NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical&Electronics Engineering

ALARM SYSTEMS WITH L.D.R.

Graduation project

EE – 400

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ACKNOWLEDGMENT

First of all I wish to express my thanks and great appreciation to my graduation project supervisor Assoc. Prof. Dr. Özgür Özerdem.for his supports,advices,comments,experiences and for the battery he gave me from the beginning till the end of my project.

Besides that I wolul like to thank and blead to my parents,Mr. Ahmet Karakaya,Mr. Adem Sevim and all my engineering teachers who always supported me and helped during my study.

ABSTRACT

The entire of this project is about a sample of panic alarm systems and photoresistive lamps which is possible to use in daily life.And I tried to show you the enjoyness and possible developmantation of the electronic circuits.

The designation of an electronic circuit can be categorized in three major sections.These are; designing the function and strucrure of the project depending on the possible using ares of the project in our daily life etc.Drawing the circuit of the project,choosing and deciding on the necessary components which are necessary in the circuit.Constructing the circuit.

On the other hand, the importance of the alarm systems and sensitive electronic projects in industry and making our lives easier is increasing day by day.That's why the improvements about this subject can not be dazzled.

The main goal of this project is to make practical training ,to collect theorotical information about the buzzer sensitive and alarm systems.Making enough knowledge for a last term student.And we hope to learn the use and application of sensors,equipments in the circuit.

As a result of this project and study;I tried to give detailed information related to electronic circuits and generally panic alarm systems with sensors and buzzers as clear as possible.I will be so glad if I had succeed this.

INTRODUCTION

We know that the technological developments for fifty years are thirty times more than the developments done for last three hundred years.As a result of this we can say that this is the age of data processing and technology.

On the other hand the excess of the supply in the market of electrical and electronics industry force the supplier to produce cheaper and more technological and useful products because of the race in the market.

Also the natural energy stocks of the earth are ran out and the potential major energy spring of the world is electrical energy for the next three hundred years.This makes the electrical and electronics engineering more and more important.

Besides that the using area of the electronics and electrical developments and devices are increasing day by day.Let's think about the using areas;the electricity is iverresible for illumination ,some devices such as TV,fridge,etc...So we can say that we use electronics and electric from the daily usage till our health ,security,comfort,transportation,etc.. We can increase these examples easily.

Chapter 1: Components used in the project

1.1 Introduction of chapter 1:

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

1.2 Capacitors:

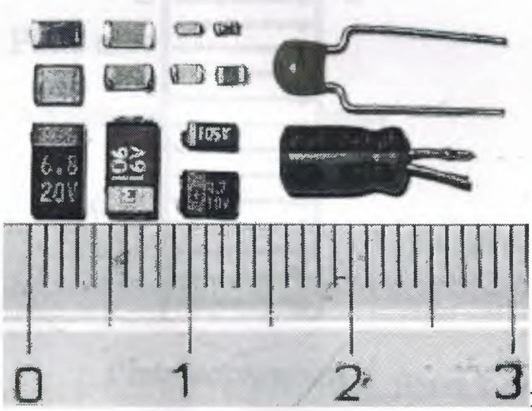


figure1

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

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

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

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

1.2.1 Overview

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

Capacitance

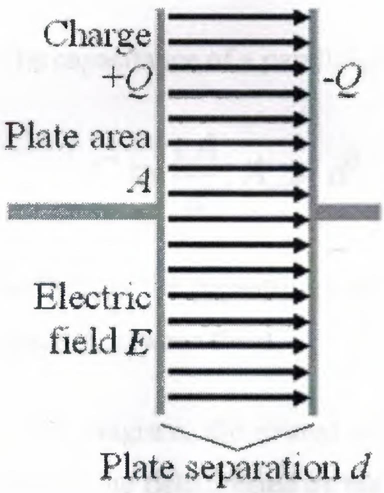


figure 2

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

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

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

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

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

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

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

where ε is the permittivity of the dielectric, A is the area of the plates and d is the spacing between them.

In the diagram, the rotated molecules create an opposing electric field that partially cancels the field created by the plates, a process called dielectric polarization.

Stored energy

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

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

where V is the voltage across the capacitor.

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

1.2.2 Hydraulic model

As electrical circuitry can be modeled by fluid flow, a capacitor can be modeled as a chamber with a flexible diaphragm separating the input from the output. As can be determined intuitively as well as mathematically, this provides the correct characteristics

- The pressure across the unit is proportional to the integral of the current
- A steady state current cannot pass through it but a pulse or alternating current can be transmitted
- the capacitance of units connected in parallel is equivalent to the sum of their individual capacitances
- applying too much pressure, above the maximum pressure, will destroy it.

1.2.3 Electric Circuits

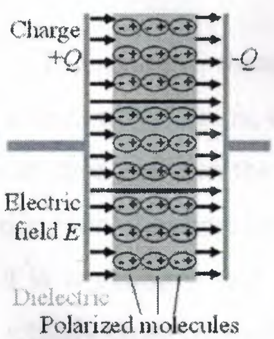


figure 3

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

DC sources

Electrons cannot easily pass directly across the dielectric from one plate of the capacitor to the other as the dielectric is carefully chosen so that it is a good insulator. When there is a current through a capacitor, electrons accumulate on one plate and electrons are removed from the other plate. This process is commonly called 'charging' the capacitor -- even though the capacitor is at all times electrically neutral. In fact, the current through the capacitor results in the separation of electric charge, rather than the accumulation of electric charge. This separation of charge causes an electric field to develop between the plates of the capacitor giving rise to voltage across the plates. This voltage V is directly proportional to the amount of charge separated Q. Since the current I through the capacitor is the rate at which charge Q is forced through the capacitor (dQ/dt), this can be expressed mathematically as:constant (DC) voltage source, the voltage across the capacitor cannot exceed the voltage of the source. (Unless the circuit includes a switch and an inductor, as in SMPS, or a switch and some diodes, as in a charge pump). Thus, an equilibrium is reached where the voltage across the capacitor is constant and the current through the capacitor is zero. For this reason, it is commonly said that capacitors block DC.

AC sources

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

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

1.2.4 Impedance

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

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

where

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

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

f is the frequency),

C is the capacitance in farads, and

j is the imaginary unit.

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

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

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

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

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

Laplace equivalent (s-domain)

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

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

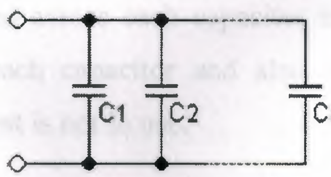
where C is the capacitance, and s (= $\sigma + j\omega$) is the complex frequency.

Displacement current

The physicist James Clerk Maxwell invented the concept of displacement current, **dD**/dt, to make Ampere's law consistent with conservation of charge in cases where charge is accumulating as in a capacitor. He interpreted this as a real motion of charges, even in vacuum, where he supposed that it corresponded to motion of dipole charges in the ether. Although this interpretation has been abandoned, Maxwell's correction to Ampere's law remains valid.

Series or parallel arrangements

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

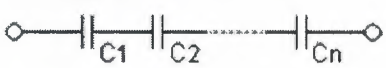


$$C_{eq} = C_1 + C_2 + \cdots + C_n$$

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

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

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



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

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

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

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

Capacitor/inductor duality

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

1.2.5 Applications

Capacitor symbols

Capacitor	Polarized capacitors	Variable capacitor

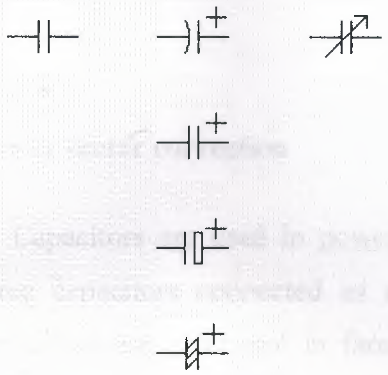


Table 1

Capacitors have various uses in electronic and electrical systems.

