type isn't too much used. It is a special use.

As for the variable resistor, most are type "A" or type "B".

2.3.3.5 CDS Elements

Some components can change resistance value by changes in the amount of light hitting them. One type is the Cadmium Sulfide Photocell. (Cd) The more light that hits it, the smaller its resistance value becomes.

There are many types of these devices. They vary according to light sensitivity, size, resistance value etc.

Figure : 2.25

Pictured at the left is a typical CDS photocell. Its diameter is 8 mm, 4 mm high, with a cylinder form. When bright light is hitting it, the value is about 200 ohms, and when in the dark, the resistance value is about 2M ohms.

This device is using for the head lamp illumination confirmation device of the car, for example.

2.3.3.6 Other Resistors

There is another type of resistor other than the carbon-film type and the metal film resistors.

It is the wirewound resistor.A wirewound resistor is made of metal resistance wire, and because of this, they can be manufactured to precise values. Also, high-wattage resistors can be made by using a thick wire material. Wirewound resistors cannot be used for high-frequency circuits. Coils are used in high frequency circuits. Since a wirewound resistor is a wire wrapped around an insulator, it is also a coil, in a manner of speaking. Using one could change the behavior of the circuit. Still another type of resistor is the Ceramic resistor. These are wirewound resistors in a ceramic case, strengthened with a special cement. They have very high power ratings, from 1 or 2 watts to dozens of watts. These resistors can become extremely hot when used for high power applications, and this must be taken into account when designing the circuit. These devices can easily get hot enough to burn you if you touch one.

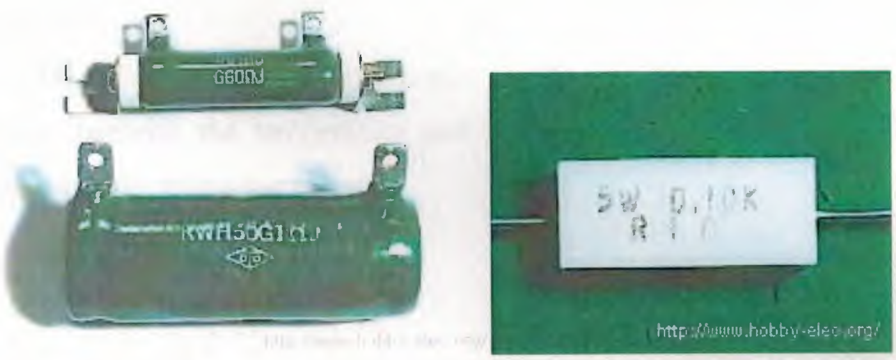


Figure : 2.26

The photograph on the left is of wirewound resistors. The upper one is 10W and is the length of 45 mm, 13 mm thickness. The lower one is 50W and is the length of 75 mm, 29 mm thickness. The upper one is has metal fittings attached. These devices are insulated with a ceramic coating.

Figure : 2.27

The photograph on above is a ceramic (or cement) resistor of 5W and is the height of 9 mm, 9 mm depth, 22 mm width.

Thermistor (Thermally sensitive resistor)

The resistance value of the thermistor changes according to temperature. This part is used as a temperature sensor.There are mainly three types of thermistor.

NTC(Negative Temperature Coefficient Thermistor) :

With this type, the resistance value decreases continuously as the temperature rises.

PTC(Positive Temperature Coefficient Thermistor) :

With this type, the resistance value increases suddenly when the temperature rises above a specific point.

CTR(Critical Temperature Resister Thermistor) :

With this type, the resistance value decreases suddenly when the temperature rises above a specific point.

The NTC type is used for the temperature control.

The relation between the temperature and the resistance value of the NTC type can be calculated using the following formula.

$$R = R_0 \cdot \exp^{B\left(\frac{1}{T} - \frac{1}{T_0}\right)}$$

Figure : 2.28

R : The resistance value at the temperature T

T : The temperature [K]

R_0 : The resistance value at the reference temperature T_0

T_0 : The reference temperature [K]

B : The coefficient

Figure : 2.29

As the reference temperature, typically, 25°C is used.

The unit with the temperature is the absolute temperature(Value of which 0 was -273°C) in K(Kelvin).

25°C are the 298 kelvins.

2.3.3.7 Resistor color code

Example 1

(Brown=1),(Black=0),(Orange=3)

10 x 10^3 = 10k ohm

Tolerance(Gold) = ±5%

Example 2

(Yellow=4),(Violet=7),(Black=0),(Red=2)

470 x 10^2 = 47k ohm

Tolerance(Brown) = ±1%

Color	Value	Multiplier	Tolerance (%)
Black	0	0	-
Brown	1	1	±1
Red	2	2	±2
Orange	3	3	±0.05
Yellow	4	4	-
Green	5	5	±0.5
Blue	6	6	±0.25
Violet	7	7	±0.1
Gray	8	8	-
White	9	9	-
Gold	-	-1	±5
Silver	-	-2	±10
None	-	-	±20

Figure : 2.30

2.4 POTENTIOMETERS

A potentiometer is a variable resistor that can be used as a voltage divider.

Originally a potentiometer was an instrument to measure the potential (or voltage) in a circuit by tapping off a fraction of a known voltage from a resistive slide wire and comparing it with the unknown voltage by means of a galvanometer.

The present popular usage of the term potentiometer (or 'pot' for short) describes an electrical device which has a user-adjustable resistance. Usually, this is a three-terminal resistor with a sliding contact in the center (the wiper). If all three terminals are used, it can act as a variable voltage divider. If only two terminals are used (one side and the wiper), it acts as a variable resistor. Its shortcoming is that of corrosion or wearing of the sliding contact, especially if it is kept in one position.

2.4.1 Potentiometer as electronic component

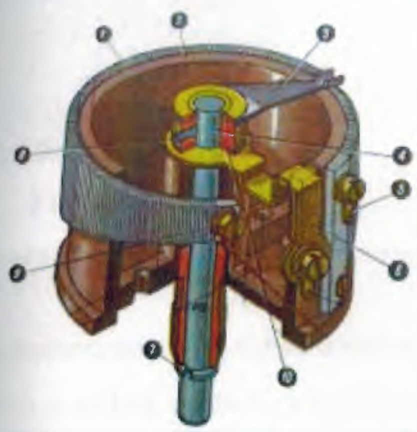


Figure : 2.31

Construction of a wire-wound circular potentiometer. The resistive element (1) of the shown device is trapezoidal, giving a non-linear relationship between resistance and turn angle. The wiper (3) rotates with the axis (4), providing the changeable resistance between the wiper contact (6) and the fixed contacts (5) and (9). The vertical position of the axis is fixed in the body (2) with the ring (7) (below) and the bolt (8) (above).

In modern usage, a potentiometer is a potential divider, a three terminal resistor where the position of the sliding connection is user adjustable via a knob or slider. Potentiometers are sometimes provided with one or more switches mounted on the same shaft. For instance, when attached to a volume control, the knob can also function as an on/off switch at the lowest volume.

Ordinary potentiometers are rarely used to control anything of significant power (even lighting) directly due to resistive losses, but they are frequently used to adjust the level of analog signals (e.g. volume controls on audio equipment) and as control inputs for electronic circuits (e.g. a typical domestic light dimmer uses a potentiometer to set the point in the cycle at which the triac turns on). Potentiometers used to control high power are normally called rheostats.

2.4.2 Types of potentiometers

2.4.2.1 Low-power types

Figure : 2.32

A typical single turn potentiometer

A potentiometer is constructed using a flat graphite annulus (ring) as the resistive element, with a sliding contact (wiper) sliding around this annulus. The wiper is connected to an axle and, via another rotating contact, is brought out as the third terminal. On panel pots, the wiper is usually the centre terminal. For single turn pots, this wiper typically travels just under one revolution around the contact. 'Multiturn' potentiometers also exist, where the resistor element may be helical and the wiper may move 10, 20, or more complete revolutions. In addition to graphite, other materials may be used for the resistive element. These may be resistance wire or carbon particles in plastic or a ceramic/metal mixture. One popular form of rotary potentiometer is called a string pot. It is a multi-turn potentiometer with an attached reel of wire turning against a spring. It's very convenient for measuring movement and therefore acts as a position transducer. In a linear slider pot, a sliding control is provided instead of a dial control. The word linear also describes the geometry of the resistive element which is a rectangular strip, (not an annulus as in a rotary potentiometer). Because of their construction, this type of pot has a greater potential for getting contaminated. Potentiometers can be obtained with either linear or logarithmic laws (or "tapers").

Figure : 2.33

PCB mount trimmer potentiometers, or "trimpots", intended for infrequent adjustment.

2.4.2.2 Linear potentiometers

A linear pot has a resistive element of constant cross-section, resulting in a device where the resistance between the contact (wiper) and one end terminal is proportional to the distance between them. Linear describes the electrical 'law' of the device, not the geometry of the resistive element.

2.4.2.3 Logarithmic potentiometers

A log pot has a resistive element that either 'tapers' in from one end to the other, or is made from a material whose resistivity varies from one end to the other. This results in a device where output voltage is a logarithmic (or inverse logarithmic depending on type) function of the mechanical angle of the pot.

Most (cheaper) "log" pots are actually not logarithmic, but use two regions of different, but constant, resistivity to approximate a logarithmic law. A log pot can also be simulated with a linear pot and an external resistor. True log pots are significantly more expensive.

2.4.2.4 High-power types

Figure : 2.34

A high power toroidal wirewound rheostat.

A rheostat is essentially a potentiometer, but is usually much larger, designed to handle much higher voltage and current. Typically these are constructed as a resistive wire wrapped to form a toroid coil (or most of one) with the wiper moving over the upper surface of the toroid, sliding from one turn of the wire to the next. Sometimes a rheostat is made from resistance wire wound on a heat resisting cylinder with the slider made from a number of metal fingers that grip lightly onto a small portion of the turns of resistance wire. The 'fingers' can be moved along the coil of resistance wire by a sliding knob thus changing the 'tapping' point. They are usually used as variable resistors rather than variable potential dividers.

2.4.2.5 Digital control

Digitally Controlled Potentiometers (DCPs) can be used in analogue signal processing circuits to replace potentiometers. They allow small adjustments to be made to the circuit by software, instead of a mechanical adjustment. Because this type of control is updated only infrequently, it often has a slow serial interface, like I^2C. Some types have non-volatile memory to enable them to remember their last settings when the power is switched off.

The same idea can be used to create Digital Volume Controls, attenuators, or other controls under digital control. Usually such devices feature quite a high degree of accuracy, and find applications in instrumention, mixing desks and other precision systems.

The DCP should not be confused with the digital to analogue converter (DAC) which actually creates an analogue signal from a digital one. A DCP only controls an existing analogue signal digitally. However, some DACs using resistive R-2R architecture have been functionally used as DCPs where the (varying) analogue signal is input to the reference voltage pin of the DAC and the digitally-controlled attenuated output is taken from the output of the DAC.

2.4.3 Applications of potentiometers

2.4.3.1 Transducers

Potentiometers are also very widely used as a part of displacement transducers because of the simplicity of construction and because they can give a large output signal.

2.4.3.2 Audio control

Figure : 2.35

Sliding potentiometers ("faders")

One of the most common uses for modern low-power potentiometers is as audio control devices. Both sliding pots (also known as faders) and rotary potentiometers (commonly called knobs) are regularly used to adjust loudness, frequency attenuation and other characteristics of audio signals.

