HIGHER DIPLOMA IN MECHANICAL AND CHEMICAL ENGINEERING

Design and construction of mobile phone based automatic security door locking system

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DHAKA-BANGLADESH

MAY, 2014

DECLARATION

I declare that this thesis posses no external or any source which has been already presented for any kind of degree or diploma in any tertiary institution in the mechanical and chemical engineering field. And that, to my knowledge and belief,
the thesis contains no material previously published or written by another person
except where due reference is made in the text of the thesis.

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ABSTRACT

This project will basically focus on the use of mobile phones to control the security locking system . The basic concept of the project is to detect a particular ringtone from a SIM supporting modem and use it to toggle the electronic circuit and the load (door lock) correspondingly. The very specific and unique ringtone – "Beep Once" or the "No Tone" is available with every NOKIA cell phone. And also this ring can be assigned to any particular fed number of the cell phone. So this ringtone becomes specific only to that particular number and will be sounded every time a call is received from the assigned number. This facility has been ideally exploited here.

DEDICATION

I dedicate this project to my beloved uncle mr.Ijosiga swaleh shaban

‘

ACKNOWLEDGEMENTS

Surely all praises is for ***Allah,*** *the most merciful, the gracious and from whom we seek knowledge and wisdom. Without His mighty help and guidance we would not be able to complete this on time.*

Coming up with such a compilation of the project thesis had never being an easy task for me, it took period to its completion which seemed as an impossible project .therefore I am so much grateful to those supported me in this project whole heartedly and with sound ideas.

My special and sincere thanks goes to my beloved uncle who tirelessly and whole heartedly gave his support, encouragement, motivation in my education, it's because of him that I gained the momentum and acceleration in the engineering field.

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CHAPTER 1

1.0 INTRODUCTION:

Due to the advancement of science and technology throughout the world, there is a consequent increase in the rate and sophistication of crime. Despite all forms of security gadgets and locks still need the attention of researchers to find a permanent solution to the well being of lives and properties of individuals. To this end, we design a cheap and effective security system for buildings, cars, doors and gates, so as to prevent unauthorized person from having access to ones properties through the use of codes, mobile phones,we therefore experiment the application of electronic devices as locks.

The earliest lock in existence is the Egyptian lock, made of wood, found with its key in the palace ruins in Nineveh, in ancient Assyria . In the 19th century, level locks, cylinder locks and keyless locks were invented and improved upon . The first successful metal key changeable combination lock was invented by James Sargent in 1857 . This lock was the prototype of those being used in contemporary bank vaults.

In 1958, the first electronic combination lock was invented . As subsequent developments were along the lines, the locks were improved upon by the improvement of materials and increasing complexity of the working mechanisms including the increasing use of automatic electronic alarm and safety devices .

1.1 LOCKS AND ITS TYPES

There are many types of lock that are in existence in our world today of which the main types are:

(1) Mechanical Key locks,

(2) Magnetic locks, and

(3) Electronic locks.

These lock types sometimes they are been categorized into:

Passage Lockset

- An interior lockset used inside the home in hallways or closets between rooms where privacy is not important.
- Has two, non-locking knobs, one on each side of the door. Some models use levers instead of knobs.
- Available in a wide variety of styles and finishes.

Privacy Lockset

- An interior lockset.
- Designed for privacy rather than for security
- Has a locking button on the inside knob but no key device on the outside knob.
- Can be either a knob or a lever.
- In an emergency, the lock can be opened from the outside by inserting a narrow object through the small hole in the outside knob and either depressing or turning the locking mechanism inside, depending on the type of lock. "
- Available in a wide variety of styles and finishes.

Dummy Knob

- Used only for decoration or applications that do not need a latch
- Has no latching mechanism and does not turn.
- Available in a wide variety of styles and finishes.

Entry Lockset

- Two doorknobs that can be locked from both the inside and the outside.
- One type locks from the inside by turning or depressing a small button, while a key must unlock the outside knob.
- Some models must be locked with a key on both the inside and outside.
- In other models, only the inside knob can lock or unlock both sides of the set.
- A medium security entrance-door lock.
- A quality feature on entry locksets is a deadlatch.

Deadbolt Lock

- Provides maximum security on a door.
- Called “dead” because there are no springs to operate the bolt. It is only operated manually with a key or a thumb turn from the inside.
- The bolt locks the door to the frame and helps prevent someone from prying the door open.
- The throw is the length the bolt is extended from the lock housing. The industry standard is a 1” throw.
- Locks are designed to fit specific size holes and backsets. Backset refers to the distance between the edge of the door and the center of the handle.
- A single-cylinder deadbolt is operated with a key from the outside and with a turn button on the inside. It is used mostly with solid metal or wood doors.
- A double-cylinder deadbolt is operated with a key on both the inside and outside. It is best used on a door with glass in or around them as the style prevents someone from breaking the glass, reaching in and unlocking the door.

- Double-cylinder deadbolts can pose a danger during an emergency. If the key is missing or not readily available, people could be trapped inside a locked house. In some areas, codes may not permit this style of deadbolt.

Surface-Mounted Deadbolt

- Squarish in shape and mounted on the surface of the inside of the door.
- The bolt may be turned with a key or a turn knob.
- Instead of sliding into the door frame, the bolt slides into a surface-mounted strike.

Mortise Lock

- Consists of a flat, rectangular box that fits into a recess in the door from its edge. Also includes two faceplates that include the knobs and keyholes.
- Available in right- or left-handed styles.
- Has a pin tumbler locking mechanism in a cylinder.
- Latch operates from either side except when the outside knob is locked.
- Deadbolt operates by a turn of the inside knob.
- A key from the outside operates both the deadbolt and latchbolt.
- Used on many types of doors, from heavy entrance doors to apartment buildings and residential doors.

Night Latch

- Installed on the inside surface of the door.
- Has an automatic locking feature. The large, spring loaded latch automatically locks whenever the door is closed.
- For light security and usually used in combination with another lock.

Keyless Entry System

- For advanced home security and convenience
- Audio and visual indicators confirm the lockset is activated.

- Audio and visual indicators confirm the lockset is activated.

- Some models will sound an alarm after the incorrect code has been entered more than three consecutive times.
- Anti-theft rolling code feature ensures the same code is never used twice.
- Some systems are compatible with some garage door openers so the homeowner only needs one remote.

Handle set

- Usually an entry set that combines a lockset with a deadbolt, the deadbolt is located just above the knob or handle. Can be a one- or two-piece unit.
- Available with both single- and double-cylinder deadbolts. Styles of locksets also will vary widely.
- Available in a variety of styles and finishes

1.2 MECHANICAL KEY LOCKS

Mechanical Key Locks: these are locks that consist of a bolt that may be slid to and fro, or rotated by a key (e.g. Padlock). In these types of locks, there are obstacles called wards or tumblers that permit only the right key to be turned on. This is mostly applicable in doors,gates and windows of houses, stores etc

In this category, you’ll find stand-alone mechanical keyless locks that do not require any wiring or batteries. These keyless locks are designed for residential, commercial, or industrial use. Usually they can be installed in place of regular locks with only minor modification to the door. They are perfect for people who don’t like to use keys, or who tend to lose their keys. They only work with one code combination, as opposed to electronic keyless access locks that can be loaded with more than one code.

They are extremely reliable, can withstand high traffic volume, and can be used on both interior and exterior doors.

1.3 MAGNETIC LOCKS

Magnetic Lock: These are locks that are operated based on the theory of magnetism. These types of locks consist of bolts connected with magnets to ensure that they are locked. The key (which is usually a ferrous metal foil) when inserted pulls the bolts thereby releasing the lock to ensure it is opened (e.g. Solenoid). It is mainly used in residential as well as administrative areas (e.g. Offices).

There are two main types of electric locking devices. Locking devices can be either "fail safe" or "fail secure". A fail-secure locking device remains locked when power is lost. Fail-safe locking devices are unlocked when de-energized. Direct pull electromagnetic locks are inherently fail-safe. Typically the electromagnet portion of the lock is attached to the door frame and a mating armature plate is attached to the door. The two components are in contact when the door is closed. When the electromagnet is energized, a current passing through the electromagnet creates a magnetic flux that causes the armature plate to attract to the electromagnet, creating a locking action. Because the mating area of the electromagnet and armature is relatively large, the force created by the magnetic flux is strong enough to keep the door locked even under stress.

Typical single door electromagnetic locks are offered in both 600 lbs. and 1200 lbs. dynamic holding force capacities. A "fail safe" magnetic lock requires power to remain locked and typically not suitable for high security applications because it is possible to disable the lock by disrupting the power supply. Despite this, by adding a magnetic bond sensor to the lock and by using a power supply that includes a battery backup capability, some specialized higher security applications can be implemented. Electromagnetic locks are well suited for use on emergency exit doors that have fire safety applications because they have no moving parts that are less likely to fail than other types of electric locks, like electric strikes.

The strength of today's magnetic locks compares well with that of conventional door locks and they cost less than conventional light bulbs to operate. There are additional pieces of release hardware installed in a typical electromagnetic locking system. Since electromagnetic locks do not interact with levers or door knobs on a door, typically a separate release button that cuts the lock power supply is mounted near the door. This button usually has a timer that, once the button is pressed, keeps the lock unlocked for either 15 or 30 seconds in accordance with NFPA fire codes. Additionally a second release is required by fire code. Either a motion sensor or crash bars with internal switch is used to unlock to door on the egress side of the door automatically.

Principle

The principle behind an electromagnetic lock is the use of electromagnetism to lock a door when energized. The holding force should be collinear with the load, and the lock and armature plate should be face-to-face to achieve optimal operation.

Operation

The magnetic lock relies upon some of the basic concepts of electromagnetism. Essentially it consists of an electromagnet attracting a conductor with a force large enough to prevent the door from being opened. In a more detailed examination, the device makes use of the fact that a current through one or more loops of wire (known as a solenoid) produces a magnetic field. This works in free space but if the solenoid is wrapped around a ferromagnetic core such as soft iron the effect of the field is greatly amplified. This is because the internal magnetic domains of the material align with each other to greatly enhance the magnetic flux density.

Technical comparison

Magnetic locks possess a number of advantages over conventional locks and electric strikes. For example, their durability and quick operation can make them valuable in a high-traffic office environment where electronic authentication is necessary.

Advantages

- Easy to install: Magnetic locks are generally easier to install than other locks since there are no interconnecting parts.
- Quick to operate: Magnetic locks unlock instantly when the power is cut, allowing for quick release in comparison to other locks.
- Sturdy: Magnetic locks may also suffer less damage from multiple blows than do conventional locks. If a magnetic lock is forced open with a crowbar, it will often do little or no damage to the door or lock. There are no moving parts in an electromagnetic lock to break.

Disadvantages

- Requires a constant power source in order to be secure.
- Can de-energize in the event of a power outage, disabling security.

- Expensive in comparison to mechanical locks and requires additional hardware for safe operation.

1.4 ELECTRONICS LOCKS

An electronic lock (or **electric lock**) is a locking device which operates by means of electric current. Electric locks are sometimes stand-alone with an electronic control assembly mounted directly to the lock. More often electric locks are connected to an access control system. The advantages of an electric lock connected to an access control system include: key control, where keys can be added and removed without re-keying the lock cylinder; fine access control, where time and place are factors; and transaction logging, where activity is recorded.

Operation

Electric locks use magnets, solenoids , or motors to actuate the lock by either supplying or removing power. Operating the lock can be as simple as using a switch, for example an apartment intercom door release, or as complex as a biometric based access control system. There are two basic types of locks: "preventing mechanism" or operation mechanism

A typical electronic lock is as shown in the figure below

Some of the electronic locks are:

i. DNA Sensor Locks: these are electronic locks that compute into their memories, the genetic make-up of the individual such that only individuals that have their DNA computed into its memory would be allowed to enter. This is used in foreign countries in places like the Pentagon where a high level of security is needed.

ii. Card sensor Locks: These are electronics locks that use the cards as keys such that when the card if inserted, it generates voltage by closing the circuit and energizing the relay which then opens the lock. These are used in industrial areas.

iii. Electronic Eye Locks: these are electronic locks that compute into their memories, the picture of the individual's eye such that only people with their eye pictures in the memory in the memory who will be allowed to enter.

iv. Thumbprint sensor locks: these are electronic locks that use the thumbprint of the user as the key such that it is only individuals whose thumbprints have been inputted in its memory would the lock open for.

v. Electronic Combination Locks: these are electronic locks that are operated by inputting the correct code by means of an external device such that only people that know the code can open the lock.

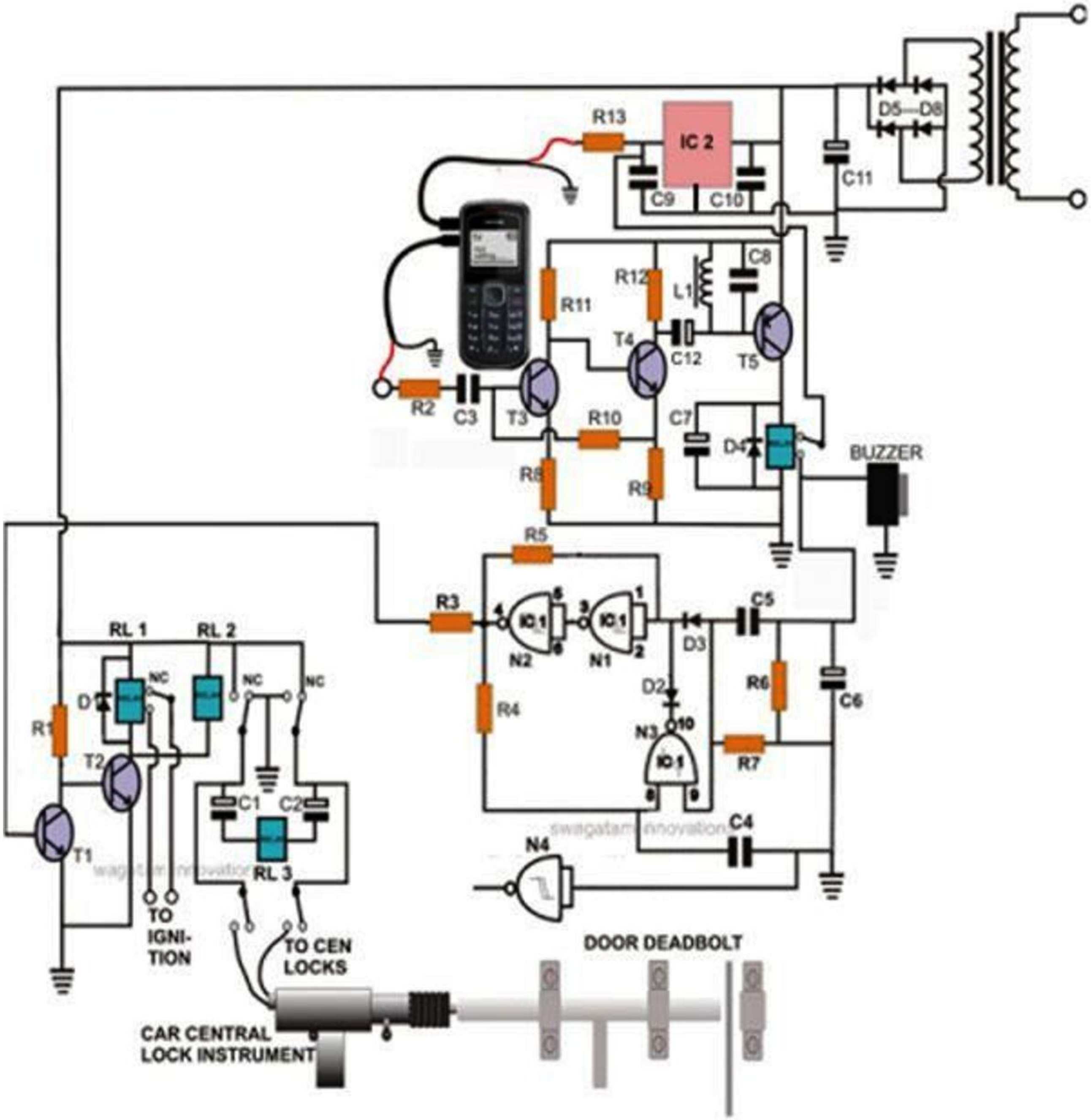
Though in this work, much attention is given to electronic combination lock as it is the subject of the design and implementation of an Electronic Digital Combination Lock: A Precise and Reliable Security System.

CHAPTER 2

2.0 DESIGN THEORY OF THE SYSTEM

Introduction:

A very simple configuration using a low cost cell phone (used as a modem) and an electronic circuit can be build to control remotely a high security door lock. Once the unit is built and attached to a door, by simply assigning your personal cell phone's number inside the modem cell phone, you can alternately lock and unlock a particular door by sending subsequent "miss calls" through your cell phone to it from any part of the world. We use a NOKIA 1202 as the modem cell phone here for the project. Let's proceed and learn the simple instructions required to complete the project.



The schematic circuit diagram.

2.2 HOW THE CIRCUIT FUNCTIONS

The basic concept of the project is to detect a particular ringtone from a SIM supporting modem and use it to toggle the electronic circuit and the load (door lock) correspondingly. The very specific and unique ringtone – “Beep Once” or the “No Tone” is available with every NOKIA cell phone. And also this ring can be assigned to any particular fed number of the cell phone. So this ringtone becomes specific only to that particular number and will be sounded every time a call is received from the assigned number. This facility has been ideally exploited here. A 5 volt regulated supply is used to trickle charge the modem round the clock so that its battery is never discharged. This supply also goes to the IC 4093 = pin 14 (+) and pin 7(-). An in-built cut-off system inside every NOKIA cell phone ensures a safe charging.

The circuit functioning may be easily understood with the following explanation.

The FIGURE above shows a simple three transistor amplifier circuit which is basically used as a tone amplifier. On receiving a “miss call” from the assigned number (owner’s cell phone), the modem immediately responds and produces the desired ringtone (“Beep Once”). This tone frequency is collected from the modem’s headphone socket and applied to the tone amplifier’s input. The ringtone is suitably amplified and is used to toggle a relay momentarily. This relay connects a 5 volt trigger pulse to the input of CMOS flip flop circuit and also sounds a buzzer. The flip flop toggles in response to the above action and activates the following transistor/relay locking mechanism. A car central lock has been effectively integrated with an ordinary manual locking shaft to form an excellent door dead bolt. The whole system activates in a push pull manner to alternately lock and unlock the door in response to every subsequent “miss call” from the owner’s cell phone.

2.3 CONSTRUCTION AND MODEM CELL PHONE CONFIGURATION

Constructing the control circuit is very easy and may be done by just assembling the procured electronic components over a general purpose board by soldering. All the connections should be accurately done with the help of the given circuit schematic. Once the assembly is completed, it's time to configure the modem cell phone.

The attached modem cell phone needs to be set up through the following steps:

Go to settings and select set the default ringtone as EMPTY. It means now at this position the modem does not produce any ringtone to any incoming calls. Also, switch off the message tone, keypad tone, start up tone etc.

Now feed your personal cell phone numbers (single or many as desired) through which the modem and the lock need to be operated.

Assign the required "beep once" ringtone to all these numbers.

