

NEAR EAST UNIVERSITY



Faculty of Engineering

**Department of Electrical and Electronical
Engineering**

COMPUTER CONTROLLED CAR

**Graduation Project
EE – 400**

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TABLE OF CONTENTS

ACKNOWLEDGEMENT.....	I
ABSTRACT.....	II
GENERAL INTRODUCTION.....	III
1.Introduction to Electronic Components.....	1
1.1.Semiconductors.....	3
1.1.1. Pn Junction(diode).....	5
1.1.2.More diodes.....	9
1.1.3. Bipolar Transistor.....	12
1.2.Resistors.....	14
1.2.1.Identifying resistors.....	15
1.2.2.Resistor standards.....	19
1.2.3.Power dissipation.....	20
1.2.4.Technology.....	21
1.2.5.Noise.....	25
1.2.6.Failure modes and pitfalls.....	25
1.3.Capacitors.....	26
1.3.1.History.....	26
1.3.2.Theory of operation.....	27
1.3.3.Hydraulic analogy.....	29
1.3.4.Aging.....	30
1.3.5.Electric circuits.....	30
1.3.6.Capacitor types.....	34

1.3.7.Dielectric materials.....	35
1.3.8. Structure.....	36
1.3.9.Applications.....	37

1.4.Switches.....43

1.4.1.Contacts.....	44
1.4.2.Actuator.....	44
1.4.4.Make-before-break, break-before-make.....	45
1.4.5.Biased switches.....	45
1.4.6.Intermediate switch.....	46
1.4.7.Multiway switchng.....	46
1.4.8.Power switching.....	51

1.5.Binary Representation of Information.....55

1.5.1.Basic Concept.....	55
1.5.2. Representing Binary Quantities.....	55
1.5.3.Boolean Variables and Logic Gates.....	56
1.5.4.Truth Table.....	57

2. PARALLEL PORT.....61

2.1. Introduction to parallel ports.....	61
2.2.History of the parallel port	61
2.3.Uses.....	62
2.4.Current use.....	63
2.5.Implementation on IBM personal computers.....	64
2.6.Monodirectional parallel ports.....	64
2.7.Pinouts.....	64

2.8.Parallel port registers.....	65
3. WORKING PRINCIPLE OF RF-CAR AND REMOTE.....	67
3.1.The principle of the remote control car.....	67
3.2. The principle of the remote control.....	68
4.PRINCIPLE OF THE CIRCUIT AND PROGRAMME.....	70
4.1.Principle of the controlling circuit.....	70
4.2.Specification of the ULN2003.....	71
4.3.Principle of the computer programme.....	74
.....	
CONCLUSION.....	77
REFERENCE.....	78

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ABSTRACT

Controlling Electronic Devices by Computer is an important part of the Controlling, in which many of electronic components and programming knowledge have been used,

The main objective of this thesis is the controlling any electric or electronic circuit by computer and receiving-transmitting data from that circuit and using that data according to our aim.

For these reason I choosed my aim as an rescue robot during any unexpected and unwanted problem to rescue life like: Act of God, Terrorism or Medical, because if they are good designed and good used they can reach or control every place or thing that is very dangerous for an human being

In my project I choosed my circuit as a RF-CONTROLLED TOY CAR to be controlled by computer this was wery important project for may aim because my data transmitter was an movable transmitter and I could sent it ewery kind of area to receive wanted data where I coulnot reach

INTRODUCTION

Parallel port controlling is a part of Control Engineering ,with this kind of data communication we can transmit any data from computer to any computer or electronic devices by wire or wireless way in this project the receiver is a electronic device and the communication way is radio wave were choosen

To get the maximum efficiency frm the project I should use a hi technology receiver-transmitter like movable image capture device or movable microphone or movable infra-red camera but the main idea that was used in my project same "Sending right data from the computer to the receiver at the right time"

This thesis is adapting controlling rf-car by computer via parallelport of the main board the part of the project and the parts of that project are given in the following parts

The first chapter introduces the basic of electronic components in this chapter we see the semiconductors diots,transistors,and types of diots.

Second capter introduces about the history of the parallel port,in this chapter we are considering about the history of the parallel port using area of the parallel port and the identification of the pins of the parallel port

Thirt chapter is about the working principle of the rf-remote and the car in that chapter we are considering the explaining of the principles with their circuits

Chapter four is explaining about the connecting car to the computer by using the ULN2003 and the working principle of the programme and specification of the ULN2003

Conclusion investigates important part of the project and future ideas.

CHAPTER ONE

GENERAL INTRODUCTION

1. Introduction to Electronic Components

In engineering, we are constantly dealing with quantities. This is why we must be able to represent their values efficiently and accurately. There are basically two ways of representing the numerical value of quantities: analogue and digital. In analogue representation, a quantity is represented by a voltage or current that is proportional to the value of that quantity. Analogue quantities have an important characteristic: they can vary over a continuous range of values. Below is a diagram of analogue voltage versus time.

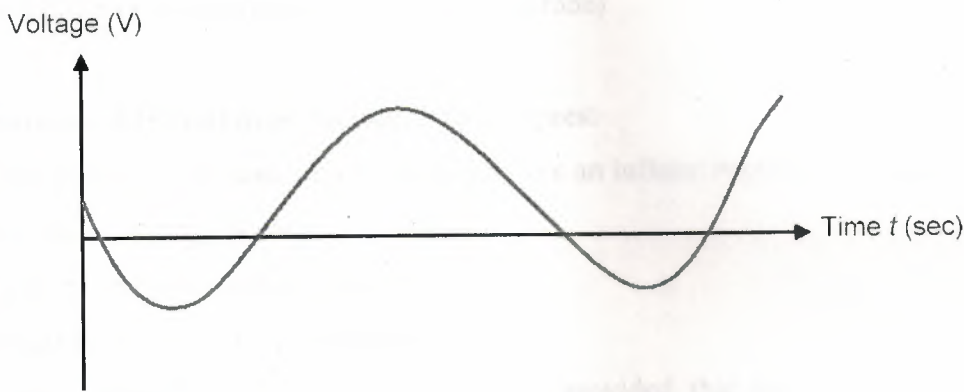


Figure 1.1 Analog voltage versus time

In digital representation, the quantities are represented not by proportional quantities but by symbols called digits. For example, a digital watch provides the time of day in the form of decimal digits which represent hours and minutes. The time of day changes continuously, but the digital watch reading does not change continuously: it changes in steps of one per minute (or per second). In other words, this digital representation of the time of day changes in discrete steps, as compared with the representation of time provided by an analogue watch, where the dial reading changes continuously. Below is a diagram of a typical digital voltage versus time.

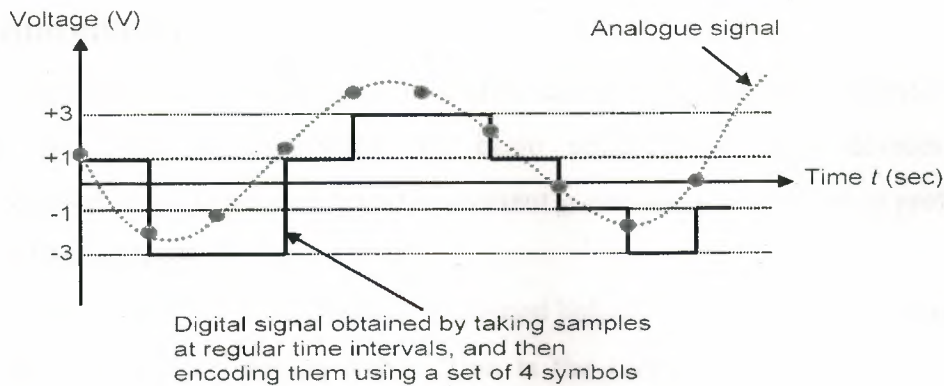


Figure 1.2 Digital voltage versus time

The major difference between analogue and digital quantities can be stated as follows:

- Analogue = continuous
- Digital = discrete (both in time and amplitude)

Advantages of Digital over Analogue techniques:

1. Easier to design because the signal cannot take an infinite number of values.
2. Information storage is easy.
3. Accuracy and precision are greater.
4. Operation can be easily programmed.
5. Digital circuits are not affected by noise, provided that the noise level remains sufficiently low for proper detection of digits.

Advantage of Analogue over Digital techniques:

The major drawback when using digital techniques is that the real world is mainly analogue: most physical quantities are analogue in nature, and it is these quantities that are often the inputs and outputs that are being monitored, operated on, and controlled by a system. To take advantage of digital techniques when dealing with analogue inputs and outputs, three steps must therefore be followed:

1. Convert the analogue inputs to digital form —→ ADC
2. Process the digital information.
3. Convert the digital outputs back to analogue form —→ DAC

1.1. Semiconductors

To understand the operation of diodes, transistors, and other semiconductor devices, we need to understand the basic structure of such devices. Early semiconductors were fabricated from the element *germanium*, but *silicon* is preferred in most modern applications.

The crystal structure of silicon is represented below. Silicon (and germanium) falls in column Iva of the Periodic Table. This is the carbon family of elements. The characteristic of these elements is that each atom has four electrons to share with adjacent atoms.

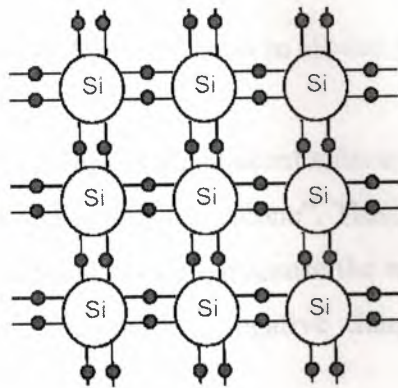


Figure 1.3 Crystal structure of silicon

The nature of a bond between two silicon atoms is such that each atom provides one electron to share with the other. The two electrons thus shared between atoms form a *covalent bond*. Such a bond is very stable and holds the two atoms together very tightly. It requires a lot of energy to break this bond.

All of the outer electrons of all silicon atoms are used to make covalent bonds with other atoms. There are no electrons available to move from place to place as an electrical current. Thus, a pure silicon crystal is quite a good insulator. A crystal of pure silicon is said to be an *intrinsic* crystal.

To allow a silicon crystal to conduct electricity, we must find a way to allow some electrons to move from one place to the other within the crystal despite the covalent bonds between atoms. One way to accomplish this is to introduce an impurity such as

arsenic or phosphorus into the crystal structure. Such process is called *doping*. These elements are from column Va of the Periodic Table, and have five outer electrons to share with other atoms.

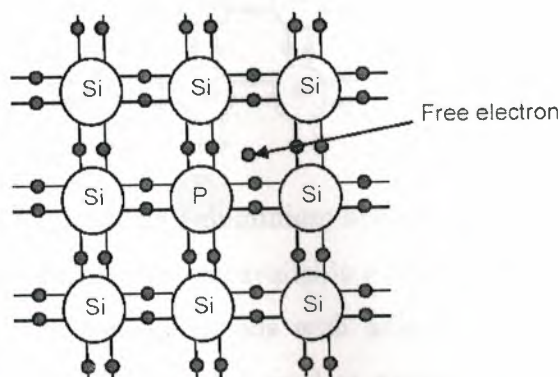


Figure 1.4 Free electron in silicon atoms

Four of these five electrons bond with adjacent silicon atoms as before, but the fifth electron cannot form a bond and is thus left “alone”. This electron can easily be moved with only a small applied electrical voltage. Because the resulting crystal has an excess of current-carrying electrons, each with a negative charge, it is known as “N-type” silicon.

Such construction does not conduct electricity as easily as, say, copper or silver since it does exhibit some resistance to the flow of electricity. It cannot properly be called a conductor, but at the same time it is no longer an insulator. Therefore, it is known as a *semiconductor*.

We obtained a semiconductor material by introducing a 5-electron impurity into a matrix of 4- electron atoms. We can also do the opposite and introduce a 3-electron impurity into such a crystal. Suppose we introduce some *aluminium* (from column IIIa in the Periodic Table) into the crystal. We could also try *gallium* which is also in column IIIa.

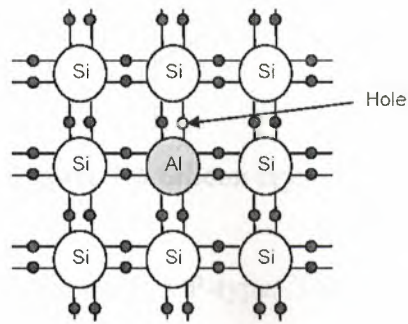


Figure 1.5 Introducing aluminium to the structure

These elements only have three electrons available to share with other atoms. Those three electrons do indeed form covalent bonds with adjacent silicon atoms, but the expected fourth bond cannot be formed. A complete connection is impossible here, leaving a "hole" in the structure of the crystal.

There is an empty place where an electron should logically go, and often an electron will try to move into that space to fill it. However, the electron filling the hole has to leave a covalent bond behind to fill this empty space, and therefore leaves another hole behind as it moves. Yet another electron may move into that hole, leaving another hole behind, and so on. In this manner, holes appear to move as positive charges through the crystal. Therefore, this type of semiconductor material is designated "P-type" silicon.

1.1.1 PN Junction (Diode)

Basic Operation

We have just seen that a crystal of pure silicon can be turned into a relatively good electrical conductor by adding an impurity such as arsenic or phosphorus (for an N-type semiconductor) or aluminium or gallium (for a P-type semiconductor).

By itself, a single type of semiconductor material is not very useful. But, something interesting happens when a single semiconductor crystal contains both P-type and N-type regions. Hereafter, we examine the properties of a single silicon crystal which is half N-type and half P-type. Consider the silicon crystal represented below.

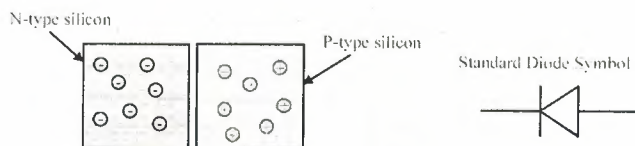


Figure 1.6 Silicon crystal

Half is N-type while the other half is P-type. The two types are shown slightly separated, as if they were two separate crystals. In the real world, two such crystals cannot be joined together usefully. Therefore, a practical PN junction can only be created by inserting different impurities into different parts of a single crystal.

When we join the N- and P-type crystals together, an interesting interaction occurs at the junction.

The extra electrons in the N region will seek to lose energy by filling the holes in the P region. This leaves an empty zone, or *depletion region*, around the junction. This action also leaves a small electrical imbalance inside the crystal. The N region is missing some electrons so it has a positive charge. Those electrons have migrated to fill holes in the P region, which therefore has a negative charge. This electrical imbalance amounts to about 0.3 volt in a germanium crystal, and about 0.65 to 0.7 volt in a silicon crystal. This will vary somewhat depending on the concentration of the impurities on either side of the junction.

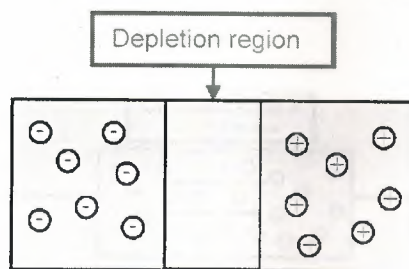


Figure 1.7 Depletion region

Suppose now we apply a voltage to the outside ends of our PN crystal.

Assume first that the positive voltage is applied to the N-type material. In such case, the positive voltage applied to the N-type material attracts free electrons towards the end of the crystal and away from the junction, while the negative voltage applied to the P-type end attracts holes away from the junction on this end.

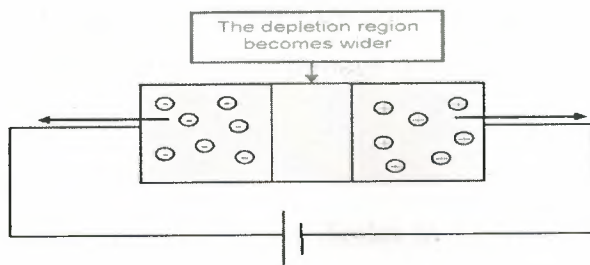


Figure 1.8 Applying voltage to the crystal

The result is that all available current carriers are attracted away from the junction, and the depletion region grows correspondingly larger.

Therefore, there is no current flow through the crystal because no current carriers can cross the junction (in practice, some tiny leakage current can still flow). This is known as *reverse bias* applied to the semiconductor crystal.

Assume now that the applied voltage polarities are reversed. The negative voltage applied to the N-type end pushes electrons towards the junction, while the positive voltage at the P-type end pushes holes towards the junction. This has the effect of shrinking the depletion region. As the applied voltage exceeds the internal electrical imbalance, current carriers of both types can cross the junction into the opposite ends of the crystal. Now, electrons in the P-type end are attracted to the positive applied voltage, while holes in the N-type end are attracted to the negative applied voltage. This is the condition of *forward bias*.

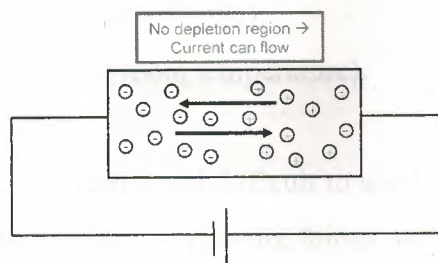


Figure 1.9 Forward biasing

The conclusion is that an electrical current can flow through the junction in the forward direction, but not in the reverse direction. This is the basic property of a semiconductor diode.

It is important to realize that holes exist only within the crystal. A hole reaching the negative terminal of the crystal is filled by an electron from the power source and

simply disappears. At the positive terminal, the power supply attracts an electron out of the crystal, leaving a hole behind to move through the crystal toward the junction again.

Mathematical model

If you have a look at the chapter on diodes in a physics book, you will find a lengthy explanation which finishes up telling you that current through a diode varies exponentially with the applied voltage.

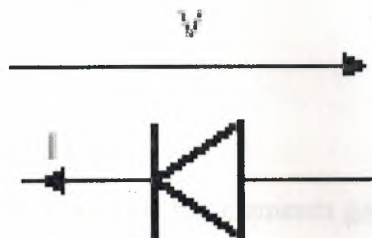


Figure 1.10 Applying voltage to the diode

The physicist's model:

$$I = I_S \left\{ \exp \left\{ \frac{qV}{kT} \right\} - 1 \right\} = I_S \left\{ \exp \left\{ \frac{V}{V_T} \right\} - 1 \right\}$$

- I_S : Saturation current of the diode (,,1 10⁻⁹ A, typically);
- q : Electron charge (= 1.602,,e10⁻¹⁹ C);
- T : Temperature in degrees Kelvin;
- k : Boltzmann's constant (= 1.38,,e10⁻²³ J/K);
- V_T : Thermal voltage (,,1 25 mV at room temperature).

This equation is a bit complicated and difficult to use for circuit analysis. Electronic engineers deal with this problem by simplifying things and using a model of the diode that suits them.

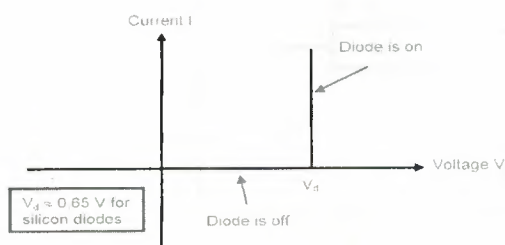


Figure 1.11 Characteristic of diode

The voltage V_d (.,1 0.6 – 0.7 V for a silicon diode) represents the height of the diode barrier when no voltage is applied.

In this popular model, we assume that the current is zero for any voltage below V_d but rises when we try to apply a voltage greater than this. In effect, the diode is viewed as a switch which is open when we apply low or negative voltages but which closes when we apply a voltage equal to or greater than V_d . It means that it is impossible to get a voltage larger than this across the diode.

1.1.2. More diodes

- **Light Emitting Diode (LED)**

Diodes made from a combination of the elements gallium, arsenic, and phosphorus glow bright red, and are some of the most common LEDs manufactured. By altering the chemical constituency of the PN junction, different colours may be obtained. Some of the currently available colours other than red are green, blue, and infra-red (invisible light at a frequency lower than red).

LEDs are designed so that, as free electrons cross the junction from the N-type side to the P-type side, the amount of energy each electron releases, as it drops into a nearby hole, corresponds to the energy of a photon of some particular colour. Because LEDs are made of different chemical substances than normal diodes, their forward voltage drops will be different. Typically, LEDs have larger forward voltage drops than normal diodes, anywhere from about 1.6 volts to over 3 volts, depending on the colour.

Typical operating current for a standard-sized LED is around 20 mA. When operating a LED from a DC voltage source greater than the LED's forward voltage, a series-connected "dropping" resistor must be included to prevent full source voltage from damaging the LED.

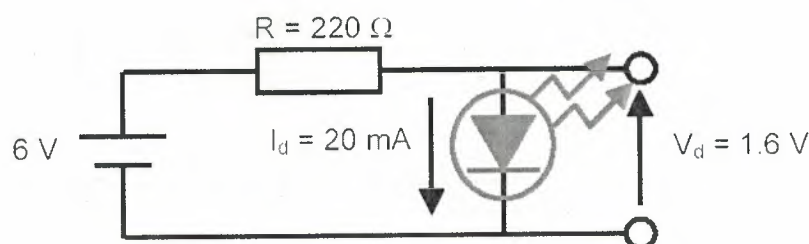


Figure 1.12 LED

LEDs are widely used in optical electronic devices. For example, in telecommunications, they are employed to transmit digital information at very high speed, as pulses of light, through empty space or fibre-optic cable.

- **P-I-N Diode**

The P-I-N diode does not actually have a junction at all. Instead, the middle part of the silicon crystal is left without doping. Hence the name for this device: P-intrinsic-N, or P-I-N. Because this device has an intrinsic middle section, it has a wide forbidden zone when unbiased. However, when a forward bias is applied, current carriers from the P- and N-type ends become available and conduct current even through the intrinsic centre region. The end regions have a heavy doping (high concentration of impurities) to provide more current carriers. The P-I-N diode is useful as a switch for very high frequency circuits. It is often used as microwave switches and limiters.