The 'log pot' is used as the volume control in audio amplifiers, where it is also called an "audio taper pot", because the amplitude response of the human ear is also logarithmic. It ensures that, on a volume control marked 0 to 10, for example, a setting of 5 sounds half as loud as a setting of 10. There is also an anti-log pot or reverse audio taper which is simply the reverse of a log pot. It is almost always used in a ganged configuration with a log pot, for instance, in an audio balance control.

A potentiometer used in combination with an inductor or capacitor acts as a "tone" control.

2.4.4 Theory of operation

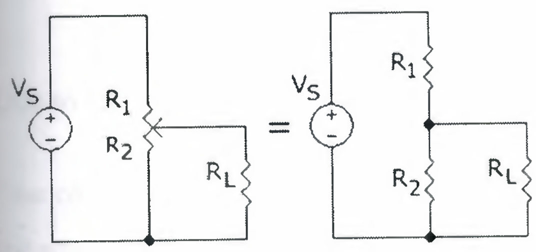


Figure : 2.36

A potentiometer with a resistive load, showing equivalent fixed resistors for clarity.

The 'modern' potentiometer can be used as a potential divider (or voltage divider) to obtain a manually adjustable output voltage at the slider (wiper) from a fixed input voltage applied across the two ends of the pot. This is the most common use of pots.

The voltage across R_L is determined by the formula:

$$V_L = \frac{R_2 \| R_L}{R_1 + R_2 \| R_L} \cdot V_s$$

The parallel lines indicate components in parallel. Expanded fully, the equation becomes:

$$V_L = \frac{R_2 R_L}{R_1 R_L + R_2 R_L + R_1 R_2} \cdot V_s$$

Although it is not always the case, if R_L is large compared to the other resistances (like the input to an operational amplifier), the output voltage can be approximated by the simpler equation:

$$V_L = \frac{R_2}{R_1 + R_2} \cdot V_s$$

As an example, assume

$V_S = 10\ \mathrm{V}$, $R_1 = 1\ \mathrm{k\Omega}$, $R_2 = 2\ \mathrm{k\Omega}$, and $R_L = 100\ \mathrm{k\Omega}$.

Since the load resistance is large compared to the other resistances, the output voltage V_L will be approximately:

$$\frac{2\ \mathrm{k}\Omega}{1\ \mathrm{k}\Omega + 2\ \mathrm{k}\Omega} \cdot 10\ \mathrm{V} = \frac{2}{3} \cdot 10\ \mathrm{V} \approx 6.667\ \mathrm{V}$$

Due to the load resistance, however, it will actually be slightly lower: ≈ 6.623 V.

One of the advantages of the potential divider compared to a variable resistor in series with the source is that, while variable resistors have a maximum resistance where some current will always flow, dividers are able to vary the output voltage from maximum (V_S) to ground (zero volts) as the wiper moves from one end of the pot to the other. There is, however, always a small amount of contact resistance.

In addition, the load resistance is often not known and therefore simply placing a variable resistor in series with the load could have a negligible effect or an excessive effect, depending on the load.

2.5 DIODES

A diode is a semiconductor device which allows current to flow through it in only one direction. Although a transistor is also a semiconductor device, it does not operate the way a diode does. A diode is specifically made to allow current to flow through it in only one direction.

Some ways in which the diode can be used are listed here.
A diode can be used as a rectifier that converts AC (Alternating Current) to DC (Direct Current) for a power supply device.
Diodes can be used to separate the signal from radio frequencies.
Diodes can be used as an on/off switch that controls current.
This symbol is used to indicate a diode in a circuit diagram.

The meaning of the symbol is (Anode)(Cathode). Current flows from the anode side to the cathode side.

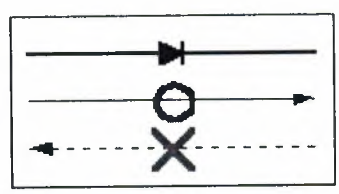


Figure : 2.37

Although all diodes operate with the same general principle, there are different types suited to different applications. For example, the following devices are best used for the applications noted.

2.5.1 Types Of Diodes

2.5.1.1 Voltage regulation diode (Zener Diode)

The circuit symbol is .

It is used to regulate voltage, by taking advantage of the fact that Zener diodes tend to stabilize at a certain voltage when that voltage is applied in the opposite direction.

2.5.1.2 Light emitting diode

The circuit symbol is .

This type of diode emits light when current flows through it in the forward direction. (Forward biased.)

2.5.1.3 Variable capacitance diode

The circuit symbol is .

The current does not flow when applying the voltage of the opposite direction to the diode. In this condition, the diode has a capacitance like the capacitor. It is a very small capacitance. The capacitance of the diode changes when changing voltage. With the change of this capacitance, the frequency of the oscillator can be changed.The graph on the right shows the electrical characteristics of a typical diode.

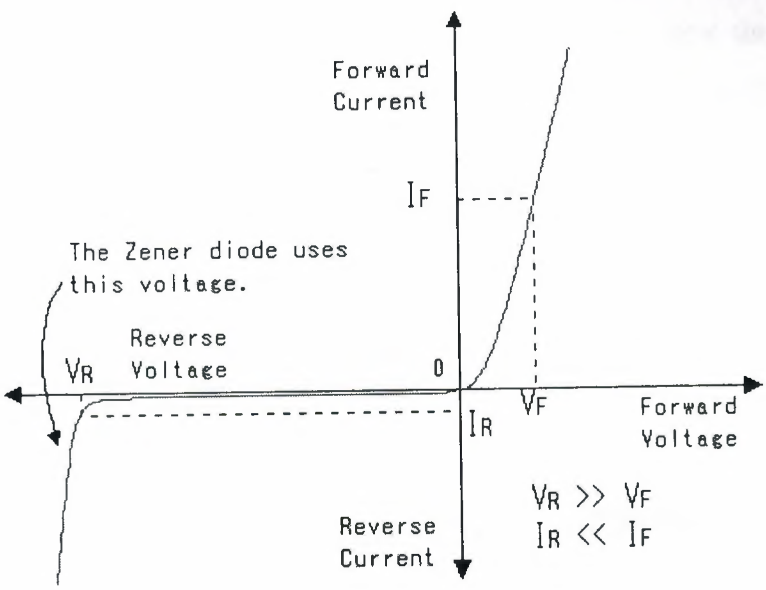


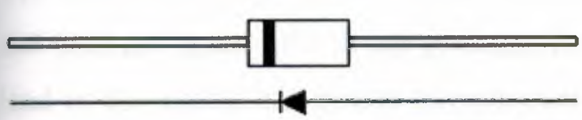
Figure : 2.38

When a small voltage is applied to the diode in the forward direction, current flows easily. Because the diode has a certain amount of resistance, the voltage will drop slightly as current flows through the diode. A typical diode causes a voltage drop of about 0.6 - 1V (V_F) (In the case of silicon diode, almost 0.6V)
This voltage drop needs to be taken into consideration in a circuit which uses many diodes in series. Also, the amount of current passing through the diodes must be considered.

When voltage is applied in the reverse direction through a diode, the diode will have a great resistance to current flow.
Different diodes have different characteristics when reverse-biased. A given diode should be selected depending on how it will be used in the circuit.
The current that will flow through a diode biased in the reverse direction will vary from several mA to just μA, which is very small.

The limiting voltages and currents permissible must be considered on a case by case basis. For example, when using diodes for rectification, part of the time they will be required to withstand a reverse voltage. If the diodes are not chosen carefully, they will break down.

2.5.1.4 Rectification / Switching / Regulation diode



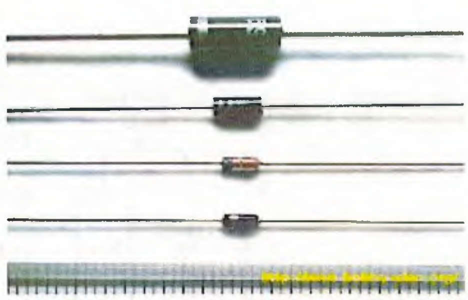


Figure : 2.39

The stripe stamped on one end of the diode shows indicates the polarity of the diode.
The stripe shows the cathode side.
The top two devices shown in the picture are diodes used for rectification. They are made to handle relatively high currents. The device on top can handle as high as 6A, and the one below it can safely handle up to 1A.

However, it is best used at about 70% of its rating because this current value is a maximum rating.

The third device from the top (red color) has a part number of 1S1588. This diode is used for switching, because it can switch on and off at very high speed. However, the maximum current it can handle is 120 mA. This makes it well suited to use within digital circuits. The maximum reverse voltage (reverse bias) this diode can handle is 30V.
The device at the bottom of the picture is a voltage regulation diode with a rating of 6V. When this type of diode is reverse biased, it will resist changes in voltage. If the input voltage is increased, the output voltage will not change. (Or any change will be an insignificant amount.) While the output voltage does not increase with an increase in input voltage, the output current will.
This requires some thought for a protection circuit so that too much current does not flow. The rated current limit for the device is 30 mA.
Generally, a 3-terminal voltage regulator is used for the stabilization of a power supply. Therefore, this diode is typically used to protect the circuit from momentary voltage spikes. 3 terminal regulators use voltage regulation diodes inside.

2.5.1.5 Light Emitting Diode (LED)

Light emitting diodes must be choosen according to how they will be used, because there are various kinds.
The diodes are available in several colors. The most common colors are red and green, but there are even blue ones.

The device on the far right in the photograph combines a red LED and green LED in one package. The component lead in the middle is common to both LEDs. As for the remaing two leads, one side is for the green, the other for the red LED. When both are turned on simultaneously, it becomes orange.

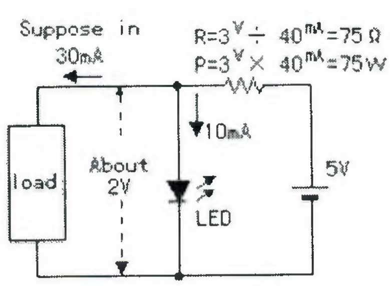


Figure : 2.40

When an LED is new out of the package, the polarity of the device can be determined by looking at the leads. The longer lead is the Anode side, and the short one is the Cathode side.

The polarity of an LED can also be determined using a resistance meter, or even a 1.5 V battery.

When using a test meter to determine polarity, set the meter to a low resistance measurement range. Connect the probes of the meter to the LED. If the polarity is correct, the LED will glow. If the LED does not glow, switch the meter probes to the opposite leads on the LED. In either case, the side of the diode which is connected to the black meter probe when the LED glows, is the Anode side. Positive voltage flows out of the black probe when the meter is set to measure resistance.

It is possible to use an LED to obtain a fixed voltage. The voltage drop (forward voltage, or V_F) of an LED is comparatively stable at just about 2V.

Figure : 2.41

2.5.1.6 Shottky barrier diyote

Diodes are used to rectify alternating current into direct current. However, rectification will not occur when the frequency of the alternating current is too high. This is due to what is known as the "reverse recovery characteristic."
The reverse recovery characteristic can be explained as follows:
IF the opposite voltage is suddenly applied to a forward-biased diode, current will continue to flow in the forward direction for a brief moment. This time until the current stops flowing is called the Reverse Recovery Time. The current is considered to be stopped when it falls to about 10% of the value of the peak reverse current.
The Shottky barrier diode has a short reverse recovery time, which makes it ideally suited to use in high frequency rectification.

