Over Voltage/Under Voltage Load Protection with GSM Alert

Report Submitted in partial fulfillment of requirement for the award of degree of

Bachelor of Engineering

In

Electrical Engineering

SUBMITTED BY

KHAN ASRAF ANEES (18DEE10)
MOMIN HASHIR RAZA NASIR HUSSAIN (18DEE16)
SAYYED MOHD AUF WAQAS AHD (18DEE24)
SHAIKH ADIL MUSHTAQUE (18DEE26)

Under the guidance of

Prof. Tahoora Qureshi

DEPARTMENT OF ELECTRICAL ENGINEERING

Anjuman-I-Islam's Kalsekar Technical Campus, Panvel

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CERTIFICATE

This is to certify that the dissertation titled **"Over Voltage/Under Voltage Load Protection with GSM Alert"**, which is being submitted herewith for the award of the, **'Bachelor of Engineering'** in **Electrical Engineering** of Anjuman-I-Islam's Kalsekar Technical Campus, New Panvel (M.S., India). This is the result of the original research work and contribution by **'Mr. khan Asraf , Mr. Momin Hashir Raza, Mr. Sayyed Auf and Mr. Shaikh Adil'** under my supervision and guidance. The work embodied in this dissertation has not formed earlier for the basis of award of any degree or compatible certificate or similar title of this for any other diploma/examining body or university to the best of knowledge and belief.

Place: Panvel

Date:

Prof. Rizwan Farade

H.O.D.

Name of Guide

Prof. Tahoora Qureshi

Name of Director

Abdul Razzak Honnutagi

DECLARATION

I hereby declare that I have formed, completed and written the dissertation entitled "**Over Voltage/Under Voltage Load Protection with GSM Alert**". It has not previously submitted for the basis of the award of any degree or diploma or either similar title of this for any other diploma/examining body/university.

Place: Panvel

Date:

Khan Asraf

Hashir Raza

Sayyed Mohd Auf

Shaikh Adil

ACKNOWLEDGEMENT

It is a matter of great pleasure and proud privilege to be able to present this project “**Over Voltage/Under Voltage Load Protection with GSM Alert**”.

We would like to express our deep regards and gratitude to the Head of the department **Mr. Rizwan Farade.**

The completion of this project work is a milestone in student life and its execution is inevitable in the hands of a guide. We are highly indebted to our project guide **Prof. Tahoora Qureshi**, for his invaluable guidance and appreciation for giving form and substance to this report. It is due to his enduring efforts, patience, and enthusiasm which has given this project a sense of direction and purposefulness to this project and ultimately made it in success.

We would also like to tender our sincere thanks to the staff members for their co-operation.

We would also like to thank the non-teaching staff and our friends who have helped us all the time in one way or another.

ABSTRACT

This project aims to build a system that monitors voltage and provides a breakpoint based low and high voltage tripping mechanism that avoids any damage to the load. Various industrial and domestic systems consist of fluctuation in the AC mains supply. There is a chance of damaging electronic devices that are quite sensitive to these fluctuations. So there needs to be a tripping system that avoids any damage to these loads. This system also includes 8051 microcontroller which finds out the voltage level which is displayed on the LCD screen. This microcontroller not only finds out the voltage level but also send SMS via GSM modem which alerts the user whenever the voltage level is crosses the limits.

Our system consists of a tripping mechanism that monitors the input voltage and trips according to limits provides. Here we use a quad comparator IC with two more comparators to be used as window comparators to it. Well the system delivers an error as soon as the input voltage falls out of the window range. This trigger then operates a relay that cuts off the load to avoid any damage to it. We here use a lamp to demonstrate as a load. Well the system is also configured with an alarm that goes on as soon as tripping takes place.

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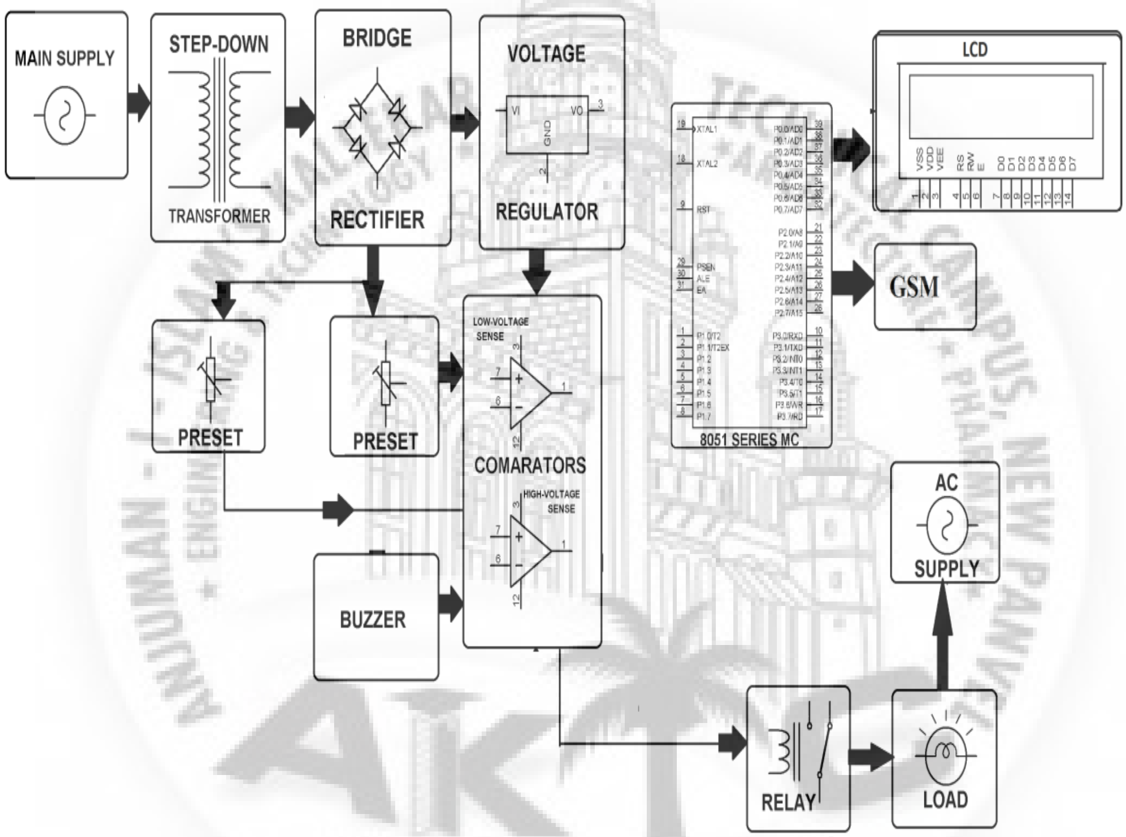
1. INTRODUCTION

Our system consists of a tripping mechanism that monitors the input voltage and trips according to limits provides. Here we use a quad comparator IC with two more comparators to be used as window comparators to it. Well the system delivers an error as soon as the input voltage falls out of the window range. This trigger then operates a relay that cuts off the load to avoid any damage to it. We here use a lamp to demonstrate as a load. Well the system is also configured with an alarm that goes on as soon as tripping takes place.

2. BLOCK DIAGRAM



3. COMPONENTS USED

1. TRANSFORMERS
2. MICRCONTROLLER AT89S52
3. LCD DISPLAY
4. GSM MODEM
5. MAX 232
6. 2.VOLTAGE REGULATOR (LM7805)
7. RECTIFIER
8. FILTER
9. RESISTOR
10. CAPACITOR
11. LED
12. 555 TIMER

3.1 TRANSFORMER

Transformers convert AC electricity from one voltage to another with a little loss of power. Step-up transformers increase voltage, step-down transformers reduce voltage. Most power supplies use a step-down transformer to reduce the dangerously high voltage to a safer low voltage.

3.1 A TYPICAL TRANSFORMER

The input coil is called the primary and the output coil is called the secondary. There is no electrical connection between the two coils; instead they are linked by an alternating magnetic field created in the soft-iron core of the transformer. The two lines in the middle of the circuit symbol represent the core. Transformers waste very little power so the power out is (almost) equal to the power in. Note that as voltage is stepped down and current is stepped up.

The ratio of the number of turns on each coil, called the turn's ratio, determines the ratio of the voltages. A step-down transformer has a large number of turns on its primary (input) coil which is connected to the high voltage mains supply, and a small number of turns on its secondary (output) coil to give a low output voltage.

$$\text{TURNS RATIO} = (V_p / V_s) = (N_p / N_s)$$

Where,

V_p = primary (input) voltage.

V_s = secondary (output) voltage

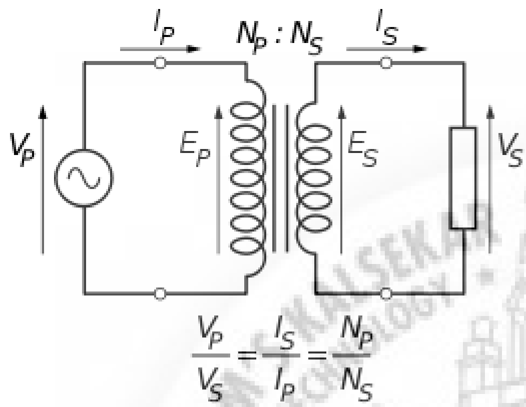
N_p = number of turns on primary coil

N_s = number of turns on secondary coil

Ip = primary (input) current

Is = secondary (output) current.

Ideal power equation



The ideal transformer as a circuit element

If the secondary coil is attached to a load that allows current to flow, electrical power is transmitted from the primary circuit to the secondary circuit. Ideally, the transformer is perfectly efficient; all the incoming energy is transformed from the primary circuit to the magnetic field and into the secondary circuit. If this condition is met, the incoming electric power must equal the outgoing power:

$$P_{\text{incoming}} = I_{\text{p}}V_{\text{p}} = P_{\text{outgoing}} = I_{\text{s}}V_{\text{s}},$$

Giving the ideal transformer equation

$$\frac{V_{\text{s}}}{V_{\text{p}}} = \frac{N_{\text{s}}}{N_{\text{p}}} = \frac{I_{\text{p}}}{I_{\text{s}}}.$$

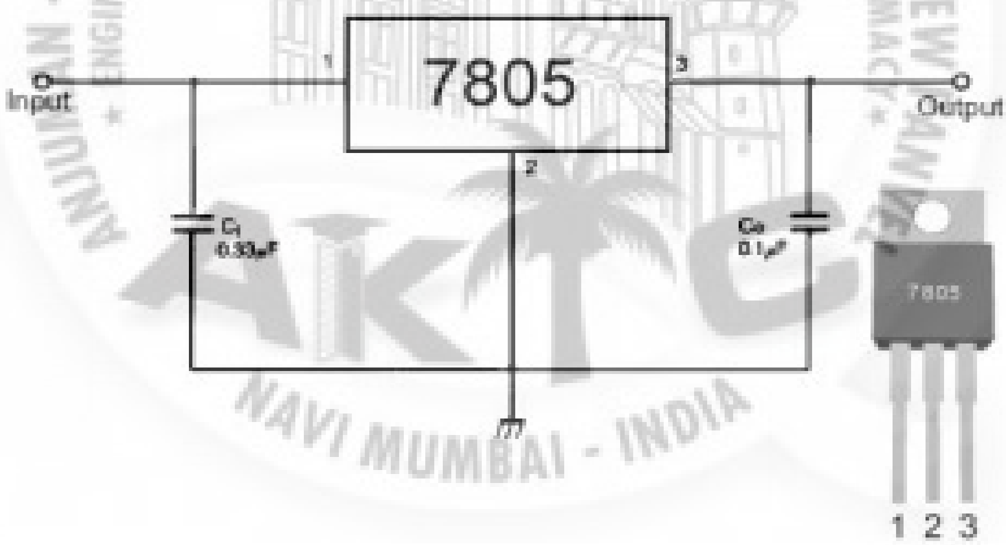
Transformers normally have high efficiency, so this formula is a reasonable approximation.

If the voltage is increased, then the current is decreased by the same factor. The impedance in one circuit is transformed by the *square* of the turns ratio.For example, if an impedance Z_s is attached across the terminals of the secondary coil, it appears to the primary circuit to have an impedance of $(N_p/N_s)^2 Z_s$. This relationship is reciprocal, so that the impedance Z_p of the primary circuit appears to the secondary to be $(N_s/N_p)^2 Z_p$.

3.2 VOLTAGE REGULATOR 7805

Features

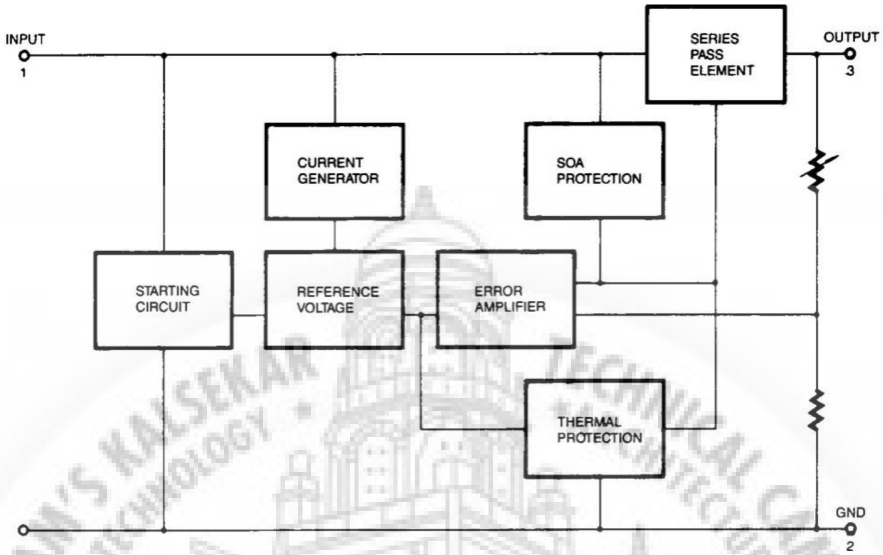
- Output Current up to 1A.
- Output Voltages of 5, 6, 8, 9, 10, 12, 15, 18, 24V.
- Thermal Overload Protection.
- Short Circuit Protection.
- Output Transistor Safe Operating Area Protection.