The modem is all set. Integrate it to the control circuit through its headphone socket pin assembly. Also, connect the charging voltage input to it as shown in the diagram.

Your high security door lock is fully ready and can be installed over the door which is to be controlled and will lock and unlock it faithfully on receiving the subsequent "miss calls" from the assigned numbers.

2.4 COMPONENT PART LISTS

Serial no	Items	Quantity	Unity price	Total price
1	Transistors	6	5	30
2	Capacitors	12	15	180
3	resistors	13	20	260
4	Diode	15	8	120
5	Ic	2	50	100
6	Transformer	1	500	500
7	PCB	3	300	900
8	Soldering wire and solder lead	1	700	700
9	Nokia phone	1	3300	3150

10	**Bread board**	**3**	**300**	**900**
11	**Car lock**	**1**	**3100**	**3100**
12	**Buzzers**	**1**	**60**	**60**
13	**TOTAL**			**10000**

2.5 APPLICATION OF THE PROJECT

It is used in automobiles for security purposes

CHAPTER 3

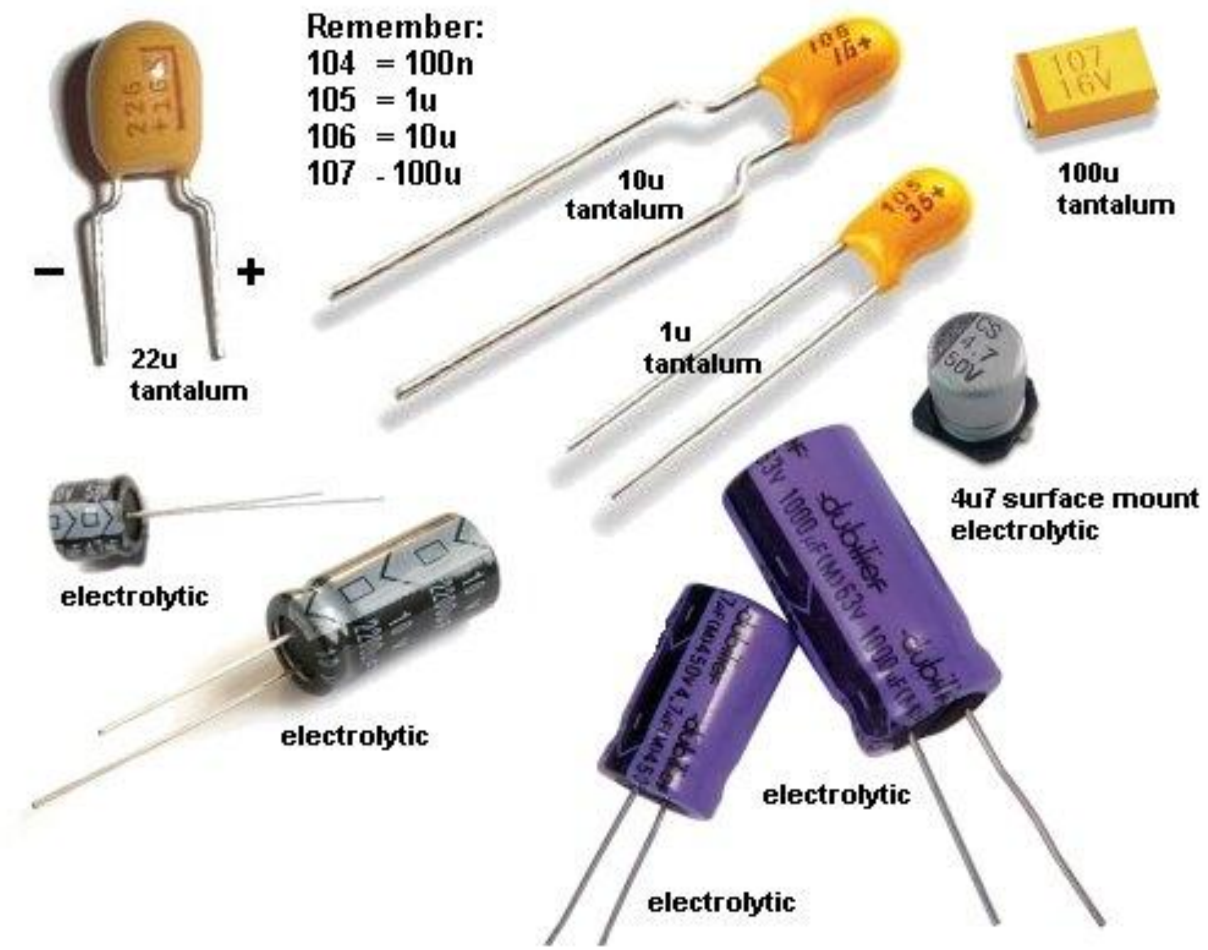
3.1 ELECTRIC COMPONENTS.

Passive components: these are electrical components that cannot produce signals wave forms by themselves. They therefore require external power supply to allow electrical signal to pass through them. Examples include resistor , capacitors and diodes.

capacitors

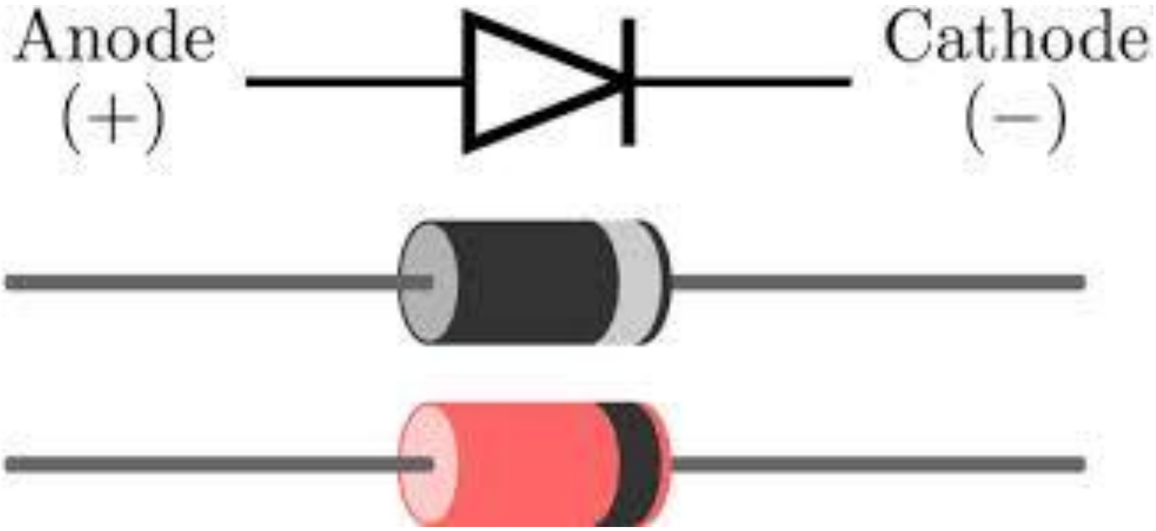
they are used to store electric charges. It consists of two parallel plates separated by an insulator. The charges stored in a capacitor are relative to the voltage across it by the equation

$$Q=CV$$



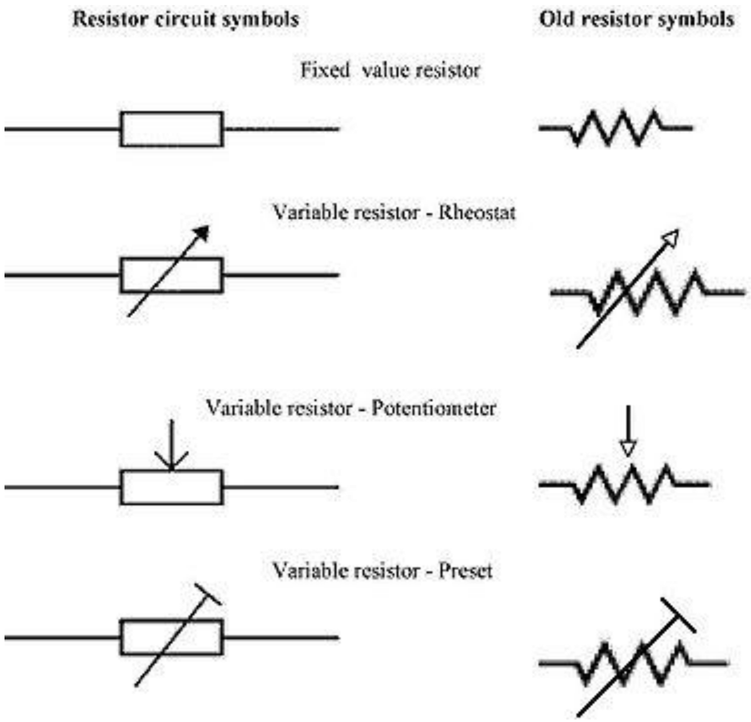
Diodes

The diode is very important and useful terminal passive and non linear device. The diode of a diode is shown as below



Resistors

They are designed to limit flow of electric current in a circuit . their opposition to the flow of current is called resistance and it is measured in ohms. It can be represented as

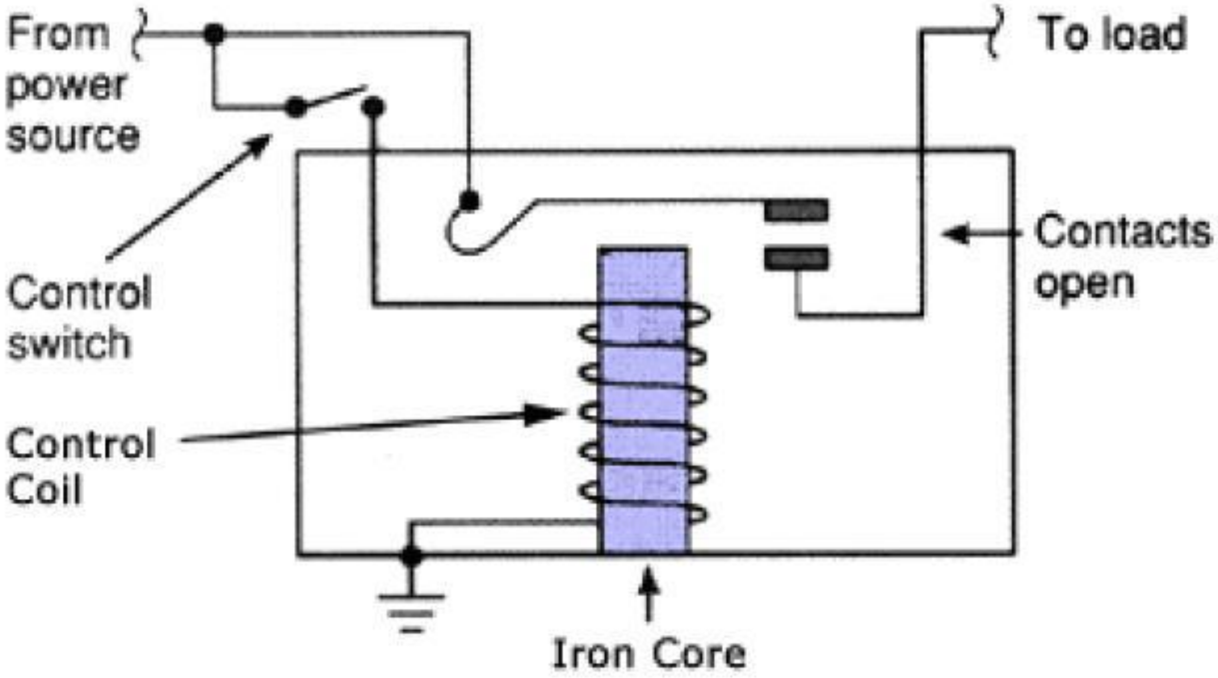


Switches

Some common switches types are toggle push button and rotary switches . toggle switches canbe SPST(single pole single throw),SPDT(single pole double throw). Rotary switches have many poles and many positions. The push button is found in useful in the foregoing work as it is used as a reset. Push button switches are used for momentary contact application. It can as well be SPST and STDT. The terminal must be labeled “NO” which means “Normally Open”, and “NC” meaning “Normally closed”

Relays

A relay is a mechanical switch used to switch other circuits ON and OFF . it enables small current in one circuit to control a much larger amount of current in another circuit. When a small current flows through the coil of the relay, it becomes electromagnet and attracts a soft iron. The movement is transmitted via the pivot, to the contacts operating the other circuit. However , when the current flowing in the coil stops , the magnet fields collapses and the armature will return to its original position, which in turn allows the contact to return to their initial states.



Active components

These are electrical component that can amplify, producing an output signal with more power than the input signal. the additional power comes from an external source of power. Examples include transistors and integrated circuits (IC)

3.2 NEW ELECTRIC IDENTIFICATION TECHNOLOGY

i) Bar code

A barcode essentially is a way to encode information in a visual pattern that a machine can read. The combination of black and white bars (elements) represents different text characters which follows a set algorithm for that barcode type. If you change the sequence of elements you get different text. A barcode scanner reads this pattern of black and white that is then turned into a line of text your computer can understand.

ii) Radio frequency identification (RFID)

RFID stands for **Radio-Frequency Identification**. The acronym refers to small electronic devices that consist of a small chip and an antenna. The chip typically is capable of carrying 2,000 bytes of data or less.

The RFID device serves the same purpose as a bar code or a magnetic strip on the back of a credit card or ATM card; it provides a unique identifier for that object. And, just as a bar code or magnetic strip must be scanned to get the information, the RFID device must be scanned to retrieve the identifying information.

A significant advantage of RFID devices over the others mentioned above is that the RFID device does not need to be positioned precisely relative to the scanner. We're all familiar with the difficulty that store checkout clerks sometimes have in making sure that a barcode can be read. And obviously, credit cards and ATM cards must be swiped through a special reader.

In contrast, RFID devices will work within a few feet (up to 20 feet for high-frequency devices) of the scanner. For example, you could just put all of your groceries or purchases in a bag, and set the bag on the scanner. It would be able to query all of the RFID devices and total your purchase immediately. (Read a more detailed article on RFID compared to barcodes.)

RFID technology has been available for more than fifty years. It has only been recently that the ability to manufacture the RFID devices has fallen to the point where they can be used as a "throwaway" inventory or control device. Alien Technologies recently sold 500 million RFID tags to Gillette at a cost of about ten cents per tag.

One reason that it has taken so long for RFID to come into common use is the lack of standards in the industry. Most companies invested in RFID technology only use the tags to track items within their control; many of the benefits of RFID come when items are tracked from company to company or from country to country.

COMMON PROBLEMS WITH RFID

Some common problems with RFID are reader collision and tag collision. Reader collision occurs when the signals from two or more readers overlap. The tag is unable to respond to simultaneous queries. Systems must be carefully set up to avoid this problem. Tag collision occurs when many tags are present in a small area; but since the read time is very fast, it is easier for vendors to develop systems that ensure that tags respond one at a time.

iii) magnetic stripes

A **magnetic stripe card** is a type of card capable of storing data by modifying the magnetism of tiny iron-based magnetic particles on a band of magnetic material on the card. The magnetic stripe, sometimes called **swipe card** or **magnetic stripe**, is read by swiping past a magnetic reading head.

vi) chip card

A chip card is a credit or debit card containing an embedded computer chip, which provides the ability to securely store and process data and provides increased protection against lost, stolen or counterfeit card fraud. Chip technology is the next evolution of electronic payments, and is helping to make an already secure payment system more secure.

CHAPTER 4

4.0 MOBILE DEVICE INTEGRATION

A poorly integrated mobile device can cause many user problems, including a lack of connectivity and access to important systems, such as email. Solution providers can offer mobile device integration services to help their customers avoid such consequences by choosing the right mobile operating system (OS) for a customer's needs. This tip provides advice on recommending an operating system for mobile devices, including a mobile OS comparison, as well as factors to consider from customer to customer.

With the launch of new mobile devices such as Netbooks, Android smartphones and forthcoming handheld devices running the Windows Mobile 7 OS, many organizations are contemplating how to incorporate and integrate those devices into their enterprise data systems. A poorly integrated device can mean a lack of connectivity, inability to access systems such as enterprise email, and the inability to track and manage the devices. For most organizations, mobile device integration will be new territory, and most will turn to their solution providers for help with choosing a mobile device OS.

Solution providers will find that the latest devices will create a paradigm shift when it comes to mobile device integration. In the past, most mobile devices were integrated based on the manufacturer's proprietary software. For example, the ever popular BlackBerry device relied on RIM's BlackBerry Enterprise Server (BES) to integrate BlackBerry

4.1 SMART PHONES

A **smart phone**, or **smart phone**, is a mobile phone with more advanced computing capability and connectivity than basic feature phones.

Early smart phones typically combined the features of a mobile phone with those of another popular consumer device, such as a personal digital assistant (PDA), a media player, a digital camera, or a GPS navigation unit. Modern smart phones include all of those features plus the features of a touch screen computer, including web browsing, Wi-Fi, and 3rd-party apps.

4.2 **BLUETOOTH**

Bluetooth is defined as being a *short-range radio technology* (or wireless technology) aimed at simplifying communications among Internet devices and between devices and the Internet. It also aims to simplify data synchronization between Internet devices and other computers.

Bluetooth products -- that is products using Bluetooth technology -- must be qualified and pass interoperability testing by the Bluetooth Special Interest Group prior to release. Bluetooth's founding members include Ericsson, IBM, Intel, Nokia and Toshiba.

When you use computers, entertainment systems or telephones, the various pieces and parts of the systems make up a community of electronic devices. These devices communicate with each other using a variety of wires, cables, radio signals and infrared light beams, and an even greater variety of connectors, plugs and protocols.

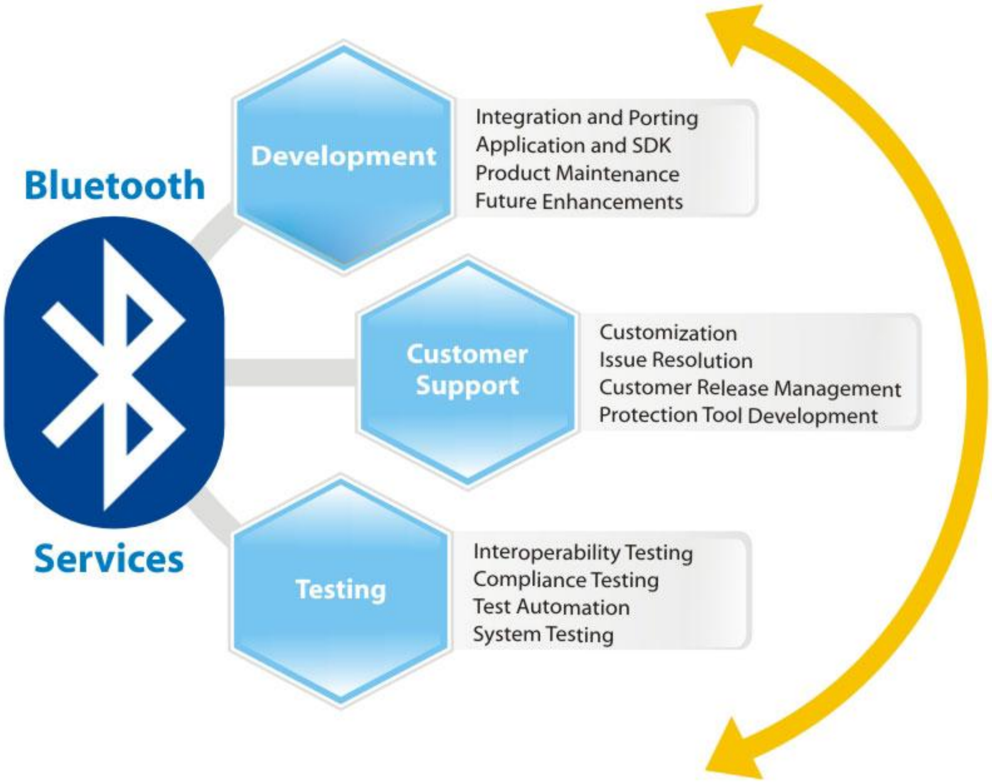
There are lots of different ways that electronic devices can connect to one another. For example:

- Component cables
- Electrical wires
- Ethernet cables
- WiFi
- Infrared signals

The art of connecting things is becoming more and more complex every day. In this article, we will look at a method of connecting devices, called **Bluetooth**, that can streamline the process. A Bluetooth connection is wireless and automatic, and it has a number of interesting features that can simplify our daily lives.