Energy storage

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

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

Capacitors are connected in parallel with the power circuits of most electronic devices and larger systems (such as factories) to shunt away and conceal current fluctuations from the primary power source to provide a "clean" power supply for signal or control circuits. Audio equipment, for example, uses several capacitors in this way, to shunt away power line hum before it gets into the signal circuitry. The capacitors act as a local reserve for the DC power source, and bypass AC currents from the power supply. This is used in car audio applications, when a stiffening capacitor compensates for the inductance and resistance of the leads to the lead-acid car battery.

Power factor correction

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

1.2.6 Filtering

Signal coupling

Because capacitors pass AC but block DC signals (when charged up to the applied dc voltage), they are often used to separate the AC and DC components of a signal. This method is known as *AC coupling*. (Sometimes transformers are used for the same effect.) Here, a large value of capacitance, whose value need not be accurately controlled, but whose reactance is small at the signal frequency, is employed. Capacitors for this purpose designed to be fitted through a metal panel are called feed-through capacitors, and have a slightly different schematic symbol.

Noise filters, motor starters, and snubbers

When an inductive circuit is opened, the current through the inductance collapses quickly, creating a large voltage across the open circuit of the switch or relay. If the inductance is large enough, the energy will generate a spark, causing the contact points to oxidize, deteriorate, or sometimes weld together, or destroying a solid-state switch. A snubber capacitor across the newly opened circuit creates a path for this impulse to bypass the contact points, thereby preserving their life; these were commonly found in contact breaker ignition systems, for instance. Similarly, in smaller scale circuits, the spark may not be enough to damage the switch but will still radiate undesirable radio frequency interference (RFI), which a **filter** capacitor absorbs. Snubber capacitors are usually employed with a low-value resistor in series, to dissipate energy and minimize RFI. Such resistor-capacitor combinations are available in a single package.

In an inverse fashion, to initiate current quickly through an inductive circuit requires a greater voltage than required to maintain it; in uses such as large motors, this can cause undesirable startup characteristics, and a **motor starting capacitor** is used to increase the coil current to help start the motor.

Capacitors are also used in parallel to interrupt units of a high-voltage circuit breaker in order to equally distribute the voltage between these units. In this case they are called grading capacitors.

In schematic diagrams, a capacitor used primarily for DC charge storage is often drawn vertically in circuit diagrams with the lower, more negative, plate drawn as an arc. The straight plate indicates the positive terminal of the device, if it is polarized (see electrolytic capacitor).

Signal processing

The energy stored in a capacitor can be used to represent information, either in binary form, as in DRAMs, or in analogue form, as in analog sampled filters and

CCDs. Capacitors can be used in analog circuits as components of integrators or more complex filters and in negative feedback loop stabilization. Signal processing circuits also use capacitors to integrate a current signal.

Tuned circuits

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

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

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

This is the frequency at which resonance occurs in an LC circuit.

Other applications

Sensing

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

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

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

Pulsed power and weapons

Groups of large, specially constructed, low-inductance high-voltage capacitors (*capacitor banks*) are used to supply huge pulses of current for many pulsed power applications. These include electromagnetic forming, Marx generator , pulsed lasers (especially TEA lasers), pulse forming networks, radar, fusion research, and particle accelerators.

Large capacitor banks are used as energy sources for the exploding-bridgewire detonators or slapper detonators in nuclear weapons and other speciality weapons. Experimental work is under way using banks of capacitors as power sources for electromagnetic armour and electromagnetic railguns or coilguns.

Hazards and safety

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

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

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

1.2.7 High-voltage

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

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

1.2.8 History

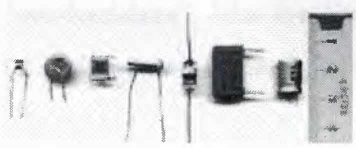


figure 4

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

figure 5

Various Capacitors

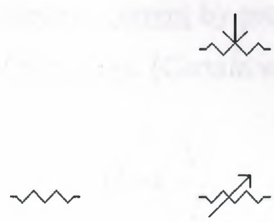
In October 1745, Ewald Georg von Kleist of Pomerania invented the first recorded capacitor: a glass jar coated inside and out with metal. The inner coating was connected to a rod that passed through the lid and ended in a metal sphere. By having this thin layer of glass insulation (a dielectric) between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

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

The earliest unit of capacitance was the 'jar', equivalent to about 1 nF.

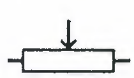
Early capacitors were also known as *condensers*, a term that is still occasionally used today. It was coined by Volta in 1782 (derived from the Italian *condensatore*), with reference to the device's ability to store a higher density of electric charge than a normal isolated conductor. Most non-English languages still use a word derived from "condensatore", like the French *"condensateur"*, the German, Norwegian or Polish *"Kondensator"*, or the Spanish *"condensador*

1.3 Resistors:



Resistor   Variable Resistor

Resistor symbols (US and Japan)



Resistor
Variable resistor

Resistor symbols (Europe, IEC)

Table 2

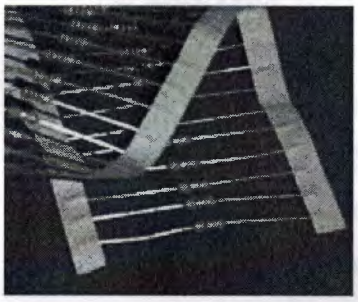


figure 6

A pack of resistors

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

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

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

1.3.1 Applications

- In general, a resistor is used to create a known voltage-to-current ratio in an electric circuit. If the current in a circuit is known, then a resistor can be used to create a known potential difference proportional to that current. Conversely, if the potential difference between two points in a circuit is known, a resistor can be used to create a known current proportional to that difference.

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

1.3.2 The ideal resistor

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

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

Nonideal characteristics

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

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

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

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

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

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

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

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

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

Vt = SQRT(4kTBR);

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

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

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

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

Contact noise has a 1/f frequency characteristic.

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

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

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

1.3.3 Types of resistor

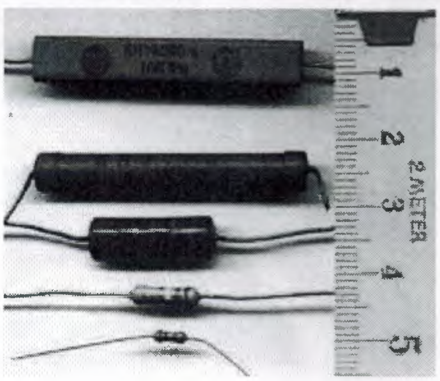


figure 7

A few types of resistors

Fixed resistors

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

Variable resistors

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

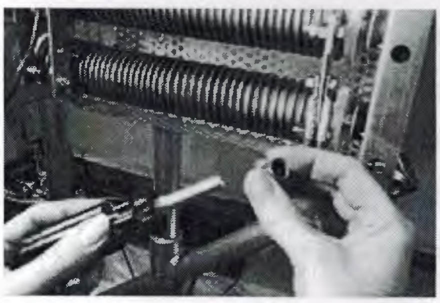


figure 8

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

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

Some examples include:

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

Other types of resistors

A *metal oxide varistor* (**MOV**) is a special type of resistor that changes its resistance with rise in voltage: a very high resistance at low voltage (below the trigger voltage) and very low resistance at high voltage (above the trigger voltage). It acts as a switch. It is usually used for short circuit protection in power strips or lightning bolt "arrestors" on street power poles, or as a "snubber" in inductive circuits.

A *thermistor* is a temperature-dependent resistor. There are two kinds, classified according to the sign of their temperature coefficients:

A *Positive Temperature Coefficient* (**PTC**) resistor is a resistor with a positive temperature coefficient. When the temperature rises the resistance of the PTC increases. PTCs are often found in televisions in series with the demagnetizing coil where they are used to provide a short-duration current burst through the coil when the TV is turned on. One specialized version of a PTC is the polyswitch which acts as a self-repairing fuse.

A *Negative Temperature Coefficient* (**NTC**) resistor is also a temperature-dependent resistor, but with a negative temperature coefficient. When the temperature rises the resistance of the NTC drops. NTCs are often used in simple temperature detectors and measuring instruments.