- **Tunnel Diode**

In the tunnel diode, the doping levels are so high that, at very low forward voltages, electrons do not have to gain energy to "tunnel through" the junction and appear at the other side. As the forward bias is slightly increased, the tunnel effect gradually vanishes and the current actually *decreases* for some time before increasing again later as it does for a normal diode. As a result, the tunnel diode exhibits a negative resistance effect. This makes the tunnel diode useful in very high frequency oscillators and related circuits.

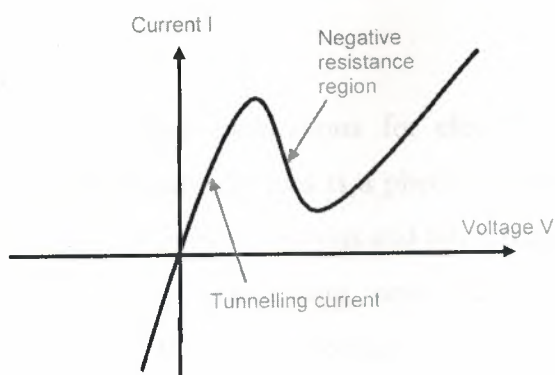


Figure 1.13 Tunnel diode characteristic diagram

- **Zener Diode**

With the application of sufficient reverse voltage, a diode experiences a breakdown and conduct current in the reverse direction. Electrons which break free under the influence of the applied electric field can be accelerated enough that they can knock loose other electrons and the subsequent collisions quickly become an avalanche.

When this process takes place, very small changes in voltage can cause very large changes in current. The breakdown process depends upon the applied electric field, so by changing the thickness of the layer to which the voltage is applied, Zener diodes can be formed which break down at voltages from about 4 volts to several hundred volts.

The useful feature here is that the voltage across the diode remains nearly constant even with large changes in current through the diode. Such diodes find wide use in electronic circuits as voltage regulators.

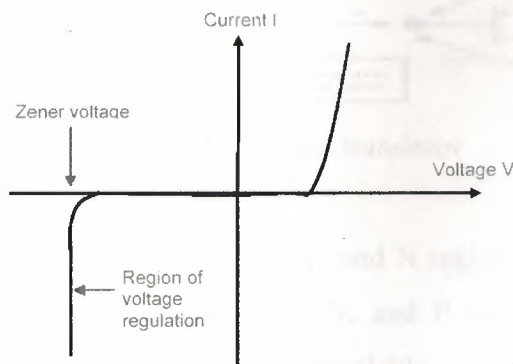


Figure 1.14 Characteristic of zener diode

- **Schottky Diode**

When we get into high-speed applications for electronic circuits, one of the problems exhibited by semiconductor devices is a phenomenon called *charge storage*. This term refers to the fact that both free electrons and holes tend to accumulate inside a semiconductor crystal while it is conducting, and must be removed before the semiconductor device can turn off. In other words, it takes time for a normal diode to completely stop conducting.

The solution is to design a semiconductor diode with no P-type semiconductor region, and therefore no holes as current carriers. Such a diode, known as a *Schottky Diode*, places a metal contact on one side on an N-type semiconductor. For example, an aluminium contact can act as the P-type connection.

Such diode can operate at very high frequencies, because it can turn off as fast as it can turn on. This feature makes Schottky diodes of great interest for high-speed analogue and digital circuit design.

1.1.3. Bipolar Transistor

A bipolar transistor is a semiconductor device consisting of a narrow P-type region between two N-type regions. The three regions are designated the *emitter* (E), *base* (B), and *collector* (C), respectively. The emitter region is heavily doped with the appropriate impurity, while the base region is very lightly doped. The collector region has a moderate doping level so that it has a low internal resistance.

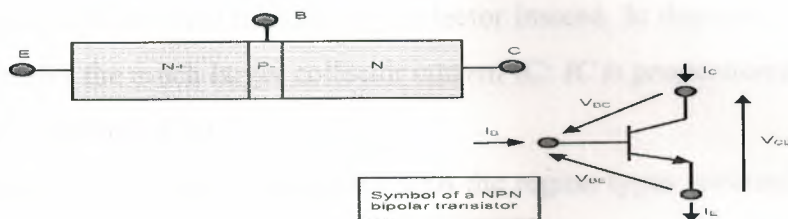


Figure 1.15 Bipolar transistor

We have shown a device consisting of N, P, and N regions in order, but there is no reason not to build equivalent devices in P, N, and P order instead. In fact, it is sometimes useful to have both types of devices available.

Let us see what happens when bias voltages are applied to such device.

Consider first that a small forward bias is applied to the emitter-base junction, and a larger reverse bias applied to the collector-base junction. These are the normal operating conditions of a bipolar transistor.

Since we already know how a PN junction operates, we would expect the base voltage to be about 0.65 to 0.7 volt positive with respect to the emitter, and to have electrons move from emitter to base, and leave the device at that point. With the collector junction reverse biased, we would expect no current to flow through that junction.

But something happens inside the base region. The forward bias on this junction does indeed attract electrons from the emitter into the base, but then the forward momentum of the electrons carries them across most of the base region and into the depletion region

around the collector junction. From there, the higher positive collector voltage attracts these electrons across the collector junction and into the collector region.

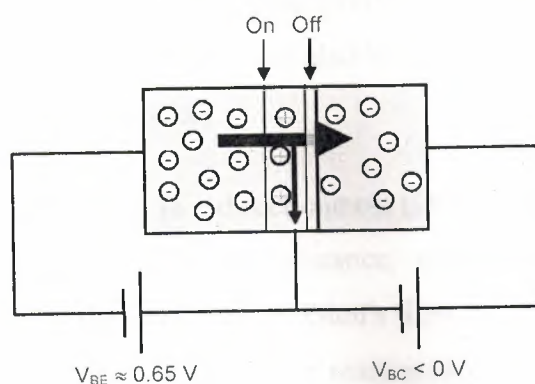


Figure 1.16 Forward biasing of transistor

A small amount of current does still leave the device through the base contact, but most of the current is diverted through the collector instead. In this way, the small base current I_B controls the much larger collector current I_C : I_C is proportional to I_B . This is known as the *transistor effect*.

It is also possible to build a transistor with the region types reversed. In this case, holes will be drawn from the emitter into the base region by the forward bias, and will then be pulled into the collector region by the higher negative bias. Otherwise, this device works the same way and has the same general properties as the one described above. To distinguish between the two types of transistors, we refer to them by the order in which the different regions appear. Thus, this is a *PNP transistor* while the device described above is an *NPN transistor*.

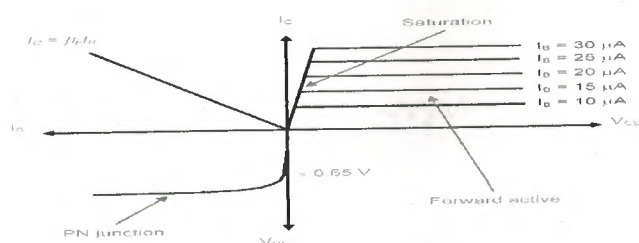


Figure 1.17 Current-voltage characteristics of a bipolar transistor

1.2.RESISTORS

A resistor is an electrical component that limits or regulates the flow of electrical current in an electronic circuit. Resistors can also be used to provide a specific voltage for an active device such as a transistor.

All other factors being equal, in a direct-current (DC) circuit, the current through a resistor is inversely proportional to its resistance, and directly proportional to the voltage across it. This is the well-known Ohm's Law. In alternating-current (AC) circuits, this rule also applies as long as the resistor does not contain inductance or capacitance.

Resistors can be fabricated in a variety of ways. The most common type in electronic devices and systems is the *carbon-composition resistor*. Fine granulated carbon (graphite) is mixed with clay and hardened. The resistance depends on the proportion of carbon to clay; the higher this ratio, the lower the resistance.

Another type of resistor is made from winding Nichrome or similar wire on an insulating form. This component, called a *wirewound resistor*, is able to handle higher currents than a carbon-composition resistor of the same physical size. However, because the wire is wound into a coil, the component acts as an inductor as well as exhibiting resistance. This does not affect performance in DC circuits, but can have an adverse effect in AC circuits because inductance renders the device sensitive to changes in frequency.

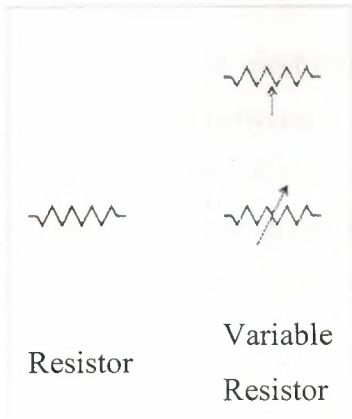


Figure 1.18 Resistor symbols (American)

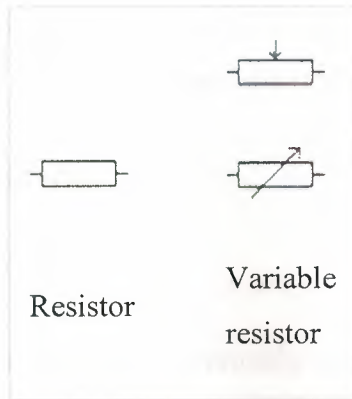


Figure 1.19 Resistor symbols (Europe, IEC)



Figure 1.20 Axial-lead resistors on tape. The tape is removed during assembly before the leads are formed and the part is inserted into the board.



Figure 1.21 Three carbon composition resistors in a 1960s valve radio.

A **resistor** is a two-terminal electrical or electronic component that opposes an electric current by producing a voltage drop between its terminals in proportion to the current, that is, in accordance with Ohm's law: $V = IR$. The *electrical resistance* R is equal to the voltage drop V across the resistor divided by the current I through the resistor. Resistors are used as part of electrical networks and electronic circuits.

1.2.1. Identifying Resistors

Most axial resistors use a pattern of colored stripes to indicate resistance. Surface-mount resistors are marked numerically. Cases are usually brown, blue, or green,

ough other colors are occasionally found such as dark red or dark grey. One can also use a multimeter or ohmmeter to test the values of a resistor.

• Four-Band Axial Resistors

Main article: Electronic color code

Four-band identification is the most commonly used color coding scheme on all resistors. It consists of four colored bands that are painted around the body of the resistor. The scheme is simple: The first two numbers are the first two significant digits of the resistance value, the third is a multiplier, and the fourth is the tolerance of the resistor (e.g. green-blue-yellow red : $56 \times (10^4)$ ohms = 56×10000 ohms = 560 kohms). Each color corresponds to a certain number, shown in the chart below. The tolerance for a 4-band resistor will be 1%, 5%, or 10%.

	1 st band	2 nd band	3 rd (multiplier)	band 4 th (tolerance)	band Temp. Coefficient
Black	0	0	$\times 10^0$		
Brown	1	1	$\times 10^1$	$\pm 1\%$ (F)	100 ppm
Red	2	2	$\times 10^2$	$\pm 2\%$ (G)	50 ppm
Orange	3	3	$\times 10^3$		15 ppm
Yellow	4	4	$\times 10^4$		25 ppm
Green	5	5	$\times 10^5$	$\pm 0.5\%$ (D)	
Blue	6	6	$\times 10^6$	$\pm 0.25\%$ (C)	
Violet	7	7	$\times 10^7$	$\pm 0.1\%$ (B)	
Purple	8	8	$\times 10^8$	$\pm 0.05\%$ (A)	
Gold	9	9	$\times 10^9$		
Silver			$\times 10^{-1}$	$\pm 5\%$ (J)	
			$\times 10^{-2}$	$\pm 10\%$ (K)	
				$\pm 20\%$ (M)	

- **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 standardized values exist in each decade (e.g. between 10 and 100, or between 100 and 1000). So resistors conforming 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). These E numbers correspond to the formula $R = 10^{(N/E)}$, So for an 1.21 ohm E96 series resistor, $N=8$ and $10^{(8/96)}=1.21$ ohm. Each multiple of 96 added to the remainder gives the next decade. So a 12.1 ohm resistor would have a $N= 8+96 = 104$. N can also be found by using the formula $E * \text{LOG}_{10}(R) = N$.

- **5-band Axial Resistors**

5-band identification is used for higher precision (lower 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 5th band. The 5th band in this case is the temperature coefficient

- **SMT Resistors**

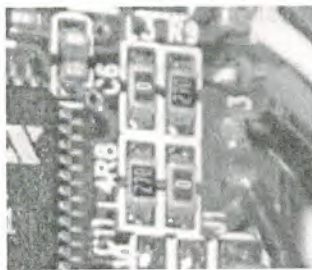


Figure 1.22 This image shows four surface-mount resistors (the component at the upper left is a capacitor) including two zero-ohm resistors. Zero-ohm links are often used instead of wire links, so that they can be inserted by a resistor-inserting machine.

Surface mounted resistors are printed with numerical values in a code related to that used on axial resistors. Standard-tolerance Surface Mount Technology (SMT) 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:

$$334 = 33 \times 10,000 \text{ ohms} = 330 \text{ kilohms}$$

$$222 = 22 \times 100 \text{ ohms} = 2.2 \text{ kilohms}$$

$$473 = 47 \times 1,000 \text{ ohms} = 47 \text{ kilohms}$$

$$105 = 10 \times 100,000 \text{ ohms} = 1 \text{ megohm}$$

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

$$100 = 10 \times 1 \text{ ohm} = 10 \text{ ohms}$$

$$220 = 22 \times 1 \text{ ohm} = 22 \text{ ohms}$$

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 (radix point). For example:

$$4R7 = 4.7 \text{ ohms}$$

$$0R22 = 0.22 \text{ ohms}$$

$$0R01 = 0.01 \text{ ohms}$$

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:

$$1001 = 100 \times 10 \text{ ohms} = 1 \text{ kilohm}$$

$$4992 = 499 \times 100 \text{ ohms} = 49.9 \text{ kilohm}$$

$$1000 = 100 \times 1 \text{ ohm} = 100 \text{ ohms}$$

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

- **Industrial Type Designation**

Power Rating at 70 °C

Tolerance Code

Type	No. rating (watts)	Power MIL-R-11 Style	MIL-R-39008 Style	Industrial type designation	Tolerance	MIL Designation
BB	1/8	RC05	RCR05	5	±5%	J
CB	¼	RC07	RCR07	2	±20%	-
EB	½	RC20	RCR20	1	±10%	K
GB	1	RC32	RCR32	-	±2%	G
HB	2	RC42	RCR42	-	±1%	F
GM	3	-	-	-	±0.5%	D
HM	4	-	-	-	±0.25%	C
				-	±0.1%	B

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 (sometimes -65 °C to 275 °C)
- Standard Grade -5°C to 60°C

1.2.2.Resistor Standards



Figure 1.21 3 resistors

- MIL-R-11
- MIL-R-39008
- MIL-R-39017
- MIL-PRF-26
- MIL-PRF-39007
- MIL-PRF-55342
- MIL-PRF-914
- BS 1852
- EIA-RS-279

There are other United States military procurement MIL-R- standards.

1.2.3. 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 the 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, the resistor may depart from its nominal resistance, and may be damaged by overheating. *Significantly* excessive power dissipation may raise the temperature of the resistor to a point where it burns out, which could cause a fire in adjacent components and materials.

1.2.4. Technology

- **Carbon Composition**

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.

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, a weak conductor, result in lower resistance. Carbon composition resistors were commonly used in the 1960s 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).

- **Carbon Film**

A spiral is used to increase the length and decrease the width of the film, which increases the resistance. Varying shapes, coupled with the resistivity of carbon, (ranging from 9 to 40 $\mu\Omega$) can make for a variety of resistances.^[2]

- **Thick and Thin Film**

Thick film resistors became popular during the 1970s, 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 a method used in 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 ultraviolet 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 an accurate value by abrasive or laser trimming.

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), ruthenium dioxide (RuO_2), lead oxide (PbO), bismuth ruthenate ($\text{Bi}_2\text{Ru}_2\text{O}_7$), nickel chromium (NiCr), and/or bismuth iridate ($\text{Bi}_2\text{Ir}_2\text{O}_7$).

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 850°C .

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 typically ± 200 or ± 250 ppm/K, depending on the resistance. Thus a 40 kelvin (70°F) 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 25 ppm/K. They are usually far more expensive than their thick film cousins. Note, though, that SMD thin film resistors, with 0.5% tolerances, and with 25 ppm/K temperature coefficients, when bought in full size reel quantities, are about twice the cost of a 1%, 250 ppm/K thick film resistors.

- **Metal Film**

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 50 ppm/K.

- **Wirewound**

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 dependent on being used with a suitable heatsink, e.g., a 50 W power rated resistor will overheat at around one fifth of the power dissipation if not used with a heatsink.

Because wirewound resistors are coils they have more inductance than other types of resistor, although this property can be minimized by winding the wire in sections with alternately reversed direction.

- **Foil Resistor**

Foil resistors have had the best precision and stability ever since they were introduced in 1958 by Felix Zandman. 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.^[3]

- **Grid Resistor**

The term "grid resistor" can mean two things:

In tube or valve electronic circuit design, a grid resistor or "grid stopper" is used to limit grid current and prevent high frequencies from entering or oscillating the circuit. Such a resistor can be composed of any one of a number of resistor technologies. One application that uses grid resistors is electric guitar amplifier circuitry.^{[4][5]}

In heavy duty, industrial, high-current applications, a grid resistor is a large convection-cooled lattice of stamped metal alloy strips connected in rows between two electrodes. Such industrial grade resistors can be as large as a refrigerator; some designs can handle over 500 amperes of current, with a range of resistances extending lower than 0.04 Ohms. They are used in applications such as dynamic braking for locomotives and trams, neutral grounding for industrial AC distribution, control loads for cranes and heavy equipment, load testing of generators and harmonic filtering for electric substations

- **Strain Gauges**

Main article: Strain gauge

Invented by Edward E. Simmons and Arthur C. Ruge in 1938, the strain gauge consists of a resistor that changes value with applied strain. The strain resistor may be applied singly, in pairs (half bridge), or four resistors connected in a Wheatstone bridge configuration. The strain resistor is bonded with adhesive to an object that will be subjected to the strain force. With the strain gauge and a filter, amplifier, and an analog/digital converter, it is possible to directly measure the strain on an object.

- **Other Types**

- Metal-oxide resistor
- Cermet
- Phenolic
- Tantalum
- Liquid-filled

1.2.5.Noise

In precision circuits, electronic noise becomes of utmost concern. As dissipative elements, resistors will naturally produce a fluctuating "noise" voltage across their terminals. This Johnson–Nyquist noise is predicted by the fluctuation–dissipation theorem and is a fundamental noise source present in all resistors which must be considered in constructing low-noise electronics. For example, the gain in a simple (non-)inverting amplifier is set using a voltage divider. Noise considerations dictate that the smallest practical resistance should be used, since the noise voltage scales with resistance, and any resistor noise in the voltage divider will be impressed upon the amplifier's output.

Although Johnson–Nyquist noise is a fundamental noise source, resistors frequently exhibit other, "non-fundamental" sources of noise. Noise due to these sources is called "excess noise." Thick-film and carbon composition resistors are notorious for excess noise at low frequencies. Wire-wound and thin-film resistors, though much more expensive, are often utilized for their better noise characteristics.

1.2.6.Failure Modes and Pitfalls

Like every part, resistors can fail; the usual way depends on their construction. Carbon composition resistors and metal film resistors typically fail as open circuits. Carbon-film resistors typically fail as short circuits.^[9] Carbon film and composition resistors can burn if too much power is dissipated. This is also possible but less likely with metal film and wirewound resistors. If not enclosed, wirewound resistors can corrode. Carbon -composition resistors are prone to drifting over time and are easily damaged by excessive heat in soldering (the binder evaporates).

Various effects become important in high-precision applications. Small voltage differentials may appear on the resistors due to thermoelectric effect if their ends are not kept at the same temperature. The voltages appear in the junctions of the resistor leads with the circuit board and with the resistor body. Common metal film resistors show such effect at magnitude of about $20 \mu\text{V}/^\circ\text{C}$. Some carbon composition resistors can go as high as $400 \mu\text{V}/^\circ\text{C}$, and specially constructed resistors can go as low as $0.05 \mu\text{V}/^\circ\text{C}$.

In applications where thermoelectric effects may become important, care has to be taken to e.g. mount the resistors horizontally to avoid temperature gradients and to mind the air flow over the board.

1.3.CAPACITORS

In October 1745, Ewald Georg von Kleist of Pomerania in Germany invented the first recorded capacitor: a glass jar with water inside as one plate was held on the hand as the other plate. A wire in the mouth of the bottle received charge from an electric machine, and released it as a spark.^[1]

In the same year, 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 charge storage capacity.

Benjamin Franklin investigated the Leyden jar, and proved that the charge was stored on the glass, not in the water as others had assumed. The earliest unit of capacitance was the 'jar', equivalent to about 1 nanofarad.

Early capacitors were also known as *condensers*, a term that is still occasionally used today. It was coined by Alessandro 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 European languages still use a word derived from "condensatore".



Figure 1.28 Capacitors

1.3.1.History

Description and drawing of von Kleist's invention of the Leyden jar

In October 1745, Ewald Georg von Kleist of Pomerania in Germany invented the first recorded capacitor: a glass jar with water inside as one plate was held on the hand

as the other plate. A wire in the mouth of the bottle received charge from an electric machine, and released it as a spark.^[1]

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1.3.2.Theory of Operation



Figure 1.29 Diagram of a parallel-plate capacitor

A capacitor consists of two conductive electrodes, or plates, separated by a dielectric, which prevents charge from moving directly between the plates. Charge may however be moved indirectly by external influences, such as a battery connecting the terminals. After removing the external influences, the charge on the plates persists. The

separated charges attract each other, and an electric field is present between the plates. The simplest practical capacitor consists of two wide, flat, parallel plates separated by a thin dielectric layer.