THE PROBLEM

When any two devices need to talk to each other, they have to agree on a number of points before the conversation can begin. The first point of agreement is physical: Will they talk over wires, or through some form of wireless signals? If they use wires, how many are required -- one, two, eight, 25? Once the physical attributes are decided, several more questions arise:


Bluetooth
Services
Development
Integration and Porting
Application and SDK
Product Maintenance
Future Enhancements
Customer Support
Customization
Issue Resolution
Customer Release Management
Protection Tool Development
Testing
Interoperability Testing
Compliance Testing
Test Automation
System Testing

4.3 WIFI

Wi-Fi, also spelled **Wifi** or **WiFi**, is a technology that allows an electronic device to exchange data or connect to the internet wirelessly using 2.4 GHz UHF and 5 GHz SHF radio waves. The name is a trademark name, and is a play on the audiophile term Hi-Fi

4.4 IMEI

IMEI or 'International Mobile Equipment Identity' is a unique 15-digit number assigned to all cellular devices. We can use this number to block a mobile phone from being used by another person or phone company if it has been lost or stolen.

Having your cell phone or tablet stolen is not just a bad day at the zoo, it potentially compromises your safety and security. Thanks to the FCC (back in the age of the dinosaurs, the early '80s), Electronic Serial Numbers were created to give a unique identifiers to mobile devices. Since then, usage of mobile devices has exploded, and the Electronic Serial Number of yore became the IMEI (International Mobile Equipment Identity) and the MEID (Mobile Equipment ID—a super set of IMEI) of today.

If a phone, iPad, or other mobile device is stolen, carriers in some countries can blacklist the IMEI or MEID so that the thief cannot use the phone in any capacity (regardless of whether or not the SIM card has been replaced). In addition, if you file a police complaint some police forces will require the IMEI number in addition to the phone model for the complaint. Some police forces will add the IMEI number to a stolen devices database and, if recovered from stolen property, they could be able to return it to you. This is a number you should keep on file, in a secure place, should the need ever arise. We'll show you a few tips on how to do this.

4.5 GPS/GSM

Global Positioning System (GPS) is a Global Navigation Satellite System (GNSS) developed by the United States Department of Defense. It is the only fully functional GNSS in the world. It uses a constellation of between 24 and 32 Medium Earth Orbit satellites that transmit precise microwave signals, which enable GPS receivers to determine their current location, the time, and their velocity. Its official name is NAVSTAR GPS. Although NAVSTAR is not an acronym, a few acronyms have been created for it. The GPS satellite constellation is managed by the United States Air Force 50th Space Wing. GPS is often used by civilians as a navigation system. A GPS receiver calculates its position by carefully timing the signals sent by the GPS satellites high above the Earth. Each satellite continually transmits messages containing the time the message was sent, precise orbital information (the ephemeris), and the general system health and rough orbits of all GPS satellites (the almanac). The receiver measures the transit time of each message and computes the distance to each satellite. Geometric trilateration is used to combine these distances with the location of the satellites to determine the receiver's location. The position is displayed, perhaps with a moving map display or latitude and longitude; elevation information may be included. Many GPS units also show derived information such as direction and speed, calculated from position changes.

Chapter 5

5.1 supply unit

A **power supply** is a device that supplies electric power to an electrical load. The term is most commonly applied to electric power converters that convert one form of electrical energy to another, though it may also refer to devices that convert another form of energy (mechanical, chemical, solar) to electrical energy. A regulated power supply is one that controls the output voltage or current to a specific value; the controlled value is held nearly constant despite variations in either load current or the voltage supplied by the power supply's energy source.

Every power supply must obtain the energy it supplies to its load, as well as any energy it consumes while performing that task, from an energy source. Depending on its design, a power supply may obtain energy from:

- Electrical energy transmission systems. Common examples of this include power supplies that convert AC line voltage to DC voltage.
- Energy storage devices such as batteries and fuel cells.
- Electromechanical systems such as generators and alternators.
- Solar power

Types of power supply

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Power supplies for electronic devices can be broadly divided into line-frequency (or "conventional") and switching power supplies. The line-frequency supply is usually a relatively simple design, but it becomes increasingly bulky and heavy for high-current equipment due to the need for large mains-frequency transformers and heat-sinked electronic regulation circuitry. Conventional line-frequency power supplies are sometimes called "linear", but that is a misnomer because the conversion from AC voltage to DC is inherently non-linear when the rectifiers feed into capacitive reservoirs. Linear voltage regulators produce regulated output voltage by means of an active voltage divider that consumes energy, thus making efficiency low. A switched-mode supply of the same rating as a line-frequency supply will be smaller, is usually more efficient, but would be more complex.

Battery

Alkaline batteries

A battery is a device that converts stored chemical energy to electrical energy. Batteries are commonly used as energy sources in many household and industrial applications.

There are two types of batteries: primary batteries (disposable batteries), which are designed to be used once and discarded, and secondary batteries (rechargeable batteries), which are designed to be recharged and used multiple times. Batteries come in many sizes, from miniature cells used in hearing aids and wristwatches to room-size battery banks that serve as backup power supplies in telephone exchanges and computer data centers.

DC power supply

An AC powered unregulated power supply usually uses a transformer to convert the voltage from the wall outlet (mains) to a different, nowadays usually lower, voltage. If it is used to produce DC, a rectifier is used to convert alternating voltage to a pulsating direct voltage, followed by a filter, comprising one or more capacitors, resistors, and sometimes inductors, to filter out (smooth) most of the pulsation. A small remaining unwanted alternating voltage component at mains or twice mains power frequency (depending upon whether half- or full-wave rectification is used)—ripple—is unavoidably superimposed on the direct output voltage.

For purposes such as charging batteries the ripple is not a problem, and the simplest unregulated mains-powered DC power supply circuit consists of a transformer driving a single diode in series with a resistor.

Before the introduction of solid-state electronics, equipment used valves (vacuum tubes) which required high voltages; power supplies used step-up transformers, rectifiers, and filters to generate one or more direct voltages of some hundreds of volts, and a low alternating voltage for filaments. Only the most advanced equipment used expensive and bulky regulated power supplies.

AC power supplies

An AC power supply typically takes the voltage from a wall outlet (mains supply) and lowers it to the desired voltage. Some filtering may take place as well.

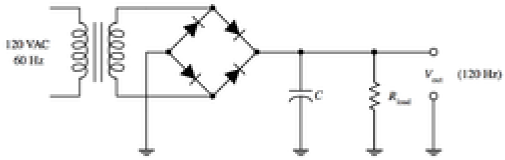
Linear regulated power supply

A linear DC power supply.

The voltage produced by an unregulated power supply will vary depending on the load and on variations in the AC supply voltage. For critical electronics applications, a linear regulator may be used to set the voltage to a precise value, stabilized against fluctuations in input voltage and load. The regulator also greatly reduces the ripple and noise in the output direct current. Linear regulators often provide current limiting, protecting the power supply and attached circuit from over current.

Adjustable linear power supplies are common laboratory and service shop test equipment, allowing the output voltage to be adjusted over a range. For example, a bench power supply used by circuit designers may be adjustable up to 30 volts and up to 5 amperes output. Some can be driven by an external signal, for example, for applications requiring a pulsed output.

AC/DC supply



Schematic of Basic AC-to-DC Power Supply

In the past, mains electricity was supplied as DC in some regions, AC in others. Transformers cannot be used for DC, but a simple, cheap unregulated power supply could run directly from either AC or DC mains without using a transformer. The power supply consisted of a rectifier and a filter capacitor. When operating from DC, the rectifier was essentially a conductor, having no effect; it was included to allow operation from AC or DC without modification.

Switched-mode power supply

A computer's switched mode power supply unit

In a switched-mode power supply (SMPS), the AC mains input is directly rectified and then filtered to obtain a DC voltage. The resulting DC voltage is then switched on and off at a high frequency by electronic switching circuitry, thus producing an AC current that will pass through a high-frequency transformer or inductor. Switching occurs at a very high frequency (typically 10 kHz — 1 MHz), thereby enabling the use of transformers and filter capacitors that are much smaller, lighter, and less expensive than those found in linear power supplies operating at mains frequency. After the inductor or transformer secondary, the high frequency AC is rectified and filtered to produce the DC output voltage. If the SMPS uses an adequately insulated high-frequency transformer, the output will be electrically isolated from the mains; this feature is often essential for safety.

Switched-mode power supplies are usually regulated, and to keep the output voltage constant, the power supply employs a feedback controller that monitors current drawn by the load. The switching duty cycle increases as power output requirements increase.

SMPSs often include safety features such as current limiting or a crowbar circuit to help protect the device and the user from harm. In the event that an abnormal high-current power draw is detected, the switched-mode supply can assume this is a direct short and will shut itself down before damage is done. PC power supplies often provide a *power good* signal to the motherboard; the absence of this signal prevents operation when abnormal supply voltages are present.

SMPSs have an absolute limit on their minimum current output. They are only able to output above a certain power level and cannot function below that point. In a no-load condition the frequency of the power slicing circuit increases to great speed, causing the isolated transformer to act as a Tesla coil, causing damage due to the resulting very high voltage power spikes. Switched-mode supplies with protection circuits may briefly turn on but then shut down when no load has been detected. A very small low-power dummy load such as a ceramic power resistor or 10-watt light bulb can be attached to the supply to allow it to run with no primary load attached.

Power factor has become an issue of concern for computer manufacturers. Switched mode power supplies have traditionally been a source of power line harmonics and have a very poor power factor. The rectifier input stage distorts the wave shape of current drawn from the supply; this can produce adverse effects on other loads. The distorted current causes extra heating in the wires and distribution equipment. Switched mode power supplies in a building can result in poor power quality for other utility customers. Customers may face higher electric bills for a low power factor load.

Some switch-mode power supplies use filters or additional switching stages in the incoming rectifier circuit to improve the waveform of the current taken from the AC line. This adds to the circuit complexity. Many computer power supplies built in the last few years now include power factor correction built right into the switched-mode supply, and may advertise the fact that they offer *1.0 power factor*.

Programmable power supply

Programmable power supplies

Programmable power supplies allow for remote control of the output voltage through an analog input signal or a computer interface such as RS232 or GPIB. Variable properties include voltage, current, and frequency (for AC output units). These supplies are composed of a processor, voltage/current programming circuits, current shunt, and voltage/current read-back circuits. Additional features can include over current, overvoltage, and short circuit protection, and temperature compensation. Programmable power supplies also come in a variety of forms including modular, board-mounted, wall-mounted, floor-mounted or bench top. Programmable power supplies generally use SCPI as programming language.

Programmable power supplies can furnish DC, AC, or AC with a DC offset. The AC output can be either single-phase or three-phase. Single-phase is generally used for low-voltage, while three-phase is more common for high-voltage power supplies.

Programmable power supplies are now used in many applications. Some examples include automated equipment testing, crystal growth monitoring, and differential thermal analysis

Uninterruptible power supply

An uninterruptible power supply (UPS) takes its power from two or more sources simultaneously. It is usually powered directly from the AC mains, while simultaneously charging a storage battery. Should there be a dropout or failure of the mains, the battery instantly takes over so that the load never experiences an interruption. In a computer installation, this gives the operators time to shut down the system in an orderly way. Other UPS schemes may use an internal combustion engine or turbine to continuously supply power to a system in parallel with power coming from the AC. The engine-driven generators would normally be idling, but could come to full power in a matter of a few seconds in order to keep vital equipment running without interruption. Such a scheme might be found in hospitals or telephone central offices.

High-voltage power supply

High voltage refers to an output on the order of hundreds or thousands of volts. High-voltage supplies use a linear setup to produce an output voltage in this range.

Additional features available on high-voltage supplies can include the ability to reverse the output polarity along with the use of circuit breakers and special connectors intended to minimize arcing and accidental contact with human hands. Some supplies provide analog inputs that can be used to control the output voltage, effectively turning them into high-voltage amplifiers albeit with very limited bandwidth.

Voltage multipliers

A voltage multiplier is an electrical circuit that converts AC electrical power from a lower voltage to a higher DC voltage, typically by means of a network of capacitors and diodes. The input voltage may be doubled (voltage doubler), tripled (voltage Tripler), quadrupled (voltage quadrupler), and so on. These circuits allow high voltages to be obtained using a much lower voltage AC source.

Typically, voltage multipliers are composed of half-wave rectifiers, capacitors, and diodes. For example, a voltage Tripler consists of three half-wave rectifiers, three capacitors, and three diodes (as in the Cockcroft Walton multiplier). Full-wave rectifiers may be used in a different configuration to achieve even higher voltages. Also, both parallel and series configurations are available. For parallel multipliers, a higher voltage rating is required at each consecutive multiplication stage, but less capacitance is required. The voltage rating of the capacitors determines the maximum output voltage.

Voltage multipliers have many applications. For example, voltage multipliers can be found in everyday items like televisions and photocopiers. Other applications can be found in the laboratory, such as cathode ray tubes, oscilloscopes, and photomultiplier tubes.

Power supply applications

Computer power supply

A modern computer power supply is a switch-mode power supply that converts AC power from the mains supply, to several DC voltages. Switch-mode supplies replaced linear supplies due to cost, weight, and size improvement. The diverse collection of output voltages also have widely varying current draw requirements.

Welding power supply

Arc welding uses electricity to melt the surfaces of the metals in order to join them together through coalescence. The electricity is provided by a *welding power supply*, and can either be AC or DC. Arc welding typically requires high currents typically between 100 and 350 amperes.

Some types of welding can use as few as 10 amperes, while some applications of spot welding employ currents as high as 60,000 amperes for an extremely short time. Older welding power supplies consisted of transformers or engines driving generators. More recent supplies use semiconductors and microprocessors reducing their size and weight.

AC adapter

Switched mode mobile phone charger

A power supply that is built into an AC mains power plug is known as a "plug pack" or "plug-in adapter", or by slang terms such as "wall wart". They are even more diverse than their names; often with either the same kind of DC plug offering different voltage or polarity, or a different plug offering the same voltage. "Universal" adapters attempt to replace missing or damaged ones, using multiple plugs and selectors for different voltages and polarities. Replacement power supplies must match the voltage of, and supply at least as much current as, the original power supply.

The least expensive AC units consist only of a small transformer, while DC adapters include a few additional diodes. Whether or not a load is connected to the power adapter, the transformer has a magnetic field continuously present and normally cannot be completely turned off unless unplugged.

Because they consume standby power, they are sometimes known as "electricity vampires" and may be plugged into a power strip to allow turning them off.

In contrast, switched-mode power supplies can cut off leaky electrolyte-capacitors, use powerless MOSFETs, and reduce their working frequency to get a gulp of energy once in a while to power, for example, a clock, which would otherwise need a battery.

Overload protection

Power supplies often have protection from short circuit or overload that could damage the supply or cause a fire. Fuses and circuit breakers are two commonly used mechanisms for overload protection.

A fuse contains a short piece of wire which melts if too much current flows. This effectively disconnects the power supply from its load, and the equipment stops working until the problem that caused the overload is identified and the fuse is replaced. Some power supplies use a very thin wire link soldered in place as a fuse. Fuses in power supply units may be replaceable by the end user, but fuses in consumer equipment may require tools to access and change.

A circuit breaker contains an element that heats, bends and triggers a spring which shuts the circuit down. Once the element cools, and the problem is identified the breaker can be reset and the power restored.

Some PSUs use a thermal cutout buried in the transformer rather than a fuse. The advantage is it allows greater current to be drawn for limited time than the unit can supply continuously. Some such cutouts are self resetting, some are single use only.

Current limiting

Some supplies use current limiting instead of cutting off power if overloaded. The two types of current limiting used are electronic limiting and impedance limiting. The former is common on lab bench PSUs, the latter is common on supplies of less than 3 watts output.

A foldback current limiter reduces the output current to much less than the maximum non-fault current.

Power conversion

The term "**power supply**" is sometimes restricted to those devices that *convert* some other form of energy into electricity (such as solar power and fuel cells and generators). A more accurate term for devices that convert one form of electric power into another form (such as transformers and linear regulators) is power converter. The most common conversion is from AC to DC.

Mechanical power supplies

- Flywheels coupled to electrical generators or alternators
- Compulsators
- Explosively pumped flux compression generators

5.2 control unit

In automotive electronics, **electronic control unit** (**ECU**) is a generic term for any embedded system that controls one or more of the electrical system or subsystems in a motor vehicle.

Types of ECU include electronic/engine control module (ECM), powertrain control module (PCM), transmission control module (TCM), brake control module (BCM or EBCM), central control module (CCM), central timing module (CTM), general electronic module (GEM), body control module (BCM), suspension control module (SCM), control unit, or control module.

Taken together, these systems are sometimes referred to as the car's computer. (Technically there is no single computer but multiple ones.) Sometimes one assembly incorporates several of the individual control modules (PCM is often both engine and transmission)

Some modern motor vehicles have up to 80 ECUs. Embedded software in ECUs continue to increase in line count, complexity, and sophistication. Managing the increasing complexity and number of ECUs in a vehicle has become a key challenge for original equipment manufacturers (OEMs).

Types of electronic control units

- Airbag control unit (ACU)
- Body control module (BCU) controls door locks, electric windows, courtesy lights, etc.
- Convenience control unit (CCU)
- Door control unit (DCU)
- Engine control unit (ECU)—not to be confused with *electronic* control unit, the generic term for all these devices

- Electric Power Steering Control Unit (PSCU)— Generally this will be integrated into the EPS power pack.
- Human-machine interface (HMI)
- Power train control module (PCM): Sometimes the functions of the Engine Control Unit and transmission control unit (TCU) are combined into a single unit called the Power train Control Module.
- Seat Control Unit
- Speed control unit (SCU)
- Telematic control unit (TCU)
- Transmission control unit (TCU)
- Brake Control Module (BCM; ABS or ESC)
- Battery management system

An **airbag** is a vehicle safety device. It is an occupant restraint system consisting of a flexible fabric envelope or cushion designed to inflate rapidly during an automobile collision. Its purpose is to cushion occupants during a crash and provide protection to their bodies when they strike interior objects such as the steering wheel or a window. Modern vehicles may contain multiple airbag modules in various side and frontal locations of the passenger seating positions, and sensors may deploy one or more airbags in an impact zone at variable rates based on the type, angle and severity of impact; the airbag is designed to only inflate in moderate to severe frontal crashes. Airbags are normally designed with the intention of supplementing the protection of an occupant who is correctly restrained with a seatbelt. Most designs are inflated through pyrotechnic means and can only be operated once. Newer side-impact airbag modules consist of compressed air cylinders that are triggered in the event of a side impact vehicle impact.