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

Identifying resistors

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

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

Resistor Standards

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

Four-band axial resistors

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

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

Color	**1st band**	**2nd band**	**3rd band (multiplier)**	**4th band (tolerance)**	**Temp. Coefficient**
Black	0	0	$\times 10^0$		
Brown	1	1	$\times 10^1$	±1% (F)	100 ppm
Red	2	2	$\times 10^2$	±2% (G)	50 ppm
Orange	3	3	$\times 10^3$		15 ppm
Yellow	4	4	$\times 10^4$		25 ppm
Green	5	5	$\times 10^5$	±0.5% (D)	

Blue	6	6	$\times 10^6$	±0.25% (C)	
Violet	7	7	$\times 10^7$	±0.1% (B)	
Gray	8	8	$\times 10^8$	±0.05% (A)	
White	9	9	$\times 10^9$		
Gold			×0.1	±5% (J)	
Silver			×0.01	±10% (K)	
None				±20% (M)	

Table 3

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

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

1.3.4 Preferred values

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

silver 10%
gold 5%
red 2%
brown 1%
green 0.5%.

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

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

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

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

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

5-band axial resistors

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

Mnemonic phrases for remembering codes

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

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

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

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

1.3.5 SMD resistors

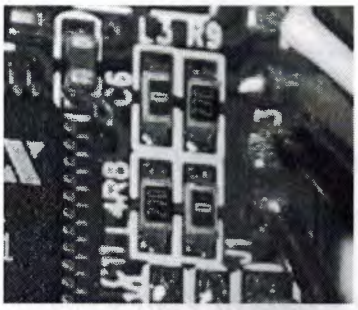


figure 9

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

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

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

"222" = 22 × 100 ohms = 2.2 kiloohms

"473" = 47 × 1,000 ohms = 47 kiloohms

"105" = 10 × 100,000 ohms = 1 megaohm

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

"100" = 10 × 1 ohm = 10 ohms

"220" = 22 × 1 ohm = 22 ohms

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

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

"4R7" = 4.7 ohms

"0R22" = 0.22 ohms

"0R01" = 0.01 ohms

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

"1001" = 100 × 10 ohms = 1 kiloohm

"4992" = 499 × 100 ohms = 49.9 kiloohm

"1000" = 100 × 1 ohm = 100 ohms

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

Power Rating at 70°C

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

Table 4

Tolerance Code

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

Table 5

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

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

1.3.6 Calculations

Ohm's law

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

$$V = IR$$

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

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

Power dissipation

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

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

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

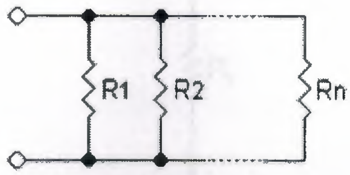
The total amount of heat energy released is the integral of the power over time:

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

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

Series and parallel circuits

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

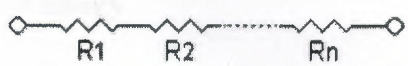


$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$$

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

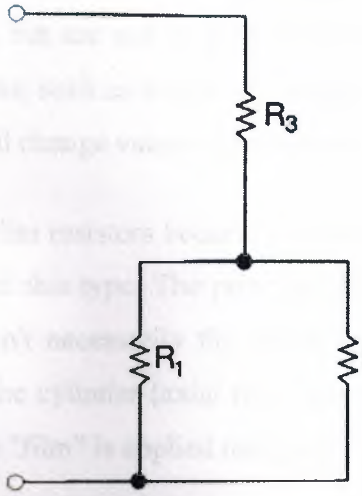
$$R_{eq} = R_1 \| R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

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



$$R_{eq} = R_1 + R_2 + \cdots + R_n$$

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



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

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

1.3.7 Technology

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

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

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

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

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

Because the time during which the sputtering is performed can be controlled, the thickness of the film of a thin-film resistor, can be accurately controlled. The type of the material is also usually different consisting of one or more ceramic (cermet) conductors such as tantalum nitride (TaN), rubidium dioxide (RuO_2), lead oxide (PbO), bismuth ruthenate ($Bi_2Ru_2O_7$), nickel chromium (NiCr), and/or bismuth iridate ($Bi_2Ir_2O_7$).

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

Traditionally thick film resistors had tolerances of 5%, but in the last few decades, standard tolerances have improved to 2% and 1%. But beware; temperature coefficients of thick film resistors, are tyically +/- 200 ppm, or +/- 250ppm, depending on the resistance. Thus a 40 degree Celsius temperature change can add another 1% variation to a 1% resistor.

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

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

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

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

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

Types of resistors:

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

Foil resistor

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

1.4 Diodes:

figure 10

Types of diodes

figure 11

closeup, showing silicon crystal

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

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

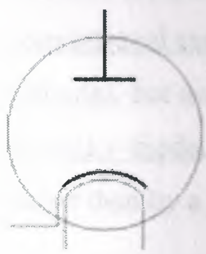
1.4.1 History

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

Thermionic diode principles were rediscovered by Thomas Edison on February 13, 1880 and he took out a patent in 1883 (U.S. Patent 307031), but developed the idea no further. Braun patented the crystal rectifier in 1899. The first radio receiver using a crystal diode was built around 1900 by Greenleaf Whittier Pickard. The first thermionic diode was patented in Britain by John Ambrose Fleming (scientific adviser to the Marconi Company and former Edison employee) on November 16, 1904 (U.S. Patent 803684 in November 1905). Pickard received a patent for a silicon crystal detector on November 20, 1906 (U.S. Patent 836531).

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

Thermionic or gaseous state diodes



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

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

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

Semiconductor diodes

1.4.2 Diode schematic symbol

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

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

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

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

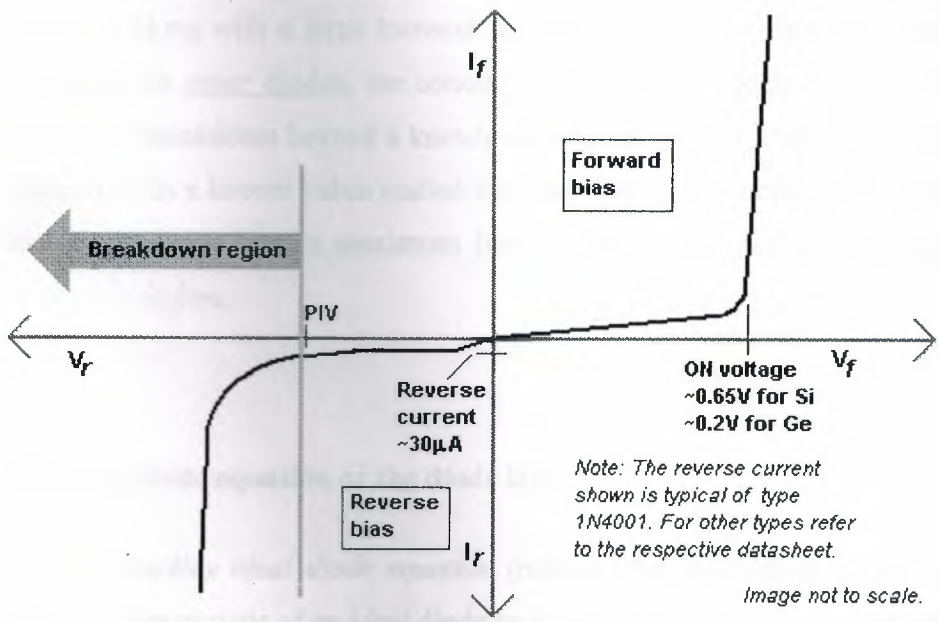


figure 12

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

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

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

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

Shockley diode equation or the diode law

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

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

where

I is the diode current,

I_S is a scale factor called the *saturation current*,

V_D is the voltage across the diode,

V_T is the *thermal voltage*,

and n is the *emission coefficient*.