The shottky barrier diode has the following characteristics.The voltage drop in the forward direction is low.The reverse recovery time is short. However, it has the following disadvantages.The diode can have relatively high leakage current.The surge resistance is low.

Because the reverse recovery time is short, this diode is often used for the switching regulator in a high frequency circuit.

2.5.2 Semiconductor diodes

Figure : 2.42

Diode schematic symbol. Conventional current can flow from the anode to the cathode, but not the other way around.

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 cannot flow 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.

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 (see also signal processing).

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.

2.5.2.1 Types of semiconductor diode

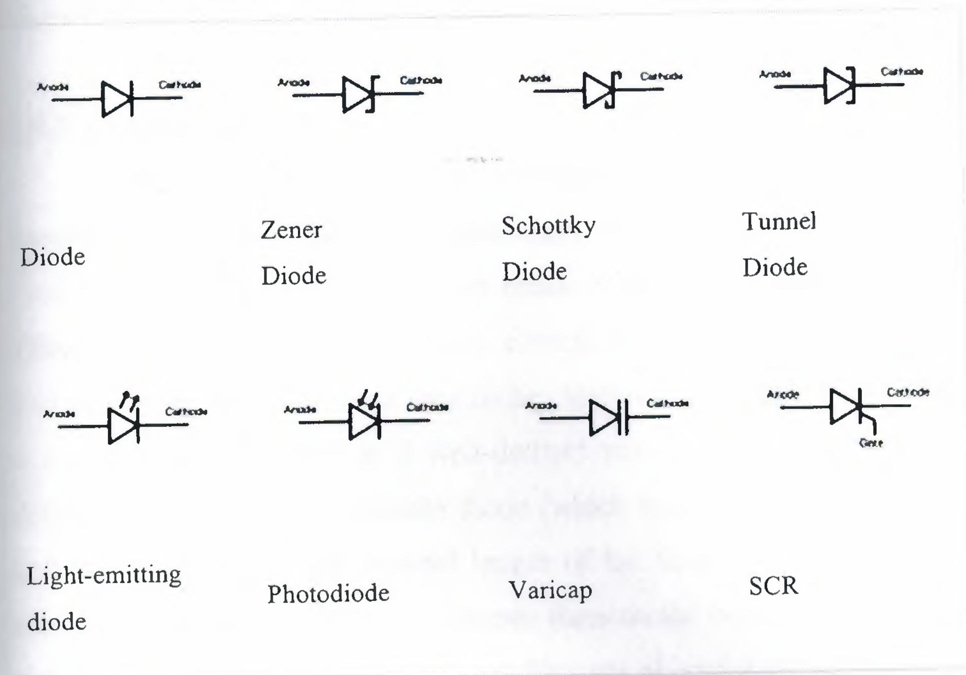


Figure : 2.43 Some diode symbols

There are several types of semiconductor junction diodes:

2.5.2.2 Normal (p-n) diodes

which operate as described above. 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.

2.5.2.3 Zener diodes

Zener 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.

2.5.2.4 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.

2.5.2.5 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.

2.6 Diode Bridge

Figure : 2.44

Three bridge rectifiers. The size is generally related to the current handling capability.

A diode bridge or bridge rectifier 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.

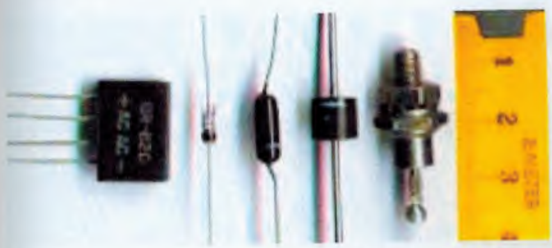
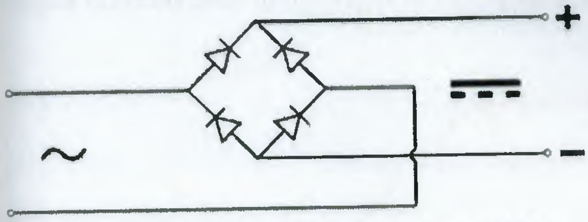


Figure : 2.45

Diodes; the one on the left is a diode bridge



Public domain, http://en.wikipedia.org/wiki/User:Wykis

Figure : 2.46

Schematic of a diode bridge

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.

2.6.1 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.

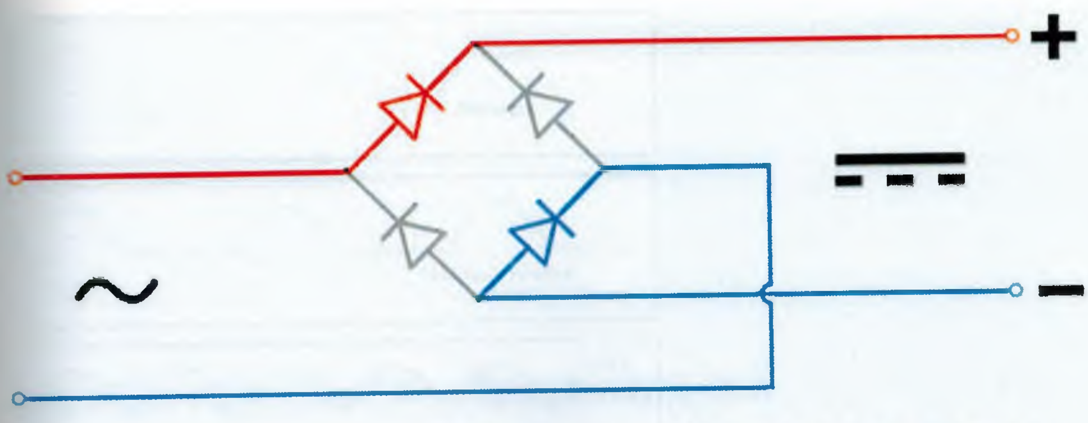


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Figure : 2.47

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.

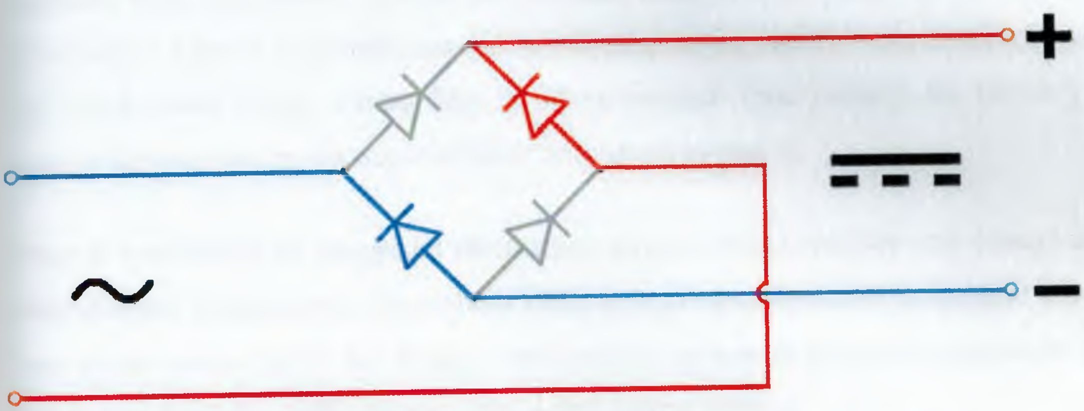

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Figure : 2.48

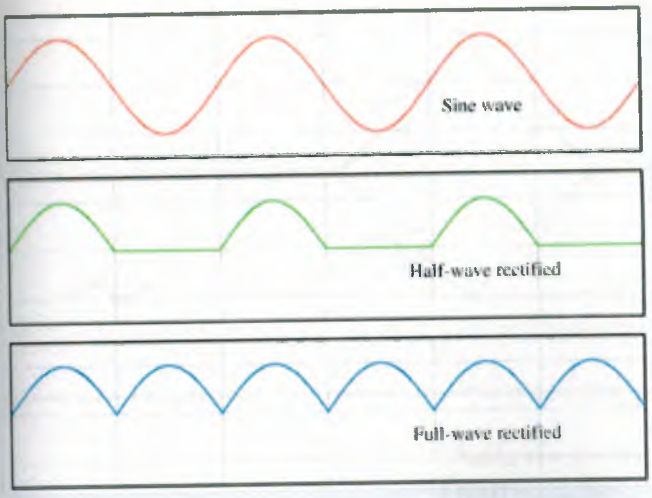


Figure : 2.49

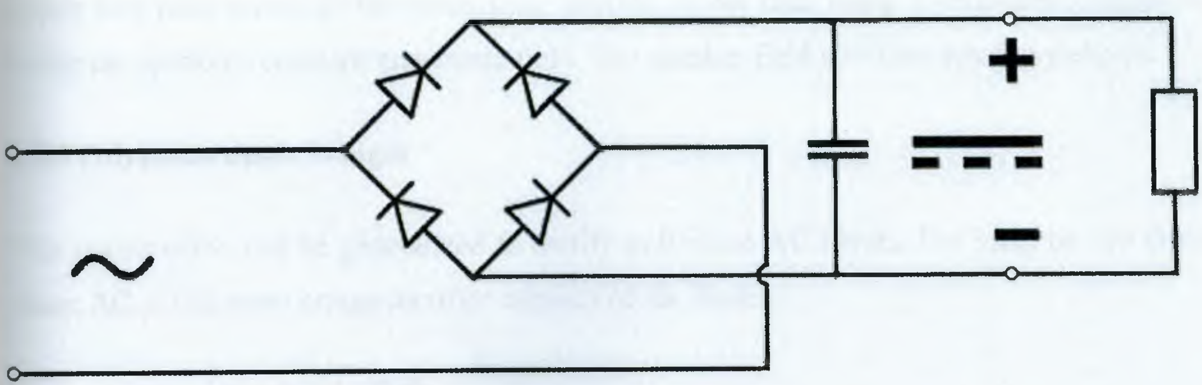
AC, half-wave and full wave rectified signals

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.

2.6.2 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).



Public domain, http://en.wikipedia.org/wiki/User:Wykis

Figure : 2.50

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. In some designs, a series resistor at the load side of the capacitor is added. The smoothing can then be improved by adding additional stages of capacitor–resistor pairs, often done only for sub-supplies to critical high-gain circuits that tend to be sensitive to supply voltage noise.

Output can also be smoothed using a choke, a coil of conductor enclosed by an iron frame (similar to a transformer in construction). This tends to keep the current (rather than the voltage) constant. Due to the relatively high cost of an effective choke compared to a resistor and capacitor this is not employed in modern equipment. Some early console radios created the speaker's constant field with the current from the high voltage ("B +") power supply, which was then routed to the consuming circuits, rather than using a permanent magnet to create the speaker's constant magenetic field. The speaker field coil thus acted as a choke.

2.6.3 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.

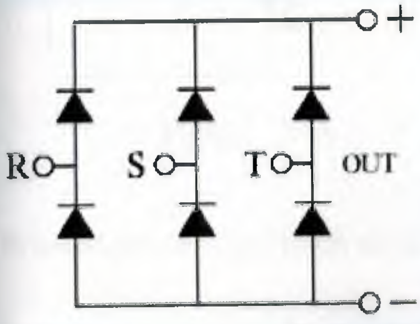


Figure : 2.51

Three Phase Bridge Rectifier for a wind turbine.

Figure : 2.52

Three Phase Bridge Rectifier for wind turbine.