Assuming that the area of the plates A is much greater than their separation d , the instantaneous electric field between the plates $E(t)$ is identical at any location away from the edges. If the instantaneous charge on a plate - $q(t)$ is spread evenly,

$$E(t) = -\frac{q(t)}{\epsilon A},$$

where ϵ is the permittivity of the dielectric. The voltage $v(t)$ between the plates is given by

$$v(t) = -\int_0^d E(t) dz = \frac{q(t)d}{\epsilon A},$$

where z is a position between the plates

• Capacitance

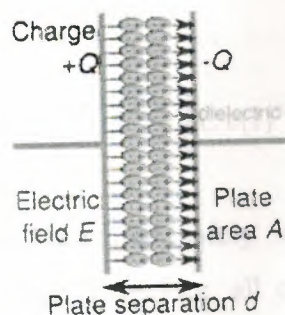


Figure 1.30: Charge separation in a parallel-plate capacitor causes an internal electric field. A polarized dielectric spacer (orange) reduces the electric field and increase the capacitance.

A property called the capacitance C , which is a measure of the charge stored on each plate for a given voltage such that

$$q(t) = Cv(t),$$

where

$$C = \frac{\epsilon A}{d}$$

for an ideal parallel plate capacitor.

In SI units, a capacitor has a capacitance of one farad when one coulomb of charge storage corresponds to one volt between its plates. Since the farad is a very large unit, capacitance is usually expressed in microfarads (μF), nanofarads (nF), or picofarads (pF). In general, capacitance is greater in devices with large plate areas, separated by small distances. When a dielectric is present between two charged plates, its molecules become polarized and reduce the internal electric field and hence the voltage. The capacitance is therefore strongly dependent on the quality of the dielectric.

• Energy Storage

Work must be done by an external influence to move charge between the plates in a capacitor. When the external influence is removed, the charge separation persists and energy is stored in the electric field. If charge is later allowed to return to its equilibrium position, the energy is released. The work done in establishing the electric field, and hence the amount of energy stored, is given by

$$W(t) = -q(t) \int_0^d E(t) dz = \frac{1}{2} \frac{q(t)^2}{C} = \frac{1}{2} C v(t)^2 = \frac{1}{2} v(t) q(t)$$

The maximum energy that can be stored safely in a capacitor is limited by the breakdown voltage of the dielectric. Therefore, all capacitors made with a particular dielectric have approximately identical maximum energy density if the dielectric dominates their volume.

1.3.3. Hydraulic Analogy

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 difference (voltage difference) across the unit is proportional to the integral of the flow (current).
- A steady state current cannot pass through it because the pressure will build up across the diaphragm until it equally opposes the source pressure,
- but a transient pulse or alternating current can be transmitted.
- An overpressure results in bursting of the diaphragm, analogous to dielectric breakdown.

The capacitance of units connected in parallel is equivalent to the sum of their individual capacitance

1.3.4.Aging

The capacitance of certain capacitors decreases as the component ages. In ceramic capacitors, this is caused by degradation of the dielectric. The type of dielectric and the ambient operating and storage temperatures are the most significant aging factors, while the operating voltage has a smaller effect. The aging process may be reversed by heating the component above the Curie point. Aging is fastest near the beginning of life of the component, and the device stabilizes over time.^[2] Electrolytic capacitors age as the electrolyte evaporates. In contrast with ceramic capacitors, this occurs towards the end of life of the component.

1.3.5.Electric Circuits

When a capacitor is connected to a current source, charge is transferred between its plates at a rate $i(t) = dq(t) / dt$. As the voltage between the plates is proportional to the charge, it follows that

$$v(t) = \frac{1}{C}q(t) = \frac{1}{C} \int_0^t i(\tau) d\tau$$

Conversely, if a capacitor is connected to a voltage source, the resulting current is

$$i(t) = C \frac{dv(t)}{dt}$$

- **DC Sources**

A simple resistor-capacitor circuit demonstrates charging of a capacitor.

A circuit containing only a resistor, a capacitor, a switch and a constant (DC) voltage source $v_{\text{src}}(t) = V_0$ in series is known as a *charging circuit*. From Kirchhoff's voltage law it follows that

$$V_0 = v_r(t) + v_c(t) = i(t)R + \frac{1}{C} \int_0^t i(\tau) d\tau,$$

where $v_r(t)$ and $v_c(t)$ are the voltages across the resistor and capacitor respectively. This reduces to a first order differential equation

$$RC \frac{di(t)}{dt} = -i(t)$$

Assuming that the capacitor is initially uncharged, there is no internal electric field, and the initial current is $I_0 = V_0 / R$. This initial condition allows solution of the differential equation as

$$i(t) = \frac{V_0}{R} \exp\left(-\frac{t}{RC}\right).$$

The corresponding voltage drop across the capacitor is

$$v(t) = V_0 \left[1 - \exp\left(-\frac{t}{RC}\right)\right]$$

Therefore, as charge increases on the capacitor plates, the voltage across the capacitor increases, until it reaches a steady-state value of V_0 , and the current drops to zero. Both the current, and the difference between the source and capacitor voltage decay exponentially with respect to time. The time constant of the decay is given by $t = RC$.

- **AC Sources**

When connected to an alternating current (AC) voltage source, the plates on a capacitor repeatedly charge and discharge relative to each other. The current varies sinusoidally, with a nonzero amplitude. For this reason, capacitors effectively conduct AC although charge ideally never passes directly through the dielectric. Since the current is proportional to the time derivative of the voltage, a sinusoidal current leads the voltage by a 90 degree phase shift, or equivalently 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 .

- **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.

See derivation Deriving capacitor impedance.

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 does not 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 as heat, 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:

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

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 Ampère'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 aether. Although this interpretation has been abandoned, Maxwell's correction to Ampère's law remains valid.

- **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.

1.3.6. Capacitor Types

Practical capacitors are available commercially in many different forms. The type of internal dielectric, the structure of the plates and the device packaging all strongly affect the characteristics of the capacitor, and its applications.

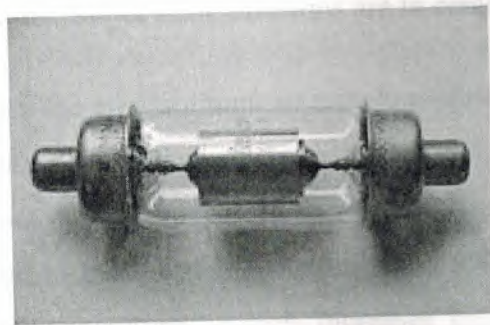


Figure 1.30 A 12 pF 20 kV fixed vacuum capacitor

1.3.7. Dielectric Materials

Most types of capacitor include a dielectric spacer, which increases their capacitance. However, low capacitance devices are available with a vacuum between their plates, which allows extremely high voltage operation and low losses. Air filled variable capacitors are also commonly used in radio tuning circuits.

Several solid dielectrics are available, including paper, plastic, glass, mica and ceramic materials. Paper was used extensively in older devices and offers relatively high voltage performance. However, it is susceptible to water absorption, and has been largely replaced by plastic film capacitors. Plastics offer better stability and aging

performance, which makes them useful in timer circuits, although they may be limited to low operating temperatures and frequencies. Ceramic capacitors are generally small, cheap and useful for high frequency applications, although their capacitance varies strongly with voltage, and they age poorly. They are broadly categorized as Class 1 dielectrics, which have predictable variation of capacitance with temperature or Class 2 dielectrics, which can operate at higher voltage. Glass and mica capacitors are extremely reliable, stable and tolerant to high temperatures and voltages, but are too expensive for most mainstream applications.



Figure 1.31 Capacitor materials. From left: multilayer ceramic, ceramic disc, multilayer polyester film, tubular ceramic, polystyrene, metalized polyester film, aluminum electrolytic. Major scale divisions are in centimetres.

Electrolytic capacitors use an aluminum or tantalum plate with an oxide dielectric layer. The second electrode is a liquid electrolyte. Electrolytic capacitors offer very high capacitance but suffer from poor tolerances, high instability, gradual loss of capacitance especially when subjected to heat, and high leakage current. The conductivity of the electrolyte drops at low temperatures, which increases equivalent series resistance. While widely used for power-supply conditioning, poor high-frequency characteristics make them unsuitable for many applications. Tantalum capacitors offer better frequency and temperature characteristics than aluminum, but higher dielectric absorption and leakage.^[3] OS-CON (or OC-CON) capacitors are a polymerized organic semiconductor solid-electrolyte type that offer longer life at higher cost than standard electrolytic capacitors.

Several other types of capacitor are available for specialist applications. Supercapacitors made from carbon aerogel, carbon nanotubes, or highly porous electrode materials offer extremely high capacity and can be used in some applications instead of rechargeable batteries. Alternating current capacitors are specifically designed to work on line (mains) voltage AC power circuits. They are commonly used in electric motor circuits and are often designed to handle large currents, so they tend to

be physically large. They are usually ruggedly packaged, often in metal cases that can be easily grounded/earthed. They also tend to have rather high direct current breakdown voltages.

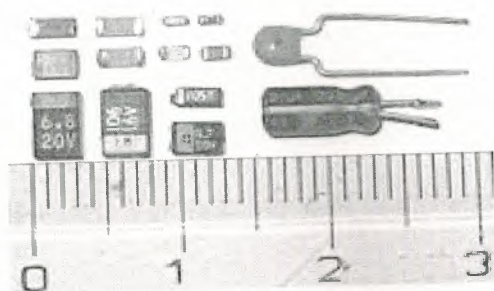


Figure 1.32: Capacitor packages: SMD ceramic at top left; SMD tantalum at bottom left; through-hole tantalum at top right; through-hole electrolytic at bottom right. Major scale divisions are cm.








1.3.8. Structure

Capacitors may have their plates arranged in many configurations, for example axially or radially. Small, cheap discoidal ceramic capacitors have existed since the 1930s, and remain in widespread use. Since the 1980s, surface mount packages for capacitors have been widely used. These packages are extremely small and lack connecting leads, allowing them to be soldered directly onto the surface of printed circuit boards. Surface mount components avoid undesirable high-frequency effects due to the leads and simplify automated assembly, although manual handling is made difficult due to their small size.

Variable capacitors are available in various forms. Mechanically controlled variable capacitors allow the plate spacing to be adjusted, for example by rotating or sliding a set of movable plates into alignment with a set of stationary plates. Very cheap variable capacitors squeeze together alternating layers of aluminum and plastic with a screw, but the resulting capacitance is unstable, and unreproducible. Electrical control of capacitance is achievable with varactors (or varicaps), which are reverse-biased semiconductor diodes whose depletion region width varies with applied voltage. They are used in phase-locked loops, amongst other applications.

1.3.9.Applications

Capacitor symbols

Capacitor	Polarized capacitors	Variable capacitor
		
		
		
		
		

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.)

- **Power Conditioning**

Reservoir 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.

- ***Filtering***

Signal coupling

Main article: capacitive 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* or "capacitive coupling". Here, a large value of capacitance, whose value need not be accurately controlled, but whose reactance is small at the signal frequency, is employed.

- ***Decoupling***

Main article: decoupling capacitor

A decoupling capacitor is a capacitor used to decouple one part of a circuit from another. Noise caused by other circuit elements is shunted through the capacitor reducing the effect they have on the rest of the circuit. It is most commonly used between the power supply and ground.

An alternative name is bypass capacitor as it is used to bypass the power supply or other high impedance component of a circuit.

- ***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 single phase squirrel cage motors, the primary winding within the motor housing isn't capable of starting a rotational motion on the rotor, but is capable of sustaining one. To start the motor, a secondary winding is used in series with a non-polarized **starting capacitor** to introduce a lag in the sinusoidal current through the secondary winding. When the secondary winding is placed at an angle with respect to the primary winding, a rotating electric field is created. The force of the rotational field is not constant, but is sufficient to start the rotor spinning. The capacitor is typically mounted to the side of the motor housing.

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 factors can change the structure of the capacitor; the resulting change in capacitance can be used to sense those factors.

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. Some fingerprint sensors use capacitors. Additionally, a user can adjust the pitch of a theremin musical instrument by moving his

NEAR EAST UNIVERSITY



Faculty of Engineering

**Department of Electrical and Electronical
Engineering**

COMPUTER CONTROLLED CAR

**Graduation Project
EE – 400**

Student: IBRAHİM BARAN ÇELİK (20032572)

Supervisor: Assoc.Prof.Dr. KADRI BÜRÜNCÜK

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TABLE OF CONTENTS

ACKNOWLEDGEMENT.....	I
ABSTRACT.....	II
GENERAL INTRODUCTION.....	III
1.Introduction to Electronic Components.....	1
1.1.Semiconductors.....	3
1.1.1. Pn Junction(diode).....	5
1.1.2.More diodes.....	9
1.1.3. Bipolar Transistor.....	12
1.2.Resistors.....	14
1.2.1.Identifying resistors.....	15
1.2.2.Resistor standards.....	19
1.2.3.Power dissipation.....	20
1.2.4.Technology.....	21
1.2.5.Noise.....	25
1.2.6.Failure modes and pitfalls.....	25
1.3.Capacitors.....	26
1.3.1.History.....	26
1.3.2.Theory of operation.....	27
1.3.3.Hydraulic analogy.....	29
1.3.4.Aging.....	30
1.3.5.Electric circuits.....	30
1.3.6.Capacitor types.....	34

1.3.7.Dielectric materials.....	35
1.3.8. Structure.....	36
1.3.9.Applications.....	37

1.4.Switches.....43

1.4.1.Contacts.....	44
1.4.2.Actuator.....	44
1.4.4.Make-before-break, break-before-make.....	45
1.4.5.Biased switches.....	45
1.4.6.Intermediate switch.....	46
1.4.7.Multiway switchng.....	46
1.4.8.Power switching.....	51

1.5.Binary Representation of Information.....55

1.5.1.Basic Concept.....	55
1.5.2. Representing Binary Quantities.....	55
1.5.3.Boolean Variables and Logic Gates.....	56
1.5.4.Truth Table.....	57

2. PARALLEL PORT.....61

2.1. Introduction to parallel ports.....	61
2.2.History of the parallel port	61
2.3.Uses.....	62
2.4.Current use.....	63
2.5.Implementation on IBM personal computers.....	64
2.6.Monodirectional parallel ports.....	64
2.7.Pinouts.....	64

2.8.Parallel port registers.....	65
3. WORKING PRINCIPLE OF RF-CAR AND REMOTE.....	67
3.1.The principle of the remote control car.....	67
3.2. The principle of the remote control.....	68
4.PRINCIPLE OF THE CIRCUIT AND PROGRAMME.....	70
4.1.Principle of the controlling circuit.....	70
4.2.Specification of the ULN2003.....	71
4.3.Principle of the computer programme.....	74
.....	
CONCLUSION.....	77
REFERENCE.....	78

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ABSTRACT

Controlling Electronic Devices by Computer is an important part of the Controlling, in which many of electronic components and programming knowledge have been used,

The main objective of this thesis is the controlling any electric or electronic circuit by computer and receiving-transmitting data from that circuit and using that data according to our aim.

For these reason I choosed my aim as an rescue robot during any unexpected and unwanted problem to rescue life like: Act of God, Terrorism or Medical, because if they are good designed and good used they can reach or control every place or thing that is very dangerous for an human being

In my project I choosed my circuit as a RF-CONTROLLED TOY CAR to be controlled by computer this was very important project for my aim because my data transmitter was an movable transmitter and I could sent it ewery kind of area to receive wanted data where I couldnot reach

INTRODUCTION

Parallel port controlling is a part of Control Engineering ,with this kind of data communication we can transmit any data from computer to any computer or electronic devices by wire or wireless way in this project the receiver is a electronic device and the communication way is radio wave were choosen

To get the maximum efficiency frm the project I should use a hi technology receiver-transmitter like movable image capture device or movable microphone or movable infra-red camera but the main idea that was used in my project same "Sending right data from the computer to the receiver at the right time"

This thesis is adapting controlling rf-car by computer via parallelport of the main board the part of the project and the parts of that project are given in the following parts

The first chapter introduces the basic of electronic components in this chapter we see the semiconductors diots,transistors,and types of diots.

Second capter introduces about the history of the parallel port,in this chapter we are considering about the history of the parallel port using area of the parallel port and the identification of the pins of the parallel port

Thirt chapter is about the working principle of the rf-remote and the car in that chapter we are considering the explaining of the principles with their circuits

Chapter four is explaining about the connecting car to the computer by using the ULN2003 and the working principle of the programme and specification of the ULN2003

Conclusion investigates important part of the project and future ideas.

CHAPTER ONE

GENERAL INTRODUCTION

1. Introduction to Electronic Components

In engineering, we are constantly dealing with quantities. This is why we must be able to represent their values efficiently and accurately. There are basically two ways of representing the numerical value of quantities: analogue and digital. In analogue representation, a quantity is represented by a voltage or current that is proportional to the value of that quantity. Analogue quantities have an important characteristic: they can vary over a continuous range of values. Below is a diagram of analogue voltage versus time.

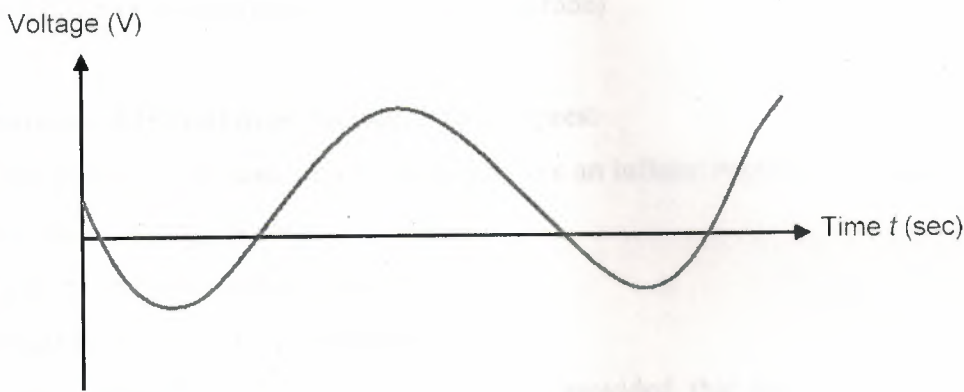


Figure 1.1 Analog voltage versus time

In digital representation, the quantities are represented not by proportional quantities but by symbols called digits. For example, a digital watch provides the time of day in the form of decimal digits which represent hours and minutes. The time of day changes continuously, but the digital watch reading does not change continuously: it changes in steps of one per minute (or per second). In other words, this digital representation of the time of day changes in discrete steps, as compared with the representation of time provided by an analogue watch, where the dial reading changes continuously. Below is a diagram of a typical digital voltage versus time.

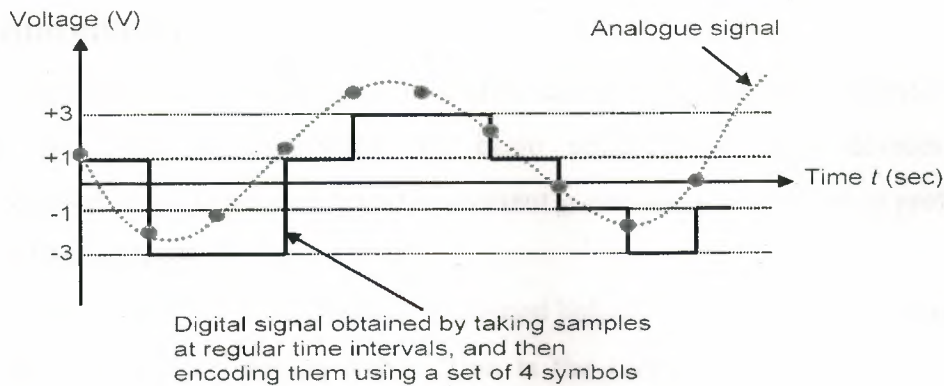


Figure 1.2 Digital voltage versus time

The major difference between analogue and digital quantities can be stated as follows:

- Analogue = continuous
- Digital = discrete (both in time and amplitude)

Advantages of Digital over Analogue techniques:

1. Easier to design because the signal cannot take an infinite number of values.
2. Information storage is easy.
3. Accuracy and precision are greater.
4. Operation can be easily programmed.
5. Digital circuits are not affected by noise, provided that the noise level remains sufficiently low for proper detection of digits.

Advantage of Analogue over Digital techniques:

The major drawback when using digital techniques is that the real world is mainly analogue: most physical quantities are analogue in nature, and it is these quantities that are often the inputs and outputs that are being monitored, operated on, and controlled by a system. To take advantage of digital techniques when dealing with analogue inputs and outputs, three steps must therefore be followed:

1. Convert the analogue inputs to digital form —→ ADC
2. Process the digital information.
3. Convert the digital outputs back to analogue form —→ DAC

1.1. Semiconductors

To understand the operation of diodes, transistors, and other semiconductor devices, we need to understand the basic structure of such devices. Early semiconductors were fabricated from the element *germanium*, but *silicon* is preferred in most modern applications.

The crystal structure of silicon is represented below. Silicon (and germanium) falls in column Iva of the Periodic Table. This is the carbon family of elements. The characteristic of these elements is that each atom has four electrons to share with adjacent atoms.

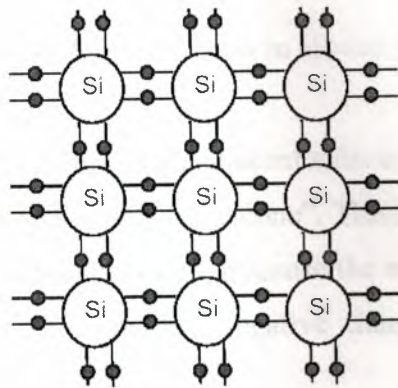


Figure 1.3 Crystal structure of silicon

The nature of a bond between two silicon atoms is such that each atom provides one electron to share with the other. The two electrons thus shared between atoms form a *covalent bond*. Such a bond is very stable and holds the two atoms together very tightly. It requires a lot of energy to break this bond.