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

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

where

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

k is Boltzmann's constant,

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

Types of semiconductor diode

Diode	Zener Diode	Schottky Diode	Tunnel Diode
			
Light-emitting diode	Photodiode	Varicap	SCR

Some diode symbols
Table 6

1.4.3 Normal (p-n) diodes

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

'Gold doped' diodes

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

Zener diodes

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

Avalanche diodes

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

Transient voltage suppression (TVS) diodes

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

Photodiodes

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

Light-emitting diodes (LEDs)

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

Laser diodes

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

Schottky diodes

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

Snap-off or 'step recovery' diodes

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

Gunn diodes

These are similar to tunnel diodes in that they are made of materials such as GaAs or InP that exhibit a region of negative differential resistance. With appropriate biasing, dipole domains form and travel across the diode, allowing high frequency microwave oscillators to be built.

Peltier diodes are used as sensors, heat engines for thermoelectric cooling. Charge carriers absorb and emit band gap energies as heat.

There are other types of diodes, which all share the basic function of allowing electrical current to flow in only one direction, but with different methods of construction.

Point-contact diodes

These work the same as the junction semiconductor diodes described above, but its construction is simpler. A block of n-type semiconductor is built, and a conducting sharp-point contact made with some group-3 metal is placed in contact with the semiconductor. Some metal migrates into the semiconductor to make a small region of p-type semiconductor near the contact. The long-popular 1N34 germanium version is still used in radio receivers as a detector and occasionally in specialized analog electronics.

Cat's whisker or crystal diodes

These are a type of point contact diode. The cat's whisker diode consists of a thin or sharpened metal wire pressed against a semiconducting crystal, typically galena or a lump of coal. The wire forms the anode and the crystal forms the cathode. Cat's whisker diodes were also called crystal diodes and found application in crystal radio receivers.

Varicap or varactor diodes

These are used as voltage-controlled capacitors. These were important in PLL (phase-locked loop) and FLL (frequency-locked loop) circuits, allowing tuning circuits, such as those in television receivers, to lock quickly, replacing older designs that took a long time to warm up and lock. A PLL is faster than a FLL, but prone to integer harmonic locking (if one attempts to lock to a broadband signal). They also enabled tunable oscillators in early discrete tuning of radios, where a cheap and stable, but fixed-frequency, crystal oscillator provided the reference frequency for a voltage-controlled oscillator.

PIN diodes

A PIN diode has a central un-doped, or *intrinsic*, layer, forming a p-type / intrinsic / n-type structure. They are used as radio frequency switches, similar to varactor diodes but with a more sudden change in capacitance. They are also used as large volume ionizing radiation detectors and as photodetectors. PIN diodes are also used in power electronics, as their central layer can withstand high voltages. Furthermore, the PIN structure can be found in many power semiconductor devices, such as IGBTs, power MOSFETs, and thyristors.

1.4.4 Current-limiting field-effect diodes

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

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

Related devices

- Thyristor or silicon controlled rectifier (SCR)
- TRIAC
- Diac
- Transistor

1.4.5 Applications

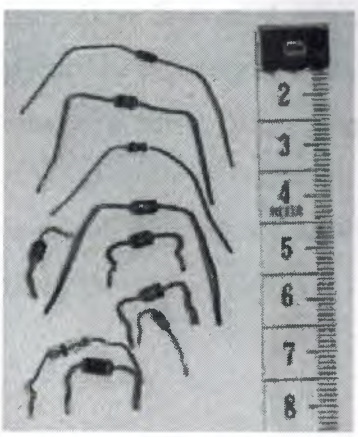


figure 13

Several types of diodes

Radio demodulation

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

Power conversion

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

Over-voltage protection

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

Logic gates

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

Ionising radiation detectors

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

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

Temperature measuring

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

Charge coupled devices

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

1.5 Photoresistor:

figure 14

1.5.1 LDR

A photoresistor is an electronic component whose resistance decreases with increasing incident light intensity. It can also be referred to as a light-dependent resistor (LDR), or photoconductor.

A photoresistor is made of a high-resistance semiconductor. If light falling on the device is of high enough frequency, photons absorbed by the semiconductor give bound electrons enough energy to jump into the conduction band. The resulting free electron (and its hole partner) conduct electricity, thereby lowering resistance.

A photoelectric device can be either intrinsic or extrinsic. In intrinsic devices, the only available electrons are in the valence band, and hence the photon must have enough energy to excite the electron across the entire bandgap. Extrinsic devices have impurities added, which have a ground state energy closer to the conduction band — since the electrons don't have as far to jump, lower energy photons (i.e. longer wavelengths and lower frequencies) are sufficient to trigger the device.

Cadmium sulphide cells

Cadmium sulphide or cadmium sulfide (CdS) cells rely on the material's ability to vary its resistance according to the amount of light striking the cell. The more light that strikes the cell, the lower the resistance. Although not accurate, even a simple CdS cell can have a wide range of resistance from less than 100 Ω in bright light to in excess of 10 MΩ in darkness. The cells are also capable of reacting to a broad range of frequencies, including infrared (IR), visible light, and ultraviolet (UV). They are often found on street lights as automatic on/off switches. They were once even used in heat-seeking missiles to sense for targets.

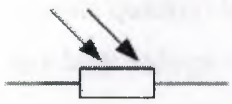
1.5.2 Applications

Light-dependent resistor.

Photoresistors come in many different types. Inexpensive cadmium sulfide cells can be found in many consumer items such as camera light meters, clock radios, security alarms, street lights and outdoor clocks. At the other end of the scale, Ge:Cu photoconductors are among the best far-infrared detectors available, and are used for infrared astronomy and infrared spectroscopy.

Circuit symbol

Below is the symbol for a photoresistor used in UK circuit diagrams.



1.6 Relay:

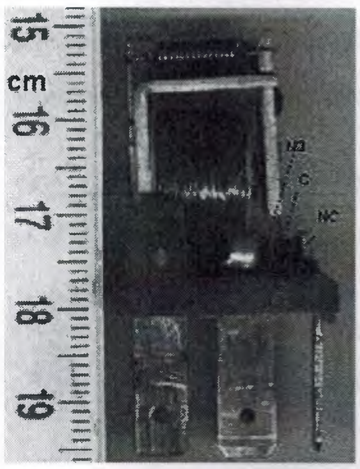


figure 15

Automotive style miniature relay

A relay is an electrical switch that opens and closes under control of another electrical circuit. In the original form, the switch is operated by an electromagnet to open or close one or many sets of contacts. It was invented by Joseph Henry in 1835. Because a relay is able to control an output circuit of higher power than the input circuit, it can be considered, in a broad sense, to be a form of electrical amplifier.

1.6.1 Operation

When a current flows through the coil, the resulting magnetic field attracts an armature that is mechanically linked to a moving contact. The movement either makes or breaks a connection with a mixed contact. When the current to the coil is switched off, the armature is returned by a force that is half as strong as the magnetic force to its relaxed position. Usually this is a spring, but gravity is also used commonly in industrial motor starters. Josh Cartmell says Relays are manufactured to operate quickly. In a low voltage application, this is to reduce noise.David Chisnel is in a high voltage or high current application, this is to reduce arcing.

If the coil is energized with DC, a diode is frequently installed across the coil, to dissipate the energy from the collapsing magnetic field at deactivation, which would otherwise generate a spike of voltage and might cause damage to circuit components. If the coil is designed to be energized with AC, a small copper ring can be crimped to the end of the solenoid. This "shading ring" creates a small out-of-phase current, which increases the minimum pull on the armature during the AC cycle. [1]

The contacts can be either Normally Open (NO), Normally Closed (NC), or change-over (CO) contacts.

- Normally-open contacts connect the circuit when the relay is activated; the circuit is disconnected when the relay is inactive. It is also called Form A contact or "make" contact. Form A contact is ideal for applications that require to switch a high-current power source from a remote device.
- Normally-closed contacts disconnect the circuit when the relay is activated; the circuit is connected when the relay is inactive. It is also called Form B contact or "break" contact. Form B contact is ideal for applications that require the circuit to remain closed until the relay is activated.
- Change-over contacts control two circuits: one normally-open contact and one normally-closed contact with a common terminal. It is also called Form C contact or "transfer" contact.