3.2.1 VOLTAGE REGULATOR

Description

The LM78XX/LM78XXA series of three-terminal positive regulators are available in the TO-220/D-PAK package and with several fixed output voltages, making them useful in a Wide range of applications. Each type employs internal current limiting, thermal shutdown and safe operating area protection, making it essentially indestructible. If adequate heat sinking is provided, they can deliver over 1A output Current. Although designed primarily as fixed voltage regulators, these devices can be used with external components to obtain adjustable voltages and currents.



Internal Block Diagram

3.2.2 BLOCK DIAGRAM OF VOLTAGE REGULATOR

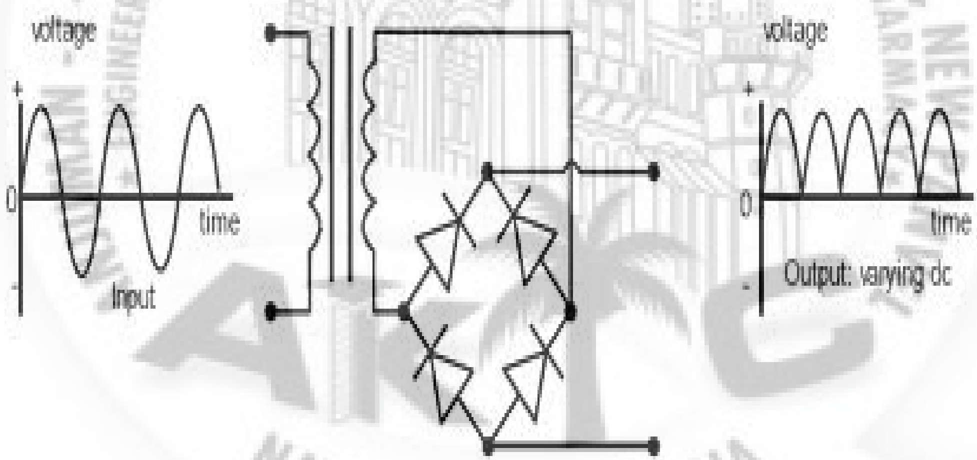
Absolute Maximum Ratings

Parameter	Symbol	Value	Unit
Input Voltage (for V_O = 5V to 18V) (for V_O = 24V)	V_I V_I	35 40	V V
Thermal Resistance Junction-Cases (TO-220)	$R_{\theta JC}$	5	°C/W
Thermal Resistance Junction-Air (TO-220)	$R_{\theta JA}$	65	°C/W
Operating Temperature Range (KA78XX/A/R)	T_{OPR}	0 ~ +125	°C
Storage Temperature Range	T_{STG}	-65 ~ +150	°C

3.2.3 RATINGS OF THE VOLTAGE REGULATOR

3.3 RECTIFIER

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), current that flows in only one direction, a process known as rectification. Rectifiers have many uses including as components of power supplies and as detectors of radio signals. Rectifiers may be made of solid statediodes, vacuum tube diodes, mercury arc valves, and other components. The output from the transformer is fed to the rectifier. It converts A.C. into pulsating D.C. The rectifier may be a half wave or a full wave rectifier. In this project, a bridge rectifier is used because of its merits like good stability and full wave rectification. In positive half cycleonly two diodes(1 set of parallel diodes) will conduct, in negative half cycle remaining two diodes will conduct and they will conduct only in forward bias only.

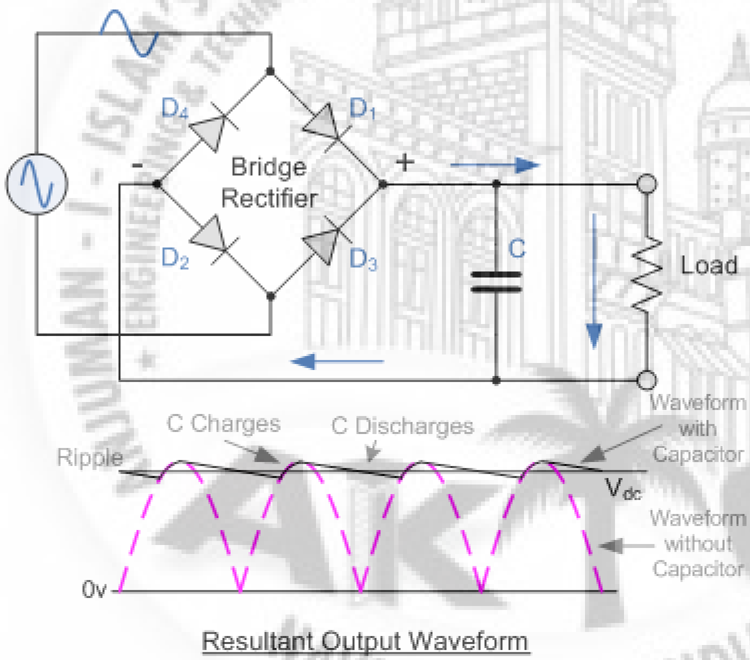


3.3 RECTIFIER

3.4 FILTER

Capacitive filter is used in this project. It removes the ripples from the output of rectifier and smoothens the D.C. Output received from this filter is constant until the mains voltage and load is maintained constant. However, if either of the two is varied, D.C. voltage received at this point changes. Therefore a regulator is applied at the output stage.

The simple capacitor filter is the most basic type of power supply filter. The use of this filter is very limited. It is sometimes used on extremely high-voltage, low-current power supplies for cathode-ray and similar electron tubes that require very little load current from the supply. This filter is also used in circuits where the power-supply ripple frequency is not critical and can be relatively high. Below figure can show how the capacitor changes and discharges.



3.4 FILTER

3.5 LCD DISPLAY

Description:

This is the example for the Parallel Port. This example doesn't use the Bi-directional feature found on newer ports, thus it should work with most, if not all Parallel Ports. It however doesn't show the use of the Status Port as an input for a 16 Character x 2 Line LCD Module to the Parallel Port. These LCD Modules are very common these days, and are quite simple to work with, as all the logic required running them is on board.

Pros:

- Very compact and light
- Low power consumption
- No geometric distortion
- Little or no flicker depending on backlight technology
- Not affected by screen burn-in
- No high voltage or other hazards present during repair/service
- Can be made in almost any size or shape
- No theoretical resolution limit

LCD Background:

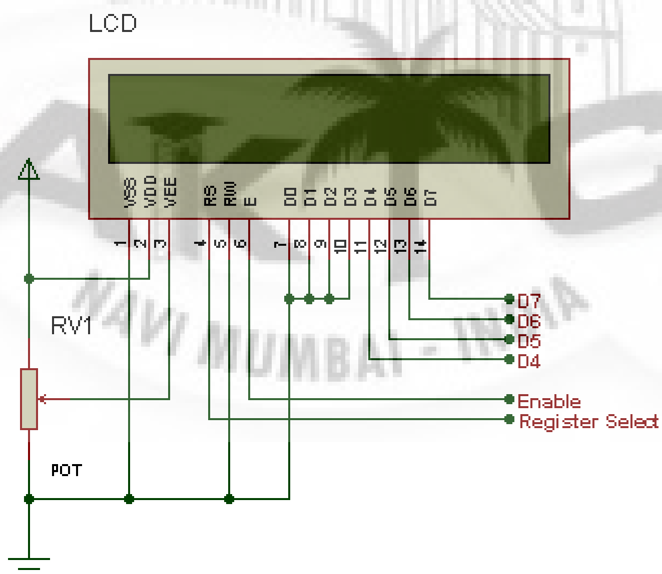
Frequently, an 8051 program must interact with the outside world using input and output devices that communicate directly with a human being. One of the most common devices attached to an 8051 is an LCD display. Some of the most common LCDs connected to the 8051 are 16x2 and 20x2 displays. This means 16 characters per line by 2 lines and 20 characters per line by 2 lines, respectively.

Fortunately, a very popular standard exists which allows us to communicate with the vast majority of LCDs regardless of their manufacturer. The standard is referred to as HD44780U, which refers to the controller chip which receives data from an external source (in this case, the 8051) and communicates directly with the LCD.

3.5.1: LCD

44780 LCD BACKGROUND

The 44780 standard requires 3 control lines as well as either 4 or 8 I/O lines for the data bus. The user may select whether the LCD is to operate with a 4-bit data bus or an 8-bit data bus. If a 4-bit data bus is used the LCD will require a total of 7 data lines (3 control lines plus the 4 lines for the data bus). If an 8-bit data bus is used the LCD will require a total of 11 data lines (3 control lines plus the 8 lines for the data bus).



3.5.2 LCD BACKGROUND

The three control lines are referred to as EN, RS, and RW.

The EN line is called "Enable." This control line is used to tell the LCD that you are sending it data. To send data to the LCD, your program should make sure this line is low (0) and then set the other two control lines and/or put data on the data bus. When the other lines are completely ready, bring EN high (1) and wait for the minimum amount of time required by the LCD datasheet (this varies from LCD to LCD), and end by bringing it low (0) again.

The RS line is the "Register Select" line. When RS is low (0), the data is to be treated as a command or special instruction (such as clear screen, position cursor, etc.). When RS is high (1), the data being sent is text data which should be displayed on the screen. For example, to display the letter "T" on the screen you would set RS high.

The RW line is the "Read/Write" control line. When RW is low (0), the information on the data bus is being written to the LCD. When RW is high (1), the program is effectively querying (or reading) the LCD. Only one instruction ("Get LCD status") is a read command. All others are write commands--so RW will almost always be low .Finally, the data bus consists of 4 or 8 lines (depending on the mode of operation selected by the user). In the case of an 8-bit data bus, the lines are referred to as DB0, DB1, DB2, DB3, DB4, DB5, DB6, and DB7.

3.6 RESISTORS

A resistor is a two-terminal electronic component designed to oppose an electric current by producing a voltage drop between its terminals in proportion to the current, that is, in accordance with Ohm's law:

$$V = IR$$

Resistors are used as part of electrical networks and electronic circuits. They are extremely commonplace in most electronic equipment. Practical resistors can be made of various compounds and films, as well as resistance wire (wire made of a high-resistivity alloy, such as nickel/chrome).

3.6.1 RESISTOR

The primary characteristics of resistors are their resistance and the power they can dissipate. Other characteristics include temperature coefficient, noise, and inductance. Less well-known is critical resistance, the value below which power dissipation limits the maximum permitted current flow, and above which the limit is applied voltage. Critical resistance depends upon the materials constituting the resistor as well as its physical dimensions; it's determined by design.

Resistors can be integrated into hybrid and printed circuits, as well as integrated circuits. Size, and position of leads (or terminals) are relevant to equipment designers; resistors must be physically large enough not to overheat when dissipating their power.

A resistor is a two-terminalpassiveelectronic component which implements electrical resistance as a circuit element. When a voltage V is applied across the terminals of a resistor, a current I will flow through the resistor in direct proportion to that voltage. The reciprocal of the constant of proportionality is known as the resistance R, since, with a given voltage V, a larger value of R further "resists" the flow of current I as given by Ohm's law:

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

Resistors are common elements of electrical networks and electronic circuits and are ubiquitous in most electronic equipment. Practical resistors can be made of various compounds and films, as well as resistance wire (wire made of a high-resistivity alloy, such as nickel-chrome). Resistors are also implemented within integrated circuits, particularly analog devices, and can also be integrated into hybrid and printed circuits.

The electrical functionality of a resistor is specified by its resistance: common commercial resistors are manufactured over a range of more than 9 orders of magnitude. When specifying that resistance in an electronic design, the required precision of the resistance may require attention to the manufacturing tolerance of the chosen resistor, according to its specific application. The temperature coefficient of the resistance may also be of concern in some precision applications. Practical resistors are also specified as having a maximum power rating which must exceed the anticipated power dissipation of that resistor in a particular circuit: this is mainly of concern in power electronics applications. Resistors with higher power ratings are physically larger and may require heat sinking. In a high voltage circuit, attention must sometimes be paid to the rated maximum working voltage of the resistor.

The series inductance of a practical resistor causes its behaviour to depart from ohms law; this specification can be important in some high-frequency applications for smaller values of resistance. In a low-noise amplifier or pre-amp the noise characteristics of a resistor may be an issue. The unwanted inductance, excess noise, and temperature coefficient are mainly dependent on the technology used in manufacturing the resistor. They are not normally specified individually for a particular family of resistors manufactured using a particular technology. A family of discrete resistors is also characterized according to its form factor, that is, the size of the device and position of its leads (or terminals) which is relevant in the practical manufacturing of circuits using them.

Units

The ohm (symbol: Ω) is the SI unit of electrical resistance, named after Georg Simon Ohm. An ohm is equivalent to a volt per ampere. Since resistors are specified and manufactured over a very large range of values, the derived units of milliohm (1 mΩ = 10^{-3} Ω), kilohms (1 kΩ = 10^3 Ω), and megohm (1 MΩ = 10^6 Ω) are also in common usage.

The reciprocal of resistance R is called conductance G = 1/R and is measured in Siemens (SI unit), sometimes referred to as a mho. Thus a Siemens is the reciprocal of an ohm: $S = \Omega^{-1}$.

Although the concept of conductance is often used in circuit analysis, practical resistors are always specified in terms of their resistance (ohms) rather than conductance.

Theory of operation

Ohm's law

The behaviour of an ideal resistor is dictated by the relationship specified in Ohm's law:

$$V = I \cdot R$$

Ohm's law states that the voltage (V) across a resistor is proportional to the current (I) passing through it, where the constant of proportionality is the resistance (R).