Retrieved from "http://en.wikipedia.org/wiki/Diode_bridge"

2.6.4 Wheatstone bridge

A Wheatstone bridge is a measuring instrument invented by Samuel Hunter Christie in 1833 and improved and popularized by Sir Charles Wheatstone in 1843. It is used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component. Its operation is similar to the original potentiometer except that in potentiometer circuits the meter used is a sensitive galvanometer.

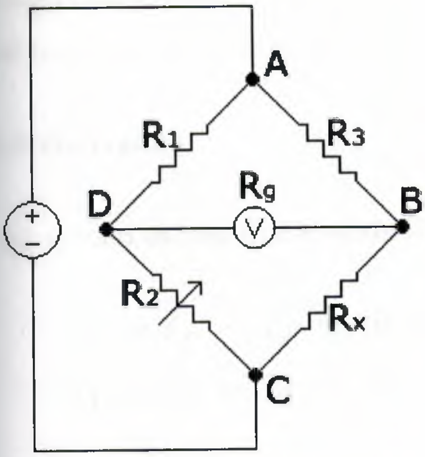


Figure : 2.53

Wheatstone's bridge circuit diagram.

In the circuit at right, R_x is the unknown resistance to be measured; R_1, R_2 and R_3 are resistors of known resistance and the resistance of R_2 is adjustable. If the ratio of the two resistances in the known leg (R_2 / R_1) is equal to the ratio of the two in the unknown leg (R_x / R_3), then the voltage between the two midpoints will be zero and no current will flow between the midpoints. R_2 is varied until this condition is reached. The current direction indicates if R_2 is too high or too low.

Detecting zero current can be done to extremely high accuracy (see Galvanometer). Therefore, if R_1, R_2 and R_3 are known to high precision, then R_x can be measured to high precision. Very small changes in R_x disrupt the balance and are readily detected.

If the bridge is balanced, which means that the current through the galvanometer R_g is equal to zero, the equivalent resistance of the circuit between the source voltage terminals is:

$R_1 + R_2$ in parallel with $R_3 + R_x$

$$R_E = \frac{(R_1 + R_2) \cdot (R_3 + R_x)}{R_1 + R_2 + R_3 + R_x}$$

Alternatively, if R_1, R_2, and R_3 are known, but R_2 is not adjustable, the voltage or current flow through the meter can be used to calculate the value of R_x, using Kirchhoff's circuit laws (also known as Kirchhoff's rules). This setup is frequently used in strain gauge and Resistance

Temperature Detector measurements, as it is usually faster to read a voltage level off a meter than to adjust a resistance to zero the voltage.

2.6.5 Derivation

First, we can use the first Kirchhoff rule to find the currents in junctions **B** and **D**:

$$I_3 - I_x - I_g = 0$$
$$I_1 + I_g - I_2 = 0$$

Then, we use Kirchhoff's second rule for finding the voltage in the loops **ABD** and **BCD**:

$$I_3 \cdot R_3 + I_g \cdot R_g - I_1 \cdot R_1 = 0$$
$$I_x \cdot R_x - I_2 \cdot R_2 - I_g \cdot R_g = 0$$

The bridge is balanced and $I_g = 0$, so we can rewrite the second set of equations:

$$I_3 \cdot R_3 = I_1 \cdot R_1$$
$$I_x \cdot R_x = I_2 \cdot R_2$$

Then, we divide the equations and rearrange them, giving:

$$R_x = \frac{R_2 \cdot I_2 \cdot I_3 \cdot R_3}{R_1 \cdot I_1 \cdot I_x}$$

From the first rule, we know that $I_3 = I_x$ and $I_1 = I_2$. The desired value of R_x is now known to be given as:

$$R_x = \frac{R_3 \cdot R_2}{R_1}$$

If all four resistor values and the supply voltage (V_s) are known, the voltage across the bridge (V) can be found by working out the voltage from each potential divider and subtracting one from the other. The equation for this is:

$$V = \frac{R_x}{R_3 + R_x} V_s - \frac{R_2}{R_1 + R_2} V_s$$

This can be simplified to:

$$V = \left(\frac{R_x}{R_3 + R_x} - \frac{R_2}{R_1 + R_2}\right) V_s$$

The Wheatstone bridge illustrates the concept of a difference measurement, which can be extremely accurate. Variations on the Wheatstone bridge can be used to measure capacitance, inductance, impedance and other quantities, such as the amount of combustible gases in a sample, with an explosimeter. The **Kelvin Double bridge** was one specially adapted for measuring very low resistances. This was invented in 1861 by William Thomson, Lord Kelvin.

The concept was extended to alternating current measurements by James Clerk Maxwell in 1865 and further improved by Alan Blumlein in about 1926.

2.7 TRIAC

A TRIAC, or TRIode for Alternating Current is an electronic component approximately equivalent to two silicon-controlled rectifiers (SCRs/thyristors) joined in inverse parallel (paralleled but with the polarity reversed) and with their gates connected together. This results in a bidirectional electronic switch which can conduct current in either direction when it is triggered (turned on). It can be triggered by either a positive or a negative voltage being applied to its gate electrode. Once triggered, the device continues to conduct until the current through it drops below a certain threshold value, such as at the end of a half-cycle of alternating current (AC) mains power. This makes the TRIAC a very convenient switch for AC circuits, allowing the control of very large power flows with milliampere-scale control currents. In addition, applying a trigger pulse at a controllable point in an AC cycle allows one to control the percentage of current that flows through the TRIAC to the load (so-called phase control).

Low power TRIACs are used in many applications such as light dimmers, speed controls for electric fans and other electric motors, and in the modern computerized control circuits of many household small and major appliances. However, when used with inductive loads such as electric fans, care must be taken to assure that the TRIAC will turn off correctly at the end of each half-cycle of the ac power.

2.8 DIMMER

Analog Circuit Design, Art, Science, and Personalities", edited by Jim Williams, 1991, Butterword HeinemannDimmer

Figure : 2.54

Another dimmer by Colortran

Dimmers are devices used to vary the brightness of a light. By decreasing or increasing the RMS voltage and hence the mean power to the lamp it is possible to vary the intensity of the light output. Although variable-voltage devices are used for various purposes, the term dimmer is generally reserved for those intended to control lighting.

Dimmers range in size from small units the size of a normal lightswitch used for domestic lighting to high power units used in large theatre or architectural lighting installations. Small domestic dimmers are generally directly controlled, although remote control systems (such as X10) are available. Modern professional dimmers are generally controlled by a digital control system like DMX.

In the professional lighting industry changes in intensity are called "fades" and can be "fades up" or "fades down". Dimmers with direct manual control had a limit on the speed they could be varied at but this issue is pretty much gone with modern digital units (although very fast changes in brightness may still be avoided for other reasons like bulb life).

They are used instead of variable resistors because they have higher efficiency. A variable resistor would dissipate power by heat (efficiency as low as 0.5). By switching on and off, theoretically a dimmer does not heat up (efficiency close to 1.0).

2.8.1 History

Some of the earliest records of dimmers were of Granville Woods "Safety Dimmer" in 1890; dimmers before that were liable to cause fires.

Early dimmers were directly controlled through the manual manipulation of large dimmer panels, but this meant that all power had to come through the lighting control location, which could be inconvenient and potentially dangerous, especially with systems that had a large number of channels, high power lights or both (such as a stage disco or other similar venues).

When thyristor dimmers came into use, analog remote control systems (often 0-10V lighting control systems) became feasible. The wire for the control systems was much smaller (with low current and lower danger) than the heavy power cables of previous lighting systems. Each dimmer had its own control wires which meant a huge number of wires leaving the lighting control location and running to each individual dimmer. Modern systems use a digital control protocol such as DMX to control a large number of dimmers (and other stage equipment) through a single cable.

In 1961 Joel Spira, founder of Lutron Electronics, invented the first solid state dimmer, which switches the current on and off 120 times per second, saving energy and allowing the dimmer to be installed in a standard electrical wallbox.

2.8.2 Types of dimmer

Early examples of a dimmer include a salt water dimmer. In a salt water dimmer, there were two metal contacts in a glass beaker. One contact was on the bottom, while the other was able to move up and down. The closer the contacts to each other, the higher the level of the light. Using salt water dimmers was a tedious and precarious task that included filling the beakers with water, checking the concentration of the salt, and raising or lowering the top contact. Salt water dimmers were not efficient due to the evaporation of water and the corrosion of the many metal pieces. These dimmers were colloquially known as "piss pots", for obvious reasons. Many old theatre electricians still recount stories of how they were initiated into the art by being requested to "top up a pot" and receiving a shock, as unbeknownst to them the pot was live...

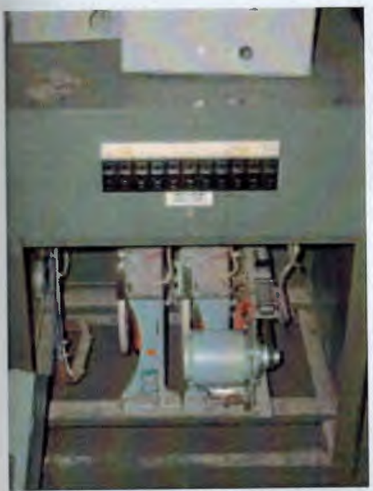


Figure : 2.55

Two 6000 watt motor driven autotransformer dimmers, used for house lighting

Dimmers were also often based on rheostats. These were inefficient; when set to the middle brightness levels, they could dissipate as heat a significant portion of the power rating of the load (up to 25% for resistive loads, more for temperature dependent loads like lamps) so they were physically large and required plenty of cooling air. Also, because their dimming effect depended a great deal on the total load applied to each rheostat, the load needed to be matched fairly carefully to the power rating of the rheostat. Finally, as they relied on mechanical control they were slow and it was difficult to change many channels at a time.

Variable autotransformers (often referred to as variacs) were then introduced. While they were still nearly as large as rheostat dimmers, they were highly efficient devices and their dimming effect was independent of the load applied so it was far easier to design the lighting that would be attached to each autotransformer channel. Remote control of the dimmers was still impractical, although some dimmers (typically, for "house light" use) were equipped with motor drives that could slowly and steadily reduce or increase the brightness of the attached lamps. Whilst variacs have fallen out of use for lighting they are still used in other applications such as under/overvoltage testing of equipment due to the fact they deliver a reasonably pure sine wave output and produce no radio frequency noise.

Figure : 2.56

A Strand CD80 thyristor dimmer rack

Thyristor (and briefly, thyratron) dimmers were introduced to solve some of these problems. Because they use switching techniques instead of potential division there is almost no wasted power, dimming can be almost instantanious and is easily controlled by remote electronics. Triacs are used instead of SCR thyristors in lower cost designs, but do not have the surge handling capacity of back-to-back SCR's, and are only suitable for loads less than about 20 Amps. The switches generate some heat during switching, and can cause interference. Large inductors are used as part of the circuitry to suppress this interference. When the dimmer is at 50% power the switches are switching their highest voltage (>300 V in Europe) and the sudden surge of power causes the coils on the inductor to move, creating buzzing sound associated with some types of dimmer; this same effect can be heard in the filaments of the incandescent lamps as "singing". The suppression circuitry adds a lot of weight to the dimmer, and is often insufficient to prevent buzzing to be heard on audio systems that share the mains supply with the lighting loads. This development also made it possible to make dimmers small enough to be used in place of normal domestic light switches. European dimmers must comply with relevant EMC legislation requirements; this involves suppressing the emissions described above to limits described in EN55104.