By analogy with the functions of the original electromagnetic device, a solid-state relay is made with a thyristor or other solid-state switching device. To achieve electrical isolation, a light-emitting diode (LED) is used with a photo transistor.

1.6.2 Types of relay

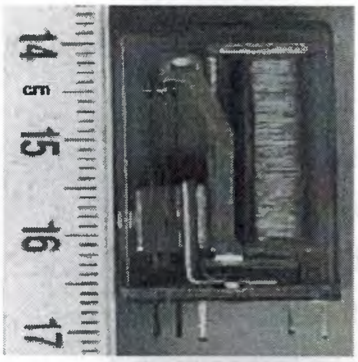


figure 16

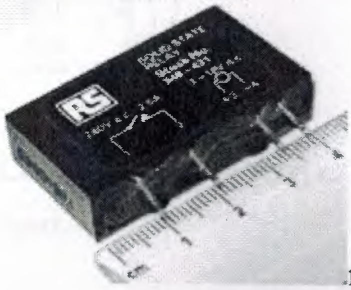
Small relay as used in electronics

- A latching relay has two relaxed states (bistable). These are also called 'keep' relays. When the current is switched off, the relay remains in its last state. This is achieved with a solenoid operating a ratchet and cam mechanism, or by having two opposing coils with an over-center spring or permanent magnet to hold the armature and contacts in position while the coil is relaxed, or with a remnant core. In the ratchet and cam example, the first pulse to the coil turns the relay on and the second pulse turns it off. In the two coil example, a pulse to one coil turns the relay on and a pulse to the opposite coil turns the relay off. This type of relay has the advantage that it consumes power only for an instant, while it is being switched, and it retains its last setting across a power outage.
- A reed relay has a set of, usually normally open, contacts inside a vacuum or inert gas filled glass tube. This protects the contacts against atmospheric corrosion. The two contacts are closed by magnetism from a coil around the glass tube. See also reed switch.
- A mercury wetted relay is a form of reed relay in which the contacts are wetted with mercury. Such relays are used to switch low-voltage signals (one volt or less) because of its low contact resistance, or for high-speed counting and timing applications where the mercury eliminated contact bounce. Mercury wetted relays are position-sensitive and must be mounted vertically

to work properly. Because of the toxicity and expense of liquid mercury, these relays are rarely specified for new equipment. See also mercury switch.

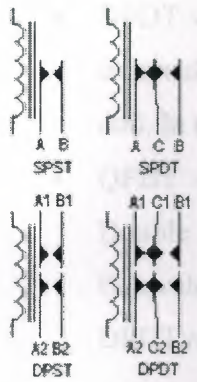
- A Polarized Relay placed the armature between the poles of a permanent magnet to increase sensitivity. Polarized relays were used in middle 20th Century telephone exchanges to detect faint pulses and correct telegraphic distortion. The poles were on screws, so a technician could first adjust them for maximum sensitivity and then apply a bias spring to set the critical current that would operate the relay.
- A machine tool relay is a type standardized for industrial control of machine tools, transfer machines, and other seqential control. They are characterized by a large number of contacts (sometimes extendable in the field) which are easily converted from normally-open to normally-closed status, easily replaceable coils, and a form factor that allows compactly installing many relays in a control panel. Although such relays once were the backbone of automation in such industries as automobile assembly, the programmable logic controller mostly displaced the machine tool relay from sequential control applications.
- A contactor is a very heavy-duty relay used for switching electric motors and lighting loads. With high current, the contacts are made with pure silver. The unavoidable arcing causes the contacts to oxidize and silver oxide is still a good conductor. Such devices are often used for motor starters. A motor starter is a contactor with an overload protection devices attached. The overload sensing devices are a form of heat operated relay where a coil heats a bi-metal strip, or where a solder pot melts, releasing a spring to operate auxiliary contacts. These auxiliary contacts are in series with the coil. If the overload senses exess current in the load, the coil is de-energized.
- A Buchholz relay is a safety device sensing the accumulation of gas in large oil-filled transformers, which will alarm on slow accumulation of gas or shut down the transformer if gas is produced rapidly in the transformer oil.
- A forced-guided contacts relay has relay contacts that are mechanically linked together, so that when the relay coil is energized or de-energized, all of the

linked contacts move together. If one set of contacts in the relay becomes immobilized, no other contact of the same relay will be able to move. The function of forced-guided contacts is to enable the safety circuit to check the status of the relay. Forced-guided contacts are also known as "positive-guided contacts", "captive contacts", "locked contacts", or "safety relays".


.figure 17

A solid state relay, which has no moving parts

- A solid state relay (SSR) is a solid state electronic component that provides a similar function to an electromechanical relay but does not have any moving components, increasing long-term reliability. With early SSR's, the tradeoff came from the fact that every transistor has a small voltage drop across it. This collective voltage drop limited the amount of current a given SSR could handle. As transistors improved, higher current SSR's, able to handle 100 to 1,200 amps, have become commercially available.
- One type of motor overload protection relay is operated by a heating element in series with the motor. The heat generated by the motor current operates a bi-metal strip or melts solder, releasing a spring to operate contacts. Where the overload relay is exposed to the same environment as the motor, a useful though crude compensation for motor ambient temperature is provided.



Circuit symbols of relays. *"C" denotes the common terminal in SPDT and DPDT types.*

Since relays are <u>switches</u>, the terminology applied to switches is also applied to relays. According to this classification, relays can be of the following types:

- SPST - Single Pole Single Throw. These have two terminals which can be switched on/off. In total, four terminals when the coil is also included.
- SPDT - Single Pole Double Throw. These have one row of three terminals. One terminal (common) switches between the other two poles. It is the same as a single change-over switch. In total, five terminals when the coil is also included.
- DPST - Double Pole Single Throw. These have two pairs of terminals. Equivalent to two SPST switches or relays actuated by a single coil. In total, six terminals when the coil is also included. This configuration may also be referred to as DPNO.

figure 18

The diagram on the package of a DPDT AC coil relay

- DPDT - Double Pole Double Throw. These have two rows of change-over terminals. Equivalent to two SPDT switches or relays actuated by a single coil. In total, eight terminals when the coil is also included.
- QPDT - Quadruple Pole Double Throw. Often referred to as Quad Pole Double Throw, or 4PDT. These have four rows of change-over terminals. Equivalent to four SPDT switches or relays actuated by a single coil or two DPDT relays. In total, fourteen terminals when the coil is also included.

1.6.3 Applications

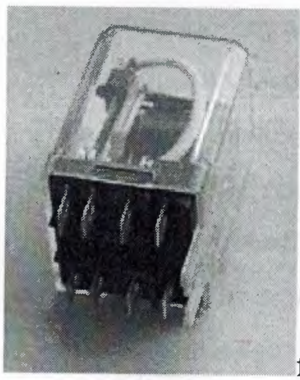


figure 19

A DPDT AC coil relay with "ice cube" packaging

Relays are used:

- to control a high-voltage circuit with a low-voltage signal, as in some types of modems,
- to control a high-current circuit with a low-current signal, as in the starter solenoid of an automobile,
- to detect and isolate faults on transmission and distribution lines by opening and closing circuit breakers (protection relays),
- to isolate the controlling circuit from the controlled circuit when the two are at different potentials, for example when controlling a mains-powered device from a low-voltage switch. The latter is often applied to control office lighting

as the low voltage wires are easily installed in partitions, which may be often moved as needs change. They may also be controlled by room occupancy detectors in an effort to conserve energy,

- to perform logic functions. For example, the boolean AND function is realised by connecting NO relay contacts in series, the OR function by connecting NO contacts in parallel. The change-over or Form C contacts perform the XOR (exclusive or) function. Similar functions for NAND and NOR are accomplished using NC contacts. Due to the failure modes of a relay compared with a semiconductor, they are widely used in safety critical logic, such as the control panels of radioactive waste handling machinery.
- to perform time delay functions. Relays can be modified to delay opening or delay closing a set of contacts. A very short (a fraction of a second) delay would use a copper disk between the armature and moving blade assembly. Current flowing in the disk maintains magnetic field for a short time, lengthening release time. For a slightly longer (up to a minute) delay, a dashpot is used. A dashpot is a piston filled with fluid that is allowed toescape slowly. The time period can be varied by increasing or decreasing the flow rate. For longer time periods, a mechanical clockwork timer is installed.

figure 20

A large relay with two coils and many sets of contacts, used in an old telephone switching system.