An **engine control unit (ECU)**, now called the power train control module (PCM), is a type of electronic control unit that controls a series of actuators on an internal combustion engine to ensure optimal engine performance. It does this by reading values from a multitude of sensors within the engine bay, interpreting the data using multidimensional performance maps (called lookup tables), and adjusting the engine actuators accordingly.

Before ECUs, air/fuel mixture, ignition timing, and idle speed were mechanically set and dynamically controlled by mechanical and pneumatic means. One of the earliest attempts to use such a unitized and automated device to manage multiple engine control functions simultaneously was the "Kommandogerät" created by BMW in 1939, for their 801 14-cylinder aviation radial engine This device replaced the 6 controls used to initiate hard acceleration with one control in the 801 series-equipped aircraft. However, it had some problems: it would surge the engine, making close formation flying of the Fw 190 somewhat difficult, and at first it switched supercharger gears harshly and at random, which could throw the aircraft into an extremely dangerous stall or spin.

Control of idle speed

Most engine systems have idle speed control built into the ECU. The engine RPM is monitored by the crankshaft position sensor which plays a primary role in the engine timing functions for fuel injection, spark events, and valve timing. Idle speed is controlled by a programmable throttle stop or an idle air bypass control stepper motor. Early carburetor-based systems used a programmable throttle stop using a bidirectional DC motor. Early TBI systems used an idle air control stepper motor. Effective idle speed control must anticipate the engine load at idle.

A full authority throttle control system may be used to control idle speed, provide cruise control functions and top speed limitation.

Control of variable valve timing

Some engines have Variable Valve Timing. In such an engine, the ECU controls the time in the engine cycle at which the valves open. The valves are usually opened sooner at higher speed than at lower speed. This can optimize the flow of air into the cylinder, increasing power and the economy.

Electronic valve control

Experimental engines have been made and tested that have no camshaft, but have full electronic control of the intake and exhaust valve opening, valve closing and area of the valve opening. Such engines can be started and run without a starter motor for certain multi-cylinder engines equipped with precision timed electronic ignition and fuel injection. Such a *static-start* engine would provide the efficiency and pollution-reduction improvements of a mild hybrid-electric drive, but without the expense and complexity of an oversized starter motor.

The first production engine of this type was invented (in 2002) and introduced (in 2009) by Italian automaker Fiat in the Alfa Romeo MiTo. Their Multiair engines use electronic valve control which drastically improve torque and horsepower, while reducing fuel consumption as much as 15%. Basically, the valves are opened by hydraulic pumps, which are operated by the ECU. The valves can open several times per intake stroke, based on engine load. The ECU then decides how much fuel should be injected to optimize combustion.

For instance, when driving at a steady speed, the valve will open and a bit of fuel will be injected, the valve then closes. But, when you suddenly stamp on the throttle, the valve will open again in that same intake stroke and much more fuel will be injected so that you start to accelerate immediately. The ECU then calculates engine load at that exact RPM and decides how to open the valve: early, or late, wide open, or just half open. The optimal opening and timing are always reached and combustion is as precise as possible. This, of course, is impossible with a normal camshaft, which opens the valve for the whole intake period, and always to full lift.

And not to be overlooked, the elimination of cams, lifters, rockers, and timing set not only reduces weight and bulk, but also friction. A significant portion of the power that an engine actually produces is used up just driving the valve train, compressing all those valve springs thousands of times a minute.

Once more fully developed, electronic valve operation will yield even more benefits. Cylinder deactivation, for instance, could be made much more fuel efficient if the intake valve could be opened on every downstroke and the exhaust valve opened on every upstroke of the deactivated cylinder or "dead hole". Another even more significant advancement will be the elimination of the convention throttle. When a car is run at part throttle, this interruption in the airflow causes excess vacuum, which causes the engine to use up valuable energy acting as a vacuum pump. BMW attempted to get around this on their V-10 powered M5, which had individual throttle butterflies for each cylinder, placed just before the intake valves. With electronic valve operation, it will be possible to control engine speed by regulating valve lift. At part throttle, when less air and gas are needed, the valve lift would not be as great. Full throttle is achieved when the gas pedal is depressed, sending an electronic signal to the ECU, which in turn regulates the lift of each valve event, and opens it all the way up.

Programmable ECUs

A special category of ECUs are those which are programmable. These units do not have a fixed behavior and can be reprogrammed by the user.

Programmable ECUs are required where significant aftermarket modifications have been made to a vehicle's engine. Examples include adding or changing of a turbocharger, adding or changing of an intercooler, changing of the exhaust system or a conversion to run on alternative fuel. As a consequence of these changes, the old ECU may not provide appropriate control for the new configuration. In these situations, a programmable ECU can be wired in. These can be programmed/mapped with a laptop connected using a serial or USB cable, while the engine is running.

The programmable ECU may control the amount of fuel to be injected into each cylinder. This varies depending on the engine's RPM and the position of the accelerator pedal (or the manifold air pressure). The engine tuner can adjust this by bringing up a spreadsheet-like page on the laptop where each cell represents an intersection between a specific RPM value and an accelerator pedal position (or the throttle position, as it is called). In this cell a number corresponding to the amount of fuel to be injected is entered. This spreadsheet is often referred to as a fuel table or fuel map.

By modifying these values while monitoring the exhausts using a wide band lambda probe to see if the engine runs rich or lean, the tuner can find the optimal amount of fuel to inject to the engine at every different combination of RPM and throttle position. This process is often carried out at a dynamometer, giving the tuner a controlled environment to work in. An engine dynamometer gives a more precise calibration for racing applications. Tuners often utilize a chassis dynamometer for street and other high performance applications.

Other parameters that are often mappable are:

- **Ignition Timing:** Defines at what point in the engine cycle the spark plug should fire for each cylinder. Modern systems allow for individual trim on each cylinder for per-cylinder optimization of the ignition timing.
- **Rev. limit:** Defines the maximum RPM that the engine is allowed to reach. After this fuel and/or ignition is cut. Some vehicles have a "soft" cut-off before the "hard" cut-off. This "soft cut" generally functions by retarding ignition timing to reduce power output and thereby slow the acceleration rate just before the "hard cut" is hit.

- **Water temperature correction:** Allows for additional fuel to be added when the engine is cold, such as in a winter cold-start scenario or when the engine is dangerously hot, to allow for additional cylinder cooling (though not in a very efficient manner, as an emergency only).
- **Transient fueling:** Tells the ECU to add a specific amount of fuel when throttle is applied. The is referred to as "acceleration enrichment".
- **Low fuel pressure modifier:** Tells the ECU to increase the injector fire time to compensate for an increase or loss of fuel pressure.
- **Closed loop lambda:** Lets the ECU monitor a permanently installed lambda probe and modify the fueling to achieve the targeted air/fuel ratio desired. This is often the stoichiometric (ideal) air fuel ratio, which on traditional petrol (gasoline) powered vehicles this air:fuel ratio is 14.7:1. This can also be a much richer ratio for when the engine is under high load, or possibly a leaner ratio for when the engine is operating under low load cruise conditions for maximum fuel efficiency.

Some of the more advanced standalone/race ECUs include functionality such as launch control, operating as a rev limiter while the car is at the starting line to keep the engine revs in a 'sweet spot', waiting for the clutch to be released to launch the car as quickly and efficiently as possible. Other examples of advanced functions are:

- **Wastegate control:** Controls the behavior of a turbocharger's wastegate, controlling boost. This can be mapped to command a specific duty cycle on the valve, or can use a PID based closed-loop control algorithm.
- **Staged injection:** Allows for an additional injector per cylinder, used to get a finer fuel injection control and atomization over a wide RPM range. An example being the use of small injectors for smooth idle and low load conditions, and a second, larger set of injectors that are 'staged in' at higher loads, such as when the turbo boost climbs above a set point.
- **Variable cam timing:** Allows for control variable intake and exhaust cams (VVT), mapping the exact advance/retard curve positioning the camshafts for maximum benefit at all load/rpm positions in the map. This functionality is often used to optimize power

output at high load/rpms, and to maximize fuel efficiency and emissions as lower loads/rpms.

- **Gear control:** Tells the ECU to cut ignition during (sequential gearbox) up shifts or blip the throttle during downshifts.

A race ECU is often equipped with a data logger recording all sensors for later analysis using special software in a PC. This can be useful to track down engine stalls, misfires or other undesired behaviors during a race by downloading the log data and looking for anomalies after the event. The data logger usually has a capacity between 0.5 and 16 megabytes.

In order to communicate with the driver, a race ECU can often be connected to a "data stack", which a simple dash board is presenting the driver with the current RPM, speed and other basic engine data. These race stacks, which are almost always digital, talk to the ECU using one of several proprietary protocols running over RS232 or CANbus, connecting to the DLC connector (Data Link Connector) usually located on the underside of the dash, in line with the steering wheel

Transformer

A **transformer** is an electrical device that transfers energy between two circuits through electromagnetic induction. A transformer may be used as a safe and efficient voltage converter to change the AC voltage at its input to a higher or lower voltage at its output without changing the frequency. Other uses include current conversion, isolation with or without changing voltage and impedance conversion.

A transformer most commonly consists of two windings of wire that are wound around a common core to provide tight electromagnetic coupling between the windings. The core material is often a laminated iron core. The coil that receives the electrical input energy is referred to as the primary winding, the output coil is the secondary winding.

An alternating electric current flowing through the primary winding (coil) of a transformer generates a varying electromagnetic field in its surroundings which induces a varying magnetic flux in the core of the transformer. The varying electromagnetic field in the vicinity of the secondary winding induces an electromotive force in the secondary winding, which appears as a voltage across the output terminals. If a load is connected across the secondary winding, a current flows through the secondary winding drawing power from the primary winding and its power source.

A transformer cannot operate with direct current. When connected to a DC source, a transformer typically produces a short output pulse as the input current rises.

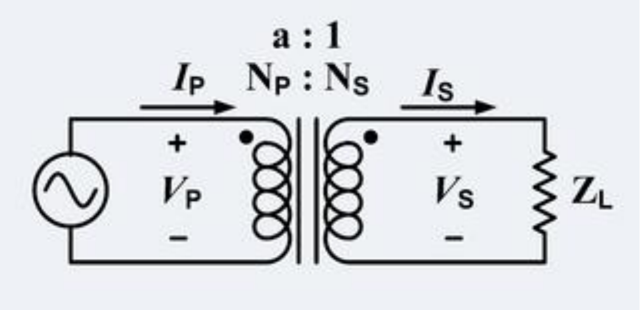
Basic principles

The operation of a transformer is based on two principles of the laws of electromagnetic induction: An electric current through a conductor, produces a magnetic field surrounding the conductor, and a changing magnetic field in the vicinity of a conductor induces a voltage across the ends of that conductor.

The magnetic field excited in the primary coil gives rise to self-induction as well as mutual induction between coils. This self-induction counters the excited field to such a degree that the resulting current through the primary winding is very small when the secondary winding is not connected to a load.

The physical principles of the inductive behavior of the transformer are most readily understood and formalized when making some assumptions to construct a simple model which is called the *ideal transformer*. This model differs from *real transformers* by assuming that the transformer is perfectly constructed and by neglecting that electrical or magnetic losses occur in the materials used to construct the device.

Ideal transformer



Ideal transformer with a source and a load. N_P and N_S are the number of turns in the primary and secondary windings respectively.

The assumptions to characterize the ideal transformer are:

- The windings of the transformer have no resistance. Thus, there is no copper loss in the winding, and hence no voltage drop.
- Flux is confined within the magnetic core. Therefore, it is the same flux that links the input and output windings.
- Permeability of the core is infinitely high which implies that net mmf (amp-turns) must be zero (otherwise there would be infinite flux) hence $I_P N_P - I_S N_S = 0$.
- The transformer core does not suffer magnetic hysteresis or eddy currents, which cause inductive loss.

If the secondary winding of an ideal transformer has no load, no current flows in the primary winding.

The circuit diagram (right) shows the conventions used for an ideal, i.e. lossless and perfectly coupled transformer having primary and secondary windings with N_P and N_S turns, respectively.

The ideal transformer induces secondary voltage V_S as a proportion of the primary voltage V_P and respective winding turns as given by the equation

$$\frac{V_\mathrm{P}}{V_\mathrm{S}} = \frac{N_\mathrm{P}}{N_\mathrm{S}} = a,$$

where,

a is the winding *turns ratio*, the value of these ratios being respectively higher and lower than unity for step-down and step-up transformers,

V_P designates source impressed voltage,

V_S designates output voltage, and,

According to this formalism, when the number of turns in the primary coil is greater than the number of turns in the secondary coil, the secondary voltage is smaller than the primary voltage. On the other hand, when the number of turns in the primary coil is less than the number of turns in the secondary, the secondary voltage is greater than the primary voltage.

Any load impedance Z_L connected to the ideal transformer's secondary winding allows energy to flow without loss from primary to secondary circuits. The resulting input and output apparent power are equal as given by the equation

$$I_P V_P = I_S V_S.$$

Combining the two equations yields the following ideal transformer identity

$$\frac{V_P}{V_S} = \frac{I_S}{I_P} = a.$$

This formula is a reasonable approximation for the typical commercial transformer, with voltage ratio and winding turns ratio both being inversely proportional to the corresponding current ratio.

The load impedance Z_L and secondary voltage V_S determine the secondary current I_S as follows

$$I_S = \frac{V_S}{Z_L}.$$

The apparent impedance Z_L' of this secondary circuit load *referred* to the primary winding circuit is governed by a squared turns ratio multiplication factor relationship derived as follows

$$Z_L' = \frac{V_P}{I_P} = \frac{aV_S}{I_S/a} = a^2\frac{V_S}{I_S} = a^2 Z_L.$$

For an ideal transformer, the power supplied to the primary and the power dissipated by the load are equal. If $Z_L = R_L$ where R_L is a pure resistance then the power is given by:

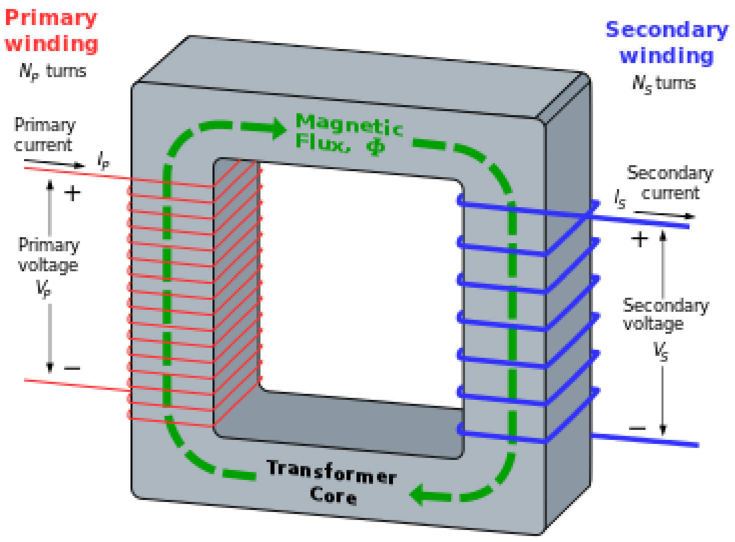
$$P = \frac{V_\mathrm{S}^2}{R_\mathrm{L}} = \frac{V_\mathrm{P}^2}{a^2 R_\mathrm{L}}$$

The primary current is given by the following equation:

$$I_\mathrm{P} = \frac{V_\mathrm{P}}{a^2 Z_L}$$

Induction law

A varying electrical current passing through the primary coil creates a varying magnetic field around the coil which induces a voltage in the secondary winding. The primary and secondary windings are wrapped around a core of very high magnetic permeability, usually iron ,so that most of the magnetic flux passes through both the primary and secondary coils. The current through a load connected to the secondary winding and the voltage across it flow in the directions indicated in the figure.



Ideal transformer and induction law

The voltage induced across the secondary coil may be calculated from Faraday's law of induction, which states that:

$$V_S = N_S \frac{\mathrm{d}\Phi}{\mathrm{d}t}.$$

where V_s is the instantaneous voltage, N_s is the number of turns in the secondary coil, and dΦ/dt is the derivative of the magnetic flux Φ through one turn of the coil. If the turns of the coil are oriented perpendicularly to the magnetic field lines, the flux is the product of the magnetic flux density *B* and the area *A* through which it cuts. The area is constant, being equal to the cross-sectional area of the transformer core, whereas the magnetic field varies with time according to the excitation of the primary. Since the same magnetic flux passes through both the primary and secondary coils in an ideal transformer, the instantaneous voltage across the primary winding equals

$$V_P = N_P \frac{\mathrm{d}\Phi}{\mathrm{d}t}.$$

Taking the ratio of the above two equations gives the same voltage ratio and turns ratio relationship shown above, that is,

$$\frac{V_\mathrm{P}}{V_\mathrm{S}} = \frac{N_\mathrm{P}}{N_\mathrm{S}} = a.$$

The changing magnetic field induces an emf across each winding.The primary emf, acting as it does in opposition to the primary voltage, is sometimes termed the counter emf This is in accordance with Lenz's law, which states that induction of emf always opposes development of any such change in magnetic field.

As still lossless and perfectly-coupled, the transformer still behaves as described above in the ideal transformer.

Polarity

Instrument transformer, with polarity dot and X1 markings on LV side terminal

The relationships of the instantaneous polarity at each of the terminals of the windings of a transformer depend on the direction the windings are wound around the core. Identically wound windings produce the same polarity of voltage at the corresponding terminals. This relationship is usually denoted by the dot convention in transformer circuit diagrams, nameplates, and on terminal markings, which marks the terminals having an in-phase relationship.

Real transformer

The ideal transformer model neglects the following basic linear aspects in real transformers.

Core losses, collectively called magnetizing current losses, consist of

- Hysteresis losses due to nonlinear application of the voltage applied in the transformer core, and
- Eddy current losses due to joule heating in the core that are proportional to the square of the transformer's applied voltage.

Whereas windings in the ideal model have no impedance, the windings in a real transformer have finite non-zero impedances in the form of:

- Joule losses due to resistance in the primary and secondary windings
- Leakage flux that escapes from the core and passes through one winding only resulting in primary and secondary reactive impedance.