An alternative to the leading-edge dimming that is typically used with SCRs is trailing edge dimming, where the falling part of the waveform is cut rather than the rising part. This is most often used in devices that use a switched-mode power supplies that need the front of the waveform complete so that it may cut itself.

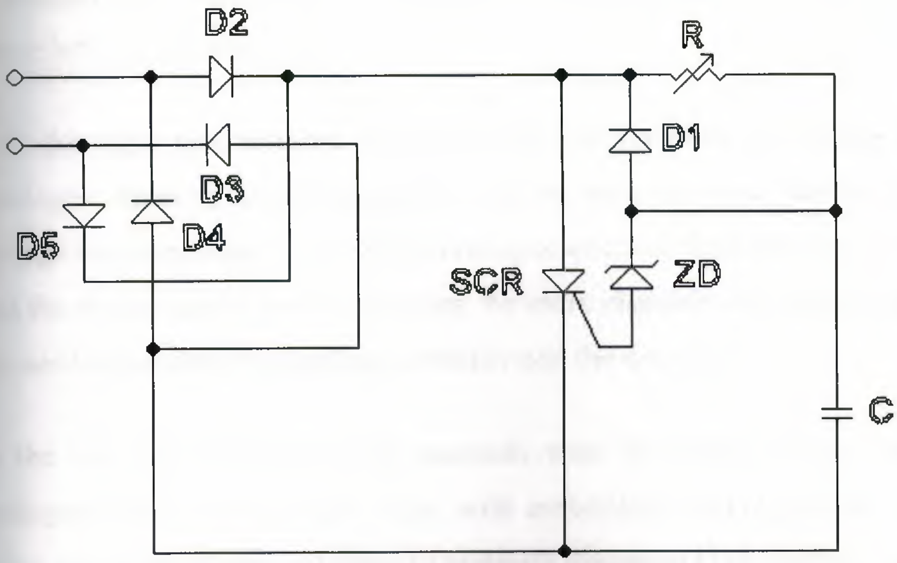


Figure : 2.57

A typical SCR based light dimmer which dims the light through phase angle control. This unit is wired in series with the load. Diodes (D_2, D_3, D_4 and D_5) form a bridge which generates DC with lots of ripple. R and C form a circuit with a time constant, as the voltage increases from zero (at the start of every halfwave) C will charge up, when C is able to make ZD conduct and inject current into the SCR the SCR will fire. When the SCR conducts then D_1 will discharge C via the SCR. The SCR will shut off when the current falls to zero when the supply voltage drops at the end of the half cycle, ready for the circuit to start work on the next half cycle.

Sine-wave dimming promises to solve the weight and interference issues that afflict thyristor dimmers. These are effectively high power switched-mode power supplies. They rely on a new generation of insulated gate bipolar transistors (IGBTs) which are still relatively expensive.

2.8.3 Control

Figure : 2.58

A dimmer rack containing 192 dimmers, with one dimmer per circuit. The black box at the upper left is a demultiplexer.

Non domestic dimmers are usually controlled remotely by means of various protocols. Analogue dimmers usually require a separate wire for each channel of dimming carrying a voltage between 0 and 10 V. Some analogue circuitry then derives a control signal from this and the mains supply for the switches. As more channels are added to the system more wires are needed between the lighting controller and the dimmers.

In the late 70s serial analogue protocols were developed. These multiplexed a series of analogue levels onto a single wire, with embedded clocking signal similar to a composite video signal (in the case of Strand Lighting's European D54 standard, handling 384 dimmers) or separate clocking signal (in the case of the US standard AMX192).

Digital protocols, such as DMX512 have proved to be the answer since the late 80s. In early implementations a digital signal was sent from the controller to a demultiplexer, which sat next to the dimmers. This converted the digital signal into a collection of 0 to +10 V or 0 to -10 V signals which could be connected to the individual analogue control circuits.

Modern dimmer designs use microprocessors to convert the digital signal directly into a control signal for the switches. This has many advantages, giving closer control over the dimming, and giving the opportunity for diagnostic feedback to be sent digitally back to the lighting controller.

2.8.4 Dimming curves

The design of most analogue dimmers meant that the output of the dimmer was not directly proportional to the input. Instead, as the operator brought up a fader the dimmer would dim slowly at first, then quickly in the middle, then quickly at the top. The shape of the curve resembled that of the third quarter of a sine wave. Different dimmers produced different dimmer curves, and different applications typically demanded different responses.

Television often uses a "Square" law, providing finer control in top part of the curve, essential to allow accurate trimming of the colour temperature of TV lighting. Theatrical dimmers tend to use a softer "S curve" or linear curve. Digital dimmers can be made to have whatever curve the manufacturer desires and may have a choice between a linear relationship and selection of different curves, so that they can be matched with older analogue dimmers. Sophisticated systems provide user-programmable or non-standard curves, and a common use of a non-standard curve it to turn a dimmer into a "non-dim", switching on at a user defined control level.

Example dimmer curves

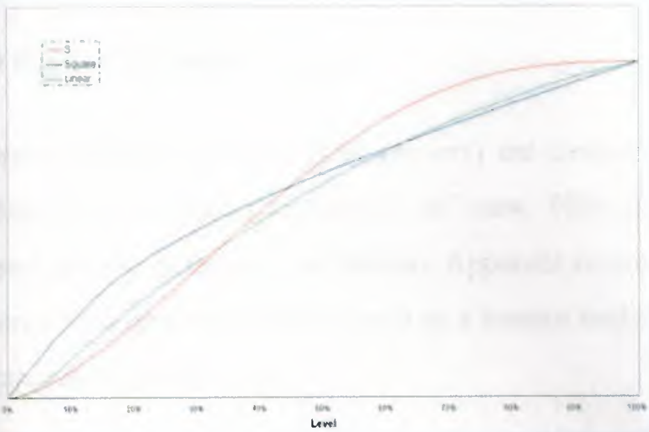


Figure : 2.59

2.8.5 Rise time

One measure of the quality of the dimmer is the "rise time". The rise time in this context is the amount of time it takes within the cut part of the waveform to get from the zero-point crossover to the start of the uncut part of the waveform. A longer rise time reduces the noise of the dimmer and the lamp as well as extending the life of the map. Unsurprisingly, a longer rise time is more expensive to implement than a short one, this is because the size of choke has to be increased.

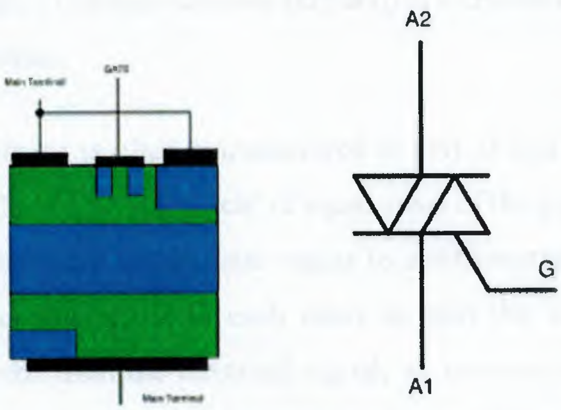


Figure : 2.60

Triac semiconductor construction

A snubber circuit is often used to assist this turn off. Snubber circuits are also used to prevent premature triggering. For higher-powered, more-demanding loads, two SCRs in inverse parallel may be used instead of one TRIAC. Because each SCR will have an entire half-cycle of reverse polarity voltage applied to it, turn-off of the SCRs is assured, no matter what the character of the load.

2.9 Passive InfraRed sensors

Passive InfraRed sensors (PIR sensors) are electronic devices which measure infrared light radiating from objects in the field of view. PIRs are often used in the construction of PIR-based motion detectors, see below. Apparent motion is detected when an infrared emitting source with one temperature, such as a human body, passes in front of a source with another temperature, such as a wall.

All objects emit infrared radiation; see black body radiation. This radiation (energy) is invisible to the human eye but can be detected by electronic devices designed for such a purpose. The term 'passive' in this instance means the PIR does not emit any energy of any type but merely sits 'passive' accepting infrared energy through the front of the sensor, known as the sensor face. At the core of a PIR is a solid state sensor or set of sensors, with approximately 1/4 inch square area. The sensor areas are made from a pyroelectric material.

The actual sensor on the chip is made from natural or artificial pyroelectric materials, usually in the form of a thin film, out of gallium nitride (GaN), caesium nitrate ($CsNO_3$), polyvinyl fluorides, derivatives of phenylpyrazine, and cobalt phthalocyanine. (See pyroelectric crystals.) Lithium tantalate ($LiTaO_3$) is a crystal exhibiting both piezoelectric and pyroelectric properties.

The sensor is often manufactured as part of an integrated circuit and may consist of one (1), two (2) or four (4) 'pixels' of equal areas of the pyroelectric material. Pairs of the sensor pixels may be wired as opposite inputs to a differential amplifier. In such a configuration, the PIR measurements cancel each other so that the average temperature of the field of view is removed from the electrical signal; an increase of IR energy across the entire sensor is self-cancelling and will not trigger the device. This allows the device to resist false indications of change in the event of being exposed to flashes of light or field-wide illumination.

(Continuous bright light could still saturate the sensor materials and render the sensor unable to register further information.) At the same time, this differential arrangement minimizes common-mode interference; this allows the device to resist triggering due to nearby electric fields. However, a differential pair of sensors cannot measure temperature in that configuration and therefore this configuration is specizliaed for motion detectors, see below.

2.10 Transformer

Figure : 2.61

Three-phase pole-mounted step-down transformer.

A transformer is a device that transfers electrical energy from one circuit to another by magnetic coupling without requiring relative motion between its parts. It usually comprises two or more coupled windings, and, in most cases, a core to concentrate magnetic flux.

An alternating voltage applied to one winding creates a time-varying magnetic flux in the core, which induces a voltage in the other windings. Varying the relative number of turns between primary and secondary windings determines the ratio of the input and output voltages, thus transforming the voltage by stepping it up or down between circuits.

The transformer principle was demonstrated in 1831 by Faraday, though practical designs did not appear until the 1880s.[1] Within less than a decade, the transformer was instrumental during the "War of Currents" in seeing alternating current systems triumph over their direct current counterparts, a position in which they have remained dominant. The transformer has since shaped the electricity supply industry, permitting the economic transmission of power over long distances. All but a fraction of the world's electrical power has passed through a series of transformers by the time it reaches the consumer.

Amongst the simplest of electrical machines, the transformer is also one of the most efficient,[2] with large units attaining performances in excess of 99.75%.[3] Transformers come in a range of sizes from a thumbnail-sized coupling transformer hidden inside a stage microphone to huge giga VA-rated units used to interconnect portions of national power grids. All operate with the same basic principles and with many similarities in their parts, though a variety of transformer designs exist to perform specialized roles throughout home and industry.

2.10.1 History

Michael Faraday built the first transformer in 1831, although he used it only to demonstrate the principle of electromagnetic induction and did not foresee its practical uses.[1] 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". The patent claimed the system could "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.

Lucien Gaulard and John Dixon Gibbs, who first exhibited a device with an open iron core called a 'secondary generator' in London in 1882 and then sold the idea to American company Westinghouse.[4] 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.