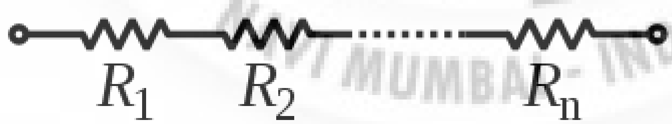
Equivalently, Ohm's law can be stated:

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

This formulation of Ohm's law states that, when a voltage (V) is present across a resistance (R), a current (I) will flow through the resistance. This is directly used in practical computations. For example, if a 300 ohm resistor is attached across the terminals of a 12 volt battery, then a current of 12 / 300 = 0.04 amperes (or 40 mill amperes) will flow through that resistor.

Series and parallel resistors

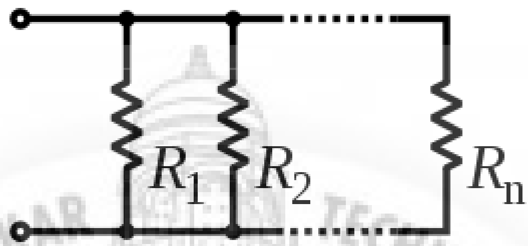
In a series configuration, the current through all of the resistors is the same, but the voltage across each resistor will be in proportion to its resistance. The potential difference (voltage) seen across the network is the sum of those voltages, thus the total resistance can be found as the sum of those resistances:



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

As a special case, the resistance of N resistors connected in series, each of the same resistance R, is given by NR.

Resistors in a parallel configuration are each subject to the same potential difference (voltage), however the currents through them add. The conductance's of the resistors then add to determine the conductance of the network. Thus the equivalent resistance (R_{eq}) of the network can be computed:



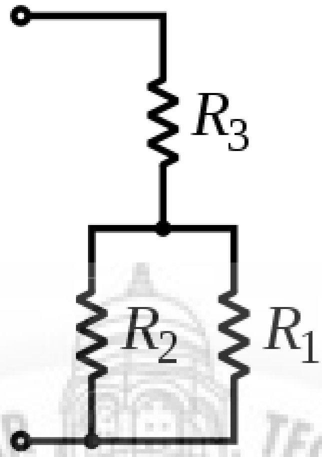
$$\frac{1}{R_{\mathrm{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_n}$$

The parallel equivalent resistance can be represented in equations by two vertical lines "||" (as in geometry) as a simplified notation. For the case of two resistors in parallel, this can be calculated using:

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

As a special case, the resistance of N resistors connected in parallel, each of the same resistance R, is given by R/N.

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



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

However, some complex networks of resistors cannot be resolved in this manner, requiring more sophisticated circuit analysis. For instance, consider a cube, each edge of which has been replaced by a resistor. What then is the resistance that would be measured between two opposite vertices? In the case of 12 equivalent resistors, it can be shown that the corner-to-corner resistance is ⅚ of the individual resistance. More generally, the Y-Δ transform, or matrix methods can be used to solve such a problem. One practical application of these relationships is that a non-standard value of resistance can generally be synthesized by connecting a number of standard values in series and/or parallel. This can also be used to obtain a resistance with a higher power rating than that of the individual resistors used. In the special case of N identical resistors all connected in series or all connected in parallel, the power rating of the individual resistors is thereby multiplied by N.

Power dissipation

The power P dissipated by a resistor (or the equivalent resistance of a resistor network) is calculated as: $P = I^2 R = IV = \frac{V^2}{R}$

The first form is a restatement of Joule's first law. Using Ohm's law, the two other forms can be derived.

The total amount of heat energy released over a period of time can be determined from the integral of the power over that period of time:

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

Practical resistors are rated according to their maximum power dissipation. The vast majority of resistors used in electronic circuits absorb much less than a watt of electrical power and require no attention to their power rating. Such resistors in their discrete form, including most of the packages detailed below, are typically rated as 1/10, 1/8, or 1/4 watt.

Resistors required to dissipate substantial amounts of power, particularly used in power supplies, power conversion circuits, and power amplifiers, are generally referred to as power resistors; this designation is loosely applied to resistors with power ratings of 1 watt or greater. Power resistors are physically larger and tend not to use the preferred values, colour codes, and external packages described below.

If the average power dissipated by a resistor is more than its power rating, damage to the resistor may occur, permanently altering its resistance; this is distinct from the reversible change in resistance due to its temperature coefficient when it warms. Excessive power dissipation may raise the temperature of the resistor to a point where it can burn the circuit board or adjacent components, or even cause a fire. There are flameproof resistors that fail (open circuit) before they overheat dangerously.

Note that the nominal power rating of a resistor is not the same as the power that it can safely dissipate in practical use. Air circulation and proximity to a circuit board, ambient temperature, and other factors can reduce acceptable dissipation significantly. Rated power dissipation may be given for an ambient temperature of 25 °C in free air. Inside an equipment case at 60 °C, rated dissipation will be significantly less; a resistor dissipating a bit less than the maximum figure given by the manufacturer may still be outside the safe operating area and may prematurely fail.

Construction

3.6.2 SINGLE IN LINE DIAGRAM

A single in line (SIL) resistor package with 8 individual, 47 ohm resistors. One end of each resistor is connected to a separate pin and the other ends are all connected together to the remaining (common) pin - pin 1, at the end identified by the white dot.

Lead arrangements

3.6.3 RESISTORS WITH WIRE LEAD FOR THROUGH-HOLE MOUNTING

Through-hole components typically have leads leaving the body axially. Others have leads coming off their body radially instead of parallel to the resistor axis. Other components may be SMT (surface mount technology) while high power resistors may have one of their leads designed into the heat sink.

Carbon composition

Carbon composition resistors consist of a solid cylindrical resistive element with embedded wire leads or metal end caps to which the lead wires are attached. The body of the resistor is protected with paint or plastic. Early 20th-century carbon composition resistors had uninsulated bodies; the lead wires were wrapped around the ends of the resistance element rod and soldered. The completed resistor was painted for colour coding of its value.

The resistive element is made from a mixture of finely ground (powdered) carbon and an insulating material (usually ceramic). A resin holds the mixture together. The resistance is determined by the ratio of the fill material (the powdered ceramic) to 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). Moreover, if internal moisture content (from exposure for some length of time to a humid environment) is significant, soldering heat will create a non-reversible change in resistance value. Carbon composition resistors have poor stability with time and were consequently factory sorted to, at best, only 5% tolerance. These resistors, however, if never subjected to overvoltage nor overheating were remarkably reliable considering the component's size.

They are still available, but comparatively quite costly. Values ranged from fractions of an ohm to 22 megohms. Because of the high price, these resistors are no longer used in most applications. However, carbon resistors are used in power supplies and welding controls.

Carbon film

A carbon film is deposited on an insulating substrate, and a helix cut in it to create a long, narrow resistive path. Varying shapes, coupled with the resistivity of carbon, (ranging from 90 to 400 nΩ m) can provide a variety of resistances. Carbon film resistors feature a power rating range of 0.125 W to 5 W at 70 °C. Resistances available range from 1 ohm to 10 megohm. The carbon film resistor has an operating temperature range of -55 °C to 155 °C. It has 200 to 600 volts maximum working voltage range. Special carbon film resistors are used in applications requiring high pulse stability.

Thick and thin film

Thick film resistors became popular during the 1970s, and most SMD (surface mount device) resistors today are of this type. The principal difference between thin film and thick film resistors is not the actual thickness of the film, but rather how the film is applied to the cylinder (axial resistors) or the surface (SMD resistors).

Thin film resistors are made by sputtering (a method of vacuum deposition) the resistive material onto an insulating substrate. The film is then etched in a similar manner to the old (subtractive) process for making printed circuit boards; that is, the surface is coated with a photo-sensitive material, then covered by a pattern film, irradiated with ultraviolet light, and then the exposed photo-sensitive coating is developed, and underlying thin film is etched away.

Thick film resistors are manufactured using screen and stencil printing processes. Because the time during which the sputtering is performed can be controlled, the thickness of the thin film can be accurately controlled. The type of 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 ($Bi_2Ru_2O_7$), nickel chromium (NiCr), and/or bismuth iridate ($Bi_2Ir_2O_7$).

The resistance of both thin and thick film resistors after manufacture is not highly accurate; they are usually trimmed to an accurate value by abrasive or laser trimming. Thin film resistors are usually specified with tolerances of 0.1, 0.2, 0.5, or 1%, and with temperature coefficients of 5 to 25 ppm/K.

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.

Thick film resistors, when first manufactured, had tolerances of 5%, but standard tolerances have improved to 2% or 1% in the last few decades. Temperature coefficients of thick film resistors are high, typically ±200 or ±250 ppm/K; a 40 kelvin (70 °F) temperature change can change the resistance by 1%.

Thin film resistors are usually far more expensive than thick film resistors. For example, 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 1%, 250 ppm/K thick film resistors.

Metal film

A common type of axial resistor today is referred to as a metal-film resistor. Metal electrode leadless face (MELF) resistors often use the same technology, but are a cylindrically shaped resistor designed for surface mounting. Note that other types of resistors (e.g., 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 that is generally between 50 and 100 ppm/K. Metal film resistors possess good noise characteristics and low non-linearity due to a low voltage coefficient. Also beneficial are the components efficient tolerance, temperature coefficient and stability.

Metal Oxide film

Metal-Oxide film resistors resemble Metal film types, but are made of metal oxides such as tin oxide. This results in a higher operating temperature and greater stability/reliability than Metal film. They are used in applications with high endurance demands.

Wire wound

3.6.4 WIRE WOUND

Types of windings in wire resistors:

1 - common

2 - bifilar

3 - common on a thin former

4 - Ayrton-Perry

Wire wound resistors are commonly made by winding a metal wire, usually nichrome, around a ceramic, plastic, or fibreglass core. The ends of the wire are soldered or welded to two caps or rings, attached to the ends of the core. The assembly is protected with a layer of paint, moulded plastic, or an enamel coating baked at high temperature. Because of the very high surface temperature these resistors can withstand temperatures of up to +450 °C. Wire leads in low power wire wound resistors are usually between 0.6 and 0.8 mm in diameter and tinned for ease of soldering. For higher power wire wound 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 heat sink to dissipate the heat; the rated power is dependent on being used with a suitable heat sink, e.g., a 50 W power rated resistor will overheat at a fraction of the power dissipation if not used with a heat sink. Large wire wound resistors may be rated for 1,000 watts or more.

Because wire wound resistors are coils they have more undesirable inductance than other types of resistor, although winding the wire in sections with alternately reversed direction can minimize inductance. Other techniques employ bifilar winding, or a flat thin former (to reduce cross-section area of the coil). For most demanding circuits resistors with Ayrton-Perry winding are used.

Applications of wire wound resistors are similar to those of composition resistors with the exception of the high frequency. The high frequency of wire wound resistors is substantially worse than that of a composition resistor.

Foil resistor

The primary resistance element of a foil resistor is a special alloy foil several micrometres thick. Since their introduction in the 1960s, foil resistors have had the best precision and stability of any resistor available. One of the important parameters influencing stability is the temperature coefficient of resistance (TCR). The TCR of foil resistors is extremely low, and has been further improved over the years. One range of ultra-precision foil resistors offers a TCR of

0.14 ppm/°C, tolerance ±0.005%, long-term stability (1 year) 25 ppm, (3 year) 50 ppm (further improved 5-fold by hermetic sealing), stability under load (2000 hours) 0.03%, thermal EMF 0.1 μV/°C, noise -42 dB, voltage coefficient 0.1 ppm/V, inductance 0.08 μH, capacitance 0.5 pF.

Ammeter shunts

An ammeter shunt is a special type of current-sensing resistor, having four terminals and a value in milliohms or even micro-ohms. Current-measuring instruments, by themselves, can usually accept only limited currents. To measure high currents, the current passes through the shunt, where the voltage drop is measured and interpreted as current. A typical shunt consists of two solid metal blocks, sometimes brass, mounted on to an insulating base. Between the blocks, and soldered or brazed to them, are one or more strips of low temperature coefficient of resistance (TCR) manganin alloy. Large bolts threaded into the blocks make the current connections, while much-smaller screws provide voltage connections. Shunts are rated by full-scale current, and often have a voltage drop of 50 mV at rated current. Such meters are adapted to the shunt full current rating by using an appropriately marked dial face; no change need be made to the other parts of the meter.

Grid resistor

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 and load banking 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.

The term grid resistor is sometimes used to describe a resistor of any type connected to the control grid of a vacuum tube. This is not a resistor technology; it is an electronic circuit topology.

Special varieties

- Metal oxide varistor

- Cermet
- Phenolic
- Tantalum
- Water resistor

Variable resistors (or) Adjustable resistors

A resistor may have one or more fixed tapping points so that the resistance can be changed by moving the connecting wires to different terminals. Some wire-wound power resistors have a tapping point that can slide along the resistance element, allowing a larger or smaller part of the resistance to be used.

Where continuous adjustment of the resistance value during operation of equipment is required, the sliding resistance tap can be connected to a knob accessible to an operator. Such a device is called a rheostat and has two terminals.

Potentiometers

A common element in electronic devices is a three-terminal resistor with a continuously adjustable tapping point controlled by rotation of a shaft or knob. These variable resistors are known as potentiometers when all three terminals are present, since they act as a continuously adjustable voltage divider. A common example is a volume control for a radio receiver.

Accurate, high-resolution panel-mounted potentiometers (or "pots") have resistance elements typically wire wound on a helical mandrel, although some include a conductive-plastic resistance coating over the wire to improve resolution. These typically offer ten turns of their shafts to cover their full range. They are usually set with dials that include a simple turns counter and a graduated dial. Electronic analog computers used them in quantity for setting coefficients, and delayed-sweep oscilloscopes of recent decades included one on their panels.