All of the outer electrons of all silicon atoms are used to make covalent bonds with other atoms. There are no electrons available to move from place to place as an electrical current. Thus, a pure silicon crystal is quite a good insulator. A crystal of pure silicon is said to be an *intrinsic* crystal.

To allow a silicon crystal to conduct electricity, we must find a way to allow some electrons to move from one place to the other within the crystal despite the covalent bonds between atoms. One way to accomplish this is to introduce an impurity such as

arsenic or phosphorus into the crystal structure. Such process is called *doping*. These elements are from column Va of the Periodic Table, and have five outer electrons to share with other atoms.

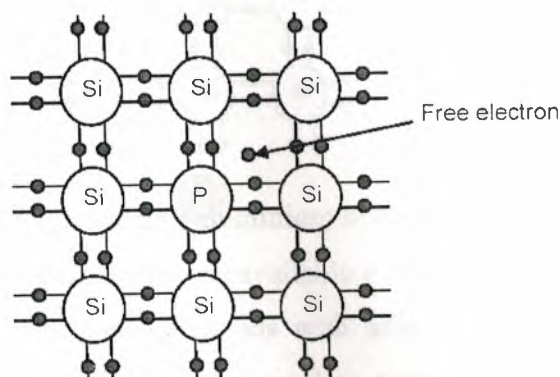


Figure 1.4 Free electron in silicon atoms

Four of these five electrons bond with adjacent silicon atoms as before, but the fifth electron cannot form a bond and is thus left “alone”. This electron can easily be moved with only a small applied electrical voltage. Because the resulting crystal has an excess of current-carrying electrons, each with a negative charge, it is known as “N-type” silicon.

Such construction does not conduct electricity as easily as, say, copper or silver since it does exhibit some resistance to the flow of electricity. It cannot properly be called a conductor, but at the same time it is no longer an insulator. Therefore, it is known as a *semiconductor*.

We obtained a semiconductor material by introducing a 5-electron impurity into a matrix of 4- electron atoms. We can also do the opposite and introduce a 3-electron impurity into such a crystal. Suppose we introduce some *aluminium* (from column IIIa in the Periodic Table) into the crystal. We could also try *gallium* which is also in column IIIa.

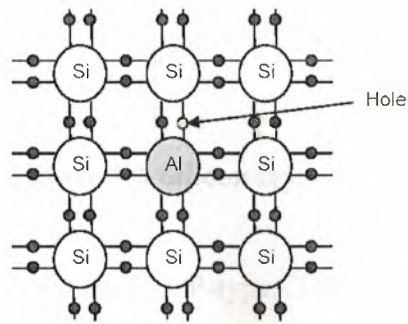


Figure 1.5 Introducing aluminium to the structure

These elements only have three electrons available to share with other atoms. Those three electrons do indeed form covalent bonds with adjacent silicon atoms, but the expected fourth bond cannot be formed. A complete connection is impossible here, leaving a "hole" in the structure of the crystal.

There is an empty place where an electron should logically go, and often an electron will try to move into that space to fill it. However, the electron filling the hole has to leave a covalent bond behind to fill this empty space, and therefore leaves another hole behind as it moves. Yet another electron may move into that hole, leaving another hole behind, and so on. In this manner, holes appear to move as positive charges through the crystal. Therefore, this type of semiconductor material is designated "P-type" silicon.

1.1.1 PN Junction (Diode)

Basic Operation

We have just seen that a crystal of pure silicon can be turned into a relatively good electrical conductor by adding an impurity such as arsenic or phosphorus (for an N-type semiconductor) or aluminium or gallium (for a P-type semiconductor).

By itself, a single type of semiconductor material is not very useful. But, something interesting happens when a single semiconductor crystal contains both P-type and N-type regions. Hereafter, we examine the properties of a single silicon crystal which is half N-type and half P-type. Consider the silicon crystal represented below.

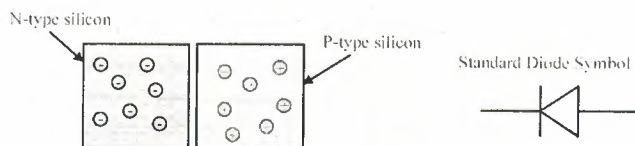


Figure 1.6 Silicon crystal

Half is N-type while the other half is P-type. The two types are shown slightly separated, as if they were two separate crystals. In the real world, two such crystals cannot be joined together usefully. Therefore, a practical PN junction can only be created by inserting different impurities into different parts of a single crystal.

When we join the N- and P-type crystals together, an interesting interaction occurs at the junction.

The extra electrons in the N region will seek to lose energy by filling the holes in the P region. This leaves an empty zone, or *depletion region*, around the junction. This action also leaves a small electrical imbalance inside the crystal. The N region is missing some electrons so it has a positive charge. Those electrons have migrated to fill holes in the P region, which therefore has a negative charge. This electrical imbalance amounts to about 0.3 volt in a germanium crystal, and about 0.65 to 0.7 volt in a silicon crystal. This will vary somewhat depending on the concentration of the impurities on either side of the junction.

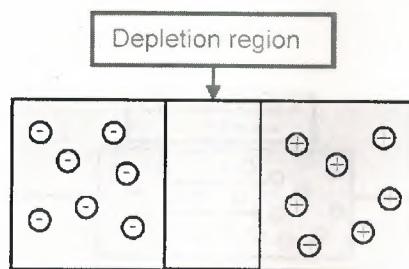


Figure 1.7 Depletion region

Suppose now we apply a voltage to the outside ends of our PN crystal.

Assume first that the positive voltage is applied to the N-type material. In such case, the positive voltage applied to the N-type material attracts free electrons towards the end of the crystal and away from the junction, while the negative voltage applied to the P-type end attracts holes away from the junction on this end.

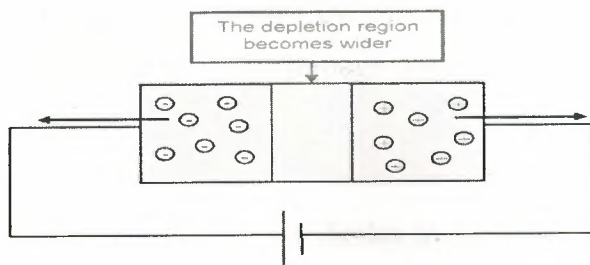


Figure 1.8 Applying voltage to the crystal

The result is that all available current carriers are attracted away from the junction, and the depletion region grows correspondingly larger.

Therefore, there is no current flow through the crystal because no current carriers can cross the junction (in practice, some tiny leakage current can still flow). This is known as *reverse bias* applied to the semiconductor crystal.

Assume now that the applied voltage polarities are reversed. The negative voltage applied to the N-type end pushes electrons towards the junction, while the positive voltage at the P-type end pushes holes towards the junction. This has the effect of shrinking the depletion region. As the applied voltage exceeds the internal electrical imbalance, current carriers of both types can cross the junction into the opposite ends of the crystal. Now, electrons in the P-type end are attracted to the positive applied voltage, while holes in the N-type end are attracted to the negative applied voltage. This is the condition of *forward bias*.

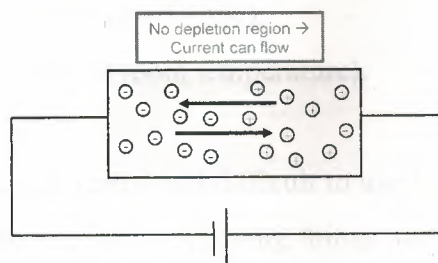


Figure 1.9 Forward biasing

The conclusion is that an electrical current can flow through the junction in the forward direction, but not in the reverse direction. This is the basic property of a semiconductor diode.

It is important to realize that holes exist only within the crystal. A hole reaching the negative terminal of the crystal is filled by an electron from the power source and

simply disappears. At the positive terminal, the power supply attracts an electron out of the crystal, leaving a hole behind to move through the crystal toward the junction again.

Mathematical model

If you have a look at the chapter on diodes in a physics book, you will find a lengthy explanation which finishes up telling you that current through a diode varies exponentially with the applied voltage.

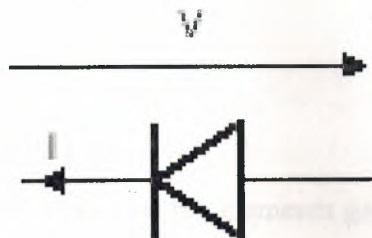


Figure 1.10 Applying voltage to the diode

The physicist's model:

$$I = I_S \left\{ \exp \left\{ \frac{qV}{kT} \right\} - 1 \right\} = I_S \left\{ \exp \left\{ \frac{V}{V_T} \right\} - 1 \right\}$$

- I_S : Saturation current of the diode (.,,1 10⁻⁹ A, typically);
- q : Electron charge (= 1.602.,,e10⁻¹⁹ C);
- T : Temperature in degrees Kelvin;
- k : Boltzmann's constant (= 1.38.,,e10⁻²³ J/K);
- V_T : Thermal voltage (.,,1 25 mV at room temperature).

This equation is a bit complicated and difficult to use for circuit analysis. Electronic engineers deal with this problem by simplifying things and using a model of the diode that suits them.

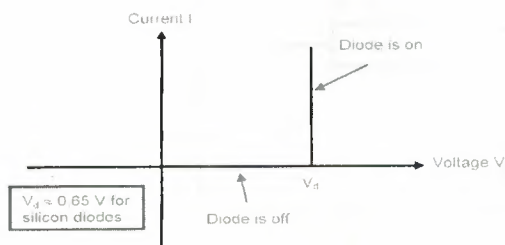


Figure 1.11 Characteristic of diode

The voltage V_d (.,1 0.6 – 0.7 V for a silicon diode) represents the height of the diode barrier when no voltage is applied.

In this popular model, we assume that the current is zero for any voltage below V_d but rises when we try to apply a voltage greater than this. In effect, the diode is viewed as a switch which is open when we apply low or negative voltages but which closes when we apply a voltage equal to or greater than V_d . It means that it is impossible to get a voltage larger than this across the diode.

1.1.2. More diodes

- **Light Emitting Diode (LED)**

Diodes made from a combination of the elements gallium, arsenic, and phosphorus glow bright red, and are some of the most common LEDs manufactured. By altering the chemical constituency of the PN junction, different colours may be obtained. Some of the currently available colours other than red are green, blue, and infra-red (invisible light at a frequency lower than red).

LEDs are designed so that, as free electrons cross the junction from the N-type side to the P-type side, the amount of energy each electron releases, as it drops into a nearby hole, corresponds to the energy of a photon of some particular colour. Because LEDs are made of different chemical substances than normal diodes, their forward voltage drops will be different. Typically, LEDs have larger forward voltage drops than normal diodes, anywhere from about 1.6 volts to over 3 volts, depending on the colour.

Typical operating current for a standard-sized LED is around 20 mA. When operating a LED from a DC voltage source greater than the LED's forward voltage, a series-connected "dropping" resistor must be included to prevent full source voltage from damaging the LED.

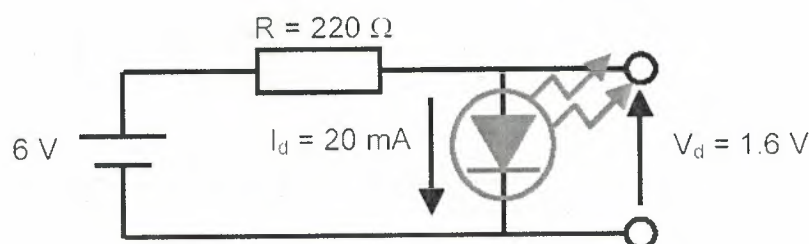


Figure 1.12 LED

LEDs are widely used in optical electronic devices. For example, in telecommunications, they are employed to transmit digital information at very high speed, as pulses of light, through empty space or fibre-optic cable.

- **P-I-N Diode**

The P-I-N diode does not actually have a junction at all. Instead, the middle part of the silicon crystal is left without doping. Hence the name for this device: P-intrinsic-N, or P-I-N. Because this device has an intrinsic middle section, it has a wide forbidden zone when unbiased. However, when a forward bias is applied, current carriers from the P- and N-type ends become available and conduct current even through the intrinsic centre region. The end regions have a heavy doping (high concentration of impurities) to provide more current carriers. The P-I-N diode is useful as a switch for very high frequency circuits. It is often used as microwave switches and limiters.

- **Tunnel Diode**

In the tunnel diode, the doping levels are so high that, at very low forward voltages, electrons do not have to gain energy to "tunnel through" the junction and appear at the other side. As the forward bias is slightly increased, the tunnel effect gradually vanishes and the current actually *decreases* for some time before increasing again later as it does for a normal diode. As a result, the tunnel diode exhibits a negative resistance effect. This makes the tunnel diode useful in very high frequency oscillators and related circuits.

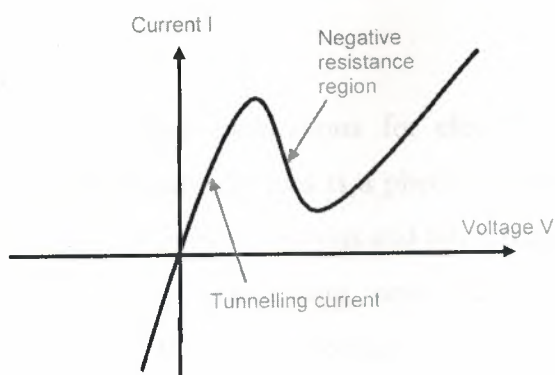


Figure 1.13 Tunnel diode characteristic diagram

- **Zener Diode**

With the application of sufficient reverse voltage, a diode experiences a breakdown and conduct current in the reverse direction. Electrons which break free under the influence of the applied electric field can be accelerated enough that they can knock loose other electrons and the subsequent collisions quickly become an avalanche.

When this process takes place, very small changes in voltage can cause very large changes in current. The breakdown process depends upon the applied electric field, so by changing the thickness of the layer to which the voltage is applied, Zener diodes can be formed which break down at voltages from about 4 volts to several hundred volts.

The useful feature here is that the voltage across the diode remains nearly constant even with large changes in current through the diode. Such diodes find wide use in electronic circuits as voltage regulators.

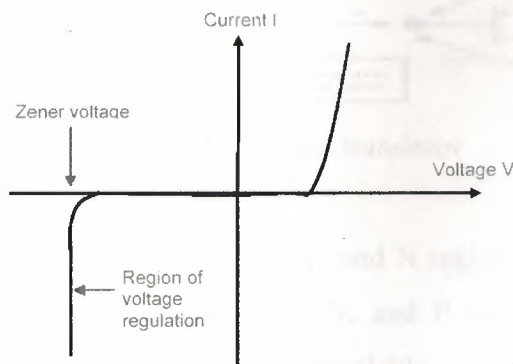


Figure 1.14 Characteristic of zener diode

- **Schottky Diode**

When we get into high-speed applications for electronic circuits, one of the problems exhibited by semiconductor devices is a phenomenon called *charge storage*. This term refers to the fact that both free electrons and holes tend to accumulate inside a semiconductor crystal while it is conducting, and must be removed before the semiconductor device can turn off. In other words, it takes time for a normal diode to completely stop conducting.

The solution is to design a semiconductor diode with no P-type semiconductor region, and therefore no holes as current carriers. Such a diode, known as a *Schottky Diode*, places a metal contact on one side on an N-type semiconductor. For example, an aluminium contact can act as the P-type connection.

Such diode can operate at very high frequencies, because it can turn off as fast as it can turn on. This feature makes Schottky diodes of great interest for high-speed analogue and digital circuit design.

1.1.3. Bipolar Transistor

A bipolar transistor is a semiconductor device consisting of a narrow P-type region between two N-type regions. The three regions are designated the *emitter* (E), *base* (B), and *collector* (C), respectively. The emitter region is heavily doped with the appropriate impurity, while the base region is very lightly doped. The collector region has a moderate doping level so that it has a low internal resistance.

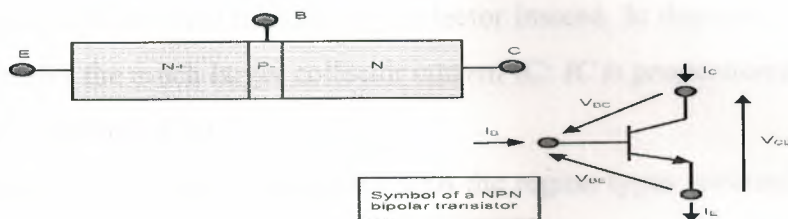


Figure 1.15 Bipolar transistor

We have shown a device consisting of N, P, and N regions in order, but there is no reason not to build equivalent devices in P, N, and P order instead. In fact, it is sometimes useful to have both types of devices available.

Let us see what happens when bias voltages are applied to such device.

Consider first that a small forward bias is applied to the emitter-base junction, and a larger reverse bias applied to the collector-base junction. These are the normal operating conditions of a bipolar transistor.

Since we already know how a PN junction operates, we would expect the base voltage to be about 0.65 to 0.7 volt positive with respect to the emitter, and to have electrons move from emitter to base, and leave the device at that point. With the collector junction reverse biased, we would expect no current to flow through that junction.

But something happens inside the base region. The forward bias on this junction does indeed attract electrons from the emitter into the base, but then the forward momentum of the electrons carries them across most of the base region and into the depletion region

around the collector junction. From there, the higher positive collector voltage attracts these electrons across the collector junction and into the collector region.

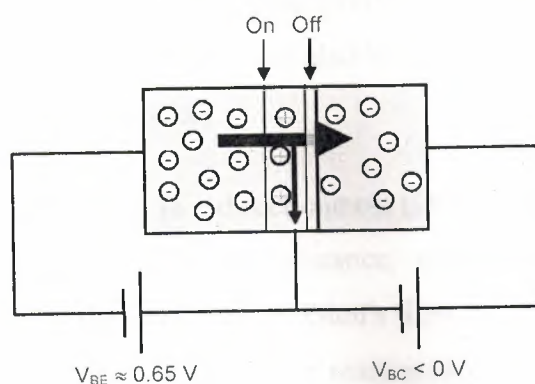


Figure 1.16 Forward biasing of transistor

A small amount of current does still leave the device through the base contact, but most of the current is diverted through the collector instead. In this way, the small base current I_B controls the much larger collector current I_C : I_C is proportional to I_B . This is known as the *transistor effect*.

It is also possible to build a transistor with the region types reversed. In this case, holes will be drawn from the emitter into the base region by the forward bias, and will then be pulled into the collector region by the higher negative bias. Otherwise, this device works the same way and has the same general properties as the one described above. To distinguish between the two types of transistors, we refer to them by the order in which the different regions appear. Thus, this is a *PNP transistor* while the device described above is an *NPN transistor*.

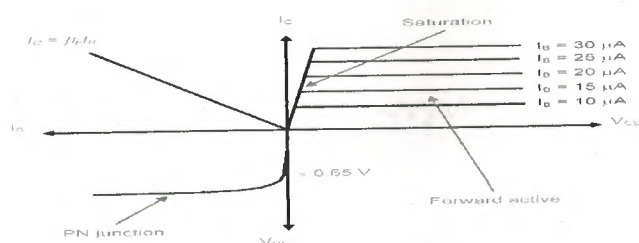


Figure 1.17 Current-voltage characteristics of a bipolar transistor

1.2.RESISTORS

A resistor is an electrical component that limits or regulates the flow of electrical current in an electronic circuit. Resistors can also be used to provide a specific voltage for an active device such as a transistor.

All other factors being equal, in a direct-current (DC) circuit, the current through a resistor is inversely proportional to its resistance, and directly proportional to the voltage across it. This is the well-known Ohm's Law. In alternating-current (AC) circuits, this rule also applies as long as the resistor does not contain inductance or capacitance.

Resistors can be fabricated in a variety of ways. The most common type in electronic devices and systems is the *carbon-composition resistor*. Fine granulated carbon (graphite) is mixed with clay and hardened. The resistance depends on the proportion of carbon to clay; the higher this ratio, the lower the resistance.

Another type of resistor is made from winding Nichrome or similar wire on an insulating form. This component, called a *wirewound resistor*, is able to handle higher currents than a carbon-composition resistor of the same physical size. However, because the wire is wound into a coil, the component acts as an inductor as well as exhibiting resistance. This does not affect performance in DC circuits, but can have an adverse effect in AC circuits because inductance renders the device sensitive to changes in frequency.

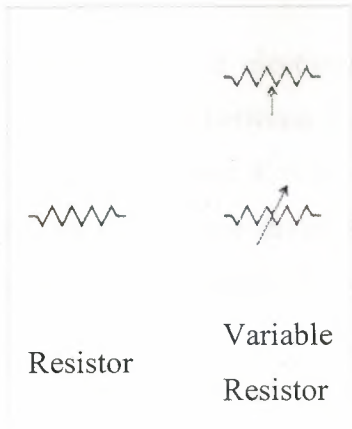


Figure 1.18 Resistor symbols (American)

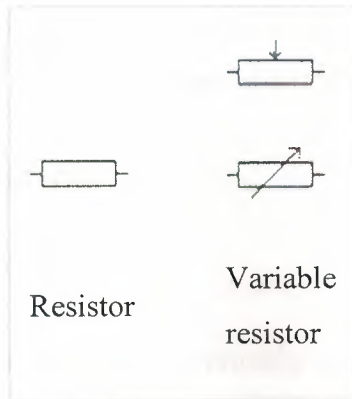


Figure 1.19 Resistor symbols (Europe, IEC)



Figure 1.20 Axial-lead resistors on tape. The tape is removed during assembly before the leads are formed and the part is inserted into the board.



Figure 1.21 Three carbon composition resistors in a 1960s valve radio.