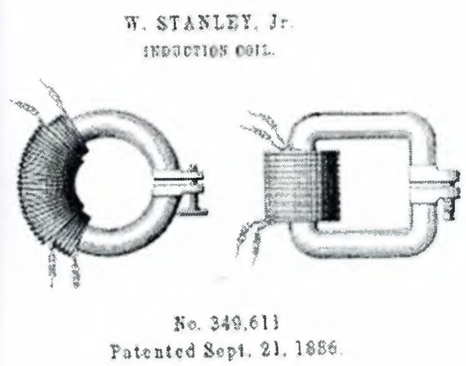


Figure : 2.62

A historical Stanley transformer.

William Stanley, an engineer for Westinghouse, built the first commercial device in 1885 after George Westinghouse had bought Gaulard and Gibbs' patents. The core was made from interlocking E-shaped iron plates. This design was first used commercially in 1886.[1] Hungarian engineers Zipernowsky, Bláthy and Déri from the Ganz company in Budapest created the efficient "ZBD" closed-core model in 1885 based on the design by Gaulard and Gibbs.[5] Their patent application made the first use of the word "transformer".[4] Russian engineer Mikhail Dolivo-Dobrovolsky developed the first three-phase transformer in 1889. In 1891 Nikola Tesla invented the Tesla coil, an air-cored, dual-tuned resonant transformer for generating very high voltages at high frequency.

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 transformers in some electronics applications obsolete, transformers are still found in many electronic devices. 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.[1] Many others have patents on transformers.

2.10.2 Basic principles

2.10.2 .1 Coupling by mutual induction

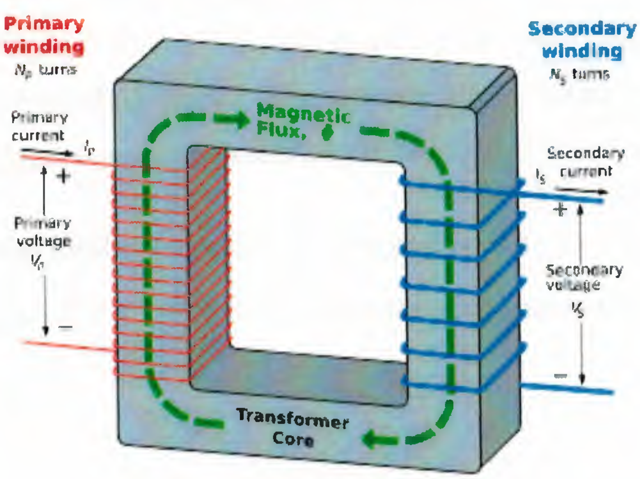


Figure : 2.63

An ideal step-down transformer showing magnetic flux in the core

The principles of the transformer are illustrated by consideration of a hypothetical ideal transformer consisting of two windings of zero resistance around a core of negligible reluctance.[6] A voltage applied to the primary winding causes a current, which develops a magnetomotive force (MMF) in the core. The current required to create the MMF is termed the magnetising current; in the ideal transformer it is considered to be negligible, although its presence is still required to drive flux around the magnetic circuit of the core.[6]

An electromotive force (EMF) is induced across each winding, an effect known as mutual inductance.[7] In accordance with Faraday's law of induction, the EMFs are proportional to the rate of change of flux:

$$e_P = N_P \frac{d\Phi_P}{dt} \quad \text{and} \quad e_S = N_S \frac{d\Phi_S}{dt}$$

where:

- e_P and e_S are the induced EMFs across primary and secondary windings,
- N_P and N_S are the numbers of turns in the primary and secondary windings,
- $\frac{d\Phi_P}{dt}$ and $\frac{d\Phi_S}{dt}$ are the time derivatives of the flux linking the primary and secondary windings.

Since the ideal windings have no impedance, they have no associated voltage drop, and so the voltages v_P and v_S, measured at the terminals of the transformer, are equal to the corresponding EMFs. The primary EMF, acting as it does in opposition to the primary voltage, is sometimes termed the "back EMF".[8]

In the ideal transformer, all flux produced by the primary winding also links the secondary,[9] and so $\Phi_P = \Phi_S$, from which the well-known transformer equation follows:

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

The ratio of primary to secondary voltage is therefore the same as the ratio of the number of turns;[6] alternatively, that the volts-per-turn is the same in both windings.

Under load

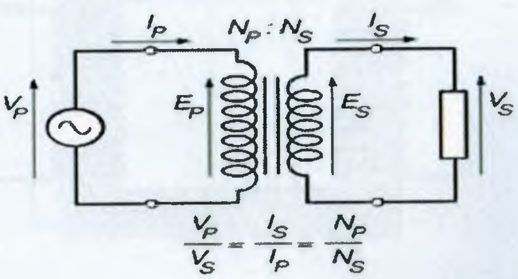


Figure : 2.64

The ideal transformer as a circuit element

If a load impedance is connected to the secondary winding, a current will flow in the secondary circuit now created. The current develops an MMF over the secondary winding in opposition to that of the primary winding, so acting to reduce the flux in the core.[9] However, any decrease in the flux reduces the primary EMF, and causes current in the primary circuit to increase until it has exactly offset the effect of the secondary MMF, so maintaining the flux and both EMFs at their former values.[10] The core flux thus remains the same regardless of the secondary current, and is instead determined by the magnitude of the primary voltage, provided that voltage is sustained.[9] In this way, the electrical energy fed into the primary circuit is delivered to the secondary circuit.
The primary and secondary MMFs differ only to the extent of the contribution by the negligible magnetising current and so approach equality: $i_P N_P \approx i_S N_S$. If these terms are equated, ignoring the magnetising current, then the transformer current relationship emerges:

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

From consideration of the voltage and current relationships, it may be readily shown that impedance in one circuit is transformed by the square of the turns ratio,[9] a secondary impedance Z_S thus appearing to the primary circuit to have a value of $Z_S\left(\frac{N_P}{N_S}\right)^2$.

2.10.3 Practical considerations

2.10.3.1 Flux leakage

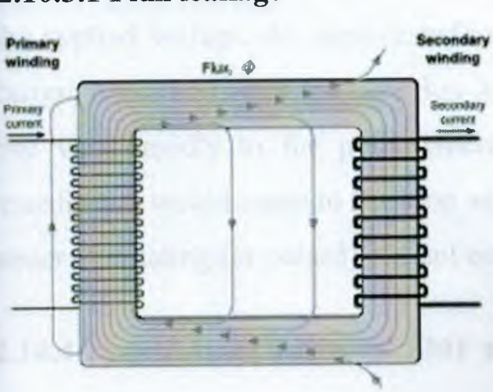


Figure : 2.65

Flux leakage in a two-winding transformer

Main article: Leakage inductance

The ideal transformer model assumes that all flux generated by the primary winding links all the turns of every winding, including itself. In practice, some flux traverses paths that take it outside the windings.[11] Such flux is termed leakage flux, and manifests itself as self-inductance in series with the mutually coupled transformer windings.[8] Leakage results in energy being alternately stored in and discharged from the magnetic fields with each cycle of the power supply. It is not itself directly a source of power loss, but results in poorer voltage regulation, causing the secondary voltage to fail to be directly proportional to the primary, particularly under heavy load.[11] Distribution transformers are therefore normally designed to have very low leakage inductance.

However, in some applications, leakage can be a desirable property, and long magnetic paths, air gaps, or magnetic bypass shunts may be deliberately introduced to a transformer's design to limit the short-circuit current it will supply.[8] Leaky transformers may be used to supply loads that exhibit negative resistance, such as electric arcs, mercury vapor lamps, and neon signs; or for safely handling loads that become periodically short-circuited such as electric arc welders. Air gaps are also used to keep a transformer from saturating, especially audio-frequency transformers that have a DC component added.

2.10.3.2 Effect of frequency

The time-derivative term in Faraday's Law implies that the flux in the core is the integral of the applied voltage. An ideal transformer would, at least hypothetically, work under direct-current excitation, with the core flux increasing linearly with time. In practice, the flux would rise very rapidly to the point where magnetic saturation of the core occurred and the transformer would cease to function as such. All practical transformers must therefore operate under alternating (or pulsed) current conditions.

2.10.4 Transformer universal EMF equation

If the flux in the core is sinusoidal, the relationship for either winding between its rms EMF E, and the supply frequency f, number of turns N, core cross-sectional area a and peak magnetic flux density B is given by the universal EMF equation:[6]

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

The EMF of a transformer at a given flux density increases with frequency, an effect predicated by the universal transformer EMF equation.[6] 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 efficiency becomes poorer with properties such as core loss and conductor skin effect also increasing with frequency. Aircraft and military equipment traditionally employ 400 Hz power supplies since the decrease in efficiency is more than offset by the reduction in core and winding weight.[12]

In general, operation of a transformer at its designed voltage but at a higher frequency than intended will lead to reduced magnetising current. At a frequency lower than the design value, with the rated voltage applied, the magnetising current may increase to an excessive level. Operation of a 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 may need to be equipped with "volts per hertz" over-excitation relays to protect the transformer from overvoltage at higher than rated frequency.

2.10.5 Energy losses

An ideal transformer would have no energy losses, and would therefore be 100% efficient. Despite the transformer being amongst the most efficient of electrical machines, with experimental models using superconducting windings achieving efficiencies of 99.85%,[13] energy is dissipated in the windings, core, and surrounding structures. Larger transformers are generally more efficient, and those rated for electricity distribution usually perform better than 95%.[14] A small transformer such as a plug-in "power brick" used for low-power consumer electronics may be less than 85% efficient.

Figure : 2.66

Transformers are amongst the most efficient of machines, but all exhibit losses

Transformer losses are attributable to several causes and may be differentiated between those originating in the windings, sometimes termed copper loss, and those arising from the magnetic circuit, sometimes termed iron loss. The losses vary with load current, and may furthermore be expressed as "no-load" or "full-load" loss, or at an intermediate loading. Winding resistance dominates load losses, whereas hysteresis and eddy currents losses contribute to over 99% of the no-load loss.

Losses in the transformer arise from:

2.10.5.1 Winding resistance

Current flowing through the windings causes resistive heating of the conductors. At higher frequencies, skin effect and proximity effect create additional winding resistance and losses.

2.10.5.2 Eddy currents

Ferromagnetic materials are also good conductors, and a solid core made from such a material also constitutes a single short-circuited turn throughout its entire length. Induced eddy currents therefore circulate within the core in a plane normal to the flux, and are responsible for resistive heating of the core material.

2.10.5.3 Hysteresis losses

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

2.10.5.4 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 produces the familiar buzzing sound, and in turn causes losses due to frictional heating in susceptible cores.

2.10.5.5 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, adding to the buzzing noise, and consuming a small amount of power.

2.10.5.6 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.

2.10.5.7 Cooling system

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

2.10.6 Equivalent circuit

The physical limitations of the practical transformer may be brought together as an equivalent circuit model built around an ideal lossless transformer.[15] Power loss in the windings is current-dependant and is easily represented as in-series resistances R_P and R_S.

Flux leakage results in a fraction of the applied voltage dropped without contributing to the mutual coupling, and thus can be modelled as self-inductances X_P and X_S in series with the perfectly-coupled region. Iron losses are caused mostly by hysteresis and eddy current effects in the core, and tend to be proportional to the square of the core flux for operation at a given frequency. [16] Since the core flux is proportional to the applied voltage, the iron loss can be represented by a resistance R_C in parallel with the ideal transformer.