Resistance decade boxes

A resistance decade box or resistor substitution box is a unit containing resistors of many values, with one or more mechanical switches which allow any one of various discrete resistances offered by the box to be dialled in. Usually the resistance is accurate to high precision, ranging from laboratory/calibration grade accuracy of 20 parts per million, to field grade at 1%. Inexpensive boxes with lesser accuracy are also available. All types offer a convenient way of selecting and quickly changing a resistance in laboratory, experimental and development work without needing to attach resistors one by one, or even stock each value. The range of resistance provided, the maximum resolution, and the accuracy characterize the box. For example, one box offers resistances from 0 to 24 megohms, maximum resolution 0.1 ohm, accuracy 0.1%.

Special devices

There are various devices whose resistance changes with various quantities. The resistance of thermistors exhibit a strong negative temperature coefficient, making them useful for measuring temperatures. Since their resistance can be large until they are allowed to heat up due to the passage of current, they are also commonly used to prevent excessive current surges when equipment is powered on. Similarly, the resistance of a humistor varies with humidity. Metal oxide varistors drop to a very low resistance when a high voltage is applied, making them useful for protecting electronic equipment by absorbing dangerous voltage surges. One sort of photodetector, the photoresistor, has a resistance which varies with illumination.

The strain gauge, invented by Edward E. Simmons and Arthur C. Ruge in 1938, is a type of resistor that changes value with applied strain. A single resistor may be used, or a pair (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 mechanical strain. With the strain gauge and a filter, amplifier, and analog/digital converter, the strain on an object can be measured.

A related but more recent invention uses a Quantum Tunnelling Composite to sense mechanical stress. It passes a current whose magnitude can vary by a factor of 10^{12} in response to changes in applied pressure.

Measurement

The value of a resistor can be measured with an ohmmeter, which may be one function of a multimeter. Usually, probes on the ends of test leads connect to the resistor. A simple ohmmeter may apply a voltage from a battery across the unknown resistor (with an internal resistor of a known value in series) producing a current which drives a meter movement. The current flow, in accordance with Ohm's Law, is inversely proportional to the sum of the internal resistance and the resistor being tested, resulting in an analog meter scale which is very non-linear, calibrated from infinity to 0 ohms. A digital multimeter, using active electronics, may instead pass a specified current through the test resistance. The voltage generated across the test resistance in that case is linearly proportional to its resistance, which is measured and displayed. In either case the low-resistance ranges of the meter pass much more current through the test leads than do high-resistance ranges, in order for the voltages present to be at reasonable levels (generally below 10 volts) but still measurable.

Measuring low-value resistors, such as fractional-ohm resistors, with acceptable accuracy requires four-terminal connections. One pair of terminals applies a known, calibrated current to the resistor, while the other pair senses the voltage drop across the resistor. Some laboratory quality ohmmeters, especially milliohm meters, and even some of the better digital multimeters sense using four input terminals for this purpose, which may be used with special test leads. Each of the two so-called Kelvin clips has a pair of jaws insulated from each other. One side of each clip applies the measuring current, while the other connections are only to sense the voltage drop. The resistance is again calculated using Ohm's Law as the measured voltage divided by the applied current.

Standards

Production resistors

Resistor characteristics are quantified and reported using various national standards. In the US, MIL-STD-202 contains the relevant test methods to which other standards refer.

There are various standards specifying properties of resistors for use in equipment:

- BS 1852
- EIA-RS-279
- MIL-PRF-26
- MIL-PRF-39007 (Fixed Power, established reliability)
- MIL-PRF-55342 (Surface-mount thick and thin film)
- MIL-PRF-914
- MIL-R-11

- MIL-R-39017 (Fixed, General Purpose, Established Reliability)
- MIL-PRF-32159 (zero ohm jumpers)

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

Resistance standards

The primary standard for resistance, the "mercury ohm" was initially defined in 1884 in as a column of mercury 106 mm long and 1 square millimetre in cross-section, at 0 degrees Celsius. Difficulties in precisely measuring the physical constants to replicate this standard result in variations of as much as 30 ppm. From 1900 the mercury ohm was replaced with a precision machined plate of manganin. Since 1990 the international resistance standard has been based on the quantized Hall Effect discovered by Klaus von Klitzing, for which he won the Nobel Prize in Physics in 1985.

Resistors of extremely high precision are manufactured for calibration and laboratory use. They may have four terminals, using one pair to carry an operating current and the other pair to measure the voltage drop; this eliminates errors caused by voltage drops across the lead resistances, because no current flows through voltage sensing leads. It is important in small value resistors (100–0.0001 ohm) where lead resistance is significant or even comparable with respect to resistance standard value.

Resistor marking

Electronic color code

Most axial resistors use a pattern of coloured stripes to indicate resistance. Surface-mount resistors are marked numerically, if they are big enough to permit marking; more-recent small sizes are impractical to mark. Cases are usually tan, brown, blue, or green, though other colours are occasionally found such as dark red or dark gray.

Early 20th century resistors, essentially uninsulated, were dipped in paint to cover their entire body for colour coding. A second colour of paint was applied to one end of the element, and a colour dot (or band) in the middle provided the third digit. The rule was "body, tip, dot", providing two significant digits for value and the decimal multiplier, in that sequence. Default tolerance was ±20%. Closer-tolerance resistors had silver (±10%) or gold-coloured (±5%) paint on the other end.

Four-band resistors

Four-band identification is the most commonly used colour-coding scheme on resistors. It consists of four coloured bands that are painted around the body of the resistor. The first two bands encode the first two significant digits of the resistance value, the third is a power-of-ten multiplier or number-of-zeroes, and the fourth is the tolerance accuracy, or acceptable error, of the value. The first three bands are equally spaced along the resistor; the spacing to the fourth band is wider. Sometimes a fifth band identifies the thermal coefficient, but this must be distinguished from the true 5-color system, with 3 significant digits.

For example, green-blue-yellow-red is $56\times10^4\ \Omega$ = 560 kΩ ± 2%. An easier description can be as followed: the first band, green, has a value of 5 and the second band, blue, has a value of 6, and is counted as 56. The third band, yellow, has a value of 10^4, which adds four 0's to the end, creating 560,000 Ω at ±2% tolerance accuracy. 560,000 Ω changes to 560 kΩ ±2% (as a kilo- is 10^3).

Color	1st band	2nd band	3rd band (multiplier)	4th band (tolerance)	Temp. Coefficient
Black	0	0	$\times10^0$		
Brown	1	1	$\times10^1$	±1% (F)	100 ppm
Red	2	2	$\times10^2$	±2% (G)	50 ppm
Orange	3	3	$\times10^3$		15 ppm
Yellow	4	4	$\times10^4$		25 ppm
Green	5	5	$\times10^5$	±0.5% (D)	
Blue	6	6	$\times10^6$	±0.25% (C)	
Violet	7	7	$\times10^7$	±0.1% (B)	
Gray	8	8	$\times10^8$	±0.05% (A)	
White	9	9	$\times10^9$		
Gold			$\times10^{-1}$	±5% (J)	
Silver			$\times10^{-2}$	±10% (K)	

3.6.5 COLOUR BAND ±20% (M)

None

There are many mnemonics for remembering these colours.

Preferred values

Early resistors were made in more or less arbitrary round numbers; a series might have 100, 125, 150, 200, 300, etc. Resistors as manufactured are subject to a certain percentage tolerance, and it makes sense to manufacture values that correlate with the tolerance, so that the actual value of a resistor overlaps slightly with its neighbours. Wider spacing leaves gaps; narrower spacing increases manufacturing and inventory costs to provide resistors that are more or less interchangeable.

A logical scheme is to produce resistors in a range of values which increase in a geometrical progression, so that each value is greater than its predecessor by a fixed multiplier or percentage, chosen to match the tolerance of the range. For example, for a tolerance of ±20% it makes sense to have each resistor about 1.5 times its predecessor, covering a decade in 6 values. In practice the factor used is 1.4678, giving values of 1.47, 2.15, 3.16, 4.64, 6.81, 10 for the 1-10 decade (a decade is a range increasing by a factor of 10; 0.1-1 and 10-100 are other examples); these are rounded in practice to 1.5, 2.2, 3.3, 4.7, 6.8, 10; followed, of course by 15, 22, 33, … and preceded by … 0.47, 0.68, 1. This scheme has been adopted as the E6 range of the IEC 60063 preferred number series. There are also E12, E24, E48, E96 and E192 ranges for components of ever tighter tolerance, with 12, 24, 96, and 192 different values within each decade. The actual values used are in the IEC 60063 lists of preferred numbers.

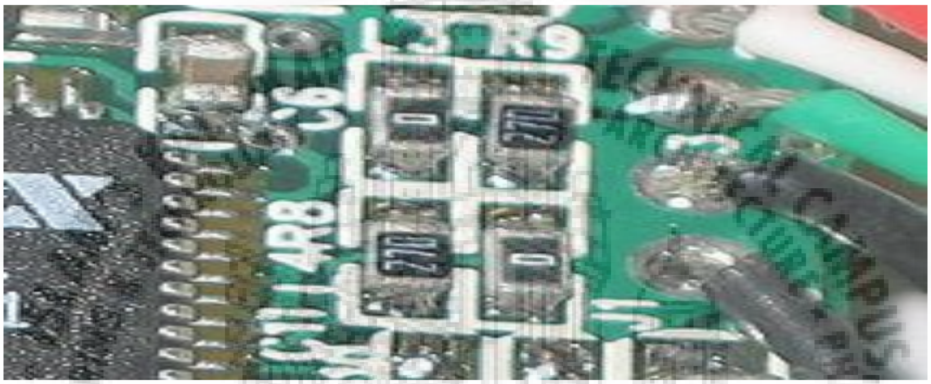
A resistor of 100 ohms ±20% would be expected to have a value between 80 and 120 ohms; its E6 neighbours are 68 (54-82) and 150 (120-180) ohms. A sensible spacing, E6 is used for ±20% components; E12 for ±10%; E24 for ±5%; E48 for ±2%, E96 for ±1%; E192 for ±0.5% or better. Resistors are manufactured in values from a few milliohms to about a gigaohm in IEC60063 ranges appropriate for their tolerance.

Earlier power wire-wound resistors, such as brown vitreous-enamelled types, however, were made with a different system of preferred values, such as some of those mentioned in the first sentence of this section.

5-band axial resistors

5-band identification is used for higher precision (lower tolerance) resistors (1%, 0.5%, 0.25%, 0.1%), to specify a third significant digit. The first three bands represent the significant digits, the fourth is the multiplier, and the fifth is the tolerance. Five-band resistors with a gold or silver 4th band are sometimes encountered, generally on older or specialized resistors. The 4th band is the tolerance and the 5th the temperature coefficient.

SMD resistors



3.6.6 SMD RESISTOR

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. Of course, their resistance is non-zero, although quite low. Zero is simply a brief description of their function.

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 × 10^4 ohms = 330 kilohms

222 = 22 × 10^2 ohms = 2.2 kilohms

473 = 47 × 10^3 ohms = 47 kilohms

105 = 10 × 10^5 ohms = 1.0 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 × 10^0 ohm = 10 ohms

220 = 22 × 10^0 ohm = 22 ohms

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

Resistances less than 10 ohms have 'R' to indicate the position of the decimal point (radix point).

For example:

4R7 = 4.7 ohms

R300 = 0.30 ohms

0R22 = 0.22 ohms

0R01 = 0.01 ohms

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

1001 = 100 × 10^1 ohms = 1.00 kilohms

4992 = 499 × 10^2 ohms = 49.9 kilohms

1000 = 100 × 10^0 ohm = 100 ohms

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

More recent surface-mount resistors are too small, physically, to permit practical markings to be applied.

Industrial type designation

Format:[two letters]<space>[resistance value (three digit)]<nospace>[tolerance code(numerical - one digit)]

Power Rating at 70 °C

Type No.	Power rating (watts)	MIL-R-11 Style	MIL-R-39008 Style
BB	⅛	RC05	RCR05
CB	¼	RC07	RCR07
EB	½	RC20	RCR20
GB	1	RC32	RCR32
HB	2	RC42	RCR42
GM	3	-	-
HM	4	-	-

Tolerance Code

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

Electrical and thermal noise

In amplifying faint signals, it is often necessary to minimize electronic noise, particularly in the first stage of amplification. As dissipative elements, even an ideal resistor will naturally produce a randomly fluctuating voltage or "noise" across its terminals. This Johnson–Nyquist noise is a fundamental noise source which depends only upon the temperature and resistance of the resistor, and is predicted by the fluctuation–dissipation theorem. Using a larger resistor produces a larger voltage noise, whereas with a smaller value of resistance there will be more current noise, assuming a given temperature. The thermal noise of a practical resistor may also be somewhat larger than the theoretical prediction and that increase is typically frequency-dependent.

However the "excess noise" of a practical resistor is an additional source of noise observed only when a current flows through it. This is specified in unit of μV/V/decade - μV of noise per volt applied across the resistor per decade of frequency. The μV/V/decade value is frequently given in dB so that a resistor with a noise index of 0 dB will exhibit 1 μV (rms) of excess noise for each volt across the resistor in each frequency decade. Excess noise is thus an example of 1/*f* noise. Thick-film and carbon composition resistors generate more excess noise than other types at low frequencies; wire-wound and thin-film resistors, though much more expensive, are often utilized for their better noise characteristics. Carbon composition resistors can exhibit a noise index of 0 dB while bulk metal foil resistors may have a noise index of -40 dB, usually making the excess noise of metal foil resistors insignificant. Thin film surface mount resistors typically have lower noise and better thermal stability than thick film surface mount resistors. However, the design engineer must read the data sheets for the family of devices to weigh the various device tradeoffs.

While not an example of "noise" per se, a resistor may act as a thermocouple, producing a small DC voltage differential across it due to the thermoelectric effect if its ends are at somewhat different temperatures. This induced DC voltage can degrade the precision of instrumentation amplifiers in particular. Such voltages appear in the junctions of the resistor leads with the circuit board and with the resistor body. Common metal film resistors show such an effect at a magnitude of about 20µV/°C. Some carbon composition resistors can exhibit thermoelectric offsets as high as 400 µV/°C, whereas specially constructed resistors can reduce this number to 0.05µV/°C. In applications where the thermoelectric effect may become important, care has to be taken (for example) to mount the resistors horizontally to avoid temperature gradients and to mind the air flow over the board.