Selection of an appropriate relay for a particular application requires evaluation of many different factors:

- Number and type of contacts - normally open, normally closed, changeover (double-throw)
- In the case of changeover, there are two types. This style of relay can be manufactured two different ways. "Make before Break" and "Break before Make". The old style telephone switch required Make-before-break so that the connection didn't get dropped while dialing the number. The railroad still uses them to control railroad crossings.
- Rating of contacts - small relays switch a few amperes, large contactors are rated for up to 3000 amperes, alternating or direct current
- Voltage rating of contacts - typical control relays rated 300 VAC or 600 VAC, automotive types to 50 VDC, special high-voltage relays to about 15,000 V
- Coil voltage - machine-tool relays usually 24 VAC or 120 VAC, relays for switchgear may have 125 V or 250 VDC coils, "sensitive" relays operate on a few milliamperes
- Package/enclosure - open, touch-safe, double-voltage for isolation between circuits, explosion proof, outdoor, oil-splashresistant
- Mounting - sockets, plug board, rail mount, panel mount, through-panel mount, enclosure for mounting on walls or equipment
- Switching time - where high speed is required
- "Dry" contacts - when switching very low level signals, special contact materials may be needed such as gold-plated contacts
- Contact protection - suppress arcing in very inductive circuits
- Coil protection - suppress the surge voltage produced when switching the coil current
- Isolation between coil circuit and contacts
- Aerospace or radiation-resistant testing, special quality assurance
- Accessories such as timers, auxiliary contacts, pilot lamps, test buttons
- Regulatory approvals
- Stray magnetic linkage between coils of adjacent relays on a printed circuit board.

1.6.4 Protection relay

A protection relay is a complex electromechanical apparatus, often with more than one coil, designed to calculate operating conditions on an electrical circuit and trip circuit breakers when a fault was found. Unlike switching type relays with fixed and usually ill-defined operating voltage thresholds and operating times, protection relays had well-established, selectable, time/current (or other operating parameter) curves. Such relays were very elaborate, using arrays of induction disks, shaded-pole magnets, operating and restraint coils, solenoid-type operators, telephone-relay style contacts, and phase-shifting networks to allow the relay to respond to such conditions as over-current, over-voltage, reverse power flow, over- and under- frequency, and even distance relays that would trip for faults up to a certain distance away from a substation but not beyond that point. An important transmission line or generator unit would have had cubicles dedicated to protection, with a score of individual electromechanical devices. Each of the protective functions available on a given relay are denoted by standard ANSI Device Numbers. For example, a relay including function 51 would be a timed overcurrent protection relay.

Design and theory of these protective devices is an important part of the education of an electrical engineer who specializes in power systems. Today these devices are nearly entirely replaced (in new designs) with microprocessor-based instruments (numerical relays) that emulate their electromechanical ancestors with great precision and convenience in application. By combining several functions in one case, numerical relays also save capital cost and maintenance cost over electromechanical relays. However, due to their very long life span, tens of thousands of these "silent sentinels" are still protecting transmission lines and electrical apparatus all over the world.

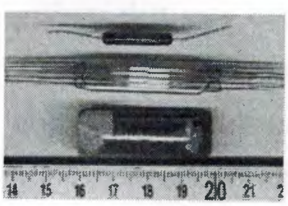


Figure 21

1.6.5 Overcurrent relay

An "Overcurrent Relay" is a type of protective relay. The ANSI Device Designation Number is 50 for an Instantaneous OverCurrent (IOC), 51 for a Time OverCurrent (TOC). In a typical application the overcurrent relay is used for overcurrent protection, connected to a current transformer and calibrated to operate at or above a specific current level. When the relay operates, one or more contacts will operate and energize a trip coil in a Circuit Breaker and trip (open) the Circuit Breaker.

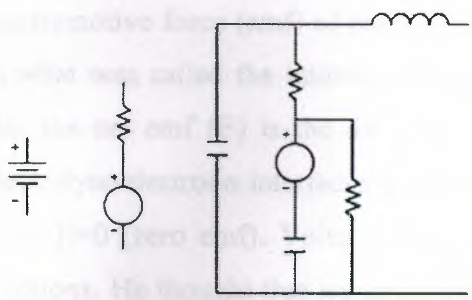
1.7 Battery (electricity):

figure 22

Four double-A (AA) rechargeable batteries

In science and technology, a battery is a device that stores chemical energy and makes it available in an electrical form. Batteries consist of electrochemical devices such as one or more galvanic cells, fuel cells or flow cells. The earliest known artifacts that may have been batteries are the *Baghdad Batteries*, from some time between 250 BC and 640 AD. The modern development of batteries started with the Voltaic pile, announced by the Italian physicist Alessandro Volta in 1800[1]. The worldwide battery industry generates US$48 billion in sales annually (2005 estimate).

Battery concepts



1.7.1 General information

Circuit symbol for a battery; simplified electrical model; and more complex but still incomplete model (the series capacitor has an extremely large value and, as it charges, simulates the discharge of the battery).

A battery is a device in which chemical energy is directly converted to electrical energy. It consists of one or more voltaic cells, each of which is composed of two half cells connected in series by the conductive electrolyte[2]. In the figure to the right, the battery consists of one or more voltaic cells in series. (The conventional symbol does not necessarily represent the true number of voltaic cells.) Each cell has a positive terminal, shown by a long horizontal line, and a negative terminal, shown by the shorter horizontal line. These do not touch each other but are immersed in a solid or liquid electrolyte.

The electrolyte is a conductor which connects the half-cells together. It also contains ions which can react with chemicals of the electrodes. Chemical energy is converted into electrical energy by chemical reactions that transfer charge between the electrode and the electrolyte at their interface. Such reactions are called *faradaic*, and are responsible for current flow through the cell. Ordinary, non-charge-transferring (*non-faradaic*) reactions also occur at the electrode-electrolyte interfaces.

Non-faradaic reactions are one reason that voltaic cells (particularly the lead-acid cell of ordinary car batteries) "run down" when sitting unused.

Around 1800, Alessandro Volta studied the effect of different electrodes on the net electromotive force (emf) of many different types of voltaic cells. (Emf is equivalent to what was called the internal voltage source in the previous section.) He showed that the net emf (E) is the difference of the emfs E1 and E2 associated with the electrolyte-electrode interfaces within the two half-cells. Hence identical electrodes yield E=0 (zero emf). Volta did not appreciate that the emf was due to chemical reactions. He thought that his cells were an inexhaustible source of energy, and that the associated chemical effects (e.g., corrosion) were a mere nuisance -- rather than, as Michael Faraday showed around 1830, an unavoidable by-product of their operation.

Voltaic cells, and batteries of voltaic cells, are rated in volts, the SI unit of electromotive force. The voltage across the terminals of a battery is known as its *terminal voltage*. The terminal voltage of a battery that is neither charging nor discharging (the open-circuit voltage) equals its emf. The terminal voltage of a battery that is discharging is less than the emf, and that of a battery that is charging is greater than the emf.

Alkaline and carbon-zinc cells are rated at about 1.5 volts, because of the nature of the chemical reactions inside. Because of the high electrochemical potentials of lithium compounds, Li cells can provide as much as 3 or more volts. However, lithium compounds can also be hazardous.