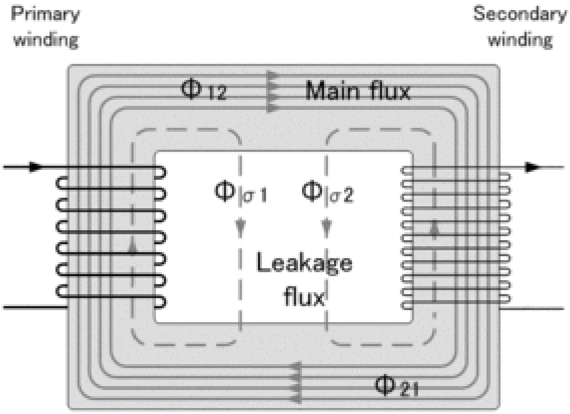
If a voltage is applied across the primary terminals of a real transformer while the secondary winding is open without load, the real transformer must be viewed as a simple inductor with an impedance Z:

$$Z_P = j\omega L_P$$

$$I_\mathrm{P} = V_\mathrm{P}/Z_\mathrm{P}.$$

Leakage flux

Main article: Leakage inductance



Leakage flux of a transformer

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. Such flux is termed *leakage flux*, and results in leakage inductance in series with the mutually coupled transformer windings. Leakage flux results in energy being alternately stored in and discharged from the magnetic fields with each cycle of the power supply. It is not directly a power loss, but results in inferior voltage regulation, causing the secondary voltage not to be directly proportional to the primary voltage, particularly under heavy load. Transformers are therefore normally designed to have very low leakage inductance. Nevertheless, it is impossible to eliminate all leakage flux because it plays an essential part in the operation of the transformer. The combined effect of the leakage flux and the electric field around the windings is what transfers energy from the primary to the secondary.

In some applications increased leakage is desired, and long magnetic paths, air gaps, or magnetic bypass shunts may deliberately be introduced in a transformer design to limit the short-circuit current it will supply 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 in circuits that have a DC component flowing in the windings.

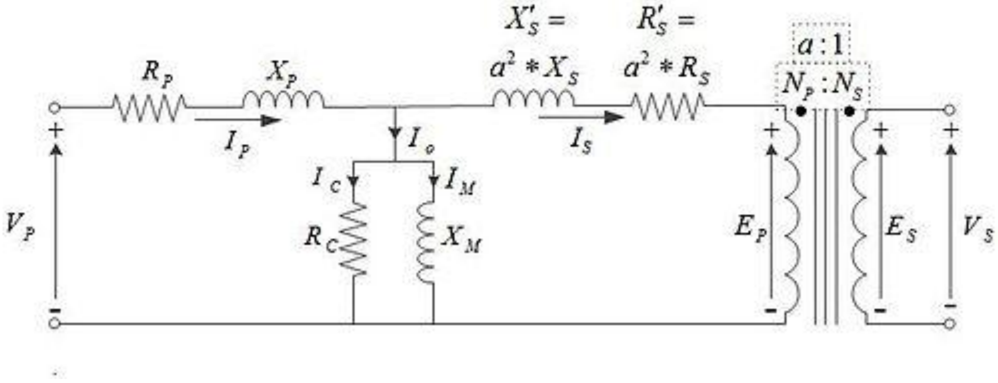
Knowledge of leakage inductance is also useful when transformers are operated in parallel. It can be shown that if the percent impedance (Z) and associated winding leakage reactance-to-resistance (X/R) ratio of two transformers were hypothetically exactly the same, the transformers would share power in proportion to their respective volt-ampere ratings (e.g. 500 kVA unit in parallel with 1,000 kVA unit, the larger unit would carry twice the current). However, the impedance tolerances of commercial transformers are significant. Also, the Z impedance and X/R ratio of different capacity transformers tends to vary, corresponding 1,000 kVA and 500 kVA units' values being, to illustrate, respectively, Z ~ 5.75%, X/R ~ 3.75 and Z ~ 5%, X/R ~

Referring to the diagram, a practical transformer's physical behavior may be represented by an equivalent circuit model, which can incorporate an ideal transformer.

Winding joule losses and leakage reactance are represented by the following series loop impedances of the model:

- Primary winding: R_P, X_P
- Secondary winding: R_S, X_S.

In normal course of circuit equivalence transformation, R_S and X_S are in practice usually referred to the primary side by multiplying these impedances by the turns ratio squared, $(N_P/N_S)^2 = a^2$.



Real transformer equivalent circuit

Core loss and reactance is represented by the following shunt leg impedances of the model:

- Core or iron losses: R_C
- Magnetizing reactance: X_M.

R_C and X_M are collectively termed the *magnetizing branch* of the model.

Core losses are caused mostly by hysteresis and eddy current effects in the core and are proportional to the square of the core flux for operation at a given frequency. The finite permeability core requires a magnetizing current I_M to maintain mutual flux in the core. Magnetizing current is in phase with the flux, the relationship between the two being non-linear due to saturation effects. However, all impedances of the equivalent circuit shown are by definition linear and such non-linearity effects are not typically reflected in transformer equivalent circuits With sinusoidal supply, core flux lags the induced emf by 90°. With open-circuited secondary winding, magnetizing branch current I_0 equals transformer no-load current.

The resulting model, though sometimes termed 'exact' equivalent circuit based on linearity assumptions, retains a number of approximations Analysis may be simplified by assuming that magnetizing branch impedance is relatively high and relocating the branch to the left of the primary impedances. This introduces error but allows combination of primary and referred secondary resistances and reactance by simple summation as two series impedances.

Transformer equivalent circuit impedance and transformer ratio parameters can be derived from the following tests: open-circuit test, short-circuit test, winding resistance test, and transformer ratio test.

Rectifier

A **rectifier** is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as **rectification**. Physically, rectifiers take a number of forms, including vacuum tube diodes, mercury-arc valves, copper and selenium oxide rectifiers, semiconductor diodes, silicon-controlled rectifiers and other silicon-based semiconductor switches. Historically, even synchronous electromechanical switches and motors have been used. Early radio receivers, called crystal radios, used a "cat's whisker" of fine wire pressing on a crystal of galena (lead sulfide) to serve as a point-contact rectifier or "crystal detector".

Rectifiers have many uses, but are often found serving as components of DC power supplies and high-voltage direct current power transmission systems. Rectification may serve in roles other than to generate direct current for use as a source of power. As noted, detectors of radio signals serve as rectifiers. In gas heating systems flame rectification is used to detect presence of flame.

Because of the alternating nature of the input AC sine wave, the process of rectification alone produces a DC current that, though unidirectional, consists of pulses of current. Many applications of rectifiers, such as power supplies for radio, television and computer equipment, require a *steady* constant DC current (as would be produced by a battery). In these applications the output of the rectifier is smoothed by an electronic filter to produce a steady current.

A more complex circuitry device that performs the opposite function, converting DC to AC, is called an inverter.

Rectifier devices

Before the development of silicon semiconductor rectifiers, vacuum tube thermionic diodes and copper oxide- or selenium-based metal rectifier stacks were used. With the introduction of semiconductor electronics, vacuum tube rectifiers became obsolete, except for some enthusiasts of vacuum tube audio equipment. For power rectification from very low to very high current, semiconductor diodes of various types (junction diodes, Schottky diodes, etc.) are widely used.

Other devices that have control electrodes as well as acting as unidirectional current valves are used where more than simple rectification is required—e.g., where variable output voltage is needed. High-power rectifiers, such as those used in high-voltage direct current power transmission, employ silicon semiconductor devices of various types. These are thyristors or other controlled switching solid-state switches, which effectively function as diodes to pass current in only one direction.

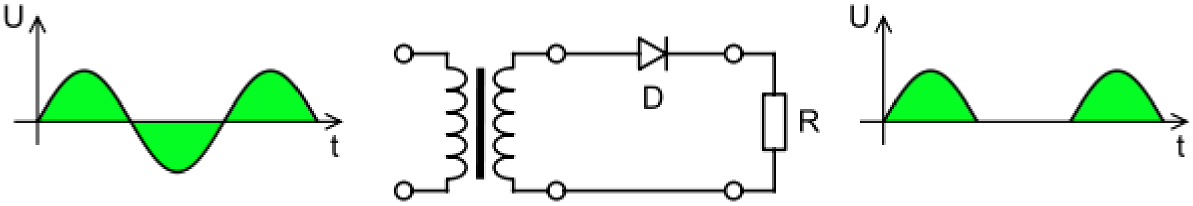
Rectifier circuits

Rectifier circuits may be single-phase or multi-phase (three being the most common number of phases). Most low power rectifiers for domestic equipment are single-phase, but three-phase rectification is very important for industrial applications and for the transmission of energy as DC (HVDC).

Single-phase rectifiers

Half-wave rectification

In half wave rectification of a single-phase supply, either the positive or negative half of the AC wave is passed, while the other half is blocked. Because only one half of the input waveform reaches the output, mean voltage is lower. Half-wave rectification requires a single diode in a single-phase supply, or three in a three-phase supply. Rectifiers yield a unidirectional but pulsating direct current; half-wave rectifiers produce far more ripple than full-wave rectifiers, and much more filtering is needed to eliminate harmonics of the AC frequency from the output.



Half-wave rectifier

The no-load output DC voltage of an ideal half wave rectifier for a sinusoidal input voltage is:[2]

$$V_{\mathrm{rms}} = \frac{V_{\mathrm{peak}}}{2}$$

$$V_{\mathrm{dc}} = \frac{V_{\mathrm{peak}}}{\pi}$$

Where:

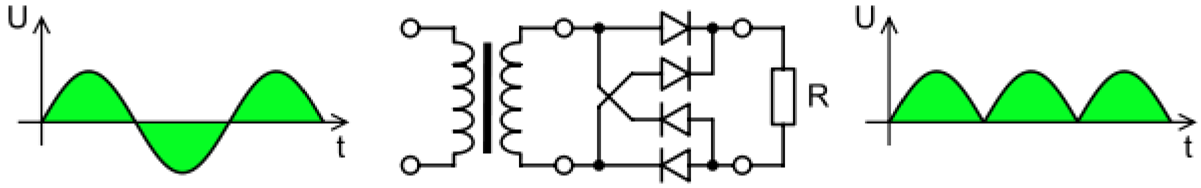
V_{dc}, V_{av} - the DC or average output voltage,

V_{peak}, the peak value of the phase input voltages,

V_{rms}, the root-mean-square value of output voltage.

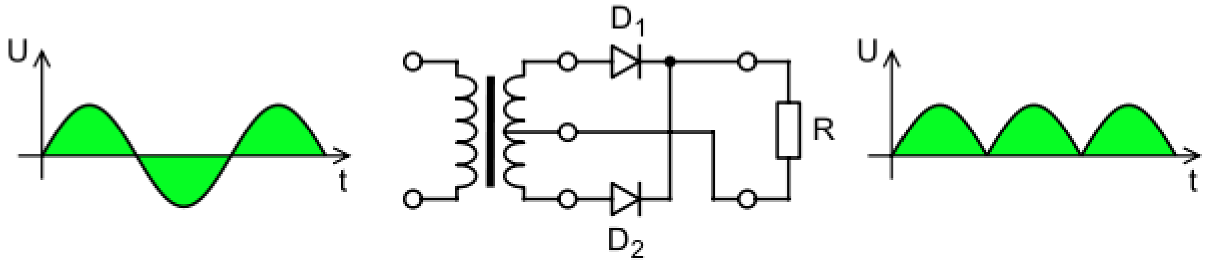
Full-wave rectification

A full-wave rectifier converts the whole of the input waveform to one of constant polarity (positive or negative) at its output. Full-wave rectification converts both polarities of the input waveform to pulsating DC (direct current), and yields a higher average output voltage. Two diodes and a center tapped transformer, or four diodes in a bridge configuration and any AC source (including a transformer without center tap), are needed. Single semiconductor diodes, double diodes with common cathode or common anode, and four-diode bridges, are manufactured as single components.

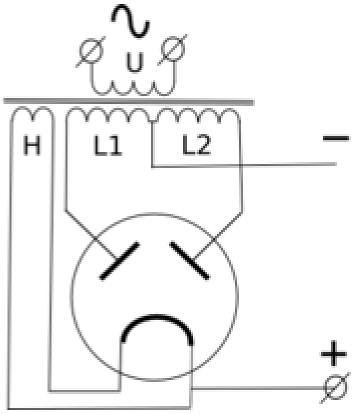


Graetz bridge rectifier: a full-wave rectifier using 4 diodes.

For single-phase AC, if the transformer is center-tapped, then two diodes back-to-back (cathode-to-cathode or anode-to-anode, depending upon output polarity required) can form a full-wave rectifier. Twice as many turns are required on the transformer secondary to obtain the same output voltage than for a bridge rectifier, but the power rating is unchanged.



Full-wave rectifier using a center tap transformer and 2 diodes.



Full-wave rectifier, with vacuum tube having two anodes.

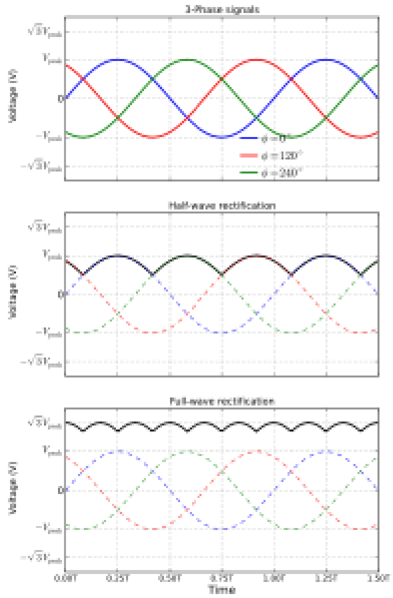
The average and root-mean-square no-load output voltages of an ideal single-phase full-wave rectifier are:

$$V_{\mathrm{dc}} = V_{\mathrm{av}} = \frac{2V_{\mathrm{peak}}}{\pi}$$

$$V_{\mathrm{rms}} = \frac{V_{\mathrm{peak}}}{\sqrt{2}}$$

Very common double-diode rectifier vacuum tubes contained a single common cathode and two anodes inside a single envelope, achieving full-wave rectification with positive output. The 5U4 and 5Y3 were popular examples of this configuration.

Three-phase rectifiers



3-phase AC input, half and full-wave rectified DC output waveforms

Single-phase rectifiers are commonly used for power supplies for domestic equipment. However, for most industrial and high-power applications, three-phase rectifier circuits are the norm. As with single-phase rectifiers, three-phase rectifiers can take the form of a half-wave circuit, a full-wave circuit using a center-tapped transformer, or a full-wave bridge circuit.

Thyristors are commonly used in place of diodes to create a circuit that can regulate the output voltage. Many devices that provide direct current actually *generate* three-phase AC. For example, an automobile alternator contains six diodes, which function as a full-wave rectifier for battery charging.

Three-phase, half-wave circuit

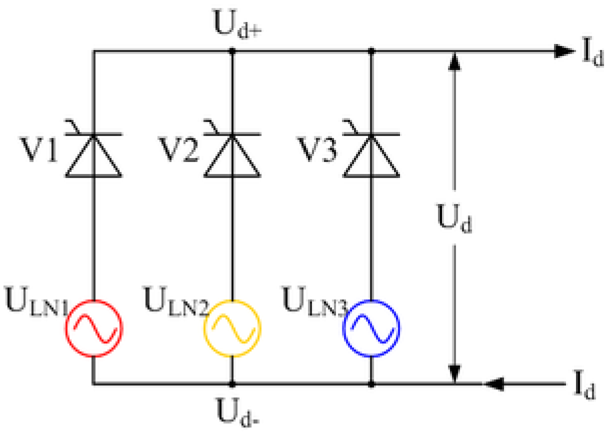
An uncontrolled three-phase, half-wave circuit requires three diodes, one connected to each phase. This is the simplest type of three-phase rectifier but suffers from relatively high harmonic distortion on both the AC and DC connections. This type of rectifier is said to have a **pulse-number** of three, since the output voltage on the DC side contains three distinct pulses per cycle of the grid frequency.

Three-phase, full-wave circuit using center-tapped transformer

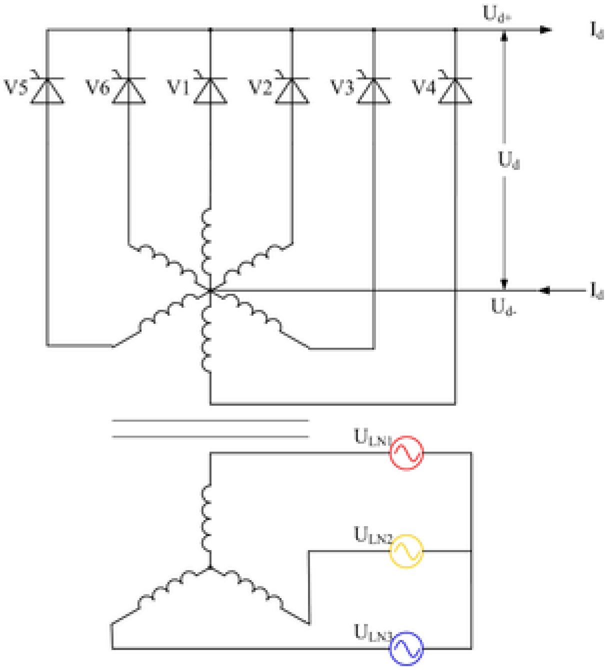
If the AC supply is fed via a transformer with a center tap, a rectifier circuit with improved harmonic performance can be obtained. This rectifier now requires six diodes, one connected to each end of each transformer secondary winding. This circuit has a pulse-number of six, and in effect, can be thought of as a six-phase, half-wave circuit.

Before solid state devices became available, the half-wave circuit, and the full-wave circuit using a center-tapped transformer, were very commonly used in industrial rectifiers using mercury-arc valves. This was because the three or six AC supply inputs could be fed to a corresponding number of anode electrodes on a single tank, sharing a common cathode.

With the advent of diodes and thyristors, these circuits have become less popular and the three-phase bridge circuit has become the most common circuit.

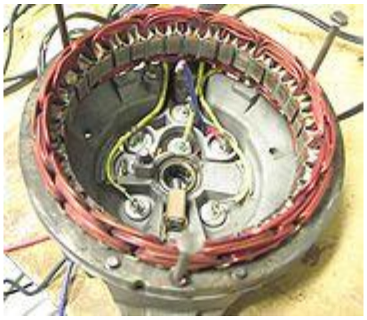


Three-phase half-wave rectifier circuit using thyristors as the switching elements, ignoring supply inductance



Three-phase full-wave rectifier circuit using thyristors as the switching elements, with a center-tapped transformer, ignoring supply inductance

Three-phase bridge rectifier

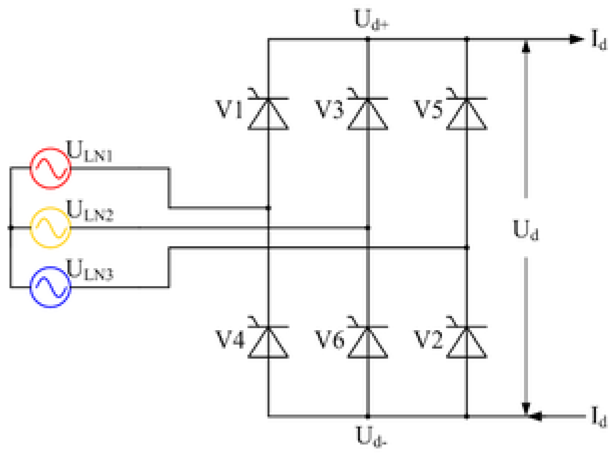


Disassembled automobile alternator, showing the six diodes that comprise a full-wave three-phase bridge rectifier.

For an uncontrolled three-phase bridge rectifier, six diodes are used, and the circuit again has a pulse number of six. For this reason, it is also commonly referred to as a **six-pulse bridge**.