Failure modes

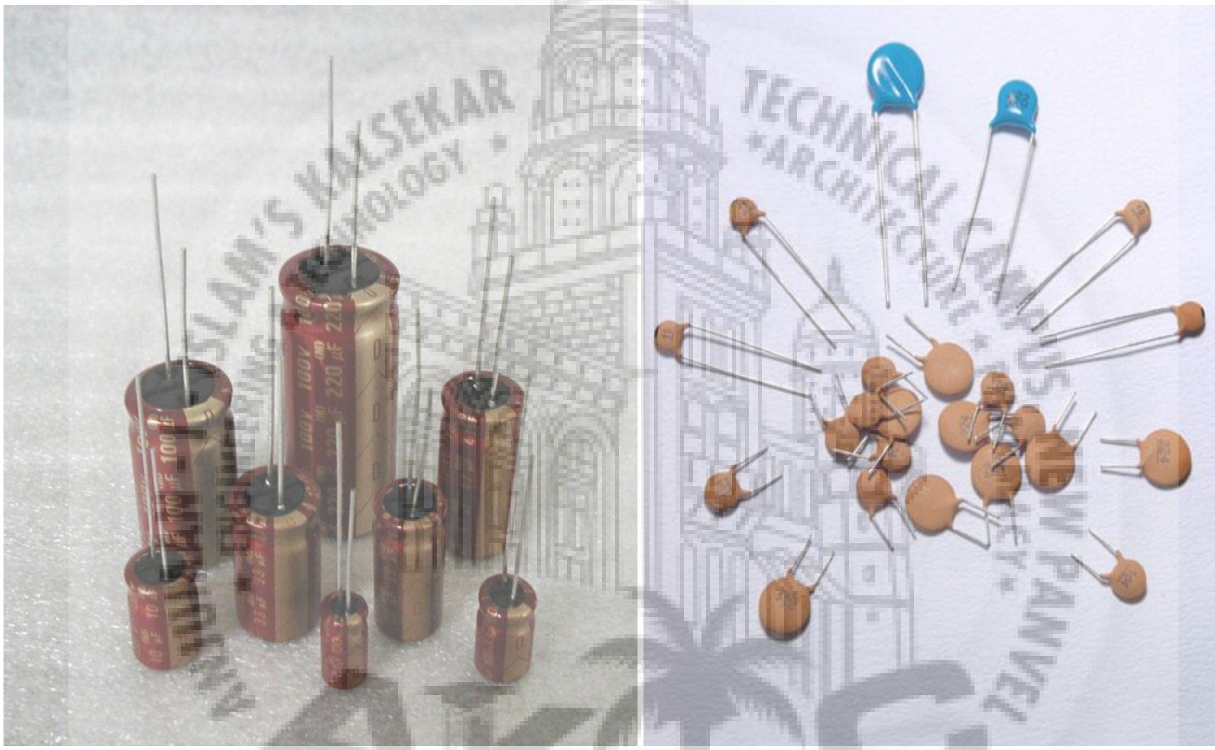
The failure rate of resistors in a properly designed circuit is low compared to other electronic components such as semiconductors and electrolytic capacitors. Damage to resistors most often occurs due to overheating when the average power delivered to it (as computed above) greatly exceeds its ability to dissipate heat (specified by the resistor's power rating). This may be due to a fault external to the circuit, but is frequently caused by the failure of another component (such as a transistor that shorts out) in the circuit connected to the resistor. Operating a resistor too close to its power rating can limit the resistor's lifespan or cause a change in its resistance over time which may or may not be noticeable. A safe design generally uses overrated resistors in power applications to avoid this danger.

When overheated, carbon-film resistors may decrease or increase in resistance. Carbon film and composition resistors can fail (open circuit) if running close to their maximum dissipation. This is also possible but less likely with metal film and wire wound resistors.

There can also be failure of resistors due to mechanical stress and adverse environmental factors including humidity. If not enclosed, wire wound resistors can corrode. Variable resistors degrade in a different manner, typically involving poor contact between the wiper and the body of the resistance. This may be due to dirt or corrosion and is typically perceived as "crackling" as the contact resistance fluctuates; this is especially noticed as the device is adjusted. This is similar to crackling caused by poor contact in switches, and like switches, potentiometers are to some extent self-cleaning: running the wiper across the resistance may improve the contact. Potentiometers which are seldom adjusted, especially in dirty or harsh environments, are most likely to develop this problem. When self-cleaning of the contact is insufficient, improvement can usually be obtained through the use of contact cleaner (also known as "tuner cleaner") spray. The crackling noise associated with turning the shaft of a dirty potentiometer in an audio circuit (such as the volume control) is greatly accentuated when an undesired DC voltage is present, often implicating the failure of a DC blocking capacitor in the circuit

3.7 CAPACITORS

A capacitor or condenser is a passive electronic component consisting of a pair of conductors separated by a dielectric. When a voltage potential difference exists between the conductors, an electric field is present in the dielectric. This field stores energy and produces a mechanical force between the plates. The effect is greatest between wide, flat, parallel, narrowly separated conductors.



3.7.1 CAPACITOR

An ideal capacitor is characterized by a single constant value, capacitance, which is measured in farads. This is the ratio of the electric charge on each conductor to the potential difference between them. In practice, the dielectric between the plates passes a small amount of leakage current. The conductors and leads introduce an equivalent series resistance and the dielectric has an electric field strength limit resulting in a breakdown voltage.

The properties of capacitors in a circuit may determine the resonant frequency and quality factor of a resonant circuit, power dissipation and operating frequency in a digital logic circuit, energy capacity in a high-power system, and many other important aspects.

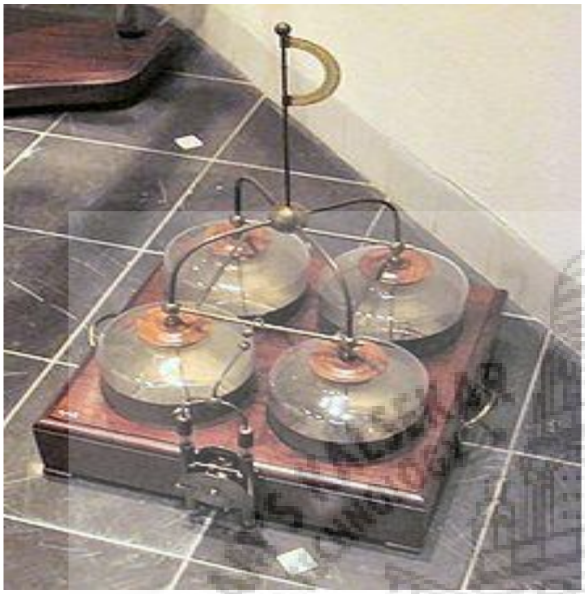
A capacitor (formerly known as condenser) is a device for storing electric charge. The forms of practical capacitors vary widely, but all contain at least two conductors separated by a non-conductor. Capacitors used as parts of electrical systems, for example, consist of metal foils separated by a layer of insulating film.

Capacitors are widely used in electronic circuits for blocking direct current while allowing alternating current to pass, in filter networks, for smoothing the output of power supplies, in the resonant circuits that tune radios to particular frequencies and for many other purposes.

A capacitor is a passiveelectronic component consisting of a pair of conductors separated by a dielectric (insulator). When there is a potential difference (voltage) across the conductors, a static electric field develops in the dielectric that stores energy and produces a mechanical force between the conductors. An ideal capacitor is characterized by a single constant value, capacitance, measured in farads. This is the ratio of the electric charge on each conductor to the potential difference between them.

The capacitance is greatest when there is a narrow separation between large areas of conductor, hence capacitor conductors are often called "plates", referring to an early means of construction. In practice the dielectric between the plates passes a small amount of leakage current and also has an electric field strength limit, resulting in a breakdown voltage, while the conductors and leads introduce an undesired inductance and resistance.

History



3.7.2 BATTERY OF FOUR LEYDEN JARS IN MUSEUM BOERHAAVE, LEIDEN, THE NETHERLANDS

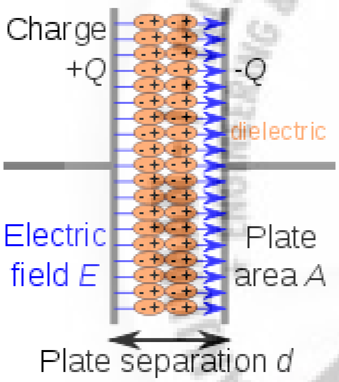
In October 1745, Ewald Georg von Kleist of Pomerania in Germany found that charge could be stored by connecting a high voltage electrostatic generator by a wire to a volume of water in a hand-held glass jar. Von Kleist's hand and the water acted as conductors and the jar as a dielectric (although details of the mechanism were incorrectly identified at the time). Von Kleist found, after removing the generator that touching the wire resulted in a painful spark. In a letter describing the experiment, he said "I would not take a second shock for the kingdom of France." The following year, the Dutch physicist Pieter van Musschenbroek invented a similar capacitor, which was named the Leyden jar, after the University of Leiden where he 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. He also adopted the term "battery", (denoting the increasing of power with a row of similar units as in a battery of cannon), subsequently applied to clusters of electrochemical cells. Leyden jars were later made by coating the inside and outside of jars with metal foil, leaving a space at the mouth to prevent arcing between the foils. The earliest unit of capacitance was the 'jar', equivalent to about 1 nanofarad Leyden jars or more powerful devices employing flat glass plates alternating with foil conductors were used exclusively up until about 1900, when the invention of wireless (radio) created a demand for standard capacitors, and the steady move to higher frequencies required capacitors with lower inductance. A more compact construction began to be used of a flexible dielectric sheet such as oiled paper sandwiched between sheets of metal foil, rolled or folded into a small package.

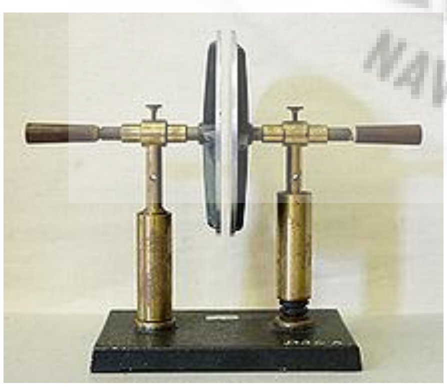
Early capacitors were also known as condensers, a term that is still occasionally used today. The term was first used for this purpose by Alessandro Volta in 1782, with reference to the device's ability to store a higher density of electric charge than a normal isolated conductor.

Theory of operation

Capacitance



Charge separation in a parallel-plate capacitor causes an internal electric field. A dielectric (orange) reduces the field and increases the capacitance.



A simple demonstration of a parallel-plate capacitor

A capacitor consists of two conductors separated by a non-conductive region. The non-conductive region is called the dielectric or sometimes the dielectric medium. In simpler terms, the dielectric is just an electrical insulator. Examples of dielectric mediums are glass, air, paper, vacuum, and even a semiconductordepletion region chemically identical to the conductors. A capacitor is assumed to be self-contained and isolated, with no net electric charge and no influence from any external electric field. The conductors thus hold equal and opposite charges on their facing surfaces, and the dielectric develops an electric field. In SI units, a capacitance of one farad means that one coulomb of charge on each conductor causes a voltage of one volt across the device.

The capacitor is a reasonably general model for electric fields within electric circuits. An ideal capacitor is wholly characterized by a constant capacitance C, defined as the ratio of charge ±Q on each conductor to the voltage V between them:

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

Sometimes charge build-up affects the capacitor mechanically, causing its capacitance to vary. In this case, capacitance is defined in terms of incremental changes:

$$C = \frac{\mathrm{d}q}{\mathrm{d}v}$$

Energy storage

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

$$W = \int_{q=0}^{Q} V\,\mathrm{d}q = \int_{q=0}^{Q} \frac{q}{C}\mathrm{d}q = \frac{1}{2}\frac{Q^2}{C} = \frac{1}{2}CV^2 = \frac{1}{2}VQ.$$

Current-voltage relation

The current i(t) through any component in an electric circuit is defined as the rate of flow of a charge q(t) passing through it, but actual charges, electrons, cannot pass through the dielectric layer of a capacitor, rather an electron accumulates on the negative plate for each one that leaves the positive plate, resulting in an electron depletion and consequent positive charge on one electrode that is equal and opposite to the accumulated negative charge on the other. Thus the charge on the electrodes is equal to the integral of the current as well as proportional to the voltage as discussed above. As with any anti-derivative, a constant of integration is added to represent the initial voltage v (t_0). This is the integral form of the capacitor equation,

$$v(t) = \frac{q(t)}{C} = \frac{1}{C}\int_{t_0}^{t} i(\tau)\mathrm{d}\tau + v(t_0).$$

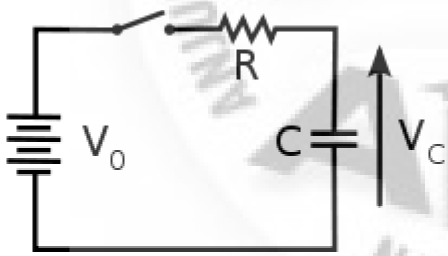
Taking the derivative of this, and multiplying by C, yields the derivative form,

$$i(t) = \frac{\mathrm{d}q(t)}{\mathrm{d}t} = C\frac{\mathrm{d}v(t)}{\mathrm{d}t}.$$

The dual of the capacitor is the inductor, which stores energy in the magnetic field rather than the electric field. Its current-voltage relation is obtained by exchanging current and voltage in the capacitor equations and replacing C with the inductance L.