A **resistor** is a two-terminal electrical or electronic component that opposes an electric current by producing a voltage drop between its terminals in proportion to the current, that is, in accordance with Ohm's law: $V = IR$. The *electrical resistance* R is equal to the voltage drop V across the resistor divided by the current I through the resistor. Resistors are used as part of electrical networks and electronic circuits.

1.2.1. Identifying Resistors

Most axial resistors use a pattern of colored stripes to indicate resistance. Surface-mount resistors are marked numerically. Cases are usually brown, blue, or green,

ough other colors are occasionally found such as dark red or dark grey. One can also use a multimeter or ohmmeter to test the values of a resistor.

• Four-Band Axial Resistors

Main article: Electronic color code

Four-band identification is the most commonly used color coding scheme on all resistors. It consists of four colored bands that are painted around the body of the resistor. The scheme is simple: The first two numbers are the first two significant digits of the resistance value, the third is a multiplier, and the fourth is the tolerance of the resistor (e.g. green-blue-yellow red : $56 \times (10^4)$ ohms = 56×10000 ohms = 560 kohms). Each color corresponds to a certain number, shown in the chart below. The tolerance for a 4-band resistor will be 1%, 5%, or 10%.

	1 st band	2 nd band	3 rd (multiplier)	band 4 th (tolerance)	band Temp. Coefficient
Black	0	0	$\times 10^0$		
Brown	1	1	$\times 10^1$	$\pm 1\%$ (F)	100 ppm
Red	2	2	$\times 10^2$	$\pm 2\%$ (G)	50 ppm
Orange	3	3	$\times 10^3$		15 ppm
Yellow	4	4	$\times 10^4$		25 ppm
Green	5	5	$\times 10^5$	$\pm 0.5\%$ (D)	
Blue	6	6	$\times 10^6$	$\pm 0.25\%$ (C)	
Violet	7	7	$\times 10^7$	$\pm 0.1\%$ (B)	
Purple	8	8	$\times 10^8$	$\pm 0.05\%$ (A)	
Gold	9	9	$\times 10^9$		
Silver			$\times 10^{-1}$	$\pm 5\%$ (J)	
			$\times 10^{-2}$	$\pm 10\%$ (K)	
				$\pm 20\%$ (M)	

- **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 standardized values exist in each decade (e.g. between 10 and 100, or between 100 and 1000). So resistors conforming 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). These E numbers correspond to the formula $R = 10^{(N/E)}$, So for an 1.21 ohm E96 series resistor, $N=8$ and $10^{(8/96)}=1.21$ ohm. Each multiple of 96 added to the remainder gives the next decade. So a 12.1 ohm resistor would have a $N= 8+96 = 104$. N can also be found by using the formula $E * \text{LOG}_{10}(R) = N$.

- **5-band Axial Resistors**

5-band identification is used for higher precision (lower 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 5th band. The 5th band in this case is the temperature coefficient

- **SMT Resistors**

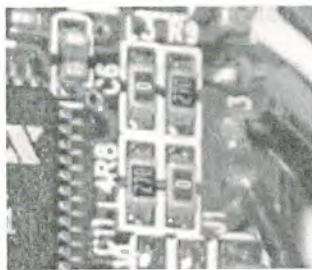


Figure 1.22 This image shows four surface-mount resistors (the component at the upper left is a capacitor) including two zero-ohm resistors. Zero-ohm links are often used instead of wire links, so that they can be inserted by a resistor-inserting machine.

Surface mounted resistors are printed with numerical values in a code related to that used on axial resistors. Standard-tolerance Surface Mount Technology (SMT) 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:

$$334 = 33 \times 10,000 \text{ ohms} = 330 \text{ kilohms}$$

$$222 = 22 \times 100 \text{ ohms} = 2.2 \text{ kilohms}$$

$$473 = 47 \times 1,000 \text{ ohms} = 47 \text{ kilohms}$$

$$105 = 10 \times 100,000 \text{ ohms} = 1 \text{ megohm}$$

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

$$100 = 10 \times 1 \text{ ohm} = 10 \text{ ohms}$$

$$220 = 22 \times 1 \text{ ohm} = 22 \text{ ohms}$$

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 (radix point). For example:

$$4R7 = 4.7 \text{ ohms}$$

$$0R22 = 0.22 \text{ ohms}$$

$$0R01 = 0.01 \text{ ohms}$$

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:

$$1001 = 100 \times 10 \text{ ohms} = 1 \text{ kilohm}$$

$$4992 = 499 \times 100 \text{ ohms} = 49.9 \text{ kilohm}$$

$$1000 = 100 \times 1 \text{ ohm} = 100 \text{ ohms}$$

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

- **Industrial Type Designation**

Power Rating at 70 °C				Tolerance Code		
Type	No. rating (watts)	MIL-R-11 Style	MIL-R-39008 Style	Industrial type designation	Tolerance	MIL Designation
BB	1/8	RC05	RCR05	5	±5%	J
CB	¼	RC07	RCR07	2	±20%	-
EB	½	RC20	RCR20	1	±10%	K
GB	1	RC32	RCR32	-	±2%	G
HB	2	RC42	RCR42	-	±1%	F
GM	3	-	-	-	±0.5%	D
HM	4	-	-	-	±0.25%	C
				-	±0.1%	B

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 (sometimes -65 °C to 275 °C)
- Standard Grade -5°C to 60°C

1.2.2.Resistor Standards



Figure 1.21 3 resistors

- MIL-R-11
- MIL-R-39008
- MIL-R-39017
- MIL-PRF-26
- MIL-PRF-39007
- MIL-PRF-55342
- MIL-PRF-914
- BS 1852
- EIA-RS-279

There are other United States military procurement MIL-R- standards.

1.2.3. 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 the 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, the resistor may depart from its nominal resistance, and may be damaged by overheating. *Significantly* excessive power dissipation may raise the temperature of the resistor to a point where it burns out, which could cause a fire in adjacent components and materials.

1.2.4. Technology

- **Carbon Composition**

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.

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, a weak conductor, result in lower resistance. Carbon composition resistors were commonly used in the 1960s 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).

- **Carbon Film**

A spiral is used to increase the length and decrease the width of the film, which increases the resistance. Varying shapes, coupled with the resistivity of carbon, (ranging from 9 to 40 $\mu\Omega$) can make for a variety of resistances.^[2]

- **Thick and Thin Film**

Thick film resistors became popular during the 1970s, 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 a method used in 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 ultraviolet 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 an accurate value by abrasive or laser trimming.

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), ruthenium dioxide (RuO_2), lead oxide (PbO), bismuth ruthenate ($\text{Bi}_2\text{Ru}_2\text{O}_7$), nickel chromium (NiCr), and/or bismuth iridate ($\text{Bi}_2\text{Ir}_2\text{O}_7$).

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 850°C .

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 typically ± 200 or ± 250 ppm/K, depending on the resistance. Thus a 40 kelvin (70°F) 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 25 ppm/K. They are usually far more expensive than their thick film cousins. Note, though, that SMD thin film resistors, with 0.5% tolerances, and with 25 ppm/K temperature coefficients, when bought in full size reel quantities, are about twice the cost of a 1%, 250 ppm/K thick film resistors.

- **Metal Film**

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 50 ppm/K.

- **Wirewound**

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 dependent on being used with a suitable heatsink, e.g., a 50 W power rated resistor will overheat at around one fifth of the power dissipation if not used with a heatsink.

Because wirewound resistors are coils they have more inductance than other types of resistor, although this property can be minimized by winding the wire in sections with alternately reversed direction.

- **Foil Resistor**

Foil resistors have had the best precision and stability ever since they were introduced in 1958 by Felix Zandman. 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.^[3]

- **Grid Resistor**

The term "grid resistor" can mean two things:

In tube or valve electronic circuit design, a grid resistor or "grid stopper" is used to limit grid current and prevent high frequencies from entering or oscillating the circuit. Such a resistor can be composed of any one of a number of resistor technologies. One application that uses grid resistors is electric guitar amplifier circuitry.^{[4][5]}

In heavy duty, industrial, high-current applications, a grid resistor is a large convection-cooled lattice of stamped metal alloy strips connected in rows between two electrodes. Such industrial grade resistors can be as large as a refrigerator; some designs can handle over 500 amperes of current, with a range of resistances extending lower than 0.04 Ohms. They are used in applications such as dynamic braking for locomotives and trams, neutral grounding for industrial AC distribution, control loads for cranes and heavy equipment, load testing of generators and harmonic filtering for electric substations

- **Strain Gauges**

Main article: Strain gauge

Invented by Edward E. Simmons and Arthur C. Ruge in 1938, the strain gauge consists of a resistor that changes value with applied strain. The strain resistor may be applied singly, in pairs (half bridge), or four resistors connected in a Wheatstone bridge configuration. The strain resistor is bonded with adhesive to an object that will be subjected to the strain force. With the strain gauge and a filter, amplifier, and an analog/digital converter, it is possible to directly measure the strain on an object.

- **Other Types**

- Metal-oxide resistor
- Cermet
- Phenolic
- Tantalum
- Liquid-filled

1.2.5.Noise

In precision circuits, electronic noise becomes of utmost concern. As dissipative elements, resistors will naturally produce a fluctuating "noise" voltage across their terminals. This Johnson–Nyquist noise is predicted by the fluctuation–dissipation theorem and is a fundamental noise source present in all resistors which must be considered in constructing low-noise electronics. For example, the gain in a simple (non-)inverting amplifier is set using a voltage divider. Noise considerations dictate that the smallest practical resistance should be used, since the noise voltage scales with resistance, and any resistor noise in the voltage divider will be impressed upon the amplifier's output.

Although Johnson–Nyquist noise is a fundamental noise source, resistors frequently exhibit other, "non-fundamental" sources of noise. Noise due to these sources is called "excess noise." Thick-film and carbon composition resistors are notorious for excess noise at low frequencies. Wire-wound and thin-film resistors, though much more expensive, are often utilized for their better noise characteristics.

1.2.6.Failure Modes and Pitfalls

Like every part, resistors can fail; the usual way depends on their construction. Carbon composition resistors and metal film resistors typically fail as open circuits. Carbon-film resistors typically fail as short circuits.^[9] Carbon film and composition resistors can burn if too much power is dissipated. This is also possible but less likely with metal film and wirewound resistors. If not enclosed, wirewound resistors can corrode. Carbon -composition resistors are prone to drifting over time and are easily damaged by excessive heat in soldering (the binder evaporates).

Various effects become important in high-precision applications. Small voltage differentials may appear on the resistors due to thermoelectric effect if their ends are not kept at the same temperature. The voltages appear in the junctions of the resistor leads with the circuit board and with the resistor body. Common metal film resistors show such effect at magnitude of about $20 \mu\text{V}/^\circ\text{C}$. Some carbon composition resistors can go as high as $400 \mu\text{V}/^\circ\text{C}$, and specially constructed resistors can go as low as $0.05 \mu\text{V}/^\circ\text{C}$.

In applications where thermoelectric effects may become important, care has to be taken to e.g. mount the resistors horizontally to avoid temperature gradients and to mind the air flow over the board.

1.3.CAPACITORS

In October 1745, Ewald Georg von Kleist of Pomerania in Germany invented the first recorded capacitor: a glass jar with water inside as one plate was held on the hand as the other plate. A wire in the mouth of the bottle received charge from an electric machine, and released it as a spark.^[1]

In the same year, 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 charge storage capacity.

Benjamin Franklin investigated the Leyden jar, and proved that the charge was stored on the glass, not in the water as others had assumed. The earliest unit of capacitance was the 'jar', equivalent to about 1 nanofarad.

Early capacitors were also known as *condensers*, a term that is still occasionally used today. It was coined by Alessandro 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 European languages still use a word derived from "condensatore".



Figure 1.28 Capacitors

1.3.1.History

Description and drawing of von Kleist's invention of the Leyden jar

In October 1745, Ewald Georg von Kleist of Pomerania in Germany invented the first recorded capacitor: a glass jar with water inside as one plate was held on the hand

as the other plate. A wire in the mouth of the bottle received charge from an electric machine, and released it as a spark.^[1]

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1.3.2.Theory of Operation



Figure 1.29 Diagram of a parallel-plate capacitor

A capacitor consists of two conductive electrodes, or plates, separated by a dielectric, which prevents charge from moving directly between the plates. Charge may however be moved indirectly by external influences, such as a battery connecting the terminals. After removing the external influences, the charge on the plates persists. The

separated charges attract each other, and an electric field is present between the plates. The simplest practical capacitor consists of two wide, flat, parallel plates separated by a thin dielectric layer.

Assuming that the area of the plates A is much greater than their separation d , the instantaneous electric field between the plates $E(t)$ is identical at any location away from the edges. If the instantaneous charge on a plate - $q(t)$ is spread evenly,

$$E(t) = -\frac{q(t)}{\epsilon A},$$

where ϵ is the permittivity of the dielectric. The voltage $v(t)$ between the plates is given by

$$v(t) = -\int_0^d E(t) dz = \frac{q(t)d}{\epsilon A},$$

where z is a position between the plates

• Capacitance

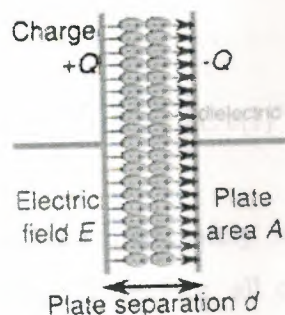


Figure 1.30: Charge separation in a parallel-plate capacitor causes an internal electric field. A polarized dielectric spacer (orange) reduces the electric field and increase the capacitance.

A property called the capacitance C , which is a measure of the charge stored on each plate for a given voltage such that

$$q(t) = Cv(t),$$

where

$$C = \frac{\epsilon A}{d}$$

for an ideal parallel plate capacitor.

In SI units, a capacitor has a capacitance of one farad when one coulomb of charge storage corresponds to one volt between its plates. Since the farad is a very large unit, capacitance is usually expressed in microfarads (μF), nanofarads (nF), or picofarads (pF). In general, capacitance is greater in devices with large plate areas, separated by small distances. When a dielectric is present between two charged plates, its molecules become polarized and reduce the internal electric field and hence the voltage. The capacitance is therefore strongly dependent on the quality of the dielectric.

- **Energy Storage**

Work must be done by an external influence to move charge between the plates in a capacitor. When the external influence is removed, the charge separation persists and energy is stored in the electric field. If charge is later allowed to return to its equilibrium position, the energy is released. The work done in establishing the electric field, and hence the amount of energy stored, is given by

$$W(t) = -q(t) \int_0^d E(t) dz = \frac{1}{2} \frac{q(t)^2}{C} = \frac{1}{2} C v(t)^2 = \frac{1}{2} v(t) q(t)$$

The maximum energy that can be stored safely in a capacitor is limited by the breakdown voltage of the dielectric. Therefore, all capacitors made with a particular dielectric have approximately identical maximum energy density if the dielectric dominates their volume.

1.3.3. Hydraulic Analogy

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 difference (voltage difference) across the unit is proportional to the integral of the flow (current).
- A steady state current cannot pass through it because the pressure will build up across the diaphragm until it equally opposes the source pressure,
- but a transient pulse or alternating current can be transmitted.
- An overpressure results in bursting of the diaphragm, analogous to dielectric breakdown.

The capacitance of units connected in parallel is equivalent to the sum of their individual capacitance

1.3.4.Aging

The capacitance of certain capacitors decreases as the component ages. In ceramic capacitors, this is caused by degradation of the dielectric. The type of dielectric and the ambient operating and storage temperatures are the most significant aging factors, while the operating voltage has a smaller effect. The aging process may be reversed by heating the component above the Curie point. Aging is fastest near the beginning of life of the component, and the device stabilizes over time.^[2] Electrolytic capacitors age as the electrolyte evaporates. In contrast with ceramic capacitors, this occurs towards the end of life of the component.

1.3.5.Electric Circuits

When a capacitor is connected to a current source, charge is transferred between its plates at a rate $i(t) = dq(t) / dt$. As the voltage between the plates is proportional to the charge, it follows that

$$v(t) = \frac{1}{C}q(t) = \frac{1}{C} \int_0^t i(\tau) d\tau$$

Conversely, if a capacitor is connected to a voltage source, the resulting current is

$$i(t) = C \frac{dv(t)}{dt}$$

- **DC Sources**

A simple resistor-capacitor circuit demonstrates charging of a capacitor.

A circuit containing only a resistor, a capacitor, a switch and a constant (DC) voltage source $v_{\text{src}}(t) = V_0$ in series is known as a *charging circuit*. From Kirchhoff's voltage law it follows that

$$V_0 = v_r(t) + v_c(t) = i(t)R + \frac{1}{C} \int_0^t i(\tau) d\tau,$$

where $v_r(t)$ and $v_c(t)$ are the voltages across the resistor and capacitor respectively. This reduces to a first order differential equation

$$RC \frac{di(t)}{dt} = -i(t)$$

Assuming that the capacitor is initially uncharged, there is no internal electric field, and the initial current is $I_0 = V_0 / R$. This initial condition allows solution of the differential equation as

$$i(t) = \frac{V_0}{R} \exp\left(-\frac{t}{RC}\right).$$

The corresponding voltage drop across the capacitor is

$$v(t) = V_0 \left[1 - \exp\left(-\frac{t}{RC}\right)\right]$$

Therefore, as charge increases on the capacitor plates, the voltage across the capacitor increases, until it reaches a steady-state value of V_0 , and the current drops to zero. Both the current, and the difference between the source and capacitor voltage decay exponentially with respect to time. The time constant of the decay is given by $t = RC$.

- **AC Sources**

When connected to an alternating current (AC) voltage source, the plates on a capacitor repeatedly charge and discharge relative to each other. The current varies sinusoidally, with a nonzero amplitude. For this reason, capacitors effectively conduct AC although charge ideally never passes directly through the dielectric. Since the current is proportional to the time derivative of the voltage, a sinusoidal current leads the voltage by a 90 degree phase shift, or equivalently 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 .

- **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.

See derivation Deriving capacitor impedance.

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 does not 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 as heat, 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:

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

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 Ampère'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 aether. Although this interpretation has been abandoned, Maxwell's correction to Ampère's law remains valid.

- **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.

1.3.6. Capacitor Types

Practical capacitors are available commercially in many different forms. The type of internal dielectric, the structure of the plates and the device packaging all strongly affect the characteristics of the capacitor, and its applications.

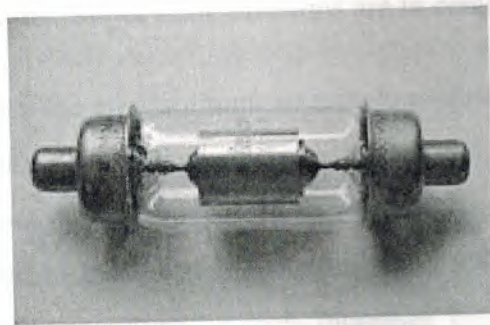


Figure 1.30 A 12 pF 20 kV fixed vacuum capacitor

1.3.7. Dielectric Materials

Most types of capacitor include a dielectric spacer, which increases their capacitance. However, low capacitance devices are available with a vacuum between their plates, which allows extremely high voltage operation and low losses. Air filled variable capacitors are also commonly used in radio tuning circuits.

Several solid dielectrics are available, including paper, plastic, glass, mica and ceramic materials. Paper was used extensively in older devices and offers relatively high voltage performance. However, it is susceptible to water absorption, and has been largely replaced by plastic film capacitors. Plastics offer better stability and aging

performance, which makes them useful in timer circuits, although they may be limited to low operating temperatures and frequencies. Ceramic capacitors are generally small, cheap and useful for high frequency applications, although their capacitance varies strongly with voltage, and they age poorly. They are broadly categorized as Class 1 dielectrics, which have predictable variation of capacitance with temperature or Class 2 dielectrics, which can operate at higher voltage. Glass and mica capacitors are extremely reliable, stable and tolerant to high temperatures and voltages, but are too expensive for most mainstream applications.



Figure 1.31 Capacitor materials. From left: multilayer ceramic, ceramic disc, multilayer polyester film, tubular ceramic, polystyrene, metalized polyester film, aluminum electrolytic. Major scale divisions are in centimetres.

Electrolytic capacitors use an aluminum or tantalum plate with an oxide dielectric layer. The second electrode is a liquid electrolyte. Electrolytic capacitors offer very high capacitance but suffer from poor tolerances, high instability, gradual loss of capacitance especially when subjected to heat, and high leakage current. The conductivity of the electrolyte drops at low temperatures, which increases equivalent series resistance. While widely used for power-supply conditioning, poor high-frequency characteristics make them unsuitable for many applications. Tantalum capacitors offer better frequency and temperature characteristics than aluminum, but higher dielectric absorption and leakage.^[3] OS-CON (or OC-CON) capacitors are a polymerized organic semiconductor solid-electrolyte type that offer longer life at higher cost than standard electrolytic capacitors.

Several other types of capacitor are available for specialist applications. Supercapacitors made from carbon aerogel, carbon nanotubes, or highly porous electrode materials offer extremely high capacity and can be used in some applications instead of rechargeable batteries. Alternating current capacitors are specifically designed to work on line (mains) voltage AC power circuits. They are commonly used in electric motor circuits and are often designed to handle large currents, so they tend to

be physically large. They are usually ruggedly packaged, often in metal cases that can be easily grounded/earthed. They also tend to have rather high direct current breakdown voltages.

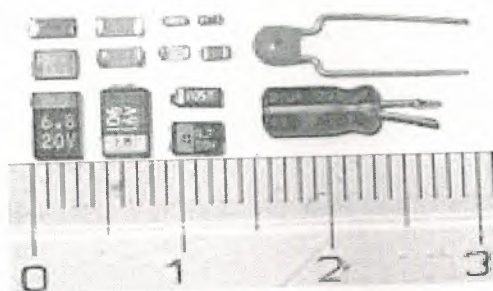


Figure 1.32: Capacitor packages: SMD ceramic at top left; SMD tantalum at bottom left; through-hole tantalum at top right; through-hole electrolytic at bottom right. Major scale divisions are cm.