A core with finite permeability requires a magnetising current I_M to maintain the mutual flux in the core. The magnetising current is in phase with the flux; saturation effects cause the relationship between the two to be non-linear, but for simplicity this effect tends to be ignored in most circuit equivalents.[16] With a sinusoidal supply, the core flux lags the induced EMF by 90° and this effect can be modelled as a magnetising reactance X_M in parallel with the core loss component. R_C and X_M are sometimes together termed the magnetising branch of the model. If the secondary winding is made open-circuit, the current I_0 taken by the magnetising branch represents the transformer's no-load current.[15]

The secondary impedance R_S and X_S is frequently moved (or "referred") to the primary side after multiplying the components by the impedance scaling factor $\left(\frac{N_P}{N_S}\right)^2$.

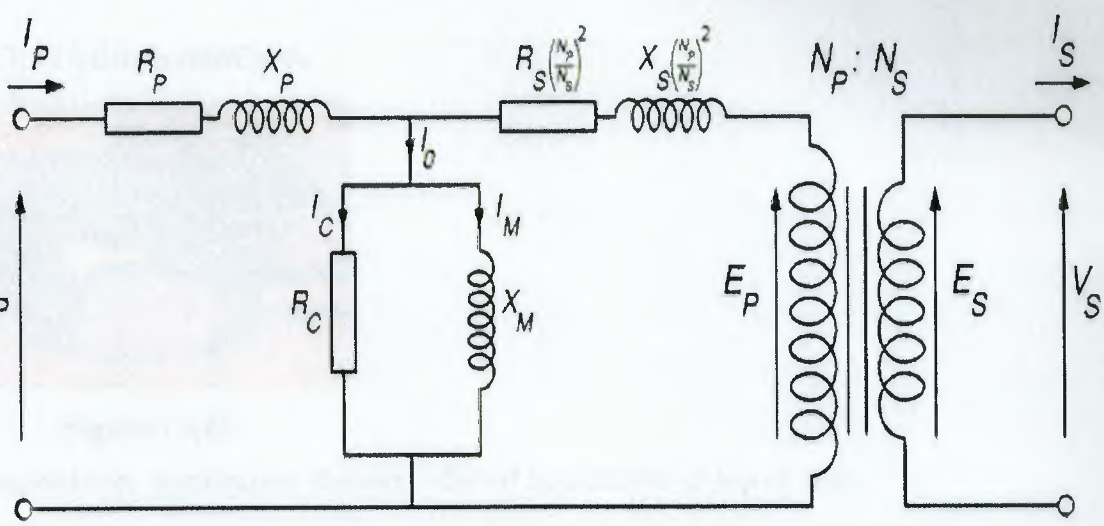


Figure : 2.67

Transformer equivalent circuit, with secondary impedances referred to the primary side

The resulting model is sometimes termed the "exact equivalent circuit", though it retains a number of approximations, such as an assumption of linearity.[15] Analysis may be simplified by moving the magnetising branch to the left of the primary impedance, an implicit assumption that the magnetising current is low, and then summing primary and referred secondary impedances.

2.10.7 Transformer types and uses

A variety of specialised transformer designs has been created to fulfil certain engineering applications. The numerous applications to which transformers are adapted lead them to be classified in many ways:

- By power level: from a fraction of a volt-ampere (VA) to over a thousand MVA;
- By frequency range: power-, audio-, or radio frequency;
- By voltage class: from a few volts to hundreds of kilovolts;
- By cooling type: air cooled, oil filled, fan cooled, or water cooled;
- By application function: such as power supply, impedance matching, or circuit isolation;
- By end purpose: distribution, rectifier, arc furnace, amplifier output;
- By winding turns ratio: step-up, step-down, isolating (near equal ratio), variable.

2.10.7.1 ConstructionCores

Figure : 2.68

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

2.10.7.2 Steel cores

Transformers for use at power or audio frequencies typically have cores made of high permeability silicon steel.[17] By concentrating the magnetic flux, more of it usefully links both primary and secondary windings, and the magnetising current is greatly reduced. Early transformer developers soon realised that cores constructed from solid iron resulted in prohibitive eddy-current losses, and their designs mitigated this effect with cores consisting of bundles of insulated iron wires.[4] Later designs constructed the core by stacking layers of thin steel laminations, a principle still in use. Each lamination is insulated from its neighbours by a coat of non-conducting paint. The universal transformer equation indicates a minimum cross-sectional area for the core to avoid saturation.

The effect of laminations is to confine eddy currents to highly elliptical paths that enclose little flux, and so reduce their magnitude. Thinner laminations reduce losses,[17] but are more laborious and expensive to construct.[18] Thin laminations are generally used on high frequency transformers, with some types of very thin steel laminations able to operate up to 10 kHz.

Figure : 2.69

E-I core construction, windings omitted

One common design of laminated core is made from interleaved stacks of E-shaped steel sheets capped with I-shaped pieces, leading to its name of "E-I transformer".[18] The cut-core or C-core type is made by winding a steel strip around a rectangular form and then bonding the layers together. It is then cut in two, forming two C shapes, and the core assembled by binding the two C halves together with a steel strap.[18] They have the advantage that the flux is always oriented parallel to the metal grains, reducing reluctance.

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 initial cost of the core material is offset over the life of the transformer by its lower losses at light load.

2.10.7.3 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. For frequencies extending to beyond the VHF band, cores made from non-conductive magnetic ceramic materials called ferrites are common.[18] Some radio-frequency transformers also have moveable cores (sometimes called 'slugs') which allow adjustment of the coupling coefficient (and bandwidth) of tuned radio-frequency circuits.

2.10.7.4 Air cores

A physical core is not an absolute requisite and a functioning transformer can be achieved simply by placing the windings in close proximity to each other, an arrangement termed an "air-core" transformer. The air which comprises the magnetic circuit is essentially lossless, and so an air-core transformer eliminates loss due to hysteresis in the core material.[8] The leakage inductance is inevitably high, resulting very poor regulation, and so such designs are unsuitable for use in power distribution.[8] They have however very high bandwidth, and are frequently employed in radio-frequency applications,[19] for which a satisfactory coupling coefficient is maintained by carefully overlapping the primary and secondary windings.

2.10.7.5 Toroidal cores

Figure : 2.70

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 E-I 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 E-I types of similar power level. Other advantages, compared to E-I 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. This can happen if the steel mounting bolt in the middle of the core is allowed to touch metalwork at both ends, making a loop of conductive material that passes through the hole in the toroid. Such a loop could result in a dangerously large current flowing in the bolt.

2.10.8 Windings

Circuit symbols

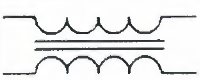
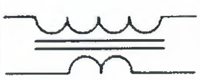
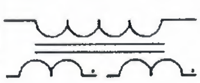
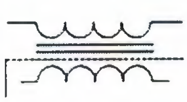
	Transformer with two windings and iron core.
	Step-down or step-up transformer. The symbol shows which winding has more turns, but not usually the exact ratio.
	Transformer with three windings. The dots show the relative configuration of the windings.
	Transformer with electrostatic screen preventing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

Figure : 2.71

The conducting material used for the windings depends upon the application, but in all cases the individual turns must be electrically insulated from each other and from the other windings.[20] For small power and signal transformers, the coils are often wound from enamelled magnet wire, such as Formvar wire. Larger power transformers operating at high voltages may be wound with wire, copper, or aluminium rectangular conductors insulated by oil-impregnated paper.[21] 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.[20] 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.[21] Each strand is individually insulated, 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, aiding manufacture.[21]

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.

Both the primary and secondary windings on power transformers may have external connections, called taps, to intermediate points on the winding to allow selection of the voltage ratio. The taps may be connected to an automatic, on-load tap changer 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 circuit. Modulation transformers in AM transmitters are very similar.

2.10.8.1 Winding 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 may suffice 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. This produces transformers suitable for damp or dirty environments, but at increased manufacturing cost.

2.10.9 Basic Impulse Insulation Level (BIL)

Outdoor electrical distribution systems are subject to lightning surges. Even if the lightning strikes the line some distance from the transformer, voltage surges can travel down the line and into the transformer. High voltage switches and circuit breakers can also create similar voltage surges when they are opened and closed. Both types of surges have steep wave fronts and can be very damaging to electrical equipment . To minimize the effects of these surges, the electrical system is protected by lighting arresters but they do not completely eliminate the surge from reaching the transformer. The basic impulse level (BIL) of the transformer measures its ability to withstand these surges. All 600 volt and below transformers are rated 10 kV BIL. The 2400 and 4160 volt transformers are rated 25 kV BIL.

2.10.9.1 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.

2.10.9.2 Coolant

Figure : 2.72

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 sulphur 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 by-products, and its accumulation in the environment, it is no longer permitted in new equipment. Old transformers that 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, non-toxic, 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.

2.10.9.3 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.

2.10.9.4 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).

3. Electric motor

An electric motor converts electrical energy into mechanical energy. The reverse task, that of converting mechanical energy into electrical energy, is accomplished by a generator or dynamo. Traction motors used on locomotives often perform both tasks if the locomotive is equipped with dynamic brakes. Electric motors are found in household appliances such as fans, refrigerators, washing machines, pool pumps and fan-forced ovens.

Most electric motors work by electromagnetism, but motors based on other electromechanical phenomena, such as electrostatic forces and the piezoelectric effect, also exist. The fundamental principle upon which electromagnetic motors are based is that there is a mechanical force on any current-carrying wire contained within a magnetic field. The force is described by the Lorentz force law and is perpendicular to both the wire and the magnetic field. Most magnetic motors are rotary, but linear motors also exist. In a rotary motor, the rotating part (usually on the inside) is called the rotor, and the stationary part is called the stator. The rotor rotates because the wires and magnetic field are arranged so that a torque is developed about the rotor's axis. The motor contains electromagnets that are wound on a frame. Though this frame is often called the armature, that term is often erroneously applied. Correctly, the armature is that part of the motor across which the input voltage is supplied. Depending upon the design of the machine, either the rotor or the stator can serve as the armature.

3.1 History and Development

The principle of conversion of electrical energy into mechanical energy by electromagnetic means was demonstrated by the British scientist Michael Faraday in 1821 and consisted of a free-hanging wire dipping into a pool of mercury. A permanent magnet was placed in the middle of the pool of mercury. When a current was passed through the wire, the wire rotated around the magnet, showing that the current gave rise to a circular magnetic field around the wire. This motor is often demonstrated in school physics classes, but brine (salt water) is sometimes used in place of the toxic mercury. This is the simplest form of a class of electric motors called homopolar motors. A later refinement is the Barlow's Wheel. These were demonstration devices, unsuited to practical applications due to limited power.

The first commutator-type direct-current electric motor capable of a practical application was invented by the British scientist William Sturgeon. He was self-educated in the natural sciences and the science of electricity, and he spent much time experimenting with electricity and lecturing on the topic. In 1825, he delivered a lecture to his class at the Royal Military College in which he demonstrated a 7-ounce electromagnet capable of carrying 9 pounds (4 kilograms) of iron when a current from a single cell was sent through the electromagnet coils. In 1832, Sturgeon invented an electric motor which had a commutator, the critical part of a modern DC motor. His other achievements include the improvement of the electrochemical battery, contributions to the theory of thermo electricity, and the discovery that the atmosphere in serene weather is positively charged with respect to the earth.