DC circuits

RC circuit



A simple resistor-capacitor circuit demonstrates charging of a capacitor

A series circuit containing only a resistor, a capacitor, a switch and a constant DC source of voltage V_0 is known as a charging circuit. If the capacitor is initially uncharged while the switch is open, and the switch is closed at t = 0, it follows from Kirchhoff's voltage law that

$$V_0 = v_{\text{resistor}}(t) + v_{\text{capacitor}}(t) = i(t)R + \frac{1}{C}\int_{0}^{t} i(\tau)\mathrm{d}\tau.$$

Taking the derivative and multiplying by C, gives a first-order differential equation,

$$RC\frac{\mathrm{d}i(t)}{\mathrm{d}t}+i(t)=0.$$

At t = 0, the voltage across the capacitor is zero and the voltage across the resistor is V_0. The initial current is then i (0) =V_0 /R. With this assumption, the differential equation yields

$$i(t)=\frac{V_0}{R}e^{-t/\tau_0}$$

$$v(t)=V_0\left(1-e^{-t/\tau_0}\right),$$

Whereτ_0 = RC is the time constant of the system.

As the capacitor reaches equilibrium with the source voltage, the voltage across the resistor and the current through the entire circuit decay exponentially. The case of discharging a charged capacitor likewise demonstrates exponential decay, but with the initial capacitor voltage replacing V_0 and the final voltage being zero.

AC circuits

Impedance, the vector sum of reactance and resistance, describes the phase difference and the ratio of amplitudes between sinusoidally varying voltage and sinusoidally varying current at a given frequency. Fourier analysis allows any signal to be constructed from a spectrum of frequencies, whence the circuit's reaction to the various frequencies may be found. The reactance and impedance of a capacitor are respectively

$$X=-\frac{1}{\omega C}=-\frac{1}{2\pi fC}$$

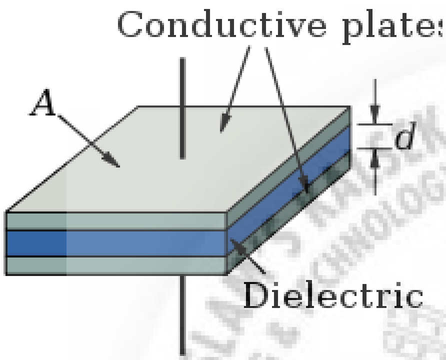
$$Z=\frac{1}{j\omega C}=-\frac{j}{\omega C}=-\frac{j}{2\pi fC}$$

where j is the imaginary unit and ω is the angular velocity of the sinusoidal signal. The - j phase indicates that the AC voltage V = Z I lags the AC current by 90°: the positive current phase corresponds to increasing voltage as the capacitor charges; zero current corresponds to instantaneous constant voltage, etc.

Note that impedance decreases with increasing capacitance and increasing frequency. This implies that a higher-frequency signal or a larger capacitor results in a lower voltage amplitude per current amplitude—an AC "short circuit" or AC coupling. Conversely, for very low frequencies, the reactance will be high, so that a capacitor is nearly an open circuit in AC analysis—those frequencies have been "filtered out".

Capacitors are different from resistors and inductors in that the impedance is inversely proportional to the defining characteristic, i.e. capacitance.

Parallel plate model



3.7.3 PARALLEL PLATE MODEL

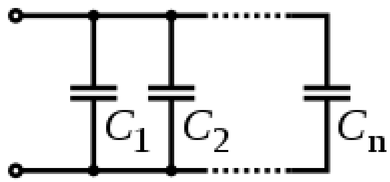
Dielectric is placed between two conducting plates, each of area A and with a separation of d.The simplest capacitor consists of two parallel conductive plates separated by a dielectric with permittivityε (such as air). The model may also be used to make qualitative predictions for other device geometries. The plates are considered to extend uniformly over an area A and a charge density ±ρ = ±Q/A exists on their surface. Assuming that the width of the plates is much greater than their separation d, the electric field near the centre of the device will be uniform with the magnitude E = ρ/ε. The voltage is defined as the line integral of the electric field between the plates.

$$V = \int_0^d E\mathrm{d}z = \int_0^d \frac{\rho}{\varepsilon}\mathrm{d}z = \frac{\rho d}{\varepsilon} = \frac{Qd}{\varepsilon A}.$$

Solving this for C = Q/V reveals that capacitance increases with area and decreases with separation

$$C = \frac{\varepsilon A}{d}.$$

The capacitance is therefore greatest in devices made from materials with a high permittivity.



Several capacitors in parallel

Networks

For capacitors in parallel

Capacitors in a parallel configuration each have the same applied voltage. Their capacitances add up. Charge is apportioned among them by size. Using the schematic diagram to visualize parallel plates, it is apparent that each capacitor contributes to the total surface area.

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

For capacitors in series

Several capacitors in series

Connected in series, the schematic diagram reveals that the separation distance, not the plate area, adds up. The capacitors each store instantaneous charge build-up equal to that of every other capacitor in the series. The total voltage difference from end to end is apportioned to each capacitor according to the inverse of its capacitance. The entire series acts as a capacitor smaller than any of its components.

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

Capacitors are combined in series to achieve a higher working voltage, for example for smoothing a high voltage power supply. The voltage ratings, which are based on plate separation, add up. In such an application, several series connections may in turn be connected in parallel, forming a matrix. The goal is to maximize the energy storage utility of each capacitor without overloading it. Series connection is also used to adapt electrolytic capacitors for AC use.

Non-ideal behavior

Capacitors deviate from the ideal capacitor equation in a number of ways. Some of these, such as leakage current and parasitic effects are linear, or can be assumed to be linear, and can be dealt with by adding virtual components to the equivalent circuit of the capacitor. The usual methods of network analysis can then be applied. In other cases, such as with breakdown voltage, the effect is non-linear and normal (i.e., linear) network analysis cannot be used; the effect must be dealt with separately. There is yet another group, which may be linear but invalidate the assumption in the analysis that capacitance is a constant. Such an example is temperature dependence.

Breakdown voltage

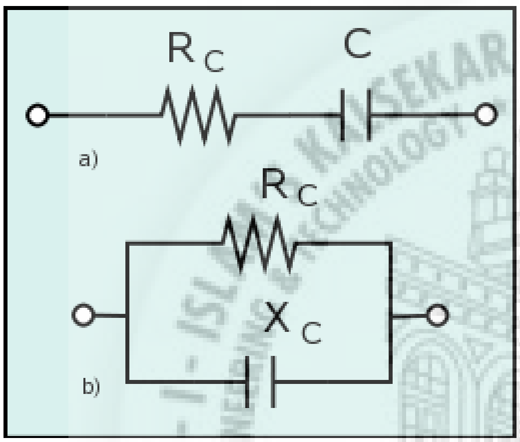
Above a particular electric field, known as the dielectric strength E_{ds}, the dielectric in a capacitor becomes conductive. The voltage at which this occurs is called the breakdown voltage of the device, and is given by the product of the dielectric strength and the separation between the conductors,

$V_{bd} = E_{ds}d$

The maximum energy that can be stored safely in a capacitor is limited by the breakdown voltage. Due to the scaling of capacitance and breakdown voltage with dielectric thickness, all capacitors made with a particular dielectric have approximately equal maximum energy density, to the extent that the dielectric dominates their volume.

For air dielectric capacitors the breakdown field strength is of the order 2 to 5MV/m; for mica the breakdown is 100 to 300 MV/m, for oil 15 to 25MV/m, and can be much less when other materials are used for the dielectric. The dielectric is used in very thin layers and so absolute breakdown voltage of capacitors is limited. Typical ratings for capacitors used for general electronics applications range from a few volts to 100V or so. As the voltage increases, the dielectric must be thicker, making high-voltage capacitors larger than those rated for lower voltages. The breakdown voltage is critically affected by factors such as the geometry of the capacitor conductive parts; sharp edges or points increase the electric field strength at that point and can lead to a local breakdown. Once this starts to happen, the breakdown will quickly "track" through the dielectric till it reaches the opposite plate and cause a short circuit. The usual breakdown route is that the field strength becomes large enough to pull electrons in the dielectric from their atoms thus causing conduction. Other scenarios are possible, such as impurities in the dielectric, and, if the dielectric is of a crystalline nature, imperfections in the crystal structure can result in an avalanche breakdown as seen in semi-conductor devices. Breakdown voltage is also affected by pressure, humidity and temperature.

Equivalent circuit



3.7.4 EQUIVALENT CIRCUIT

Two different circuit models of a real capacitor

An ideal capacitor only stores and releases electrical energy, without dissipating any. In reality, all capacitors have imperfections within the capacitor's material that create resistance. This is specified as the equivalent series resistance or ESR of a component. This adds a real component to the impedance:

$$R_{\mathrm{C}} = Z + R_{\mathrm{ESR}} = \frac{1}{j\omega C} + R_{\mathrm{ESR}}$$

As frequency approaches infinity, the capacitive impedance (or reactance) approaches zero and the ESR becomes significant. As the reactance becomes negligible, power dissipation approaches $P_{RMS} = V_{RMS}^2 / R_{ESR}$.

Similarly to ESR, the capacitor's leads add equivalent series inductance or ESL to the component. This is usually significant only at relatively high frequencies. As inductive reactance is positive and increases with frequency, above a certain frequency capacitance will be cancelled by inductance. High-frequency engineering involves accounting for the inductance of all connections and components.

If the conductors are separated by a material with a small conductivity rather than a perfect dielectric, then a small leakage current flows directly between them. The capacitor therefore has a finite parallel resistance, and slowly discharges over time (time may vary greatly depending on the capacitor material and quality).

Ripple current

Ripple current is the AC component of an applied source (often a switched-mode power supply) whose frequency may be constant or varying. Certain types of capacitors, such as electrolytic tantalum capacitors, usually have a rating for maximum ripple current (both in frequency and magnitude). This ripple current can cause damaging heat to be generated within the capacitor due to the current flow across resistive imperfections in the materials used within the capacitor, more commonly referred to as equivalent series resistance (ESR). For example electrolytic tantalum capacitors are limited by ripple current and generally have the highest ESR ratings in the capacitor family, while ceramic capacitors generally have no ripple current limitation and have some of the lowest ESR ratings.

Capacitance instability

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. Electrolytic capacitors age as the electrolyte evaporates. In contrast with ceramic capacitors, this occurs towards the end of life of the component.

Temperature dependence of capacitance is usually expressed in parts per million (ppm) per °C. It can usually be taken as a broadly linear function but can be noticeably non-linear at the temperature extremes. The temperature coefficient can be either positive or negative, sometimes even amongst different samples of the same type. In other words, the spread in the range of temperature coefficients can encompass zero. See the data sheet in the leakage current section above for an example.

Capacitors, especially ceramic capacitors, and older designs such as paper capacitors, can absorb sound waves resulting in a micro phonic effect. Vibration moves the plates, causing the capacitance to vary, in turn inducing AC current. Some dielectrics also generate piezoelectricity. The resulting interference is especially problematic in audio applications, potentially causing feedback or unintended recording. In the reverse micro phonic effect, the varying electric field between the capacitor plates exerts a physical force, moving them as a speaker. This can generate audible sound, but drains energy and stresses the dielectric and the electrolyte, if any.

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.

Values available range from very low (picofarad range; while arbitrarily low values are in principle possible, stray (parasitic) capacitance in any circuit is the limiting factor) to about 5 kF super capacitors.

Above approximately 1 microfarad electrolytic capacitors are usually used because of their small size and low cost compared with other technologies, unless their relatively poor stability, life and polarised nature make them unsuitable. Very high capacity super capacitors use a porous carbon-based electrode material.

Dielectric materials

3.7.5 DIELECTRIC MATERIAL

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

Most types of capacitor include a dielectric spacer, which increases their capacitance. These dielectrics are most often insulators. However, low capacitance devices are available with a vacuum between their plates, which allows extremely high voltage operation and low losses. Variable capacitors with their plates open to the atmosphere were commonly used in radio tuning circuits. Later designs use polymer foil dielectric between the moving and stationary plates, with no significant air space between them.

In order to maximise the charge that a capacitor can hold, the dielectric material needs to have as high a permittivity as possible, while also having as high a breakdown voltage as possible.

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. Electrolytic capacitors and supercapacitors are used to store small and larger amounts of energy, respectively, ceramic capacitors are often used in resonators, and parasitic capacitance occurs in circuits wherever the simple conductor-insulator-conductor structure is formed unintentionally by the configuration of the circuit layout.

Electrolytic capacitors use an aluminium or tantalum plate with an oxide dielectric layer. The second electrode is a liquid electrolyte, connected to the circuit by another foil plate. 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. Poor quality capacitors may leak electrolyte, which is harmful to printed circuit boards. 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. Electrolytic capacitors will self-degrade if unused for a period (around a year), and when full power is applied may short circuit, permanently damaging the capacitor and usually blowing a fuse or causing arcing in rectifier tubes. They can be restored before use (and damage) by gradually applying the operating voltage, often done on antique vacuum tube equipment over a period of 30 minutes by using a variable transformer to supply AC power. Unfortunately, the use of this technique may be less satisfactory for some solid state equipment, which may be damaged by operation below its normal power range, requiring that the power supply first be isolated from the consuming circuits. Such remedies may not be applicable to modern high-frequency power supplies as these produce full output voltage even with reduced input.

Tantalum capacitors offer better frequency and temperature characteristics than aluminium, but higher dielectric absorption and leakage. OS-CON (or OC-CON) capacitors are a polymerized organic semiconductor solid-electrolyte type that offers longer life at higher cost than standard electrolytic capacitors.

Several other types of capacitor are available for specialist applications. Supercapacitors store large amounts of energy. Supercapacitors made from carbon aerogel, carbon nanotubes, or highly porous electrode materials offer extremely high capacitance (up to 5 kF as of 2010) 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 are designed with direct current breakdown voltages of at least five times the maximum AC voltage.