1.3.8. Structure

Capacitors may have their plates arranged in many configurations, for example axially or radially. Small, cheap discoidal ceramic capacitors have existed since the 1930s, and remain in widespread use. Since the 1980s, surface mount packages for capacitors have been widely used. These packages are extremely small and lack connecting leads, allowing them to be soldered directly onto the surface of printed circuit boards. Surface mount components avoid undesirable high-frequency effects due to the leads and simplify automated assembly, although manual handling is made difficult due to their small size.

Variable capacitors are available in various forms. Mechanically controlled variable capacitors allow the plate spacing to be adjusted, for example by rotating or sliding a set of movable plates into alignment with a set of stationary plates. Very cheap variable capacitors squeeze together alternating layers of aluminum and plastic with a screw, but the resulting capacitance is unstable, and unreproducible. Electrical control of capacitance is achievable with varactors (or varicaps), which are reverse-biased semiconductor diodes whose depletion region width varies with applied voltage. They are used in phase-locked loops, amongst other applications.

1.3.9.Applications

Capacitor symbols

Capacitor	Polarized capacitors	Variable capacitor
		
		
		
		
		

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.)

- **Power Conditioning**

Reservoir 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.

- ***Filtering***

Signal coupling

Main article: capacitive 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* or "capacitive coupling". Here, a large value of capacitance, whose value need not be accurately controlled, but whose reactance is small at the signal frequency, is employed.

- ***Decoupling***

Main article: decoupling capacitor

A decoupling capacitor is a capacitor used to decouple one part of a circuit from another. Noise caused by other circuit elements is shunted through the capacitor reducing the effect they have on the rest of the circuit. It is most commonly used between the power supply and ground.

An alternative name is bypass capacitor as it is used to bypass the power supply or other high impedance component of a circuit.

- ***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 single phase squirrel cage motors, the primary winding within the motor housing isn't capable of starting a rotational motion on the rotor, but is capable of sustaining one. To start the motor, a secondary winding is used in series with a non-polarized **starting capacitor** to introduce a lag in the sinusoidal current through the secondary winding. When the secondary winding is placed at an angle with respect to the primary winding, a rotating electric field is created. The force of the rotational field is not constant, but is sufficient to start the rotor spinning. The capacitor is typically mounted to the side of the motor housing.

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 factors can change the structure of the capacitor; the resulting change in capacitance can be used to sense those factors.

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. Some fingerprint sensors use capacitors. Additionally, a user can adjust the pitch of a theremin musical instrument by moving his

hand since this changes the effective capacitance between the user's hand and the antenna.

Changing the effective area of the plates: capacitive touch switches [1] [2] [3].

- ***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 generators, pulsed lasers (especially TEA lasers), pulse forming networks, radar, fusion research, and particle accelerators.

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

See also Explosively pumped flux compression generator.

- **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 shock.

Care must be taken to ensure that any large or high-voltage capacitor is properly discharged before servicing the containing equipment. 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.

- **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 called an arc fault; within oil-filled units, that vaporizes dielectric fluid, resulting in case bulging, rupture, or even an explosion, called flash meltdown, 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. 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.

1.4.SWITCHES

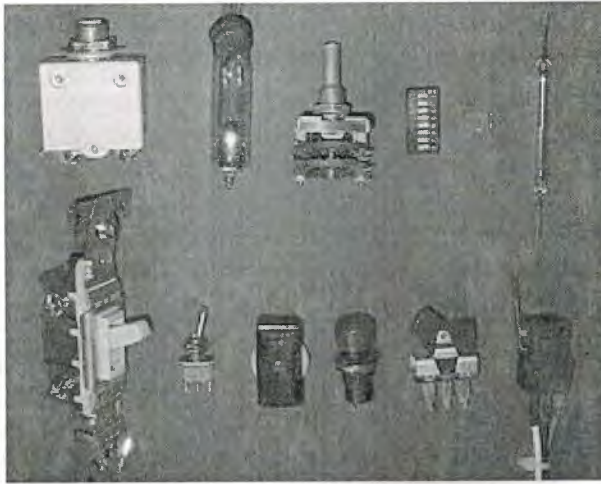


Figure 1.32:Electrical switches. Top, left to right: circuit breaker, mercury switch, wafer switch, DIP switch, surface mount switch, reed switch. Bottom, left to right: wall switch (U.S. style), miniature toggle switch, in-line switch, push-button switch, rocker switch, microswitch.

A **switch** is a mechanical device used to connect and disconnect a circuit at will. Switches cover a wide range of types, from subminiature up to industrial plant switching megawatts of power on high voltage distribution lines.

In applications where multiple switching options are required (e.g., a telephone service), mechanical switches have long been replaced by electronic switching devices which can be automated and intelligently controlled.

The prototypical model is perhaps a mechanical device (for example a railroad switch) which can be disconnected from one course and connected to another.

The switch is referred to as a "gate" when abstracted to mathematical form. In the philosophy of logic, operational arguments are represented as logic gates. The use of electronic *gates* to function as a system of logical gates is the fundamental basis for the computer—i.e. a computer is a system of electronic switches which function as logical gates.

1.4.1.Contacts



Figure 1.33:A toggle switch in the "on" position.

In the simplest case, a switch has two pieces of metal called *contacts* that touch to make a circuit, and separate to break the circuit. The contact material is chosen for its resistance to corrosion, because most metals form insulating oxides that would prevent the switch from working. Contact materials are also chosen on the basis of electrical conductivity, hardness (resistance to abrasive wear), mechanical strength, low cost and low toxicity^[1].

Sometimes the contacts are plated with noble metals. They may be designed to wipe against each other to clean off any contamination. Nonmetallic conductors, such as conductive plastic, are sometimes used.

1.4.2.Actuator

The moving part that applies the operating force to the contacts is called the actuator, and may be a **toggle** or *dolly*, a **rocker**, a **push-button** or any type of mechanical linkage (*see photo*).

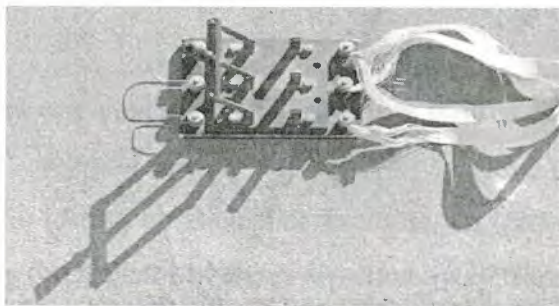


Figure 1.34:Triple Pole Single Throw (TPST or 3PST) knife switch used to short the windings of a 3 phase wind turbine for braking purposes. Here the switch is shown in the open position.

A pair of contacts is said to be 'closed' when there is no space between them, allowing electricity to flow from one to the other. When the contacts are separated by a space, they are said to be 'open', and no electricity can flow.

Switches can be classified according to the arrangement of their contacts. Some contacts are normally open until closed by operation of the switch, while others are normally closed and opened by the switch action. A switch with both types of contact is called a changeover switch.

The terms *pole* and *throw* are used to describe switch contacts. A *pole* is a set of contacts that belong to a single circuit. A *throw* is one of two or more positions that the switch can adopt. These terms give rise to abbreviations for the types of switch which are used in the electronics industry. In mains wiring names generally involving the word *way* are used; however, these terms differ between British and American English and the terms *two way* and *three way* are used in both with different meanings.

1.4.4. Make-Before-Break, Break-Before-Make

In a multi-throw switch, there are two possible transient behaviors as you move from one position to another. In some switch designs, the new contact is made before the old contact is broken. This is known as make-before-break, and ensures that the moving contact never sees an open circuit (also referred to as a shorting switch). The alternative is break-before-make, where the old contact is broken before the new one is made. This ensures that the two fixed contacts are never shorted to each other. Both types of design are in common use, for different applications.

1.4.5. Biased Switches

A biased switch is one containing a spring that returns the actuator to a certain position. The "on-off" notation can be modified by placing parentheses around all positions other than the resting position. For example, an (on)-off-(on) switch can be switched on by moving the actuator in either direction away from the centre, but returns to the central off position when the actuator is released.

The momentary push-button switch is a type of biased switch. The most common type is a **push-to-make switch**, which makes contact when the button is pressed and



breaks when the button is released. A **push-to-break switch**, on the other hand, breaks contact when the button is pressed and makes contact when it is released. An example of a push-to-break switch is a button used to release a door held open by an electromagnet. Changeover push button switches do exist but are even less common.

1.4.6. Intermediate Switch

A DPDT switch has six connections, but since polarity reversal is a very common usage of DPDT switches, some variations of the DPDT switch are internally wired specifically for polarity reversal. These crossover switches only have four terminals rather than six. Two of the terminals are inputs and two are outputs. When connected to a battery or other DC source, the 4-way switch selects from either normal or reversed polarity. Intermediate switches are also an important part of multiway switching systems with more than two switches (see next section).

1.4.7. Multiway Switching

Multiway switching is a method of connecting switches in groups so that any switch can be used to connect or disconnect the load. This is most commonly done with lighting.

Two locations

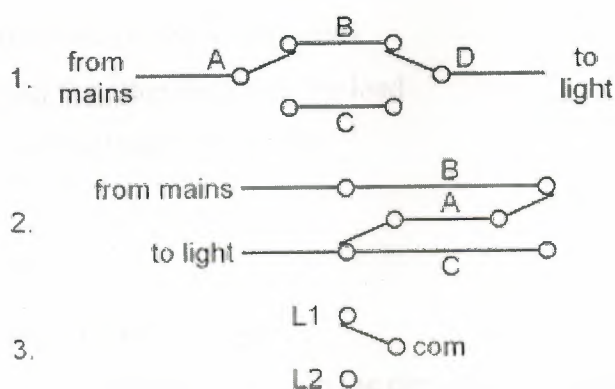


Figure 1.35: 1. First method
2. Second method
3. Labelling of switch terminals

Switching a load on or off from two locations (for instance, turning a light on or off from either end of a flight of stairs) requires two SPDT switches. There are two basic methods of wiring to achieve this, and another not recommended.

In the first method, mains is fed into the common terminal of one of the switches; the switches are then connected through the L1 and L2 terminals (swapping the L1 and L2 terminals will just make the switches work the other way round), and finally a feed to the light is taken from the common of the second switch. A connects to B or C, D connects to B or C; the light is on if A connects to D, i.e. if A and D both connect to B or both connect to C.

The second method is to join the three terminals of one switch to the corresponding terminals on the other switch and take the incoming supply and the wire out to the light to the L1 and L2 terminals. Through one switch A connects to B or C, through the other also to B or C; the light is on if B connects to C, i.e. if A connects to B with one switch and to C with the other.

Wiring needed in addition to the mains network (not including protective earths):

First method:

- double wire between both switches
- single wire from one switch to the mains
- single wire from the other switch to the load
- single wire from the load to the mains

Second method:

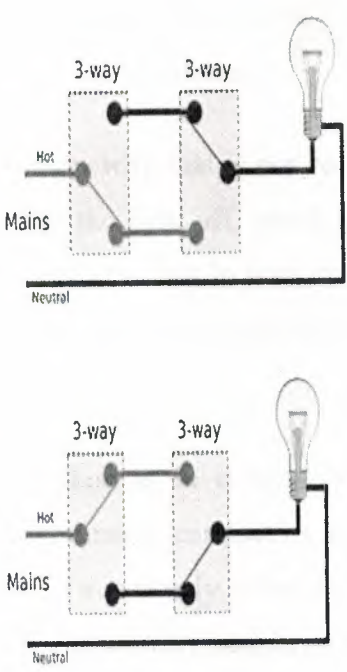
- triple wire between both switches
- single wire from any position between the two switches, to the mains
- single wire from any position between the two switches, to the load
- single wire from the load to the mains

If the mains and the load are connected to the system of switches at one of them, then in both methods we need three wires between the two switches. In the first method one of the three wires just has to pass through the switch, which tends to be less convenient

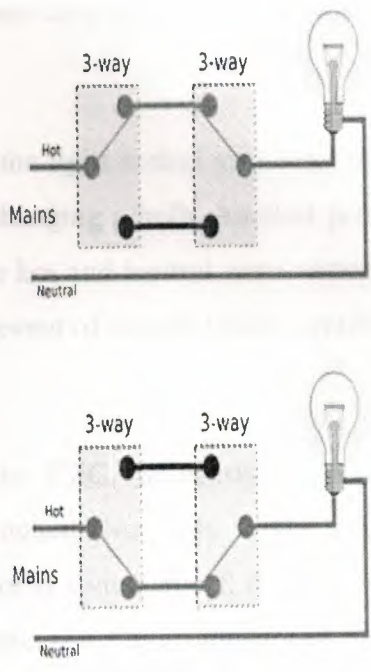
than being connected. When multiple wires come to a terminal they can often all be put directly in the terminal. When wires need to be joined without going to a terminal a crimped joint, piece of terminal block, wirenut or similar device must be used and the bulk of this may require use of a deeperbackbox.

Using the first method, there are four possible combinations of switch positions: two with the light on and two with the light off.

Off



On



An unrecommended method

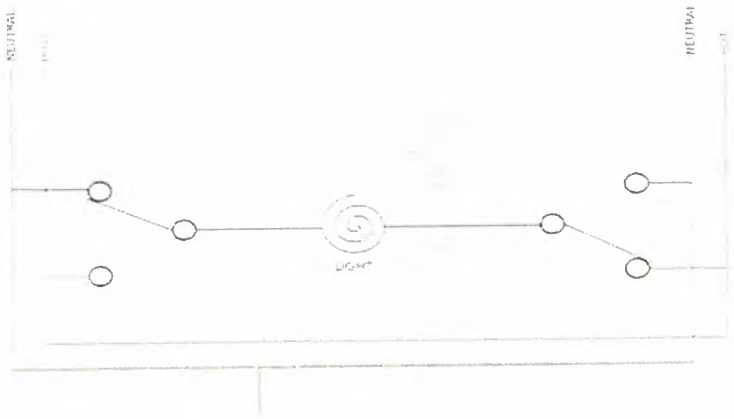


Figure 1.35:The unrecommended way using the hot and neutral directly

If there is a hot (a unique phase) and a neutral wire in both switches and just one wire between them where the light is connected (as in the picture), you can then solve the two way switch problem easily: just plug the hot in the top from switch, the neutral in the bottom from switch and the wire that goes to the light in the middle from the switch. This in both switches. Now you have a fully functional two way switch.

This works like the first method above: there are four possibilities and just in two of them there is a hot and a neutral connected in the poles of the light. In the other ones, both poles are neutral or hot and then no current flows because the potential difference is zero.

The advantage of this method is that it uses just one wire to the light, having a hot and neutral in both switches.

The reason why this is not recommended is that the light socket pins may still be hot even with the light off, which poses a risk when changing a bulb. Another problem with this method is that in both switches there will be hot and neutral wires entering a single switch, which can lead to a short circuit in the event of switch failure, unlike the other methods.

This method is in defiance of the NEC and the CEC. In nearly any and all applications, neutral conductors should never be switched. Not only is this a shock hazard due to mistakenly believing that a hot conductor is switched off; it is also a fire hazard and can destroy sensitive equipment due to excessive and unbalanced current flowing on hot conductors that would outhewise flow back to ground on the neutral conductor.

More than two locations

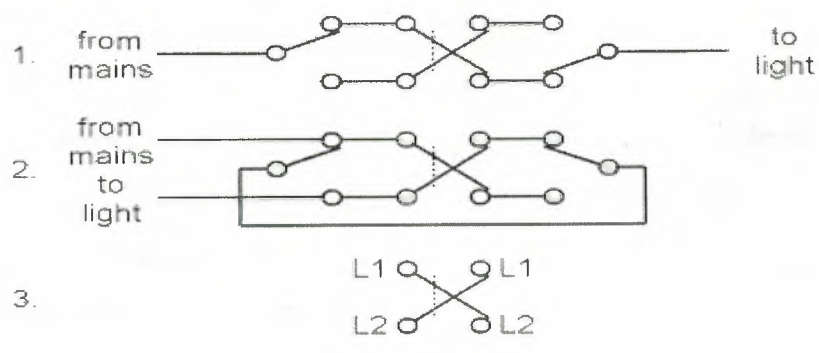


Figure 1.37: Three-way switching. 1. First method 2. Second method 3. Labelling of switch terminals

For more than two locations, the two cores connecting the L1 and L2 of the switches must be passed through an intermediate switch (as explained above) wired to swap them over. Any number of intermediate switches can be inserted, allowing for any number of locations.

Wiring needed in addition to the mains network (not including protective earths):

First method:

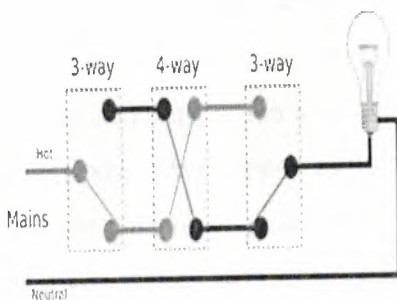
- double wire along the sequence of switches
- single wire from the first switch to mains
- single wire from the last switch to the load
- single wire (neutral) from load to mains

Second method:

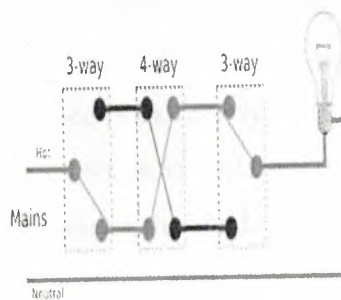
- double wire along the sequence of switches
- single wire from first switch to last switch
- single wire from anywhere between two of the switches to the mains
- single wire from anywhere between the same two switches to the load
- single wire (neutral) from load to mains

Using the first method, there are eight possible combinations of switch positions: four with the light on and four with the light off.

Off



On



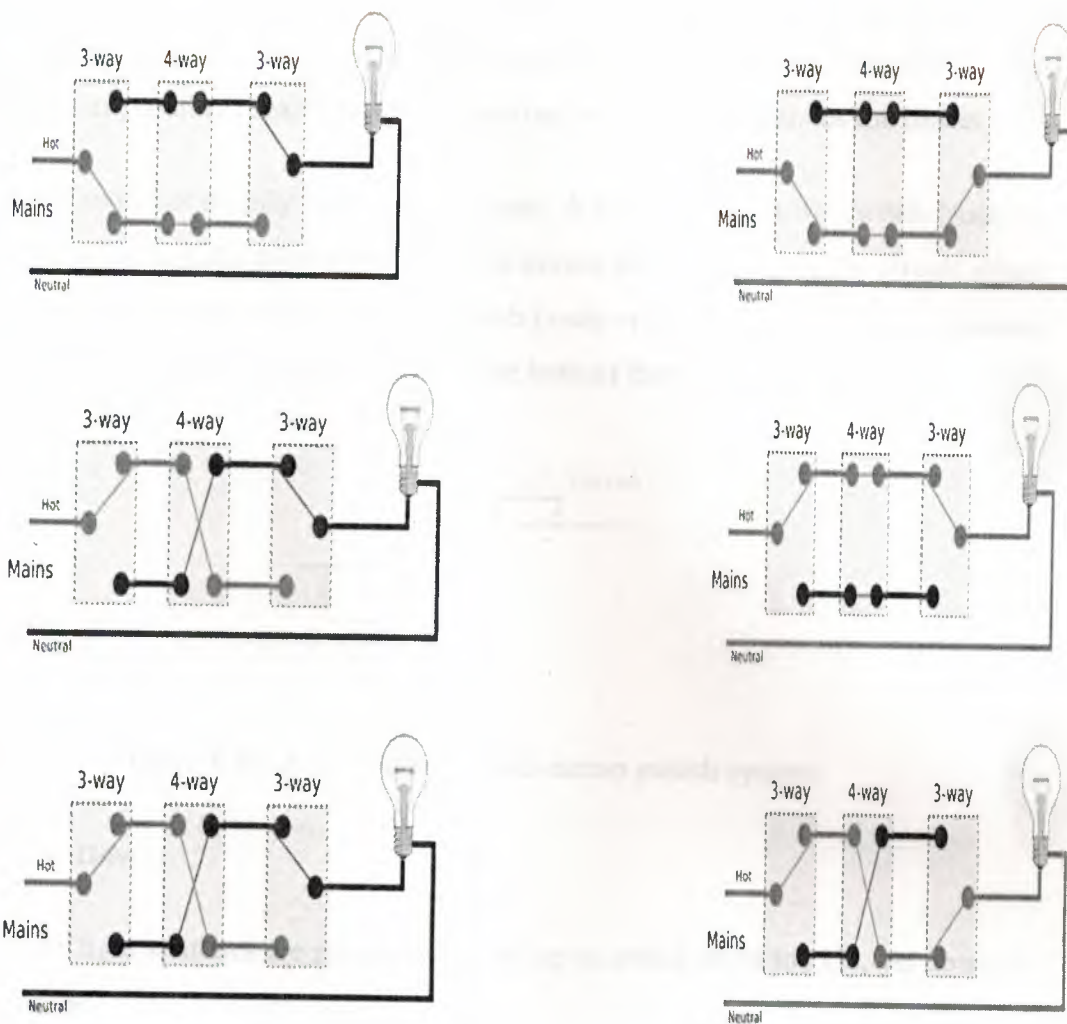


Figure 1.36:As mentioned above, the above circuit can be extended by using multiple 4-way switches between the 3-way switches to extend switching ability to any number of locations.

1.4.8.Power Switching

When a switch is designed to switch significant power, the transitional state of the switch as well as the ability to stand continuous operating currents must be considered. When a switch is on its resistance is near zero and very little power is dropped in the contacts; when a switch is in the off state its resistance is extremely high and even less power is dropped in the contacts. However when the switch is flicked the resistance must pass through a state where briefly a quarter (or worse if the load is not purely resistive) of the load's rated power is dropped in the switch.