A commutator-type direct-current electric motor built with the intention of commercial use was invented by the American Thomas Davenport and patented in 1837. Although several motors were built and operated equipment such as a printing press, due to the high cost of primary battery power, the motors were unsuccessful commercially and Davenport went bankrupt.

Although several inventors followed Sturgeon in the development of DC motors, in the days before electric power distribution these motors had to depend on expensive primary battery power. This meant that these motors had no practical commercial market.

The modern DC motor was invented by accident in 1873, when Zénobe Gramme connected a spinning dynamo to a second similar unit, driving it as a motor. The Gramme machine was the first industrially useful electric motor; earlier inventions were used as toys or laboratory curiosities.

3.2 Speed control

Generally, the rotational speed of a DC motor is proportional to the voltage applied to it, and the torque is proportional to the current. Speed control can be achieved by variable battery tappings, variable supply voltage, resistors or electronic controls. The direction of a wound field DC motor can be changed by reversing either the field or armature connections but not both. This is commonly done with a special set of contactors (direction contactors).

The effective voltage can be varied by inserting a series resistor or by an electronically controlled switching device made of thyristors, transistors, or, formerly, mercury arc rectifiers. In a circuit known as a chopper, the average voltage applied to the motor is varied by switching the supply voltage very rapidly. As the "on" to "off" ratio is varied to alter the average applied voltage, the speed of the motor varies. The percentage "on" time multiplied by the supply voltage gives the average voltage applied to the motor. Therefore, with a 100 V supply and a 25% "on" time, the average voltage at the motor will be 25 V. During the "off" time, the armature's inductance causes the current to continue flowing through a diode called a "flywheel diode", in parallel with the motor. At this point in the cycle, the supply current will be zero, and therefore the average motor current will always be higher than the supply current unless the percentage "on" time is 100%. At 100% "on" time, the supply and motor current are equal. The rapid switching wastes less energy than series resistors. This method is also called pulse width modulation, or PWM, and is often controlled by a microprocessor. An output filter is sometimes installed to smooth the average voltage applied to the motor and reduce motor noise.

Since the series-wound DC motor develops its highest torque at low speed, it is often used in traction applications such as electric locomotives, and trams. Another application is starter motors for petrol and small diesel engines. Series motors must never be used in applications where the drive can fail (such as belt drives). As the motor accelerates, the armature (and hence field) current reduces. The reduction in field causes the motor to speed up (see 'weak field' in the last section) until it destroys itself. This can also be a problem with railway motors in the event of a loss of adhesion since, unless quickly brought under control, the motors can reach speeds far higher than they would do under normal circumstances. This can not only cause problems for the motors themselves and the gears, but due to the differential speed between the rails and the wheels it can also cause serious damage to the rails and wheel treads as they heat and cool rapidly. Field weakening is used in some electronic controls to increase the top speed of an electric vehicle. The simplest form uses a contactor and field weakening resistor, the electronic control monitors the motor current and switches the field weakening resistor into circuit when the motor current reduces below a preset value (this will be when the motor is at its full design speed). Once the resistor is in circuit, the motor will increase speed above its normal speed at its rated voltage. When motor current increases, the control will disconnect the resistor and low speed torque is made available.

One interesting method of speed control of a DC motor is the Ward-Leonard control. It is a method of controlling a DC motor (usually a shunt or compound wound) and was developed as a method of providing a speed-controlled motor from an AC supply, though it is not without its advantages in DC schemes. The AC supply is used to drive an AC motor, usually an induction motor that drives a DC generator or dynamo. The DC output from the armature is directly connected to the armature of the DC motor (sometimes but not always of identical construction). The shunt field windings of both DC machines are independently excited through variable resistors. Extremely good speed control from standstill to full speed, and consistent torque, can be obtained by varying the generator and/or motor field current. This method of control was the de facto method from its development until it was superseded by solid state thyristor systems. It found service in almost any environment where good speed control was required, from passenger lifts through to large mine pit head winding gear and even industrial process machinery and electric cranes. Its principal disadvantage was that three machines were required to implement a scheme (five in very large installations, as the DC machines were often duplicated and controlled by a tandem variable resistor). In many applications, the motor-generator set was often left permanently running, to avoid the delays that would otherwise be caused by starting it up as required. Although electronic (thyristor) controllers have replaced most small to medium Ward Leonard systems, some very large ones (thousands of horsepower) remain in service. The field currents are much lower than the armature currents, allowing a moderate sized thryistor unit to control a much larger motor than it could control directly. For example, in one installation, a 300 amp thyristor unit controls the field of the generator. The generator output current is in excess of 15,000 amps, which would be prohibitively expensive (and inefficient) to control directly with thyristors.

3.2.1 DC motors

Figure : 3.1
Electric motors of various sizes.

If the shaft of a DC motor is turned by an external force, the motor will act like a generator and produce an Electromotive force (EMF). During normal operation, the spinning of the motor produces a voltage, known as the counter-EMF (CEMF) or back EMF, because it opposes the applied voltage on the motor. This is the same EMF that is produced when the motor is used as a generator (for example when an electrical load (resistance) is placed across the terminals of the motor and the motor shaft is driven with an external torque). Therefore, the voltage drop across a motor consists of the voltage drop, due to this CEMF, and the parasitic voltage drop resulting from the internal resistance of the armature's windings. The current through a motor is given by the following equation:

$$I = (V_{applied} - V_{cemf}) / R_{armature}$$

The mechanical power produced by the motor is given by:

$$P = I * (V_{cemf})$$

3.2.2 Mechanism of the DC motors:

When a current passes through the coil wound around a soft iron core, the side of the positive pole is acted upon by an upwards force, while the other side is acted upon by a downward force. According to Fleming's left hand rule, the forces cause a turning effect on the coil, making it rotate. To make the motor rotate in a constant direction, "direct current" commutators make the current reverse in direction every half a cycle thus causing the motor to rotate in the same direction. The problem facing the motor is when the plane of the coil is parallel to the magnetic field; i. e. the turning effect is ZERO-when coil is at 90 degree from its original position-yet, the coil continues to rotate by inertia.

Since the CEMF is proportional to motor speed, when an electric motor is first started or is completely stalled, there is zero CEMF. Therefore the current through the armature is much higher. This high current will produce a strong magnetic field which will start the motor spinning. As the motor spins, the CEMF increases until it is equal to the applied voltage, minus the parasitic voltage drop. At this point, there will be a smaller current flowing through the motor. Basically, the following three equations can be used to find the speed, current, and back EMF of a motor under a load:

$$Load = V_{cemf} * I$$

$$V_{applied} = I * R_{armature} + V_{cemf}$$

$$V_{cemf} = speed * Flux_{armature}$$

3.2.3 AC Motors

In 1882, Nikola Tesla identified the rotating magnetic field principle, and pioneered the use of a rotary field of force to operate machines. He exploited the principle to design a unique two-phase induction motor in 1883. In 1885, Galileo Ferraris independently researched the concept. In 1888, Ferraris published his research in a paper to the Royal Academy of Sciences in Turin.

Introduction of Tesla's motor from 1888 onwards initiated what is sometimes referred to as the Second Industrial Revolution, making possible the efficient generation and long distance distribution of electrical energy using the alternating current transmission system, also of Tesla's invention (1888).[1] Before the invention of the rotating magnetic field, motors operated by continually passing a conductor through a stationary magnetic field (as in homopolar motors).

Tesla had suggested that the commutators from a machine could be removed and the device could operate on a rotary field of force. Professor Poeschel, his teacher, stated that would be akin to building a perpetual motion machine.[2] Tesla would later attain U.S. Patent 0,416,194 , Electric Motor (December 1889), which resembles the motor seen in many of Tesla's photos. This classic alternating current electro-magnetic motor was an induction motor.

Michail Osipovich Dolivo-Dobrovolsky later invented a three-phase "cage-rotor" in 1890. This type of motor is now used for the vast majority of commercial applications.

3.2.4 Components and types

A typical AC motor consists of two parts:

1. An outside stationary stator having coils supplied with AC current to produce a rotating magnetic field, and;
2. An inside rotor attached to the output shaft that is given a torque by the rotating field.

There are two fundamental types of AC motor, depending on the type of rotor used:

- The synchronous motor, which rotates exactly at the supply frequency or a submultiple of the supply frequency, and;

- The induction motor, which turns slightly slower, and typically (though not necessarily always) takes the form of the squirrel cage motor.

3.3 Torque motors

A torque motor is a specialized form of induction motor which is capable of operating indefinitely at stall (with the rotor blocked from turning) without damage. In this mode, the motor will apply a steady torque to the load (hence the name). A common application of a torque motor would be the supply- and take-up reel motors in a tape drive. In this application, driven from a low voltage, the characteristics of these motors allow a relatively-constant light tension to be applied to the tape whether or not the capstan is feeding tape past the tape heads. Driven from a higher voltage, (and so delivering a higher torque), the torque motors can also achieve fast-forward and rewind operation without requiring any additional mechanics such as gears or clutches. In the computer world, torque motors are used with force feedback steering wheels.

3.4 Stepper motors

Closely related in design to three-phase AC synchronous motors are stepper motors, where an internal rotor containing permanent magnets or a large iron core with salient poles is controlled by a set of external magnets that are switched electronically. A stepper motor may also be thought of as a cross between a DC electric motor and a solenoid. As each coil is energized in turn, the rotor aligns itself with the magnetic field produced by the energized field winding. Unlike a synchronous motor, in its application, the motor may not rotate continuously; instead, it "steps" from one position to the next as field windings are energized and de-energized in sequence. Depending on the sequence, the rotor may turn forwards or backwards.

Simple stepper motor drivers entirely energize or entirely de-energize the field windings, leading the rotor to "cog" to a limited number of positions; more sophisticated drivers can proportionally control the power to the field windings, allowing the rotors to position "between" the "cog" points and thereby rotate extremely smoothly. Computer controlled stepper motors are one of the most versatile forms of positioning systems, particularly when part of a digital servo-controlled system.

Stepper motors can be rotated to a specific angle with ease, and hence stepper motors are used in pre-gigabyte era computer disk drives, where the precision they offered was adequate for the correct positioning of the read/write head of a hard disk drive. As drive density increased, the precision limitations of stepper motors made them obsolete for hard drives, thus newer hard disk drives use read/write head control systems based on voice coils.

Stepper motors were up scaled to be used in electric vehicles under the term SRM (switched reluctance machine).

CONCLUCTION

In this project, mostly mechanization is considered which the system needs an operator as controller. Because the system is running with 2 main switches. In industrial machinery, this system is operating with large capacities of equipments such as kV classified AC motors, 20-30 m. band lengths and acceptable rated electronic devices as circuits. But during the preparation of this simulation I used 12 v dc high torque drill motors. Because of the current in motor connections are higher than model circuits. So, I used 250 W 220 – 12 V transformer to serve this need. And also I used a dimmer circuit with 40 A triac and 2 bridge diodes (KBPC 3510) (this dimmer and diode combinations are using on welder machines). By this dimmer circuit I 'am adjusting the input voltage of 250W transformer, so the motors which are connected to this transformer running both higher and lower speeds. Right along with these connections, there is a 2. Transformer with its diode bridge as 15 W for to run the counter, 2 sensor controlled relay and time delay circuits.

By this mechanic control system, the controller (as operator) can be sure the number of produced material with serious energy saving in industrial factories.

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