Structure

3.7.6 STRUCTURE

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.
The arrangement of plates and dielectric has many variations depending on the desired ratings of the capacitor. For small values of capacitance (microfarads and less), ceramic disks use metallic coatings, with wire leads bonded to the coating. Larger values can be made by multiple stacks of plates and disks. Larger value capacitors usually use a metal foil or metal film layer deposited on the surface of a dielectric film to make the plates, and a dielectric film of impregnated paper or plastic – these are rolled up to save space. To reduce the series resistance and inductance for long plates, the plates and dielectric are staggered so that connection is made at the common edge of the rolled-up plates, not at the ends of the foil or metalized film strips that comprise the plates.

The assembly is encased to prevent moisture entering the dielectric – early radio equipment used a cardboard tube sealed with wax. Modern paper or film dielectric capacitors are dipped in a hard thermoplastic. Large capacitors for high-voltage use may have the roll form compressed to fit into a rectangular metal case, with bolted terminals and bushings for connections. The dielectric in larger capacitors is often impregnated with a liquid to improve its properties.

Capacitors may have their connecting leads arranged in many configurations, for example axially or radially. "Axial" means that the leads are on a common axis, typically the axis of the capacitor's cylindrical body – the leads extend from opposite ends. Radial leads might more accurately be referred to as tandem; they are rarely actually aligned along radii of the body's circle, so the term is inexact, although universal. The leads (until bent) are usually in planes parallel to that of the flat body of the capacitor, and extend in the same direction; they are often parallel as manufactured.

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.

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. Low cost variable capacitors squeeze together alternating layers of aluminium and plastic with a screw. Electrical control of capacitance is achievable with varactors (or varicaps), which are reverse-biasedsemiconductor diodes whose depletion region width varies with applied voltage. They are used in phase-locked loops, amongst other applications.

Capacitor markings

Most capacitors have numbers printed on their bodies to indicate their electrical characteristics. Larger capacitors like electrolytics usually display the actual capacitance together with the unit (for example, 220 μF). Smaller capacitors like ceramics, however, use a shorthand consisting of three numbers and a letter, where the numbers show the capacitance in pF (calculated as XY x 10^Z for the numbers XYZ) and the letter indicates the tolerance (J, K or M for ±5%, ±10% and ±20% respectively).

Additionally, the capacitor may show its working voltage, temperature and other relevant characteristics.

Example

A capacitor with the text 473K 330V on its body has a capacitance of 47 x 10^3 pF = 47 nF (±10%) with a working voltage of 330 V.

Applications

Capacitors have many uses in electronic and electrical systems. They are so common that it is a rare electrical product that does not include at least one for some purpose.

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.)

Conventional capacitors provide less than 360 joules per kilogram of energy density, while capacitors using developing technologies could provide more than 2.52 kilojoules per kilogram.

In car audio systems, large capacitors store energy for the amplifier to use on demand. Also for a flash tube a capacitor is used to hold the high voltage.

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 bridge wire detonators or slapper detonators in nuclear weapons and other specialty weapons. Experimental work is under way using banks of capacitors as power sources for electromagneticarmour and electromagnetic railguns and coilguns.

Power conditioning

3.7.7 POWER CONDITIONING

A 10,000 microfarad capacitor in a TRM-800 amplifier

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-acidcar battery.

Power factor correction

In electric power distribution, capacitors are used for power factor correction. Such capacitors often come as three capacitors connected as a three phaseload. 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 devices like electric motors and transmission lines to make the load appear to be mostly resistive. Individual motor or lamp loads may have capacitors for power factor correction, or larger sets of capacitors (usually with automatic switching devices) may be installed at a load centre within a building or in a large utility substation.

Suppression and coupling

Signal coupling

Because capacitors pass AC but block DC signals (when charged up to the applied dc voltage), they are often used to separate the AC and DC components of a signal. This method is known as AC coupling 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

A decoupling capacitor is a capacitor used to protect one part of a circuit from the effect of another, for instance to suppress noise or transients. 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 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 breakerignition 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.

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).

Motor starters

In single phase squirrel cage motors, the primary winding within the motor housing is not 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 starting 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. When the rotor comes close to operating speed, a centrifugal switch (or current-sensitive relay in series with the main winding) disconnects the capacitor. The start capacitor is typically mounted to the side of the motor housing. These are called capacitor-start motors that have relatively high starting torque.

There are also capacitor-run induction motors which have a permanently connected phase-shifting capacitor in series with a second winding. The motor is much like a two-phase induction motor.

Motor-starting capacitors are typically non-polarized electrolytic types, while running capacitors are conventional paper or plastic film dielectric types.

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.

The resonant frequencyf of a tuned circuit is a function of the inductance (L) and capacitance (C) in series, and is given by:

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

where L is in henries and C is in farads.

Sensing

Most capacitors are designed to maintain a fixed physical structure. However, various factors can change the structure of the capacitor, and 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 be used for sensing purposes. Capacitors with an exposed and porous dielectric can be used to measure humidity in air. Capacitors are used to accurately measure the fuel level in airplanes; as the fuel covers more of a pair of plates, the circuit capacitance increases.

Changing the distance between the plates:

Capacitors with a flexible plate can be used to measure strain or pressure. Industrial pressure transmitters used for process control use pressure-sensing diaphragms, which form a capacitor plate of an oscillator circuit. 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, e.g. 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 are now used on many consumer electronic products.

Hazards and safety

Capacitors may retain a charge long after power is removed from a circuit; this charge can cause dangerous or even potentially fatal shocks or damage 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 a shock. Service procedures for electronic devices usually include instructions to discharge large or high-voltage capacitors. Capacitors may also have built-in discharge resistors to dissipate stored energy to a safe level within a few seconds after power is removed. High-voltage capacitors are stored with the terminals shorted, as protection from potentially dangerous voltages due to dielectric absorption.

Some old, large oil-filled capacitors contain polychlorinated biphenyls (PCBs). It is known that waste PCBs can leak into groundwater under landfills. Capacitors containing PCB were labelled as containing "Askarel" and several other trade names. PCB-filled capacitors are found in very old (pre-1975) fluorescent lamp ballasts, and other applications.

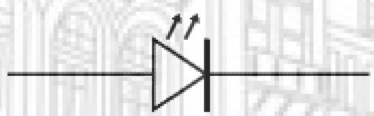
Capacitors may catastrophically fail when subjected to voltages or currents beyond their rating, or as they reach their normal end of life. Dielectric or metal interconnection failures may create arcing that vaporizes the dielectric fluid, resulting in case bulging, rupture, or even an explosion. Capacitors used in RF or sustained high-current applications can overheat, especially in the centre of the capacitor rolls. Capacitors used within high-energy capacitor banks can violently explode when a short 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 preventive 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 high voltage direct current (HVDC) circuits. This will extend the life of the component and may mitigate high-voltage hazards.

3.8 LED

LEDs are semiconductor devices. Like transistors, and other diodes, LEDs are made out of silicon. What makes an LED give off light are the small amounts of chemical impurities that are added to the silicon, such as gallium, arsenide, indium, and nitride.

When current passes through the LED, it emits photons as a byproduct. Normal light bulbs produce light by heating a metal filament until it is white hot. LEDs produce photons directly and not via heat, they are far more efficient than incandescent bulbs.



3.8.1: CIRCUIT SYMBOL

Not long ago LEDs were only bright enough to be used as indicators on dashboards or electronic equipment. But recent advances have made LEDs bright enough to rival traditional lighting technologies. Modern LEDs can replace incandescent bulbs in almost any application.

Types of LED'S

LEDs are produced in an array of shapes and sizes. The 5 mm cylindrical package is the most common, estimated at 80% of world production. The color of the plastic lens is often the same as the actual color of light emitted, but not always. For instance, purple plastic is often used for infrared LEDs, and most blue devices have clear housings. There are also LEDs in extremely tiny packages, such as those found on blinkers and on cell phone keypads. The main types of LEDs are miniature, high power devices and custom designs such as alphanumeric or multi-color.

3.8.2 DIFFERENT TYPES OF LED'S

Colors and materials of LED'S

Conventional LED'S are made from a variety of inorganic semiconductor materials, the following table shows the available colours with wavelength range, voltage drop and material.

Color	Wavelength (nm)	Voltage (V)	Semiconductor Material
Infrared	$\lambda > 760$	$\Delta V < 1.9$	Gallium arsenide (GaAs) Aluminum gallium arsenide (AlGaAs)
Red	$610 < \lambda < 760$	$1.63 < \Delta V < 2.03$	Aluminum gallium arsenide (AlGaAs) Gallium arsenide phosphide (GaAsP) Aluminum gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Orange	$590 < \lambda < 610$	$2.03 < \Delta V < 2.10$	Gallium arsenide phosphide (GaAsP) Aluminum gallium indium phosphide (AlGaInP)

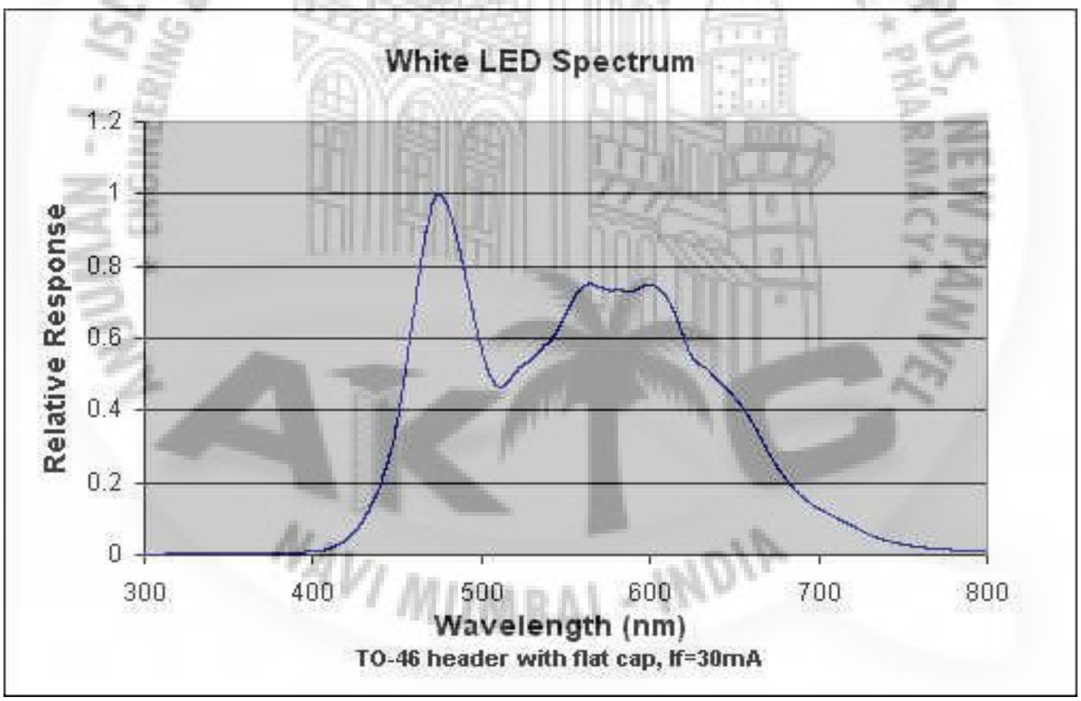
			Gallium(III) phosphide (GaP)
Yellow	570 <λ< 590	2.10 < ΔV< 2.18	Gallium arsenide phosphide (GaAsP) Aluminum gallium indium phosphide (AlGaInP) Gallium(III) phosphide (GaP)
Green	500 <λ< 570	1.9 < ΔV< 4.0	Indium gallium nitride (InGaN) / Gallium(III) nitride (GaN) Gallium(III) phosphide (GaP) Aluminum gallium indium phosphide (AlGaInP) Aluminum gallium phosphide (AlGaP)
Blue	450 <λ< 500	2.48 < ΔV< 3.7	Zinc selenide (ZnSe) Indium gallium nitride (InGaN) Silicon carbide (SiC) as substrate Silicon (Si) as substrate — (under development)
Violet	400 <λ< 450	2.76 < ΔV< 4.0	Indium gallium nitride (InGaN)
Purple	multiple types	2.48 < ΔV< 3.7	Dual blue/red LEDs, blue with red phosphor, or white with purple plastic
Ultraviolet	λ< 400	3.1 < ΔV< 4.4	Diamond (235 nm) Boron nitride (215 nm)[43] Aluminum nitride (AlN) (210 nm)[45] Aluminum gallium nitride (AlGaN) Aluminum gallium indium nitride (AlGaInN) — (down to 210 nm)
White	Broad spectrum	ΔV = 3.5	Blue/UV diode with yellow phosphor

White LED’S

Light Emitting Diodes (LED) have recently become available that are white and bright, so bright that they seriously compete with incandescent lamps in lighting applications. They are still pretty expensive as compared to a GOW lamp but draw much less current and project a fairly well focused beam.

The diode in the photo came with a neat little reflector that tends to sharpen the beam a little but doesn't seem to add much to the overall intensity.

When run within their ratings, they are more reliable than lamps as well. Red LEDs are now being used in automotive and truck tail lights and in red traffic signal lights. You will be able to detect them because they look like an array of point sources and they go on and off instantly as compared to conventional incandescent lamps.



3.8.3 WHITE LED SPECTRUM

LEDs are monochromatic (one color) devices. The color is determined by the band gap of the semiconductor used to make them. Red, green, yellow and blue LEDs are fairly common. White light contains all colors and cannot be directly created by a single LED. The most common form of "white" LED really isn't white. It is a Gallium Nitride blue LED coated with a phosphor that, when excited by the blue LED light, emits a broad range spectrum that in addition to the blue emission, makes a fairly white light.

There is a claim that these white LED's have a limited life. After 1000 hours or so of operation, they tend to yellow and dim to some extent. Running the LEDs at more than their rated current will certainly accelerate this process.

There are two primary ways of producing high intensity white-light using LED'S. One is to use individual LED'S that emit three primary colours—red, green, and blue—and then mix all the colours to form white light. The other is to use a phosphor material to convert monochromatic light from a blue or UV LED to broad-spectrum white light, much in the same way a fluorescent light bulb works. Due to metamerism, it is possible to have quite different spectra that appear white.