For this reason, most power switches (most light switches and almost all larger switches) have spring mechanisms in them to make sure the transition between on and off is as short as possible regardless of the speed at which the user moves the rocker.

Power switches usually come in two types. A momentary on-off switch (such as on a laser pointer) usually takes the form of a button and only closes the circuit when the button is depressed. A regular on-off switch (such as on a flashlight) has a constant on-off feature. Dual-action switches incorporate both of these features.

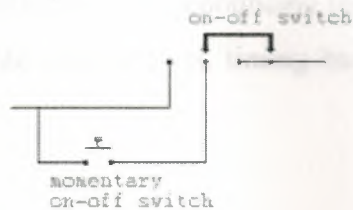


Figure 1.37: A diagram of a dual-action switch system

- **Up or Down**

Domestic light switches are generally moved up to switch on in the US, yet down in most of Europe.

The reason for the difference remains a bit of a mystery. A few hypotheses are often put forward, but none have been validated. Since there is no significant technical reason for either preference, the standards likely developed due to chance and some degree of cultural isolation.

- **Contact Bounce**

Contact bounce (also called *chatter*) is a common problem with mechanical switches and relays. Switch and relay contacts are usually made of springy metals that are forced into contact by an actuator. When the contacts strike together, their momentum and elasticity act together to cause bounce. The result is a rapidly pulsed electrical current instead of a clean transition from zero to full current. The waveform is then further modified by the parasitic inductances and capacitances in the switch and wiring, resulting in a series of damped sinusoidal oscillations. This effect is usually

unnoticeable in AC mains circuits, where the bounce happens too quickly to affect most equipment, but causes problems in some analogue and logic circuits that respond fast enough to misinterpret the on-off pulses as a data stream.

Sequential digital logic circuits are particularly vulnerable to contact bounce. The voltage waveform produced by switch bounce usually violates the amplitude and timing specifications of the logic circuit. The result is that the circuit may fail, due to problems such as metastability, race conditions, runt pulses and glitches.

There are a number of techniques for debouncing (mitigating the effects of switch bounce). They can be split into wet contacts, timing based techniques and Hysteresis based techniques.

- **Wet Contacts**

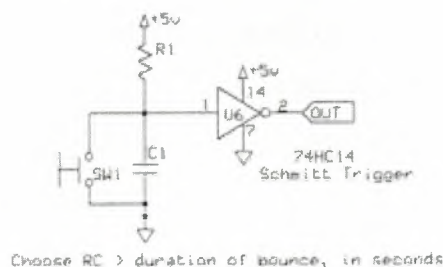
Mercury wetted switch contacts do not suffer from bounce, as once the connection is made the mercury keeps the contact conducting during mechanical bounce.

Mercury wetted switches are not a popular option today, primarily due to mercury's toxicity.

- **Timing Based**

Timing based techniques rely on adding sufficient delays that the extra transitions introduced by bounce are ignored. Their big advantage is they do not require any special design on the switch side and so are generally cheaper. However for good performance they must be designed to suit the switch (too much delay and the response will be needlessly sluggish, too little and bounce will not be eliminated).

- **Resistor/Capacitor**



If an on/off switch is used with a pull up (or pull down) resistor and a single capacitor is placed over the switch (or across the resistor, but this can cause nasty spikes of current on the power supply lines) then when the switch is closed (generally pressed) the capacitor will almost instantly discharge through the switch. But when the switch is opened (generally released) the capacitor takes some time to recharge. Therefore contact bounce will have negligible effect on the output. The slow edges can be cleaned up with a Schmitt trigger if necessary. This method has the advantage of fast response to the initial press but the current surges through the switch may be undesirable. Other RC based systems are also possible with various responses and such systems are probably the easiest method when constructing with simple logic gates and discrete components.

- ***State Machines and Software***

A finite state machine or software running on a CPU can be designed to wait a fixed number of clock cycles after any transition before registering another one. This provides a cheap option for debouncing when a microprocessor, microcontroller or gate array is already in use but is unlikely to be worthwhile if constructing with single logic gates CLPD's.

- **Hysteresis**

Alternatively, it is possible to build in hysteresis by making the position where a press is detected separate from that where a release is detected. As long as the bounces are small enough not to take the switch between these positions, bounce problems will be eliminated. Hysteresis can be mechanical or electronic (e.g. a Schmitt trigger).

1.4.9. Changeover Switch

A changeover switch provides two distinct events, the making of one contact and the breaking of the other. These can be used to feed the inputs of a flip-flop. This way the press will only be detected when the pressed contact is made and the release will only be detected when the released contact is made. When the switch is bouncing around in the middle no change is detected. To get a single logic signal from such a setup a simple SR latch can be used.

Variable Resistance

Normal switches are designed to give a hard on-off but it is also possible to design one that varies more gradually between the hard-on and hard-off states. This keeps the output changes caused by bouncing small. Then by feeding the output to a Schmitt trigger the effect of those bounce based changes can be eliminated.

1.5.BINARY REPRESENTATION OF INFORMATION

1.5.1.Basic Concept

The decimal system is the most familiar number system to us because we use it every day. It is composed of 10 symbols, which are 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. Using these symbols as digits of a number, we can express any quantity. The decimal system is also called the base-10 system because it has 10 digits.

$$(1672.63)_{10} = 1 \times 10^3 + 6 \times 10^2 + 7 \times 10^1 + 2 \times 10^0 + 6 \times 10^{-1} + 3 \times 10^{-2}$$

10^3	10^2	10^1	10^0		10^{-1}	10^{-2}
1	6	7	2	.	6	3
Most Significant Digit				Decimal point		Least Significant Digit

Figure 1.38 Example converting number from decimal to binary

Digital systems use the binary system in which there are only two symbols or possible digit values, 0 and 1. This base-2 system can be used to represent any decimal.

$$(1011.01)_2 = 1 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0 + 0 \times 2^{-1} + 1 \times 2^{-2}$$

With such binary system, it is possible to process any set of quantities exactly as we do with the decimal system ,³ Addition, subtraction, multiplication, etc.

1.5.2.Representing Binary Quantities

In digital systems, the information is presented in binary form. Binary quantities can be

represented by any device that has only two operating states or possible conditions, for instance by a switch (either open or closed). A typical voltage assignment in an electronic circuit is as follows: binary 1 „³ any voltage from 1.0 V to 1.5 V, binary 0 „³ any voltage from 0 V to 0.5 V. In such case, voltage values ranging from 0.5 V to 1.0 V are not used because this may cause error in a digital circuit.

We previously saw that any analogue signal can be converted into a digital signal with an arbitrary number of levels:

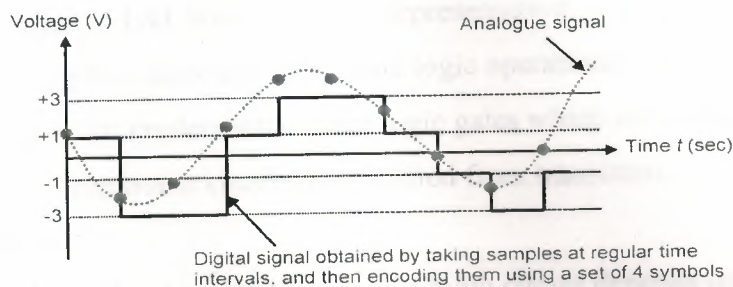


Figure 1.39

Generally, the number of levels is a power of 2 so that the digital signal can be further converted into a binary digital signal, i.e. a string of bits:

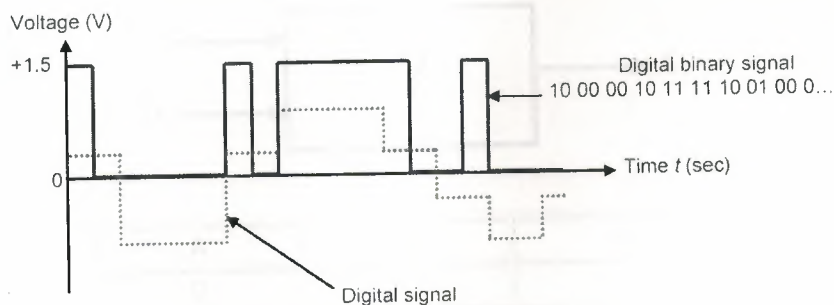


Figure 1.40 Digital binary signal

We can see another significant difference between digital and analogue systems. In digital systems, the exact value of a voltage is not important. For instance, a voltage of 1.0 V means the same as a voltage of 1.5 V. In analogue systems, the exact value of a voltage is important.

1.5.3. Boolean Variables and Logic Gates

- **Boolean algebra**

Boolean algebra differs from ordinary algebra in the sense that Boolean constants and variables can only take two values: 0 or 1. Booleans 0 and 1 do not represent actual

numbers but instead represent the state of a voltage variable, or what is called its logic level. Some common representations of 0 and 1 are shown in the following table.

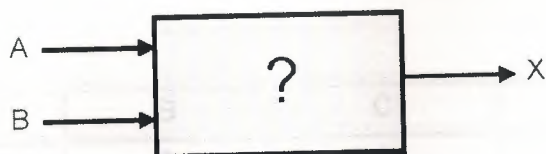
Logic 0	Logic 1
False	True
Off	On
Low	High
No	Yes
Open Switch	Close Switch

Figure 1.41 Some common representations of 0 and 1

In Boolean algebra, there are three basic logic operations: OR, AND, and NOT. These operations are implemented using logic gates which are in practice simple electronic circuits constructed from transistors.

1.5.4. Truth Table

A truth table describes how the output of a logic circuit depends on the logic levels present at the input. In the following two-input logic circuit, the table lists all possible combinations of logic levels present at inputs A and B along with the corresponding output level X.



A	B	X
0	0	0
0	1	1
1	0	1
1	1	1

Figure 1.42 Truth table for the logic circuit

When either input A OR B is 1, the output X is 1. Therefore the "?" in the box is an OR gate.

• OR Gate

The OR operation produces a result of 1 when any of the input variables is 1, and it produces a result of 0 only when all the input variables are 0.

An example of three-input OR gate and its truth table is as follows:



A	B	C	X
0	0	0	0
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	1

Figure 1.43 OR gate

• AND Gate

The AND operation produces a result of 1 only when all the input variables are 1.

The output is 0 for any case where one or more inputs are 0.

An example of three-input AND gate and its truth table is as follows:



A	B	C	X
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	1

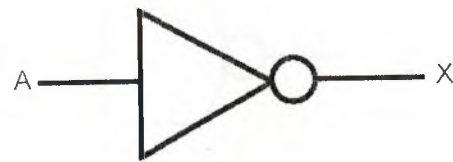
$$\Rightarrow X = ABC$$

Figure 1.44 AND gate

• NOT Gate (Inverter)

The NOT operation is performed on a single input variable. Its symbol and truth table are as follows:

A	X
0	1
1	0

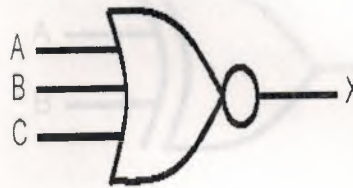


$$\Rightarrow X = A'$$

Figure 1.45 NOT gate

- Other Popular Logic Gates

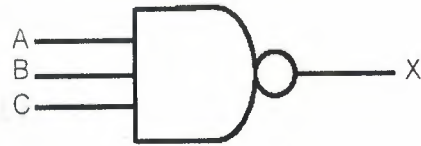
NOR Gate: $X = (A + B + C)'$



A	B	C	X
0	0	0	1
0	0	1	0
0	1	0	0
0	1	1	0
1	0	0	0
1	0	1	0
1	1	0	0
1	1	1	0

Figure 1.46 NOR gate

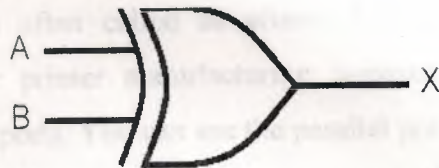
NAND Gate: $X = (AB)'$



A	B	C	X
0	0	0	1
0	0	1	1
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	1
1	1	0	1
1	1	1	0

Figure 1.47 NAND gate

XOR Gate: $X = A \oplus B = AB' + A'B$



A	B	X
0	0	0
0	1	1
1	0	1
1	1	0

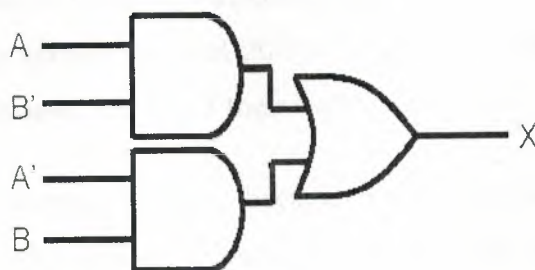


Figure 1.28 XOR gate

CHAPTER TWO

PARALLEL PORT

2.1.Introduction to Parallel Ports

Parallel port is a simple and inexpensive tool for building computer controlled devices and projects. The simplicity and ease of programming makes parallel port popular in electronics hobbyist world. The parallel port is often used in Computer controlled robots, Atmel/PIC programmers, home automation, ...etc... Here a simple tutorial on parallel port interfacing and programming with some examples.

Everybody knows what is parallel port, where it can be found, and for what it is being used. the primary use of parallel port is to connect printers to computer and is specifically designed for this purpose. Thus it is often called as printer Port or Centronics port (this name came from a popular printer manufacturing company 'Centronics' who devised some standards for parallel port). You can see the parallel port connector in the rear panel of your PC. It is a 25 pin female (DB25) connector (to which printer is connected). On almost all the PCs only one parallel port is present, but you can add more by buying and inserting ISA/PCI parallel port cards.

2.2.History of the Parallel Port

The Centronics Model 101 printer was introduced in 1970 and included the first parallel interface for printers.^[1] The interface was developed by Dr. An Wang, Robert Howard and Prentice Robinson at Wang Laboratories. The now-familiar connector was selected because Wang had a surplus stock of 20,000 Amphenol 36-pin micro ribbon connectors that were originally used for one of their early calculators.

The Centronics parallel interface quickly became a de facto industry standard; manufacturers of the time tended to use various connectors on the system side, so a variety of cables were required. For example, early VAX systems used a DC-37 connector, NCR used the 36-pin micro ribbon connector, Texas Instruments used a 25-pin card edge connector and Data General used a 50-pin micro ribbon connector.

Dataproducts introduced a very different implementation of the parallel interface for their printers. It used a DC-37 connector on the host side and a 50 pin connector on the printer side—either a DD-50 (sometimes incorrectly referred to as a "DB50") or the block shaped M-50 connector; the M-50 was also referred to as Winchester.^{[2][3]} Dataproducts parallel was available in a short-line for connections up to 50 feet (15 m) and a long-line version for connections from 50 feet (15 m) to 500 feet (150 m). The Dataproducts interface was found on many mainframe systems up through the 1990s, and many printer manufacturers offered the Dataproducts interface as an option.

IBM released the IBM Personal Computer in 1981 and included a variant of the Centronics interface— only IBM logo printers (rebranded from Epson) could be used with the IBM PC.^[4] IBM standardized the parallel cable with a DB25F connector on the PC side and the Centronics connector on the printer side. Vendors soon released printers compatible with both standard Centronics and the IBM implementation.

IBM implemented an early form of bidirectional interface in 1987. HP introduced their version of bidirectional, known as *Bitronics*, on the LaserJet 4 in 1992. The Bitronics and Centronics interfaces were superseded by the IEEE 1284 standard in 1994.

2.3.Uses

Before the advent of USB, the parallel interface was adapted to access a number of peripheral devices other than printers. Probably one of the earliest devices to use parallel were dongles used as a hardware key form of software copy protection. Zip drives and scanners were early implementations followed by external modems, sound cards, webcams, gamepads, joysticks and external hard disk drives and CD-ROM drives. Adapters were available to run SCSI devices via parallel. Other devices such as EPROM programmers and hardware controllers could be connected parallel.

2.4.Current Use

At the consumer level, the USB interface—and in some cases Ethernet—has effectively replaced the parallel printer port. Many manufacturers of personal computers and laptops consider parallel to be a legacy port and no longer include the parallel

interface. USB to parallel adapters are available to use parallel-only printers with USB-only systems.

2.5.Implementation on IBM Personal Computers

Port Addresses

Traditionally IBM PC systems have allocated their first three parallel ports according to the configuration in the table below.

PORT NAME	Interrupt #	Starting I/O	Ending I/O
-----------	-------------	--------------	------------

LPT1	IRQ 7	0x378	0x37f
LPT2	IRQ 7	0x278	0x27f
LPT3	IRQ 5	0x3bc	0x3bf

If there is an unused LPTx slot, the port addresses of the others are moved up. (For example, if a port at 0x3bc does not exist, the port at 0x378 will then become LPT1.)^[citation needed] The IRQ lines, however, remain fixed (therefore, 0x378 at LPT1 would use IRQ 7)^[citation needed]. Unfortunately the default IRQ used by the first two addresses is the same, and it's difficult to get correct interrupt behaviour if both of these addresses are in use. The port addresses assigned to each LPTx slot can be determined by reading the BIOS Data Area (BDA) at 0000:0408.

Bit to Pin Mapping for the Standard Parallel Port (SPP):

Address	MSB	LSB
	Bit: 7	6 5 4 3 2 1 0
Base	Pin: 9	8 7 6 5 4 3 2
Base+1	Pin: ~11	10 12 13 15
Base+2	Pin:	~17 16 ~14 ~1

~ indicates a hardware inversion of the bit.

2.6.Monodirectional Parallel Ports

In early parallel ports the data lines were monodirectional (data out only) so it was not easily possible to feed data in to the computer. However, a workaround was possible by using 4 of the 5 status lines. A circuit could be constructed to split each 8-bit byte into two 4-bit nibbles which were fed in sequentially through the status lines. Each pair of nibbles was then re-combined into an 8-bit byte.

2.7.Pinouts

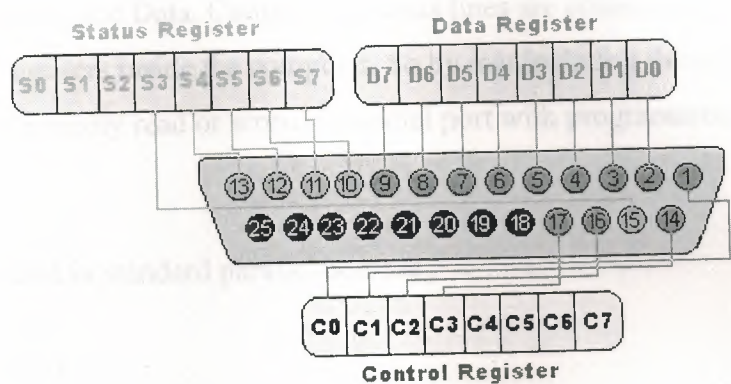


Figure 2.1:Parallel port

Pin No (DB25)	Signal name	Direction	Register - bit	Inverted
1	nStrobe	Out	Control-0	Yes
2	Data0	In/Out	Data-0	No
3	Data1	In/Out	Data-1	No
4	Data2	In/Out	Data-2	No
5	Data3	In/Out	Data-3	No
6	Data4	In/Out	Data-4	No
7	Data5	In/Out	Data-5	No
8	Data6	In/Out	Data-6	No
9	Data7	In/Out	Data-7	No
10	nAck	In	Status-6	No
11	Busy	In	Status-7	Yes
12	Paper-Out	In	Status-5	No

13	Select	In	Status-4	No
14	Linefeed	Out	Control-1	Yes
15	nError	In	Status-3	No
16	nInitialize	Out	Control-2	No
17	nSelect-Printer	Out	Control-3	Yes
18-25	Ground	-	-	-

2.8.Parallel Port Registers

As you know, the Data, Control and status lines are connected to there corresponding registers inside the computer. So by manipulating these registers in program , one can easily read or write to parallel port with programming languages like 'C' and BASIC.

The registers found in standard parallel port are ,

- 1) data register
- 2) Status register
- 3) Control register

As there names specifies, Data register is connected to Data lines, Control register is connected to control lines and Status register is connected to Status lines. (Here the word connection does not mean that there is some physical connection between data/control/status lines. The registers are virtually connected to the corresponding lines.). So what ever you write to these registers , will appear in corresponding lines as voltages, Of course, you can measure it with a multimeter. And What ever you give to Parallel port as voltages can be read from these registers(with some restrictions). For example , if we write '1' to Data register , the line Data0 will be driven to +5v. Just like this ,we can programmatically turn on and off any of the data lines and Control lines.

Where these registers are?

In an IBM PC, these registers are IO mapped and will have unique address. We have to find these addresses to work with parallel port. For a typical PC , the base address of LPT1 is 0x378 and of LPT2 is 0x278. The data register resides at this base

address , status register at baseaddress + 1 and the control register is at baseaddress + 2.
So once we have the base address , we can calculate the address of each registers in this
manner. The table below shows the register addresses of LPT1 and LPT2

CHAPTER THREE

WORKING PRINCIPLE OF RF-CAR AND REMOTE

3.1.Circuit of the Remote Control Car

This add-on circuit enables remote switching on/off of battery-operated toy cars with the help of a TV/ video remote control handset operating at 30–40 kHz. When the circuit is energised from a 6V battery, the decade counter CD4017 (IC2), which is configured as a toggle flip-flop, is immediately reset by the power-on reset combination of capacitor C3 and resistor R6. LED1 connected to pin 3 (Q0) of IC2 via resistor R5 glows to indicate the standby condition.

In standby condition, data output pin of the integrated infrared receiver/demodulator SFH505A or TSOP1738) is at a high level (about 5 volts) and transistor T1 is 'off' (reverse biased). The monostable wired around IC1 is inactive in this condition. When any key on the remote control handset is depressed, the output of the IR receiver momentarily transits through low state and transistor T1 conducts. As a result, the monostable is triggered and a short pulse is applied to the clock input (pin 14) of IC2, which takes Q1 output (pin 2) of IC2 high to switch on motor driver transistor T2 via base bias resistor R7 and the motor starts rotating continuously (car starts running).