The conventional model for a voltaic cell, as drawn above, has the internal resistance drawn outside the cell. This is a correct Thevenin equivalent for circuit applications, but it oversimplifies the chemistry and physics. In a more accurate (and more complex) model, a voltaic cell can be thought of as two electrical pumps, one at each terminal (the faradaic reactions at the corresponding electrode-electrolyte interfaces), separated by an internal resistance largely due to the electrolyte. Even this is an oversimplification, since it cannot explain why the behavior of a voltaic cell depends strongly on its rate of discharge. For example, it is well known that a cell that is discharged rapidly (but incompletely) will recover spontaneously after a waiting time, but a cell that is discharged slowly (but completely) will not recover spontaneously.

The simplest characterization of a battery would give its emf (voltage), its internal resistance, and its capacity. In principle, the energy stored by a battery equals the product of its emf and its capacity.

1.7.2 Battery capacity

Since the voltage of a battery is relatively constant, the capacity of a battery to store energy is often expressed in terms of the total amount of charge able to pass through the device. This is expressed in ampere hours, where one A·h equals 3600 coulombs. If a battery can pump charges for one hour at a rate of one coulomb/sec or one ampere (1 A), it has a capacity of 1 A·h. If it can provide 1 A for 100 hours, its capacity is 100 A·h. The more electrolyte and electrode material in the cell, the greater the capacity of the cell. Thus a tiny cell has much less capacity than a much larger cell, even if both rely on the same chemical reactions (e.g. alkaline cells), which produce the same terminal voltage. Because of the chemical reactions within the cells, the capacity of a battery depends on the discharge conditions such as the magnitude of the current, the duration of the current, the allowable terminal voltage of the battery, temperature, and other factors.

Battery manufacturers use a standard method to determine how to rate their batteries. The battery is discharged at a constant rate of current over a fixed period of time, such as 10 hours or 20 hours, down to a set terminal voltage per cell. So a 100 ampere-hour battery is rated to provide 5 A for 20 hours at room temperature. The efficiency of a battery is different at different discharge rates. When discharging at low rate, the battery's energy is delivered more efficiently than at higher discharge rates. This is known as Peukert's Law.

Special "reserve" batteries intended for long storage in emergency equipment or munitions keep the electrolyte of the battery separate from the plates until the battery is activated, allowing the cells to be filled with the electrolyte. Shelf times for such batteries can be years or decades. However, their construction is more expensive than more common forms

Various batteries(clockwise from bottom left): two 9-volt, two "AA", one "D", a cordless phone battery, a camcorder battery, a 2-meter handheld ham radio battery, and a button battery, one "C" and two "AAA", plus a U.S. quarter, for scale.

Chapter 2: Panic Alarm & Communication Systems

2.1 Introduction to alarm and communication systems:

Electric and electronic alarm systems installed in all clinical environments are a central part of the Trust's approach to the management of risk towards patients and staff. Several different systems are in use around the Trust's estate. Historically, these are hard-wired electric systems with wall-mounted call-points which are button operated. Lights over doorways identify the location of incidents. In recent years there has been a move to wireless electronic systems using hand held alarms which are location-sensitive for any incident. The market leader in these systems is recognised to be Ascom UK Limited, several of whose systems are in use by the Trust. Research has not highlighted any comparable, alternative systems.

2.2 Development

Discussions with users have identified a preference for not being totally reliant on a single system in the clinical environment, but to have a dual system to minimise the risk of failure. Both equipment failure and access blocking are seen as significant issues for both systems. As a hard-wired system exists in most areas around the Trust, an opportunity exists to double this up with a hand-held system which would provide the duality sought. Where hard-wired systems already exist, it is felt that there is little point in deactivating them in favour of another system, so the concept of dual systems has much merit. The hard-wired system would remain as the primary system around the Trust, with an electronic wireless system being complimentary as support, extension and back-up.

2.3 History of Alarm Systems across the Trust

The Bethlem and Maudsley Hospitals started using the Ascom system as pagers some 16 years ago and so the opportunity existed to upgrade these to provide fully integrated wireless communication/alarm systems. The infrastructure across the Bethlem site, to expand the capability of the Ascom system, was installed in 2002. The Ascom system allows for panic alarms, paging, speech and text communication within the same platform, and allowed the integration with the fire alarms.

Whilst some work remains to be done with user groups to ensure that this rationale fits with their requirements, reports from users where the system is fully functional state (see para. 7) that this dual system provides full coverage for use across the ward environment and affords staff protection in any situation.

Lambeth Hospital use the "Blick" system, which although now taken over by Stanley Security Solution and now trading as Stanley Blick, has not had the research and development investment of Ascom UK Ltd. It is not thought necessary to replace this with another system as users are familiar with it and it provides adequate functionality. In any event, further study is needed of the particular user requirements of that site.

The Ladywell Unit has an obsolete hard-wired system that regularly malfunctions and is overdue for replacement throughout the unit. Following various reviews the management team visited Bethlem wards where the Ascom system was introduced and favoured the option, based on enhanced coverage and the additional functions offered by a radio system. The Johnson Unit was duly upgraded with a new hard wired system and supplemented by the Ascom system in June 2006 which is working well. Therefore it is suggested that the system be implemented for the remainder of the building.

2.4 Risks

Hard-wired electrical systems are relatively robust in operation, given appropriate maintenance, and should continue to provide reliable, if basic, service for some years to come. The technology is well understood and there are a number of companies in the market place. The risks associated with these systems lie principally around their non-specific function and the consequently enhanced danger to staff. The location of call points provides an inherent risk. A dual system would comprehensively address this risk.

Electronic systems are open to levels of failure predominately due to operator error and unfamiliarity.

There is a risk where the trust invests in proprietary systems and supplies. The Trust is dependant on the supplier's continuation and on-going product development and maintenance.

It should also be noted that two units at the Bethlem Royal Hospital site (Chelsham and Monks Orchard House) are using a further system, "Pinpoint", which was introduced some eight years ago. This system is very limited when compared with the other two systems and has been discounted for the purpose of this report.

2.5 Buzzer info

This novel buzzer circuit uses a relay in series with a small audio transformer and speaker. When the switch is pressed, the relay will operate via the transformer primary and closed relay contact. As soon as the relay operates the normally closed contact will open, removing power from the relay, the contacts close and the sequence repeats, all very quickly...so fast that the pulse of current causes fluctuations in the transformer primary, and hence secondary. The speakers tone is thus proportional to relay operating frequency. The capacitor C can be used to "tune" the note. The nominal value is 0.001uF, increasing capacitance lowers the buzzers tone.

2.6 Some information about classical alarm systems

Trade associations in the alarm system sector have regulations for professional alarm systems, applicable in the Nordic countries and in many other countries, setting out requirements in respect of the various elements of which the systems consist, such as the central unit, power supply, detectors etc. Although compliance with the regulations is voluntary, there are obviously advantages in marketing certified products.

Manufacturers can have their products certified/approved against these regulations by certification bodies in the various countries.

There are differences in the requirements in the regulations from one country to another, which means that the equipment has to be examined and tested against the parts concerned.

Certification bodies refer increasingly in their regulations to common European standards, which means that, in the longer term, the test material and results can be used as a basis for certification in several countries.

2.7 Recommendation:

It is recommended that the Ascom system is the system of preference for the Trust as an integral part of the alarm installations. It is felt that it would provide a powerful complement to existing hard-wired systems and ensure development capacity within the Trust's system based on the technical flexibility and development of the product.

2.8 Common functional models of transistors:

The operation of a transistor is difficult to explain and understand in terms of its internal structure. It is more helpful to use this functional model:

- The base-emitter junction behaves like a diode.
- A base current I_B flows only when the voltage V_{BE} across the base-emitter junction is 0.7V or more.
- The small base current I_B controls the large collector current Ic.
- $Ic = h_{FE} \times I_B$ (unless the transistor is full on and saturated) h_{FE} is the current gain (strictly the DC current gain), a typical value for h_{FE} is 100 (it has no units because it is a ratio)
- The collector-emitter resistance R_{CE} is controlled by the base current I_B:
    - $I_B = 0$ R_{CE} = infinity transistor off
    - I_B small R_{CE} reduced transistor partly on
    - I_B increased $R_{CE} = 0$ transistor full on ('saturated')

Additional notes:

- A resistor is often needed in series with the base connection to limit the base current I_B and prevent the transistor being damaged.
- Transistors have a maximum collector current Ic rating.
- The **current gain h_{FE} can vary widely**, even for transistors of the same type!
- A transistor that is **full on** (with $R_{CE} = 0$) is said to be **'saturated'**.
- When a transistor is saturated the collector-emitter voltage V_{CE} is reduced to almost 0V.
- When a transistor is saturated the collector current Ic is determined by the supply voltage and the external resistance in the collector circuit, not by the transistor's current gain. As a result the ratio Ic/I_B for a saturated transistor is less than the current gain h_{FE}.
- The emitter current $I_E = Ic + I_B$, but Ic is much larger than I_B, so roughly I_E = Ic.