For low-power applications, double diodes in series, with the anode of the first diode connected to the cathode of the second, are manufactured as a single component for this purpose. Some commercially available double diodes have all four terminals available so the user can configure them for single-phase split supply use, half a bridge, or three-phase rectifier.

For higher-power applications, a single discrete device is usually used for each of the six arms of the bridge. For the very highest powers, each arm of the bridge may consist of tens or hundreds of separate devices in parallel (where very high current is needed, for example in aluminum smelting) or in series (where very high voltages are needed, for example in high-voltage direct current power transmission).



Three-phase full-wave bridge rectifier circuit using thyristors as the switching elements, ignoring supply inductance

For a three-phase full-wave diode rectifier, the ideal, no-load average output voltage is

$$V_{\text{dc}} = V_{\text{av}} = \frac{3\sqrt{3}V_{\text{peak}}}{\pi}$$

If thyristors are used in place of diodes, the output voltage is reduced by a factor cos (α):

$$V_{\mathrm{dc}} = V_{\mathrm{av}} = \frac{3\sqrt{3}V_{\mathrm{peak}}}{\pi}\cos\alpha$$

Or, expressed in terms of the line to line input voltage:

$$V_{\mathrm{dc}} = V_{\mathrm{av}} = \frac{3V_{\mathrm{LLpeak}}}{\pi}\cos\alpha$$

Where:

V_{LLpeak}, the peak value of the line to line input voltages,

V_{peak}, the peak value of the phase (line to neutral) input voltages,

α, firing angle of the thyristor (0 if diodes are used to perform rectification)

The above equations are only valid when no current is drawn from the AC supply or in the theoretical case when the AC supply connections have no inductance. In practice, the supply inductance causes a reduction of DC output voltage with increasing load, typically in the range 10–20% at full load.

The effect of supply inductance is to slow down the transfer process (called **commutation**) from one phase to the next. As result of this is that at each transition between a pair of devices, there is a period of **overlap** during which three (rather than two) devices in the bridge are conducting simultaneously. The **overlap angle** is usually referred to by the symbol μ (or u), and may be 20 30° at full load.

With supply inductance taken into account, the output voltage of the rectifier is reduced to:

$$V_{\mathrm{dc}} = V_{\mathrm{av}} = \frac{3V_{\mathrm{LLpeak}}}{\pi}\cos(\alpha + \mu)$$

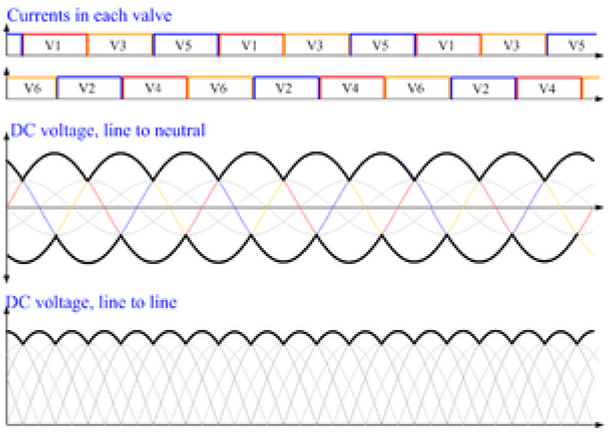
The overlap angle μ is directly related to the DC current, and the above equation may be re-expressed as:

$$V_{\mathrm{dc}} = V_{\mathrm{av}} = \frac{3V_{\mathrm{LLpeak}}}{\pi}\cos(\alpha) - 6fL_{\mathrm{c}}I_{\mathrm{d}}$$

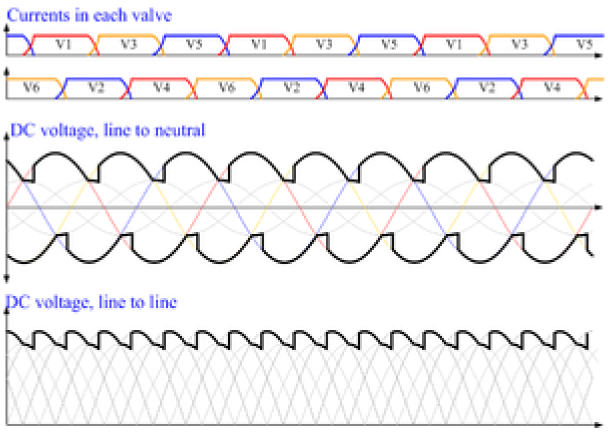
Where:

L_{c}, the commutating inductance per phase

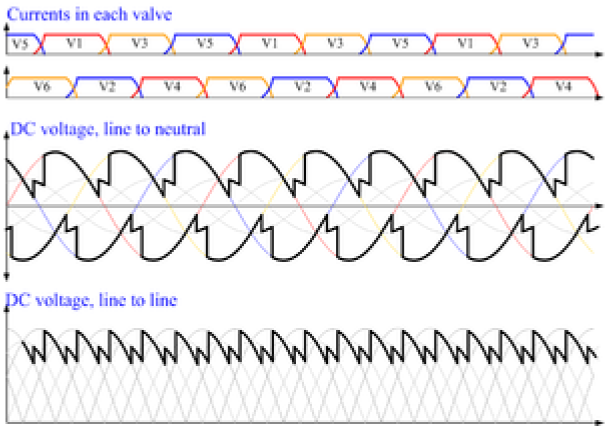
I_{d}, the direct current

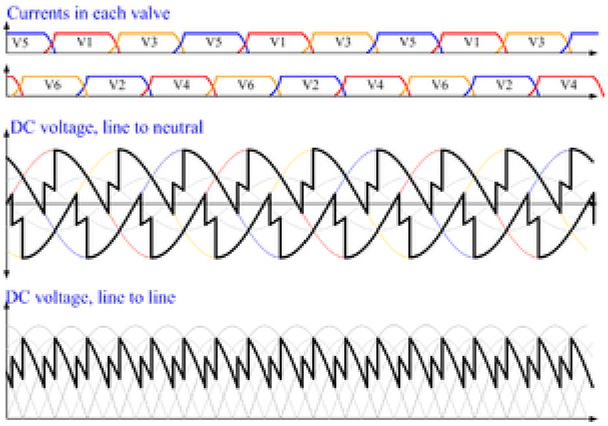


Three-phase Graetz bridge rectifier at alpha=0° without overlap



Three-phase Graetz bridge rectifier at alpha=0° with overlap angle of 20°



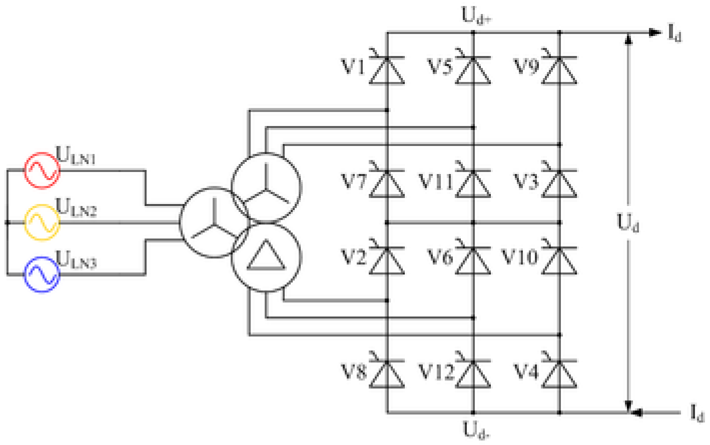


Three-phase controlled Graetz bridge rectifier at

Three-phase controlled Graetz bridge rectifier at alpha=20° with overlap angle of 20°

alpha=40° with overlap angle of 20°

Twelve-pulse bridge

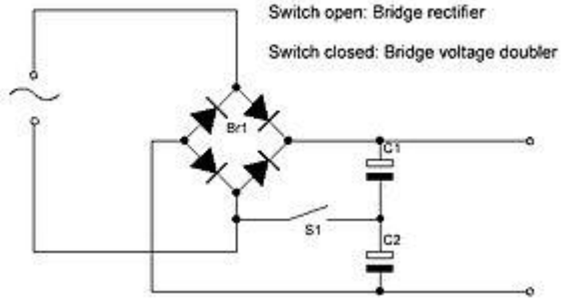


Twelve pulse bridge rectifier using thyristors as the switching elements

Although better than single-phase rectifiers or three-phase half-wave rectifiers, six-pulse rectifier circuits still produce considerable harmonic distortion on both the AC and DC connections. For very high-power rectifiers the **twelve-pulse bridge** connection is usually used. A twelve-pulse bridge consists of two six-pulse bridge circuits connected in series, with their AC connections fed from a supply transformer that produces a 30° phase shift between the two bridges. This cancels many of the characteristic harmonics the six-pulse bridges produce.

The 30 degree phase shift is usually achieved by using a transformer with two sets of secondary windings, one in star (wye) connection and one in delta connection.

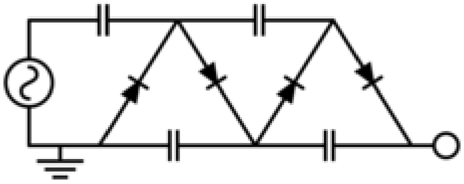
Voltage-multiplying rectifiers



Switchable full bridge/voltage doubler.

The simple half wave rectifier can be built in two electrical configurations with the diode pointing in opposite directions, one version connects the negative terminal of the output direct to the AC supply and the other connects the positive terminal of the output direct to the AC supply. By combining both of these with separate output smoothing it is possible to get an output voltage of nearly double the peak AC input voltage. This also provides a tap in the middle, which allows use of such a circuit as a split rail power supply.

A variant of this is to use two capacitors in series for the output smoothing on a bridge rectifier then place a switch between the midpoint of those capacitors and one of the AC input terminals. With the switch open, this circuit acts like a normal bridge rectifier. With the switch closed, it act like a voltage doubling rectifier. In other words, this makes it easy to derive a voltage of roughly 320 V (±15%, approx.) DC from any 120 V or 230 V mains supply in the world, this can then be fed into a relatively simple switched-mode power supply.



Cockcroft Walton Voltage multiplier

Cascaded diode and capacitor stages can be added to make a voltage multiplier (Cockroft-Walton circuit). These circuits are capable of producing a DC output voltage potential tens of times that of the peak AC input voltage, but are limited in current capacity and regulation. Diode voltage multipliers, frequently used as a trailing boost stage or primary high voltage (HV) source, are used in HV laser power supplies, powering devices such as cathode ray tubes (CRT) (like those used in CRT based television, radar and sonar displays), photon amplifying devices found in image intensifying and photo multiplier tubes (PMT), and magnetron based radio frequency (RF) devices used in radar transmitters and microwave ovens. Before the introduction of semiconductor electronics, transformer less powered vacuum tube receivers powered directly from AC power sometimes used voltage doublers to generate about 170 VDC from a 100–120 V power line.

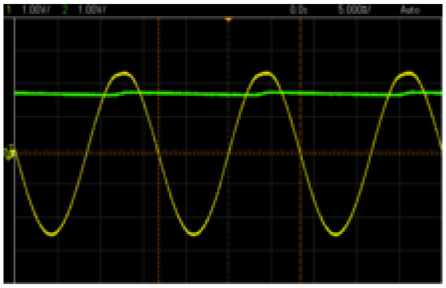
Rectifier losses

A real rectifier characteristically drops part of the input voltage (a voltage drop, for silicon devices, of typically 0.7 volts plus an equivalent resistance, in general non-linear)—and at high frequencies, distorts waveforms in other ways. Unlike an ideal rectifier, it dissipates some power.

An aspect of most rectification is a loss from the peak input voltage to the peak output voltage, caused by the built-in voltage drop across the diodes (around 0.7 V for ordinary silicon p–n junction diodes and 0.3 V for Schottky diodes). Half-wave rectification and full-wave rectification using a center-tapped secondary produces a peak voltage loss of one diode drop. Bridge rectification has a loss of two diode drops. This reduces output voltage, and limits the available output voltage if a very low alternating voltage must be rectified. As the diodes do not conduct below this voltage, the circuit only passes current through for a portion of each half-cycle, causing short segments of zero voltage (where instantaneous input voltage is below one or two diode drops) to appear between each "hump".

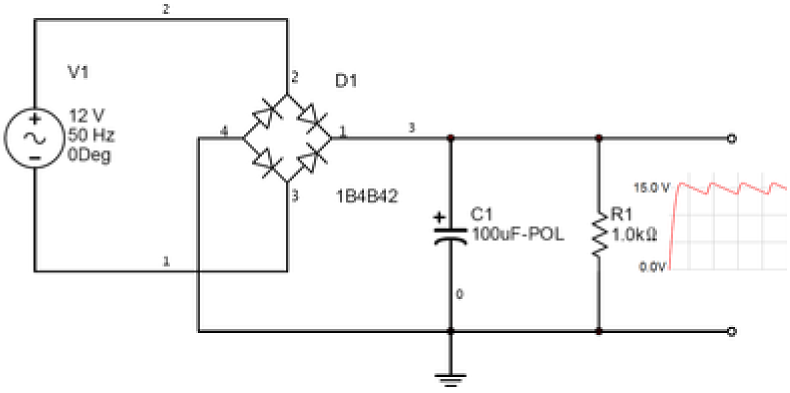
Peak loss is very important for low voltage rectifiers (for example, 12 V or less) but is insignificant in high-voltage applications such as HVDC.

Rectifier output smoothing



The AC input (yellow) and DC output (green) of a half-wave rectifier with a smoothing capacitor. Note the ripple in the DC signal.

While half-wave and full-wave rectification can deliver unidirectional current, neither produces a constant voltage. Producing steady DC from a rectified AC supply requires a smoothing circuit or filter. In its simplest form this can be just a reservoir capacitor or smoothing capacitor, placed at the DC output of the rectifier. There is still an AC ripple voltage component at the power supply frequency for a half-wave rectifier, twice that for full-wave, where the voltage is not completely smoothed.



RC-Filter Rectifier: This circuit was designed and simulated using Multisim 8 software.

Sizing of the capacitor represents a tradeoff. For a given load, a larger capacitor reduces ripple but costs more and creates higher peak currents in the transformer secondary and in the supply that feeds it. The peak current is set in principle by the rate of rise of the supply voltage on the rising edge of the incoming sine-wave, but in practice it is reduced by the resistance of the transformer windings. In extreme cases where many rectifiers are loaded onto a power distribution circuit, peak currents may cause difficulty in maintaining a correctly shaped sinusoidal voltage on the ac supply.

To limit ripple to a specified value the required capacitor size is proportional to the load current and inversely proportional to the supply frequency and the number of output peaks of the rectifier per input cycle. The load current and the supply frequency are generally outside the control of the designer of the rectifier system but the number of peaks per input cycle can be affected by the choice of rectifier design.

A half-wave rectifier only gives one peak per cycle, and for this and other reasons is only used in very small power supplies. A full wave rectifier achieves two peaks per cycle, the best possible with a single-phase input. For three-phase inputs a three-phase bridge gives six peaks per cycle. Higher numbers of peaks can be achieved by using transformer networks placed before the rectifier to convert to a higher phase order.

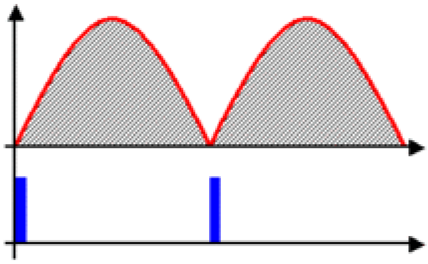
To further reduce ripple, a capacitor-input filter can be used. This complements the reservoir capacitor with a choke (inductor) and a second filter capacitor, so that a steadier DC output can be obtained across the terminals of the filter capacitor. The choke presents high impedance to the ripple current. For use at power-line frequencies inductors require cores of iron or other magnetic materials, and add weight and size. Their use in power supplies for electronic equipment has therefore dwindled in favor of semiconductor circuits such as voltage regulators.

A more usual alternative to a filter, and essential if the DC load requires very low ripple voltage, is to follow the reservoir capacitor with an active voltage regulator circuit. The reservoir capacitor must be large enough to prevent the troughs of the ripple dropping below the minimum voltage required by the regulator to produce the required output voltage. The regulator serves both to significantly reduce the ripple and to deal with variations in supply and load characteristics. It would be possible to use a smaller reservoir capacitor (these can be large on high-current power supplies) and then apply some filtering as well as the regulator, but this is not a common strategy. The extreme of this approach is to dispense with the reservoir capacitor altogether and put the rectified waveform straight into a choke-input filter. The advantage of this circuit is that the current waveform is smoother and consequently the rectifier no longer has to deal with the current as a large current pulse, but instead the current delivery is spread over the entire cycle. The disadvantage, apart from extra size and weight, is that the voltage output is much lower – approximately the average of an AC half-cycle rather than the peak.

Applications

The primary application of rectifiers is to derive DC power from an AC supply (AC to DC converter). Virtually all electronic devices require DC, so rectifiers are used inside the power supplies of virtually all electronic equipment.

Converting DC power from one voltage to another is much more complicated. One method of DC-to-DC conversion first converts power to AC (using a device called an inverter), then uses a transformer to change the voltage, and finally rectifies power back to DC. A frequency of typically several tens of kilohertz is used, as this requires much smaller inductance than at lower frequencies and obviates the use of heavy, bulky, and expensive iron-cored units.



Output voltage of a full-wave rectifier with controlled thyristors

Rectifiers are also used for detection of amplitude modulated radio signals. The signal may be amplified before detection. If not, a very low voltage drop diode or a diode biased with a fixed voltage must be used. When using a rectifier for demodulation the capacitor and load resistance must be carefully matched: too low a capacitance makes the high frequency carrier pass to the output, and too high makes the capacitor just charge and staying charged.

Rectifiers supply polarized voltage for welding. In such circuits control of the output current is required; this is sometimes achieved by replacing some of the diodes in a bridge rectifier with thyristors, effectively diodes whose voltage output can be regulated by switching on and off with phase fired controllers.

Thyristors are used in various classes of railway rolling stock systems so that fine control of the traction motors can be achieved. Gate turn-off thyristors are used to produce alternating current from a DC supply, for example on the Eurostar Trains to power the three-phase traction motors.

Rectification technologies

Electromechanical

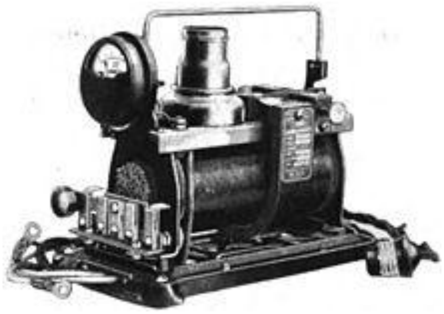
Before about 1905 when tube type rectifiers were developed, power conversion devices were purely electro-mechanical in design. Mechanical rectification systems used some form of rotation or resonant vibration (e.g. vibrators) driven by electromagnets, which operated a switch or commutator to reverse the current.

These mechanical rectifiers were noisy and had high maintenance requirements. The moving parts had friction, which required lubrication and replacement due to wear. Opening mechanical contacts under load resulted in electrical arcs and sparks that heated and eroded the contacts. They also were not able to handle AC frequencies above several thousand cycles per second.