Resistor R8 limits the starting current. When any key on the handset is depressed again, the monostable is retriggered to reset decade counter IC2 and the motor is switched off. Standby LED1 glows again. This circuit can be easily fabricated on a general-purpose printed board.

After construction, enclose it inside the toy car and connect the supply wires to the battery of the toy car with right polarity. Rewire the DC motor connections and fix the IR receiver module in a suitable location, for example, behind the front glass, and connect its wires to the circuit board using a short 3-core ribbon cable/shielded wire.

Note. Since the circuit uses modulated infrared beam for control function, ambient light reflections will not affect the circuit operation. However, fluorescent tubelights with electronic ballasts and CFL lamps may cause malfunctioning of the circuit.

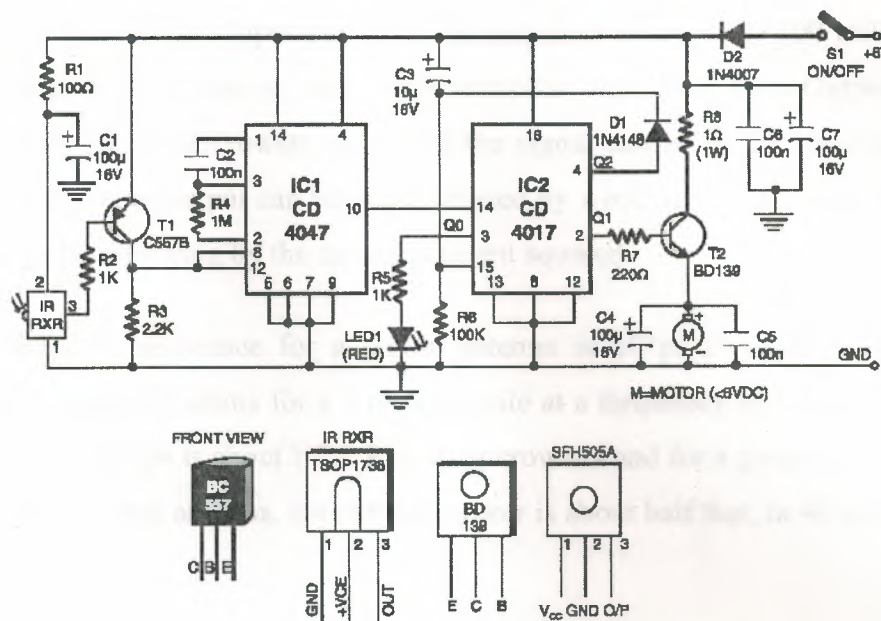


Figure 3.1. Circuit of the remote control car

3.2. Circuit of the Remote Control

In this circuit, a 74HC14 hex Schmitt trigger inverter is used as a square wave oscillator to drive a small signal transistor in a class C amplifier configuration. The oscillator frequency can be either fixed by a crystal or made adjustable (VFO) with a capacitor/resistor combination. A 100pF capacitor is used in place of the crystal for VFO operation.

Amplitude modulation is accomplished with a second transistor that controls the DC voltage to the output stage. The modulator stage is biased so that half the supply voltage or 6 volts is applied to the output stage with no modulation. The output stage is tuned and matched to the antenna with a standard variable 30-365 pF capacitor. Approximately 20 milliamps of current will flow in the antenna lead (at frequencies near the top of the band) when the output stage is optimally tuned to the oscillator frequency. A small 'grain of wheat' lamp is used to indicate antenna current and optimum settings.

The 140 uH inductor was made using a 2 inch length of 7/8 inch (OD) PVC pipe wound with 120 turns of #28 copper wire. Best performance is obtained near the high end of the broadcast band (1.6 MHz) since the antenna length is only a very small fraction of a wavelength. Input power to the amplifier is less than 100 milliwatts and antenna length is 3 meters or less which complies with FCC rules. Output power is somewhere in the 40 microwatt range and the signal can be heard approximately 80 feet. Radiated power output can be approximated by working out the antenna radiation resistance and multiplying by the antenna current squared.

The radiation resistance for a dipole antenna is $80 \cdot \pi^2 \cdot (\text{length}/\text{wavelength})^2$ which yields about 0.2 ohms for a 3 meter dipole at a frequency of 1.6 MHz. Radiated power at 20 milliamps is about $I^2 \cdot R = 80$ microwatts and for a grounded system with a single element whip antenna, the radiated power is about half that, or 40 microwatts.

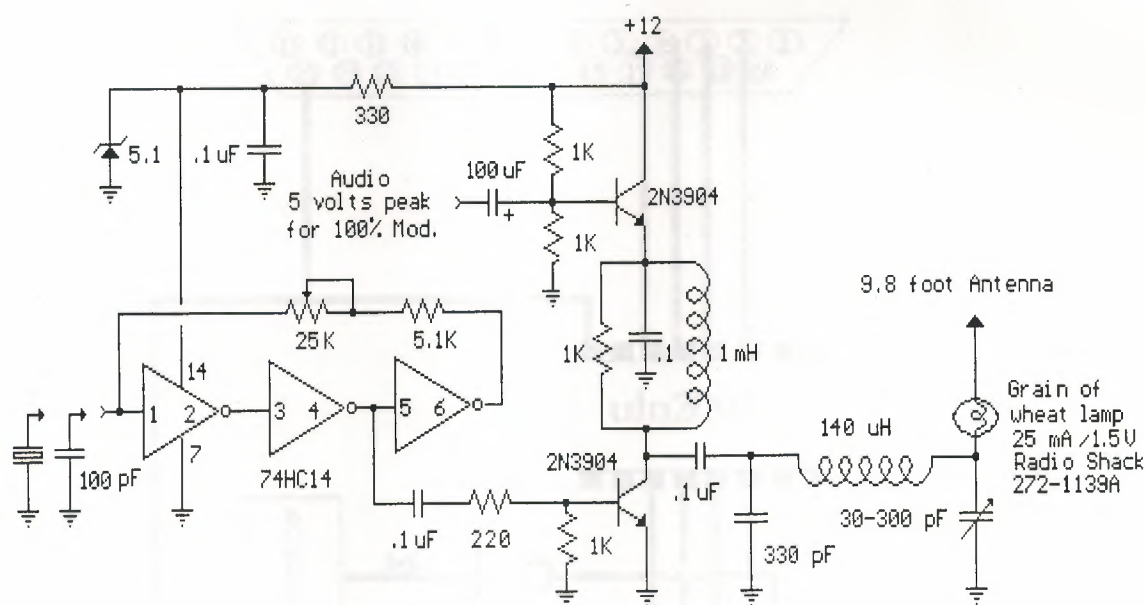


Figure 3.2. Circuit of remote control

CHAPTER FOUR

PRINCIPLE OF THE CIRCUIT AND PROGRAMME

4.1.Principle of the Controlling Crcuit

In the diagram ULN2003 is used,ULN2003 contains 7 NPN-TRANSISTOR and included DIOT the using of ULN2003 is shown at the diagram;
The numbers of pin 3,4,5, and 6 is controlled by the DATA pin of the parallel-port that is 5V for example if we apply 5V to pin-3 the pin-14 will be grounded the principle is same for all the conditions like for 4;13 for 5;12 for 6;11 numbers of pin will be grounded

In the project we must concern about the connecting remote-control's ground with parallel port's ground in this situation the groud that is used for the applying signal to ULN2003 will be common for the remote control's ground

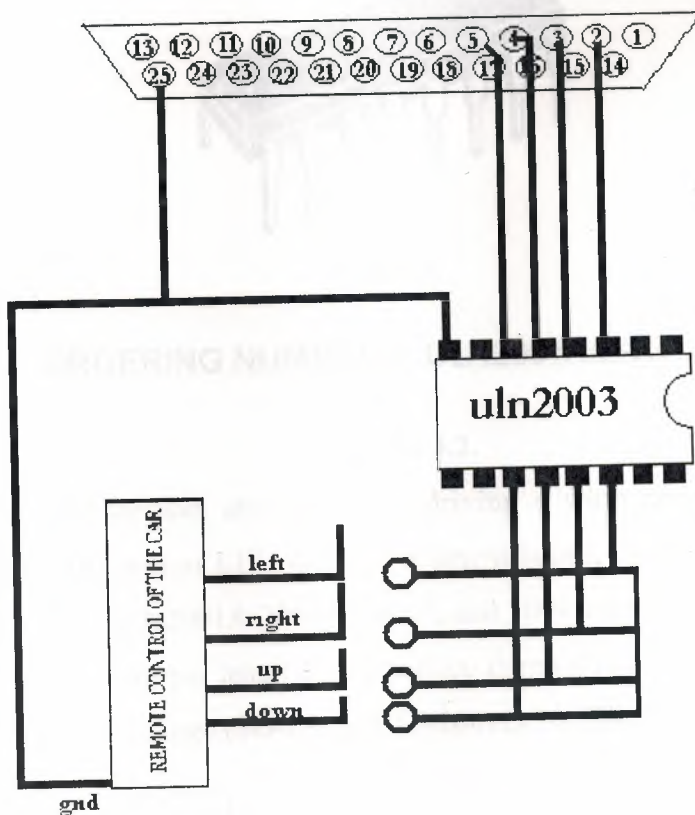
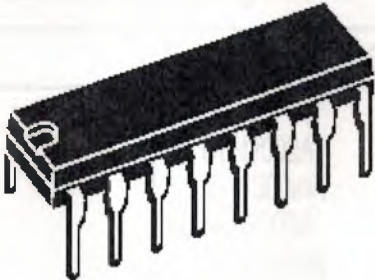


Figure 4.1. Connecting circuit to the computer

4.2.Specification of the ULN2003

Outputs to simplify layouts description The ULN2001A,ULN2002A, ULN2003 and ULN2004A are high voltage, high current darlington arrays each containing seven open collector darlington pairs with common emitters. Each channel rated at 500mA and can withstand peak currents of 600mA. Suppression diodes are included for inductive load driving and the inputs are pinned opposite the outputs to simplify board layout.

ULN2001A	General Purpose, DTL, TTL, PMOS, CMOS
ULN2002A	14-25V PMOS
ULN2003A	5V TTL, CMOS
ULN2004A	6-15V CMOS, PMOS

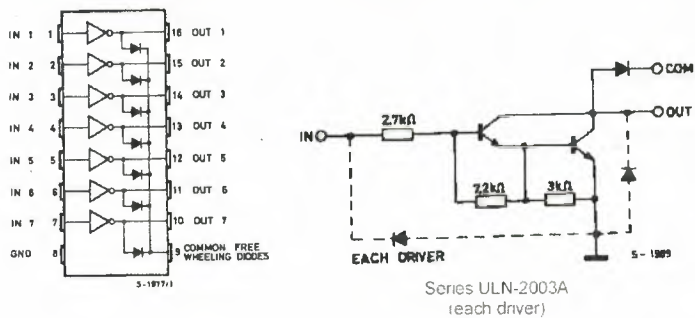


DIP16

ORDERING NUMBERS: ULN2001A/2A/3A/4A

Figure 4.2.

These versatile devices are useful for driving a wide range of loads including solenoids, relays DC motors, LED displays filament lamps, thermal printheads and high power buffers. The ULN2001A/2002A/2003A and 2004A are supplied in 16 pin plastic DIP packages with a copper leadframe to reduce thermal resistance. They are available also in small outline package (SO-16) as ULN2001D/2002D/2003D/2004D.



ELECTRICAL CHARACTERISTICS ($T_{amb} = 25^{\circ}\text{C}$ unless otherwise specified)

Symbol	Parameter	Test Conditions	Min.	Typ.	Max.	Unit	Fig.
I_{CEX}	Output Leakage Current	$V_{CE} = 50\text{V}$			50	μA	1a
		$T_{amb} = 70^{\circ}\text{C}, V_{CE} = 50\text{V}$			100	μA	1a
		$T_{amb} = 70^{\circ}\text{C}$ for ULN2002A $V_{CE} = 50\text{V}, V_i = 6\text{V}$			500	μA	1b
		for ULN2004A $V_{CE} = 50\text{V}, V_i = 1\text{V}$			500	μA	1b
$V_{CE(sat)}$	Collector-emitter Saturation Voltage	$I_C = 100\text{mA}, I_B = 250\mu\text{A}$		0.9	1.1	V	2
		$I_C = 200\text{mA}, I_B = 350\mu\text{A}$		1.1	1.3	V	2
		$I_C = 350\text{mA}, I_B = 500\mu\text{A}$		1.3	1.6	V	2
$I_{i(on)}$	Input Current	for ULN2002A, $V_i = 17\text{V}$		0.82	1.25	mA	3
		for ULN2003A, $V_i = 3.85\text{V}$		0.93	1.35	mA	3
		for ULN2004A, $V_i = 5\text{V}$		0.35	0.5	mA	3
		$V_i = 12\text{V}$		1	1.45	mA	3
$I_{i(off)}$	Input Current	$T_{amb} = 70^{\circ}\text{C}, I_C = 500\mu\text{A}$	50	65		μA	4
$V_{i(on)}$	Input Voltage	$V_{CE} = 2\text{V}$ for ULN2002A $I_C = 300\text{mA}$ for ULN2003A $I_C = 200\text{mA}$ $I_C = 250\text{mA}$ $I_C = 300\text{mA}$ for ULN2004A $I_C = 125\text{mA}$ $I_C = 200\text{mA}$ $I_C = 275\text{mA}$ $I_C = 350\text{mA}$			13 2.4 2.7 3 5 6 7 8	V	5
h_{FE}	DC Forward Current Gain	for ULN2001A $V_{CE} = 2\text{V}, I_C = 350\text{mA}$	1000				2
C_i	Input Capacitance			15	25	pF	
t_{PLH}	Turn-on Delay Time	$0.5 V_i$ to $0.5 V_o$		0.25	1	μs	
t_{PHL}	Turn-off Delay Time	$0.5 V_i$ to $0.5 V_o$		0.25	1	μs	
I_R	Clamp Diode Leakage Current	$V_R = 50\text{V}$			50	μA	6
		$T_{amb} = 70^{\circ}\text{C}, V_R = 50\text{V}$			100	μA	6
V_F	Clamp Diode Forward Voltage	$I_F = 350\text{mA}$		1.7	2	V	7

ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Value	Unit
V_o	Output Voltage	50	V
V_{in}	Input Voltage (for ULN2002A/D - 2003A/D - 2004A/D)	30	V
I_c	Continuous Collector Current	500	mA
I_b	Continuous Base Current	25	mA
T_{amb}	Operating Ambient Temperature Range	- 20 to 85	°C
T_{stg}	Storage Temperature Range	- 55 to 150	°C
T_j	Junction Temperature	150	°C

THERMAL DATA

Symbol	Parameter	DIP16	SO16	Unit
$R_{th\ j-amb}$	Thermal Resistance Junction-ambient Max.	70	120	°C/W

4.3.Principle of the Computer Programme

If we want to turn to the left we must 'HI' the data pin 1 to make it HI we must sent the data '00000001' to the parallel port. In that situation the number 3 of ULN2003s pin will be hi for the '1' because of that 14'th pin will be low mean 'GROUND' actually we've already apply this ground to the remote-control's buttons.

Another probability is the applying 2 command in the same time for example pushing forward and left in the same time so the pins these are going to ULN2003 must be 1 both like forward-right is '00000101' in decimal degree it is 5=forward+right if the opposite jobs like forward and backward must be done together the first command is done

In the program we are keeping open the property of KEYPREVIEW to see which button is used in the programme

For every pressed button we have one variable for example if we press right button data(0) becomes '1' ,for forward data(2) becomes '4' and everytime the sum lf all 4 variables (data(0)+data(1)+data(2)+data(3)) are sent to parallel port .

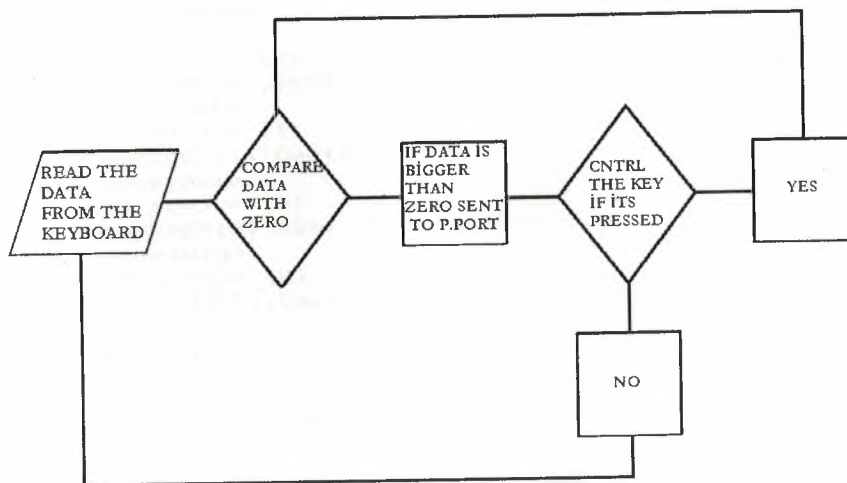


Figure 4.3.Flowchard of the program

```

Dim data(7) As Integer, top_data As Integer, adres As Integer
Private Sub Command2_Click(Index As Integer)
    If adres = 0 Then MsgBox "Please enter the parallel port address then click adjust
        example:&h378", vbCritical + vbOKOnly, "Uyarı": Exit Sub
    Select Case Command2(Index).Caption
        Case "0"
            led_yak (Index)
            Command2(Index).Caption = "1"
        Case "1"
            led_sondur (Index)
            Command2(Index).Caption = "0"
    End Select
    lbl_data = top_data
End Sub
Private Sub Command3_Click()
    adres = Int(Val(txt_adres.Text))
End Sub
Private Sub Form_KeyDown(KeyCode As Integer, Shift As Integer)
    Select Case KeyCode
        Case vbKeyUp
            led_yak (2)
            Command2(2).Caption = "1"
        Case vbKeyLeft
            led_yak (1)
            Command2(1).Caption = "1"
        Case vbKeyDown
            led_yak (3)
            Command2(3).Caption = "1"
        Case vbKeyRight
            led_yak (0)
            Command2(0).Caption = "1"
    End Select
    lbl_data = top_data
End Sub
Private Sub Form_KeyUp(KeyCode As Integer, Shift As Integer)
    Select Case KeyCode
        Case vbKeyUp
            led_sondur (2)
            Command2(2).Caption = "0"
        Case vbKeyLeft
            led_sondur (1)
            Command2(1).Caption = "0"
        Case vbKeyDown
            led_sondur (3)
            Command2(3).Caption = "0"
        Case vbKeyRight
            led_sondur (0)
            Command2(0).Caption = "0"
    End Select
    lbl_data = top_data
End Sub
Private Sub Form_Load()
    adres = Int(Val(txt_adres.Text))
    Out adres, 0
End Sub
Sub led_yak(pin_no As Integer)
    led(pin_no).FillColor = &HFF&
    top_data = 0
    Select Case pin_no
        Case 0
            data(0) = 1
        Case 1
            data(1) = 2
        Case 2
            data(2) = 4
        Case 3
            data(3) = 8
        Case 4
            data(4) = 16
        Case 5
            data(5) = 32
    End Select
End Sub

```



```

Case 6
    data(6) = 64
Case 7
    data(7) = 128
End Select
For i = 0 To 7
    top_data = top_data + data(i)
Next i
Out adres, top_data
End Sub
Sub led_sondur(pin_no As Integer)
    led(pin_no).FillColor = &H000000
    top_data = 0
    data(pin_no) = 0
    For i = 0 To 7
        top_data = top_data + data(i)
    Next i
    Out adres, top_data
End Sub

```

CONCLUSION

Parallel port controlling to any electronical device by computer is combining two kind of different work; Programming and Controlling; the remote controll toy car is also can be consumed as rf-circuit the good thing of controlling that circuit with parallel port is sending data and by these datas see the result(answer)

But the madelian has a bad face too its the being not able to receiving data actually for a good experiment that aims the getting all the conditions of the place that receiver is in it, like RESCUING robot this kind of robot must send also data from the area to computer

Actually my aim before starting that project is a kind of two dimensional data robot sending and receiving data but this project is just one dimension getting data but also this is wery good point for the beginning of rescue robot

With suitable situations and parts we could create better robot such that this has property of getting image of the room and temperature that has infra-red lens that can see in the dark and receive the informations to the computers

Controlling engineering is my dream department becaose it contains all de department that is usefull for the life and the producing good things just enought information brave and hard working its not so hard to getting steps to the robotic future, but on my all four years in my school i alsa learned wery good information from my teachers A GOOD ENGINEER MUST HAVE 3 PROPERTY ;GOOD CHARACTER, LANGUAGE, TECHNICAL PRACTISE...

REFERENCES

- [1] S. Le Goff School of Electrical, Electronic & Computer Engineering Newcastle University “<http://www.ncl.ac.uk/eece/lecture-notes/eee2010/EEE235.pdf>“
- [2] Implementation on IBM personal computers
“http://en.wikipedia.org/wiki/Parallel_port“
- [3] Circuit ideas “http://www.qsl.net/yo5ofh/hobby%20circuits/rf_circuits.htm“
- [4] Bill Bowden, “http://ourworld.compuserve.com/homepages/Bill_Bowden/“
- [5] datasheet“www.datasheetcatalog.com“
- [6] <http://en.wikipedia.org/wiki/Capacitor>
- [7] <http://en.wikipedia.org/wiki/Resistor>
- [8][http://logix4u.net/Legacy_Ports/Parallel_Port/A_tutorial_on_Parallel_port_Interfacin
g.html](http://logix4u.net/Legacy_Ports/Parallel_Port/A_tutorial_on_Parallel_port_Interfacin_g.html)
- [9]<http://en.wikipedia.org/wiki/Switch>