There is a table showing technical data for some popular transistors on the transistors page.

Darlington pair

This is two transistors connected together so that the current amplified by the first is amplified further by the second transistor. The overall current gain is equal to the two individual gains multiplied together:

Darlington pair current gain, $h_{FE} = h_{FE1} \times h_{FE2}$ (h_{FE1} and h_{FE2} are the gains of the individual transistors)

This gives the Darlington pair a very high current gain, such as 10000, so that only a tiny base current is required to make the pair switch on.

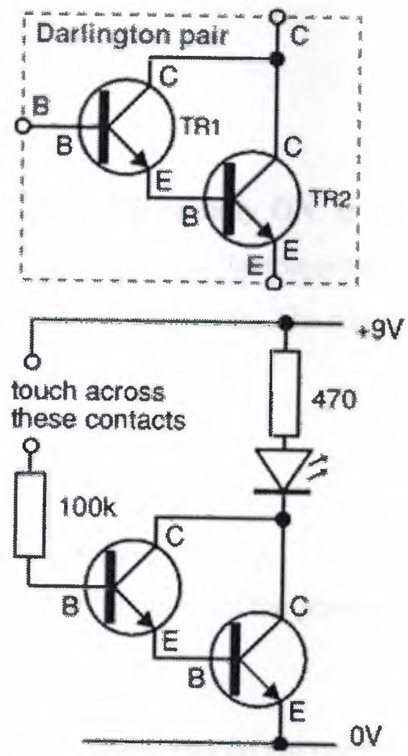


figure 23

A Darlington pair behaves like a single transistor with a very high current gain.

It has three leads (**B**, **C** and **E**) which are equivalent to the leads of a standard individual transistor. To turn on there must be 0.7V across both the base-emitter junctions which are connected in series inside the Darlington pair, therefore it requires 1.4V to turn on.

Darlington pairs are available as complete packages but you can make up your own from two transistors; TR1 can be a low power type, but normally TR2 will need to be high power. The maximum collector current Ic(max) for the pair is the same as Ic(max) for TR2.

A Darlington pair is sufficiently sensitive to respond to the small current passed by your skin and it can be used to make a **touch-switch** as shown in the diagram. For this circuit which just lights an LED the two transistors can be any general purpose low power transistors. The 100kΩ resistor protect the transistors if the contacts are linked with a piece of wire.

Using a transistor as a switch

When a transistor is used as a switch it must be either **OFF** or **fully ON**. In the fully ON state the voltage V_{CE} across the transistor is almost zero and the transistor is said to be **saturated** because it cannot pass any more collector current Ic. The output device switched by the transistor is usually called the 'load'.

The power developed in a switching transistor is very small:

- In the **OFF** state: power = Ic × V_{CE}, but Ic = 0, so the power is zero.
- In the **full ON** state: power = Ic × V_{CE}, but V_{CE} = 0 (almost), so the power is very small.

This means that the transistor should not become hot in use and you do not need to consider its maximum power rating. The important ratings in switching circuits are the **maximum collector current Ic(max)** and the **minimum current gain h_{FE}(min)**. The transistor's voltage ratings may be ignored unless you are using a supply voltage of more than about 15V.

Protection diode

If the load is a **motor**, **relay** or **solenoid** (or any other device with a coil) a diode must be connected across the load to protect the transistor (and chip) from damage when the load is switched off. The diagram shows how this is connected 'backwards' so that it will normally NOT conduct. Conduction only occurs when the load is switched off, at this moment current tries to continue flowing through the coil and it is harmlessly diverted through the diode. Without the diode no current could flow and the coil would produce a damaging high voltage 'spike' in its attempt to keep the current flowing.

Chapter 3:Automatic Security Lamp with Light Detecting Resistor(L.D.R.)

3.1 Components used in the circuit mentioned above:

- 1 Resistors 3,9 k ohms
- 2 Resistors 4,1 k ohms
- 3 Resistor 210 ohms
- 1 Resistor 1 k ohms
- 1 Potentiometer(variable resistor) 100 k ohms
- Transistors equal values of BC237 series
- Silicon diodes (activates with 0,7 volt)
- 1 Capacitor with 22 micro f.
- 1 Automaitc relay activates with 9-12 volts
- 1 Buzzer activates with 2-6 volts
- 1 Led with green light
- 1 Light Detecting Resistor(L.D.R.) or photoresistor
- 1 Switch
- 1 1 9volts battery to energize the circuit

3.2 The main objective the general structure of the project:

This is a training and a potential prototype project of a lamp sensitive to sunshine.

It is aimed to make economy saving from the electricity and practical usage.Now I want to give a summary about my project;by using the energy in the battery L.E.D. turns on directly unless we don't use the photoresistor(light detecting resistor).With this resistor it is possible to cut off the circuit by the help of the relay as dependent to sunshine.I mean the L.D.R. senses the outside light and the relay cuts off or on the circuit according to a certain resistance on the photoresistor.But it is possible to change the sensitivity of L.D.R. in this way we can make the led to turn off or on as optional.

Besides that the buzzer that we have added to the circuit gives a treble sound when the led is on (when the circuit operates).It is possible for you to think that the buzzer is unnecessary at first.In fact this is an idealist approach because this kind of circuits can bu used in security, panic alarm, control gate systems.It is possible to add more using areas of these kind of circuits. You can see the circuit diagram of the project which was drawn by circuit maker 6 pro.

3.3 Operations done in the duration of constructing circuit:

Before to start constructing the circuit i have made the calculations necessary to draw the circuit diagram of the project. As we know this calculations are the fundamentals of engineering. Then I started collect the necessary components which I mentioned above. After that I was ready to start the construction of the circuit of the project.

Now everything was ready to start the project. I have connected the elements to the plate and to each other with solder. But it is important that to check the soldered components on the circuit plate whether there is any fault or mistake. Because detecting a fault is much harder than re-construct a connection or circuit. So we must not forget to check the general structure of the circuit in each step.

At last my circuit was ready to energize. Then I have connected a 9 volts battery to energize the circuit and it was ok except the sensitivity of photoresistor.It was not sensitive enough to sense the outside light so it is needed to calibrate it on the variable resistor.After this little problem the whole project was ready to be presented my supervisor. Assoc. Prof. Dr. Özgür Özerdem.

But he suggested me to ad a little buzzer to the circuit. As a result of this addition when we energize the circuit the L.D.R. will be activate if there is not enough light and the led will turn on as we explained in upper section have done this addition although this addition will make the project go astrain of its major objective. Now the circuit wiels and the led turns on when it is active condition.

After this operation it is just left to put the project into a proper project box in order to be seen well. We can see the outside view of he final state of the project below.

Figure 24

Figure 25

CONCLUSION

I have tried to exhibit all of my experiences,studies,comments I have taken in my mind during three and a half year.

However I have learned and noticed a lot of information in this porject.I can just write the majors of these such as the functions an structures of the circuit components.I realized that I had not known enough things about them although I often use them in the projects and experiments.Besides that now I'm more dominant about the circuits with sensors than my friends.I have seen the importance and magnificency of them.

Addition to all of these mentioned above I've improved my practical capability during the construction of the circuit of the project.

As a summary I can proudly say that in this faculty I have improved myself in the area of engineering,electrical techniques,laboratory experiences etc.. by the help of my esteemed faculty teachers.

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