Synchronous rectifier

To convert alternating into direct current in electric locomotives, a **synchronous rectifier** may be used. It consists of a synchronous motor driving a set of heavy-duty electrical contacts. The motor spins in time with the AC frequency and periodically reverses the connections to the load at an instant when the sinusoidal current goes through a zero-crossing. The contacts do not have to *switch* a large current, but they must be able to *carry* a large current to supply the locomotive's DC traction motors.

Vibrating rectifier



A vibrator battery charger from 1922. It produced 6A DC at 6V to charge automobile batteries.

These consisted of a resonant reed, vibrated by an alternating magnetic field created by an AC electromagnet, with contacts that reversed the direction of the current on the negative half cycles. They were used in low power devices, such as battery chargers, to rectify the low voltage produced by a step-down transformer. Another use was in battery power supplies for portable vacuum tube radios, to provide the high DC voltage for the tubes. These operated as a mechanical version of modern solid state switching inverters, with a transformer to step the battery voltage up, and a set of vibrator contacts on the transformer core, operated by its magnetic field, to repeatedly break the DC battery current to create a pulsing AC to power the transformer. Then a second set of rectifier contacts on the vibrator rectified the high AC voltage from the transformer secondary to DC.

Motor-generator set

A small motor-generator set

A *motor-generator set*, or the similar *rotary converter*, is not strictly a rectifier as it does not actually *rectify* current, but rather *generates* DC from an AC source. In an "M-G set", the shaft of an AC motor is mechanically coupled to that of a DC generator. The DC generator produces multiphase alternating currents in its armature windings, which a commutator on the armature shaft converts into a direct current output; or a homopolar generator produces a direct current without the need for a commutator. M-G sets are useful for producing DC for railway traction motors, industrial motors and other high-current applications, and were common in many high-power D.C. uses (for example, carbon-arc lamp projectors for outdoor theaters) before high-power semiconductors became widely available.

Electrolytic

The electrolytic rectifier was a device from the early twentieth century that is no longer used. A home-made version is illustrated in the 1913 book *The Boy Mechanic* .but it would only be suitable for use at very low voltages because of the low breakdown voltage and the risk of electric shock. A more complex device of this kind was patented by G. W. Carpenter in 1928 (US Patent 1671970).

When two different metals are suspended in an electrolyte solution, direct current flowing one way through the solution sees less resistance than in the other direction. Electrolytic rectifiers most commonly used an aluminum anode and a lead or steel cathode, suspended in a solution of tri-ammonium ortho-phosphate.

HVDC in 1971: this 150 kV mercury-arc valve converted AC hydropower voltage for transmission to distant cities from Manitoba Hydro generators.

The rectification action is due to a thin coating of aluminum hydroxide on the aluminum electrode, formed by first applying a strong current to the cell to build up the coating. The rectification process is temperature-sensitive, and for best efficiency should not operate above 86 °F (30 °C). There is also a breakdown voltage where the coating is penetrated and the cell is short-circuited. Electrochemical methods are often more fragile than mechanical methods, and can be sensitive to usage variations, which can drastically change or completely disrupt the rectification processes.

Similar electrolytic devices were used as lightning arresters around the same era by suspending many aluminum cones in a tank of tri-ammonium ortho-phosphate solution. Unlike the rectifier above, only aluminum electrodes were used, and used on A.C., there was no polarization and thus no rectifier action, but the chemistry was similar.

The modern electrolytic capacitor, an essential component of most rectifier circuit configurations was also developed from the electrolytic rectifier.

Plasma type

Mercury-arc

A rectifier used in high-voltage direct current (HVDC) power transmission systems and industrial processing between about 1909 to 1975 is a *mercury-arc rectifier* or *mercury-arc valve*. The device is enclosed in a bulbous glass vessel or large metal tub. One electrode, the cathode, is submerged in a pool of liquid mercury at the bottom of the vessel and one or more high purity graphite electrodes, called anodes, are suspended above the pool. There may be several auxiliary electrodes to aid in starting and maintaining the arc. When an electric arc is established between the cathode pool and suspended anodes, a stream of electrons flows from the cathode to the anodes through the ionized mercury, but not the other way (in principle, this is a higher-power counterpart to flame rectification, which uses the same one-way current transmission properties of the plasma naturally present in a flame).

These devices can be used at power levels of hundreds of kilowatts, and may be built to handle one to six phases of AC current. Mercury-arc rectifiers have been replaced by silicon semiconductor rectifiers and high-power thyristor circuits in the mid 1970s. The most powerful mercury-arc rectifiers ever built were installed in the Manitoba Hydro Nelson River Bipole HVDC project, with a combined rating of more than 1 GW and 450 kV.

Argon gas electron tube

Tungar bulbs, 2 ampere *(left)* and 6 ampere

The General Electric Tungar rectifier was an argon gas-filled electron tube device with a tungsten filament cathode and a carbon button anode. It operated similarly to the thermionic vacuum tube diode, but the gas in the tube ionized during forward conduction, giving it a much lower forward voltage drop so it could rectify lower voltages. It was used for battery chargers and similar applications from the 1920s until lower-cost metal rectifiers, and later semiconductor diodes, supplanted it. These were made up to a few hundred volts and a few amperes rating, and in some sizes strongly resembled an incandescent lamp with an additional electrode.

The 0Z4 was a gas-filled rectifier tube commonly used in vacuum tube car radios in the 1940s and 1950s. It was a conventional full-wave rectifier tube with two anodes and one cathode, but was unique in that it had no filament (thus the "0" in its type number). The electrodes were shaped such that the reverse breakdown voltage was much higher than the forward breakdown voltage. Once the breakdown voltage was exceeded, the 0Z4 switched to a low-resistance state with a forward voltage drop of about 24 V.

Vacuum tube (valve)

Vacuum tube diodes

The thermionic vacuum tube diode, originally called the Fleming valve, was invented by John Ambrose Fleming in 1904 as a detector for radio waves in radio receivers, and evolved into a general rectifier. It consisted of an evacuated glass bulb with a filament heated by a separate current, and a metal plate anode. The filament emitted electrons by thermionic emission (the Edison effect), discovered by Thomas Edison in 1884, and a positive voltage on the plate caused a current of electrons through the tube from filament to plate. Since only the filament produced electrons, the tube would only conduct current in one direction, allowing the tube to rectify an alternating current.

Vacuum diode rectifiers were widely used in power supplies in vacuum tube consumer electronic products, such as phonographs, radios, and televisions, for example the All American Five radio receiver, to provide the high DC plate voltage needed by other vacuum tubes. "Full-wave" versions with two separate plates were popular because they could be used with a center-tapped transformer to make a full-wave rectifier. Vacuum rectifiers were made for very high voltages, such as the high voltage power supply for the cathode ray tube of television receivers, and the kenotron used for power supply in X-ray equipment. However, vacuum rectifiers had high internal resistance due to space charge and therefore high voltage drops, causing high power dissipation and low efficiency. They could rarely handle currents exceeding 250 mA owing to the limits of plate power dissipation, and could not be used for low voltage applications, such as battery chargers. Another limitation of the vacuum tube rectifier was that the heater power supply often required special arrangements to insulate it from the high voltages of the rectifier circuit.

In instrument amplification, the slight delay or "sag" between a signal increase (for instance, when a guitar chord is struck hard and fast) and the corresponding increase in output voltage is a notable effect of tube rectification, and results in compression. The choice between tube rectification and diode rectification is a matter of taste; some amplifiers have both and allow the player to choose.

Solid state

Crystal detector

Galena cat's whisker detector

The cat's-whisker detector was the earliest type of semiconductor diode. It consisted of a crystal of some semiconducting mineral, usually galena (lead sulfide), with a light springy wire touching its surface. Invented by Jagadish Chandra Bose and developed by G. W. Pickard around 1906, it served as the radio wave rectifier in the first widely used radio receivers, called crystal radios. Its fragility and limited current capability made it unsuitable for power supply applications. It became obsolete around 1920, but later versions served as microwave detectors and mixers in radar receivers during World War 2.

Selenium and copper oxide rectifiers

Selenium rectifier

Once common until replaced by more compact and less costly silicon solid-state rectifiers in the 1970s, these units used stacks of metal plates and took advantage of the semiconductor properties of selenium or copper oxide. While selenium rectifiers were lighter in weight and used less power than comparable vacuum tube rectifiers, they had the disadvantage of finite life expectancy, increasing resistance with age, and were only suitable to use at low frequencies. Both selenium and copper oxide rectifiers have somewhat better tolerance of momentary voltage transients than silicon rectifiers.

Typically these rectifiers were made up of stacks of metal plates or washers, held together by a central bolt, with the number of stacks determined by voltage; each cell was rated for about 20 V. An automotive battery charger rectifier might have only one cell: the high-voltage power supply for a vacuum tube might have dozens of stacked plates. Current density in an air-cooled selenium stack was about 600 mA per square inch of active area (about 90 mA per square centimeter).

Silicon and germanium diodes

In the modern world, silicon diodes are the most widely used rectifiers for lower voltages and powers, and have largely replaced earlier germanium diodes. For very high voltages and powers, the added need for controllability has in practice led to replacing simple silicon diodes with high-power thyristors (see below) and their newer actively gate-controlled cousins.

High power: thyristors (SCRs) and newer silicon-based voltage sourced converters

Two of three high-power thyristor valve stacks used for long distance transmission of power from Manitoba Hydro dams. Compare with mercury-arc system from the same dam-site, above.

In high-power applications, from 1975 to 2000, most mercury valve arc-rectifiers were replaced by stacks of very high power thyristors, silicon devices with two extra layers of semiconductor, in comparison to a simple diode.

In medium-power transmission applications, even more complex and sophisticated voltage sourced converter (VSC) silicon semiconductor rectifier systems, such as insulated gate bipolar transistors (IGBT) and gate turn-off thyristors (GTO), have made smaller high voltage DC power transmission systems economical. All of these devices function as rectifiers.

As of 2009 it was expected that these high-power silicon "self-commutating switches," in particular IGBTs and a variant thyristor (related to the GTO) called the integrated gate-commutated thyristor (IGCT), would be scaled-up in power rating to the point that they would eventually replace simple thyristor-based AC rectification systems for the highest power-transmission DC applications.

Current research

A major area of research is to develop higher frequency rectifiers, that can rectify into terahertz and light frequencies. These devices are used in optical heterodyne detection, which has myriad applications in optical fiber communication and atomic clocks. Another prospective application for such devices is to directly rectify light waves picked up by tiny antenna, called nantennas, to produce DC electric power. It is thought that arrays of nantennas could be a more efficient means of producing solar power than solar cells.

A related area of research is to develop smaller rectifiers, because a smaller device has a higher cutoff frequency. Research projects are attempting to develop a unimolecular rectifier, a single organic molecule that would function as a rectifier.

Voltage regulator

A **voltage regulator** is designed to automatically maintain a constant voltage level. A voltage regulator may be a simple "feed-forward" design or may include negative feedback control loops. It may use an electromechanical mechanism, or electronic components. Depending on the design, it may be used to regulate one or more AC or DC voltages.

Electronic voltage regulators are found in devices such as computer power supplies where they stabilize the DC voltages used by the processor and other elements. In automobile alternators and central power station generator plants, voltage regulators control the output of the plant. In an electric power distribution system, voltage regulators may be installed at a substation or along distribution lines so that all customers receive steady voltage independent of how much power is drawn from the line.

Measures of regulator quality

The output voltage can only be held *roughly* constant; the regulation is specified by two measurements:

- **load regulation** is the change in output voltage for a given change in load current (for example: "typically 15 mV, maximum 100 mV for load currents between 5 mA and 1.4 A, at some specified temperature and input voltage").
- **line regulation** or **input regulation** is the degree to which output voltage changes with input (supply) voltage changes - as a ratio of output to input change (for example "typically 13 mV/V"), or the output voltage change over the entire specified input voltage range (for example "plus or minus 2% for input voltages between 90 V and 260 V, 50-60 Hz").

Other important parameters are:

- **Temperature coefficient** of the output voltage is the change with temperature (perhaps averaged over a given temperature range).
- **Initial accuracy** of a voltage regulator (or simply "the voltage accuracy") reflects the error in output voltage for a fixed regulator without taking into account temperature or aging effects on output accuracy.
- **Dropout voltage** is the minimum difference between input voltage and output voltage for which the regulator can still supply the specified current. A low drop-out (LDO) regulator is designed to work well even with an input supply only a volt or so above the output voltage. The input-output differential at which the voltage regulator will no longer maintain regulation is the dropout voltage. Further reduction in input voltage will result in reduced output voltage. This value is dependent on load current and junction temperature.
- **Absolute maximum ratings** are defined for regulator components, specifying the continuous and peak output currents that may be used (sometimes internally limited), the maximum input voltage, maximum power dissipation at a given temperature, etc.
- **Output noise** (thermal white noise) and **output dynamic impedance** may be specified as graphs versus frequency, while output **ripple** noise (mains "hum" or switch-mode "hash" noise) may be given as peak-to-peak or RMS voltages, or in terms of their spectra.
- **Quiescent current** in a regulator circuit is the current drawn internally, not available to the load, normally measured as the input current while no load is connected (and hence a source of inefficiency; some linear regulators are, surprisingly, more efficient at very low current loads than switch-mode designs because of this).
- **Transient response** is the reaction of a regulator when a (sudden) change of the load current (called the *load transient*) or input voltage (called the *line transient*) occurs. Some regulators will tend to oscillate or have a slow response time which in some cases might lead to undesired results. This value is different from the regulation parameters, as that is the stable situation definition. The transient response shows the behavior of the regulator on a change. This data is usually provided in the technical documentation of a regulator and is also dependent on output capacitance.
- **Mirror-image insertion protection** means that a regulator is designed for use when a voltage, usually not higher than the maximum input voltage of the regulator, is applied to

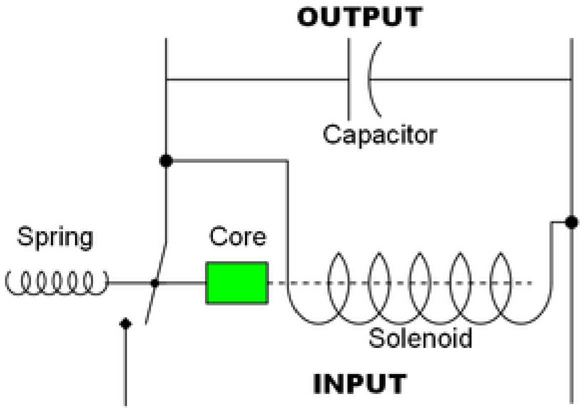
its output pin while its input terminal is at a low voltage, volt-free or grounded. Some regulators can continuously withstand this situation; others might only manage it for a limited time such as 60 seconds, as usually specified in the datasheet. This situation can occur when a three terminal regulator is incorrectly mounted for example on a PCB, with the output terminal connected to the unregulated DC input and the input connected to the load. Mirror-image insertion protection is also important when a regulator circuit is used in battery charging circuits, when external power fails or is not turned on and the output terminal remains at battery voltage.

Electronic voltage regulators

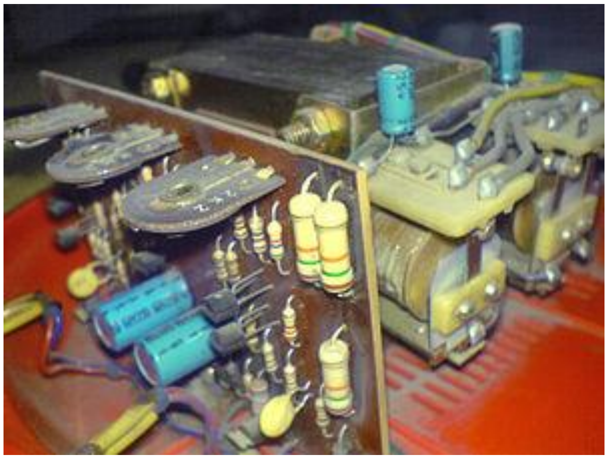
A simple voltage regulator can be made from a resistor in series with a diode (or series of diodes). Due to the logarithmic shape of diode V-I curves, the voltage across the diode changes only slightly due to changes in current drawn or changes in the input. When precise voltage control and efficiency are not important, this design may work fine.

Feedback voltage regulators operate by comparing the actual output voltage to some fixed reference voltage. Any difference is amplified and used to control the regulation element in such a way as to reduce the voltage error. This forms a negative feedback control loop; increasing the open-loop gain tends to increase regulation accuracy but reduce stability (stability is avoidance of oscillation, or ringing, during step changes). There will also be a trade-off between stability and the speed of the response to changes. If the output voltage is too low (perhaps due to input voltage reducing or load current increasing), the regulation element is commanded, *up to a point*, to produce a higher output voltage–by dropping less of the input voltage (for linear series regulators and buck switching regulators), or to draw input current for longer periods (boost-type switching regulators); if the output voltage is too high, the regulation element will normally be commanded to produce a lower voltage. However, many regulators have over-current protection, so that they will entirely stop sourcing current (or limit the current in some way) if the output current is too high, and some regulators may also shut down if the input voltage is outside a given range (see also: crowbar circuits).

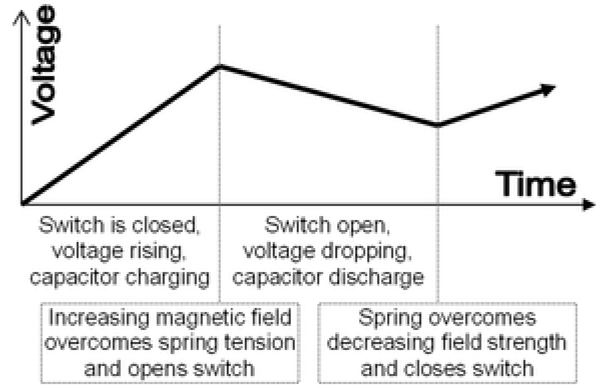
Electromechanical regulators



Circuit design for a simple electromechanical voltage regulator.



A voltage stabilizer using electromechanical relays for switching.



Graph of voltage output on a time scale.

In electromechanical regulators, voltage regulation is easily accomplished by coiling the sensing wire to make an electromagnet. The magnetic field produced by the current attracts a moving ferrous core held back under spring tension or gravitational pull. As voltage increases, so does the current, strengthening the magnetic field produced by the coil and pulling the core towards the field. The magnet is physically connected to a mechanical power switch, which opens as the magnet moves into the field. As voltage decreases, so does the current, releasing spring tension or the weight of the core and causing it to retract. This closes the switch and allows the power to flow once more.

If the mechanical regulator design is sensitive to small voltage fluctuations, the motion of the solenoid core can be used to move a selector switch across a range of resistances or transformer windings to gradually step the output voltage up or down, or to rotate the position of a moving-coil AC regulator.

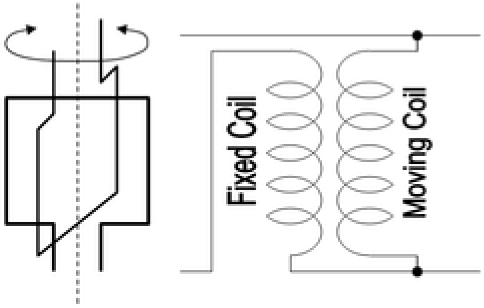
Early automobile generators and alternators had a mechanical voltage regulator using one, two, or three relays and various resistors to stabilize the generator's output at slightly more than 6 or 12 V, independent of the engine's rpm or the varying load on the vehicle's electrical system. Essentially, the relay(s) employed pulse width modulation to regulate the output of the generator, controlling the field current reaching the generator (or alternator) and in this way controlling the output voltage produced.

The regulators used for DC generators (but not alternators) also disconnect the generator when it was not producing electricity, thereby preventing the battery from discharging back into the generator and attempting to run it as a motor. The rectifier diodes in an alternator automatically perform this function so that a specific relay is not required; this appreciably simplified the regulator design.

More modern designs now use *solid state* technology (transistors) to perform the same function that the relays perform in electromechanical regulators.

Electromechanical regulators are used for mains voltage stabilization — see AC voltage stabilizers below.

Coil-rotation AC voltage regulator



Basic design principle and circuit diagram for the rotating-coil AC voltage regulator.

This is an older type of regulator used in the 1920s that uses the principle of a fixed-position field coil and a second field coil that can be rotated on an axis in parallel with the fixed coil, similar to a variocoupler.

When the movable coil is positioned perpendicular to the fixed coil, the magnetic forces acting on the movable coil balance each other out and voltage output is unchanged. Rotating the coil in one direction or the other away from the center position will increase or decrease voltage in the secondary movable coil.

This type of regulator can be automated via a servo control mechanism to advance the movable coil position in order to provide voltage increase or decrease. A braking mechanism or high ratio gearing is used to hold the rotating coil in place against the powerful magnetic forces acting on the moving coil.

AC voltage stabilizers

Magnetic mains regulator

Electromechanical

Electromechanical regulators called *voltage stabilizers* or *tap-changers*, have also been used to regulate the voltage on AC power distribution lines. These regulators operate by using a servomechanism to select the appropriate tap on an auto transformer with multiple taps, or by moving the wiper on a continuously variable auto transformer. If the output voltage is not in the acceptable range, the servomechanism switches the tap, changing the turns ratio of the transformer, to move the secondary voltage into the acceptable region. The controls provide a dead band wherein the controller will not act, preventing the controller from constantly adjusting the voltage ("hunting") as it varies by an acceptably small amount.

Constant-voltage transformer

The **ferroresonant transformer**, **ferroresonant regulator** or **constant-voltage transformer** is a type of saturating transformer used as a voltage regulator. These transformers use a tank circuit composed of a high-voltage resonant winding and a capacitor to produce a nearly constant average output voltage with a varying input current or varying load. The circuit has a primary on one side of a magnet shunt and the tuned circuit coil and secondary on the other side. The regulation is due to magnetic saturation in the section around the secondary.

The ferroresonant approach is attractive due to its lack of active components, relying on the square loop saturation characteristics of the tank circuit to absorb variations in average input voltage. Saturating transformers provide a simple rugged method to stabilize an AC power supply.

Older designs of ferroresonant transformers had an output with high harmonic content, leading to a distorted output waveform. Modern devices are used to construct a perfect sine wave. The ferroresonant action is a flux limiter rather than a voltage regulator, but with a fixed supply frequency it can maintain an almost constant average output voltage even as the input voltage varies widely.

The ferroresonant transformers, which are also known as Constant Voltage Transformers (CVTs) or ferros, are also good surge suppressors, as they provide high isolation and inherent short-circuit protection.

A ferroresonant transformer can operate with an input voltage range ±40% or more of the nominal voltage.

Output power factor remains in the range of 0.96 or higher from half to full load.

Because it regenerates an output voltage waveform, output distortion, which is typically less than 4%, is independent of any input voltage distortion, including notching.

Efficiency at full load is typically in the range of 89% to 93%. However, at low loads, efficiency can drop below 60%. The current-limiting capability also becomes a handicap when a CVT is used in an application with moderate to high inrush current like motors, transformers or magnets.

In this case, the CVT has to be sized to accommodate the peak current, thus forcing it to run at low loads and poor efficiency.

Minimum maintenance is required, as transformers and capacitors can be very reliable. Some units have included redundant capacitors to allow several capacitors to fail between inspections without any noticeable effect on the device's performance.

Output voltage varies about 1.2% for every 1% change in supply frequency. For example, a 2 Hz change in generator frequency, which is very large, results in an output voltage change of only 4%, which has little effect for most loads.

It accepts 100% single-phase switch-mode power supply loading without any requirement for rerating, including all neutral components.

Input current distortion remains less than 8% THD even when supplying nonlinear loads with more than 100% current THD.

Drawbacks of CVTs are their larger size, audible humming sound, and the high heat generation caused by saturation.

DC voltage stabilizers

Many simple DC power supplies regulate the voltage using a *shunt regulator* such as a Zener diode, avalanche breakdown diode, or voltage regulator tube. Each of these devices begins conducting at a specified voltage and will conduct as much current as required to hold its terminal voltage to that specified voltage. The power supply is designed to only supply a maximum amount of current that is within the safe operating capability of the shunt regulating device (commonly, by using a series resistor).

If the stabilizer must provide more power, the shunt regulator output is only used to provide the standard voltage reference for the electronic device, known as the voltage stabilizer. The voltage stabilizer is the electronic device, able to deliver much larger currents on demand.

Active regulators

Active regulators employ at least one active (amplifying) component such as a transistor or operational amplifier. Shunt regulators are often (but not always) passive and simple, but always inefficient because they (essentially) dump the excess current not needed by the load. When more power must be supplied, more sophisticated circuits are used. In general, these active regulators can be divided into several classes:

- Linear series regulators
- Switching regulators
- SCR regulators

Linear regulators

Linear regulators are based on devices that operate in their linear region (in contrast, a switching regulator is based on a device forced to act as an on/off switch). In the past, one or more vacuum tubes were commonly used as the variable resistance. Modern designs use one or more transistors instead, perhaps within an Integrated Circuit. Linear designs have the advantage of very "clean" output with little noise introduced into their DC output, but are most often much less efficient and unable to step-up or invert the input voltage like switched supplies. All linear regulators require a higher input than the output. If the input voltage approaches the desired output voltage, the regulator will "drop out". The input to output voltage differential at which this occurs is known as the regulator's drop-out voltage.

Entire linear regulators are available as integrated circuits. These chips come in either fixed or adjustable voltage types.

Switching regulators

Switching regulators rapidly switch a series device on and off. The duty cycle of the switch sets how much charge is transferred to the load. This is controlled by a similar feedback mechanism as in a linear regulator. Because the series element is either fully conducting, or switched off, it dissipates almost no power; this is what gives the switching design its efficiency. Switching regulators are also able to generate output voltages which are higher than the input, or of opposite polarity — something not possible with a linear design.

Like linear regulators, nearly-complete switching regulators are also available as integrated circuits. Unlike linear regulators, these usually require one external component: an inductor that acts as the energy storage element. (Large-valued inductors tend to be physically large relative to almost all other kinds of component, so they are rarely fabricated within integrated circuits and IC regulators — with some exceptions.)

Comparing linear vs. switching regulators

The two types of regulators have their different advantages:

- Linear regulators are best when low output noise (and low RFI radiated noise) is required
- Linear regulators are best when a fast response to input and output disturbances is required.
- At low levels of power, linear regulators are cheaper and occupy less printed circuit board space.
- Switching regulators are best when power efficiency is critical (such as in portable computers), *except* linear regulators are more efficient in a small number of cases (such as a 5V microprocessor often in "sleep" mode fed from a 6V battery, *if* the complexity of the switching circuit and the junction capacitance charging current means a high quiescent current in the switching regulator).
- Switching regulators are required when the only power supply is a DC voltage, and a higher output voltage is required.
- At high levels of power (above a few watts), switching regulators are cheaper (for example, the cost of removing heat generated is less).

SCR regulators

Regulators powered from AC power circuits can use silicon controlled rectifiers (SCRs) as the series device. Whenever the output voltage is below the desired value, the SCR is triggered, allowing electricity to flow into the load until the AC mains voltage passes through zero (ending the half cycle). SCR regulators have the advantages of being both very efficient and very simple, but because they cannot terminate an on-going half cycle of conduction, they are not capable of very accurate voltage regulation in response to rapidly-changing loads. An alternative is the SCR shunt regulator which uses the regulator output as a trigger, both series and shunt designs are noisy, but powerful, as the device has a low on resistance.

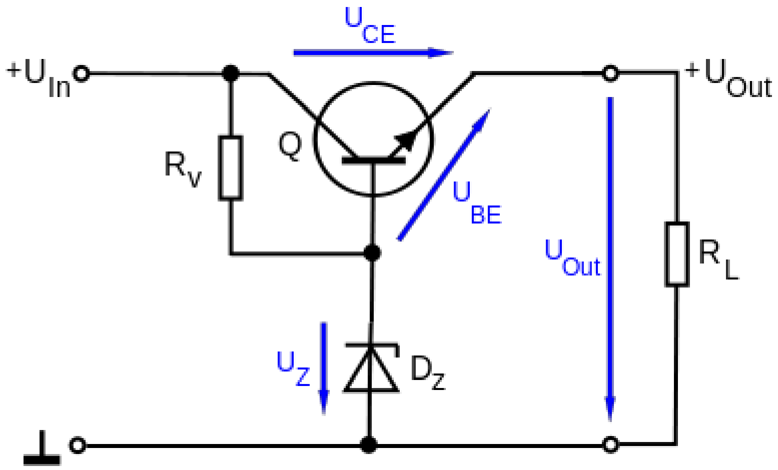
Combination (hybrid) regulators

Many power supplies use more than one regulating method in series. For example, the output from a switching regulator can be further regulated by a linear regulator. The switching regulator accepts a wide range of input voltages and efficiently generates a (somewhat noisy) voltage slightly above the ultimately desired output. That is followed by a linear regulator that generates exactly the desired voltage and eliminates nearly all the noise generated by the switching regulator. Other designs may use an SCR regulator as the "pre-regulator", followed by another type of regulator. An efficient way of creating a variable-voltage, accurate output power supply is to combine a multi-tapped transformer with an adjustable linear post-regulator.

Example linear regulators

Transistor regulator

In the simplest case a common collector transistor (emitter follower) is used with the base of the regulating transistor connected directly to the voltage reference:



A simple transistor regulator will provide a relatively constant output voltage, U_{out}, for changes in the voltage of the power source, U_{in}, and for changes in load, R_L, provided that U_{in} exceeds U_{out} by a sufficient margin, and that the power handling capacity of the transistor is not exceeded.

The output voltage of the stabilizer is equal to the zener diode voltage less the base–emitter voltage of the transistor, $U_Z - U_{BE}$, where U_{BE} is usually about 0.7 V for a silicon transistor, depending on the load current. If the output voltage drops for any external reason, such as an increase in the current drawn by the load (causing a decrease in the Collector-Emitter junction voltage to obseve KVL), the transistor's base–emitter voltage (U_{BE}) increases, turning the transistor on further and delivering more current to increase the load voltage again.

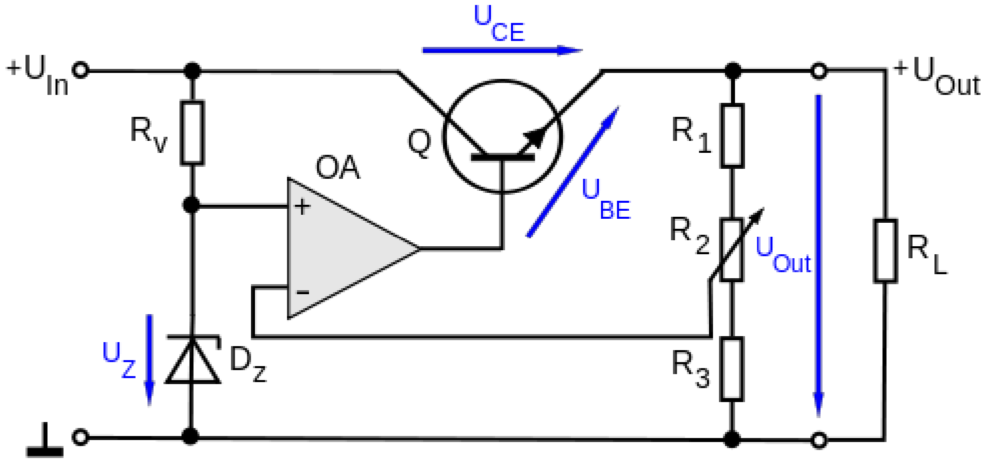
R_v provides a bias current for both the zener diode and the transistor. The current in the diode is minimum when the load current is maximum. The circuit designer must choose a minimum voltage that can be tolerated across R_v, bearing in mind that the higher this voltage requirement is, the higher the required input voltage, U_{in}, and hence the lower the efficiency of the regulator. On the other hand, lower values of R_v lead to higher power dissipation in the diode and to inferior regulator characteristics.

$$R_v = \frac{V_{Rmin}}{I_{Dmin} + I_{Lmax}/(h_{FE} + 1)}$$

where $V_{R\ min}$ is the minimum voltage to be maintained across R_v
$I_{D\ min}$ is the minimum current to be maintained through the zener diode
$I_{L\ max}$ is the maximum design load current
h_{FE} is the forward current gain of the transistor, $I_{Collector} / I_{Base}$

Regulator with an operational amplifier

The stability of the output voltage can be significantly increased by using an operational amplifier:



In this case, the operational amplifier drives the transistor with more current if the voltage at its inverting input drops below the output of the voltage reference at the non-inverting input. Using the voltage divider (R1, R2 and R3) allows choice of the arbitrary output voltage between U_z and U_{in}.

Commercial Voltage Regulators

The Voltage regulators or stabilizers are used and commercially sold mostly in third world countries like India,Bangladesh,Pakistan,Afghanistan etc. due to high voltage fluctuations.Voltage regulators normally commercially produced normally operate on a range of voltage i.e. 150V-240V , 90V-280V etc. Servo Stabilizers are also manufactured and used widely in-spite of the fact that they are obsolete and use back dated technology.

Voltage regulators are used in devices like AC,Fridge,Tv etc. in order to protect them from input fluctuating voltage. The major problem faced is the use of relays in voltage regulators. Relays create sparks which result in faults in the product.

5.3 common sensors

Sensor

A sensor is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena. The output is generally a signal that is converted to human-readable display at the sensor location or transmitted electronically over a network for reading or further processing.

Here are a few examples of the many different types of sensors:

In a mercury-based glass thermometer, the input is temperature. The liquid contained expands and contracts in response, causing the level to be higher or lower on the marked gauge, which is human-readable.

An oxygen sensor in a car's emission control system detects the gasoline/oxygen ratio, usually through a chemical reaction that generates a voltage. A computer in the engine reads the voltage and, if the mixture is not optimal, readjusts the balance.

Motion sensors in various systems including home security lights, automatic doors and bathroom fixtures typically send out some type of energy, such as microwaves, ultrasonic waves or light beams and detect when the flow of energy is interrupted by something entering its path.

A photosensor detects the presence of visible light, infrared transmission (IR), and/or ultraviolet (UV) energy.

Microwave

The term microwave refers to electromagnetic energy having a frequency higher than 1 gigahertz (billions of cycles per second), corresponding to wavelength shorter than 30 centimeters.

Microwave signals propagate in straight lines and are affected very little by the troposphere. They are not refracted or reflected by ionized regions in the upper atmosphere. Microwave beams do not readily diffract around barriers such as hills, mountains, and large human-made structures. Some attenuation occurs when microwave energy passes through trees and frame houses. Radio-frequency (RF) energy at longer wavelengths is affected to a lesser degree by such obstacles.

The microwave band is well suited for wireless transmission of signals having large bandwidth. This portion of the RF electromagnetic radiation spectrum encompasses many thousands of megahertz. Compare this with the so-called shortwave band that extends from 3 MHz to 30 MHz, and whose total available bandwidth is only 27 MHz. In communications, a large allowable bandwidth translates into high data speed. The short wavelengths allow the use of dish antennas having manageable diameters. These antennas produce high power gain in transmitting applications, and have excellent sensitivity and directional characteristics for reception of signals.

Ultrasound

Ultrasound is acoustic (sound) energy in the form of waves having a frequency above the human hearing range. The highest frequency that the human ear can detect is approximately 20 thousand cycles per second (20,000 Hz). This is where the sonic range ends, and where the ultrasonic range begins. Ultrasound is used in electronic, navigational, industrial, and security applications. It is also used in medicine to view internal organs of the body.

Ultrasound can be used to locate objects by means similar to the principle by which radar works. High-frequency acoustic waves reflect from objects, even comparatively small ones, because of the short wavelength. The distance to an object can be determined by measuring the delay between the transmission of an ultrasound pulse and the return of the echo. This is the well-known means by which bats navigate in darkness. It is also believed to be used underwater by cetaceans such as dolphins and whales. Ultrasound can be used in sonar systems to determine the depth of the water in a location, to find schools of fish, to locate submarines, and to detect the presence of SCUBA divers.

In an ultrasonic intrusion detection system, a constant, high-frequency acoustic signal is transmitted by a group of transducers. The ultrasound waves flood the protected area. Receiving transducers monitor the ultrasound reflected by objects in the protected zone. If anything moves, it produces a change in the phase of some of the reflected waves. This phase change is detected by sensitive electronic circuits, which send signals to an alarm or dispatch center. Ultrasonic security systems are also popular among automobile owners. These devices detect motion in the immediate vicinity of a vehicle.

In ultrasonic medical imaging, high-frequency acoustic energy is transmitted into the human body using a set of transducers attached to the skin. The ultrasound waves reflect from boundaries between organs and surrounding fluid, and between regions of differing tissue density. This technique has been used to observe the condition and behavior of fetuses prior to birth. It has also been used to locate tumors, and to observe the condition of the human muscles and bones.

Ultrasound is used in industry to analyze the uniformity and purity of liquids and solids. It can also be used for cleaning purposes. Subminiature ultrasonic cleaning instruments are used by some dentists during routine examinations.

Photosensor

A photosensor is an electronic component that detects the presence of visible light, infrared transmission (IR), and/or ultraviolet (UV) energy. Most photosensors consist of semiconductor having a property called photoconductivity, in which the electrical conductance varies depending on the intensity of radiation striking the material.

The most common types of photosensor are the photodiode, the bipolar phototransistor, and the photoFET (photosensitive field-effect transistor). These devices are essentially the same as the ordinary diode , bipolar transistor , and field-effect transistor , except that the packages have transparent windows that allow radiant energy to reach the junctions between the semiconductor materials inside. Bipolar and field-effect phototransistors provide amplification in addition to their sensing capabilities.

Photosensors are used in a great variety of electronic devices, circuits, and systems, including:

- fiber optic systems
- optical scanners
- wireless LAN
- automatic lighting controls
- machine vision systems
- electric eyes
- optical disk drives
- optical memory chips
- remote control devices

CHAPTER 6

6.0 FUTURE SCOPE.

in the future we shall integrate this circuit with combination of :

1) **keypads**
2) **DNA**
3) **Fingerprint**
4) **Face recognition**

6.1 CONCLUSION

The advancement in technology has narrowed much of our needs to provide security , ranging from personal to public places

6.2 REFERENCE

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