Advantages of using LEDs

- **Efficiency:**

  LEDs produce more light per watt than incandescent bulbs; this is useful in battery powered or energy-saving devices.

- **Size:**

  LEDs can be very small (smaller than 2 mm^2) and are easily populated onto printed circuit boards.

- **On/Off time:**

  LEDs light up very quickly. A typical red indicator LED will achieve full brightness in microseconds. LEDs used in communications devices can have even faster response times.

- **Cycling:**

  LEDs are ideal for use in applications that are subject to frequent on-off cycling, unlike fluorescent lamps that burn out more quickly when cycled frequently, or HID lamps that require a long time before restarting.

- **Cool light:**

  In contrast to most light sources, LEDs radiate very little heat in the form of IR that can cause damage to sensitive objects or fabrics. Wasted energy is dispersed as heat through the base of the LED.

- **Lifetime:**

  LEDs can have a relatively long useful life. One report estimates 35,000 to 50,000 hours of useful life, though time to complete failure may be longer.

- **No Toxicity:**

  LEDs do not contain mercury, unlike fluorescent lamps.

Disadvantages of using LEDs

- **High price:**

  LEDs are currently more expensive, price per lumen, on an initial capital cost basis, than most conventional lighting technologies.

- **Temperature dependence:**

  LED performance largely depends on the ambient temperature of the operating environment. Over-driving the LED in high ambient temperatures may result in overheating of the LED package, eventually leading to device failure.

- **Voltage sensitivity:**

  LEDs must be supplied with the voltage above the threshold and a current below the rating. This can involve series resistors or current-regulated power supplies.

- **Area light source:**

  LEDs do not approximate a "point source" of light, but rather a lambertian distribution. So LEDs are difficult to use in applications requiring a spherical light field. LEDs are not capable of providing divergence below a few degrees. This is contrasted with lasers, which can produce beams with divergences of 0.2 degrees or less.

- **Blue Hazard:**

  There is increasing concern that blue LEDs and cool-white LEDs are now capable of exceeding safe limits of the so-called blue-light hazard as defined in eye safety.

3.9 555 TIMER

The 555 Timer IC is an integrated circuit (chip) implementing a variety of timer and multivibrator applications. The IC was designed by Hans R. Camenzind in 1970 and brought to market in 1971 by Signetics (later acquired by Philips). The original name was the SE555 (metal can)/NE555 (plastic DIP) and the part was described as "The IC Time Machine".[1] It has been claimed that the 555 gets its name from the three 5 kΩ resistors used in typical early implementations,[2] but Hans Camenzind has stated that the number was arbitrary.[3] The part is still in wide use, thanks to its ease of use, low price and good stability. As of 2003, it is estimated that 1 billion units are manufactured every year.

3.9.1 555TIMER IC

Depending on the manufacturer, the standard 555 package includes over 20 transistors, 2 diodes and 15 resistors on a silicon chip installed in an 8-pin mini dual-in-line package (DIP-8).[4] Variants available include the 556 (a 14-pin DIP combining two 555s on one chip), and the 558 (a 16-pin DIP combining four slightly modified 555s with DIS & THR connected internally, and TR falling edge sensitive instead of level sensitive).

Ultra-low power versions of the 555 are also available, such as the 7555 and TLC555.[5] The 7555 is designed to cause less supply glitching than the classic 555 and the manufacturer claims that it usually does not require a "control" capacitor and in many cases does not require a power supply bypass capacitor.

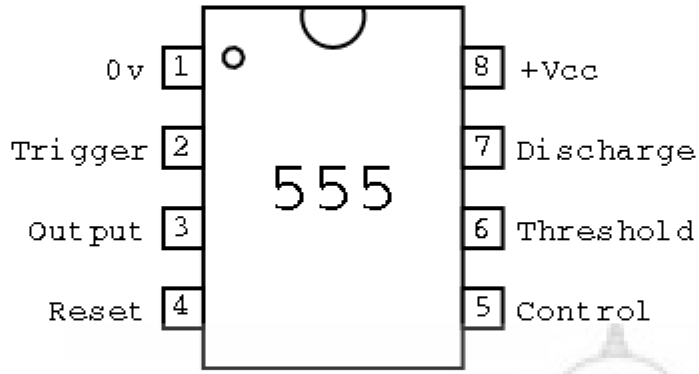
The 555 has three operating modes:

- Monostable mode: in this mode, the 555 functions as a "one-shot". Applications include timers, missing pulse detection, bouncefree switches, touch switches, frequency divider, capacitance measurement, pulse-width modulation (PWM) etc
- Astable - free running mode: the 555 can operate as an oscillator. Uses include LED and lamp flashers, pulse generation, logic clocks, tone generation, security alarms, pulse position modulation, etc.
- Bistable mode or Schmitt trigger: the 555 can operate as a flip-flop, if the DIS pin is not connected and no capacitor is used. Uses include bouncefree latched switches, etc.

Usage

The connection of the pins is as follows:

Pin	**Name**	**Purpose**
1	**GND**	Ground, low level (0 V)
2	**TRIG**	OUT rises, and interval starts, when this input falls below 1/3 V_{CC}.
3	**OUT**	This output is driven to +V_{CC} or GND.
4	**RESET**	A timing interval may be interrupted by driving this input to GND.
5	**CTRL**	"Control" access to the internal voltage divider (by default, 2/3 V_{CC}).
6	**THR**	The interval ends when the voltage at THR is greater than at CTRL.
7	**DIS**	Open collector output; may discharge a capacitor between intervals.
8	**$V+$, V_{CC}**	Positive supply voltage is usually between 3 and 15 V.



3.9.2 555TIMER PIN DIAGRAM

555 Basics

The 555 timer IC is a simple 8 pin DIL package IC. It can:

- be used as a monostable
- be used as an astable
- source or sink 100mA
- use supply voltages of 5v to 15v
- disrupt the power supply - use a decoupling capacitor!

Using the 555 as a buffer

A buffer circuit allows an input circuit to be connected to an output circuit, it is like an interface between one circuit and another. The buffer circuit requires very little input current but should be able to supply adequate output current. The 555 can supply in excess of 100mA of current and so can be used as a convenient buffer for logic gates which cannot supply much current. The 555 can also 'sink' a similar amount of current.

The circuit used is:

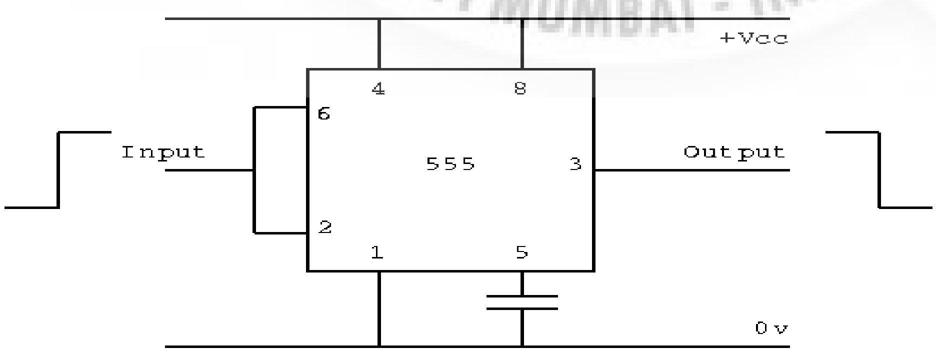


FIG 3.7 (c): 555 TIMERS AS A BUFFER

The circuit acts like an inverter or NOT gate. When the input is held low, the output is high and will provide (source) current. When the input is held high, the output is low and will sink current. Remember, for a buffer for even higher power devices that require even larger currents, the 555 buffer can be used to drive a relay or a transistor circuit.

Using the 555 as a monostable

The 555 can be used as a monostable using the circuit shown:

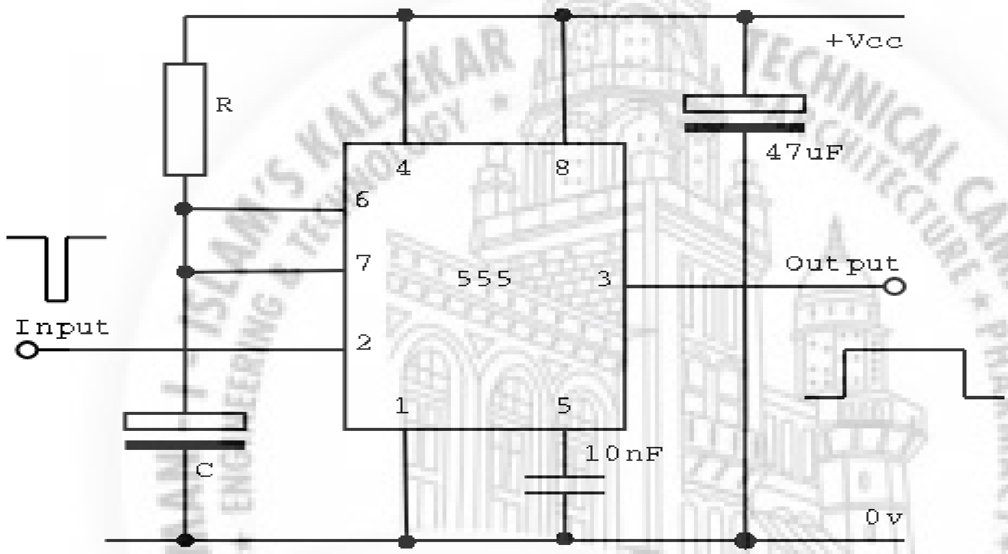


FIG 3.7 (d) 555TIMER AS A MONOSTABLE

- The output is normally low but will go high for a short length of time depending on the values of the other components
- R and C determine the time period of the output pulse
- The input is normally high and goes low to trigger the output (falling edge triggered)
- The length of the input pulse must be less than the length of the output pulse
- The 47uF capacitor 'decouples' the supply to avoid affecting other parts of the circuit
- It is standard to add a 10nF capacitor from pin5 to gnd

T = 1.1 R C

T - seconds, R - ohms, C – Farads

The minimum value of R should be about 1k to avoid too much current flowing into the 555. The maximum value of R should be about 1M so that enough current can flow into the input of the 555 and there is also current to allow for the electrolytic capacitors leakage current. The minimum value of C = 100pF to avoid the timing equation being too far off The maximum value of C should be about 1000µF as any bigger capacitors will discharge too much current through the chip. These maximum and minimum values give a minimum period of 0.1 µs and a maximum period of 1000s.

Using the 555 as an astable

The 555 can be used as an astable using the circuit shown:

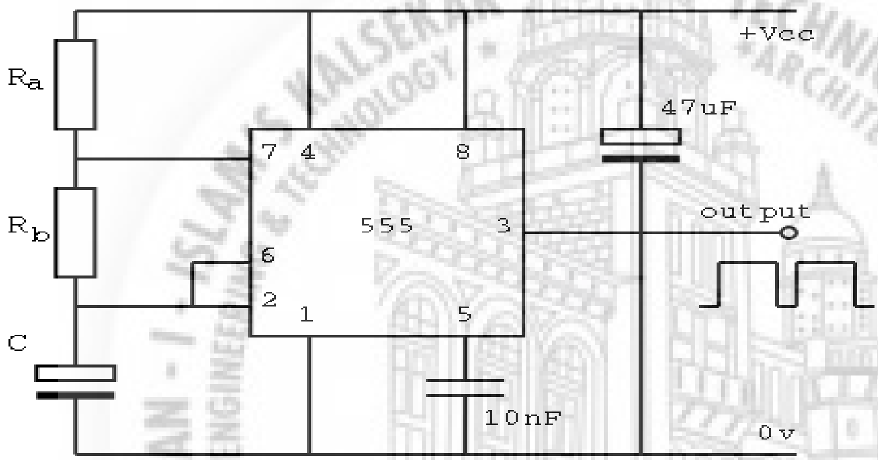


FIG 3.7 (e): 555 TIMER AS A ASTABLE

- The output will oscillate between high and low continuously - the circuit is not stable in any state.
- R_a, R_b and C determine the time period of the output
- The reset, pin 4, must be held high for the circuit to oscillate. If pin 4 is held low then the output remains low. Pin 4 can be used to turn the astable 'on' and 'off' in effect
- The 47uF capacitor 'decouples' the supply to avoid affecting other parts of the circuit
- It is standard to add a 10nF capacitor from pin5 to gnd.

$T = 0.7 (R_a + 2R_b) C$

T - seconds, R - ohms, C – Farads

As with the monostable the minimum value of Ra should be about 1k to avoid too much current flowing into the 555. The maximum value of Ra or Rb should be about 1M so that enough current can flow into the input of the 555 and there is also current to allow for the electrolytic capacitors leakage current. The minimum value of C = 100pF to avoid the timing equation being too far off. The maximum value of C should be about 1000µF as any bigger capacitors will discharge too much current through the chip. These maximum and minimum values give a minimum frequency of 0.001 Hz and a maximum frequency of 4.8 MHz (in reality it would not be able to attain these frequencies).

Considering the oscillations in more detail:

- the output is controlled by the charging and discharging of the capacitor
- The capacitor charges through Ra and Rb
- but discharges through the discharge pin (pin 7) and thus only through Rb
- The time that the capacitor takes to charge or discharge is given as T = 0.7 R C
- Thus the charge time is 0.7 (Ra + Rb) C
- The discharge time is 0.7 Rb C
- Giving a total time of (0.7 (Ra + Rb) C) + (0.7 Rb C) = 0.7 (Ra + 2Rb) C
- The time the output is high (mark) is thus always longer than the time the output is low (space)
- The 555 astable cannot produce a square wave!

Operation of the 555

It is not necessary to know how the 555 works. In fact a systems approach to electronics would never consider how any such sub-block works. However, a knowledge of how the 555 functions is useful. A much simplified block diagram of the 555 timer is shown:

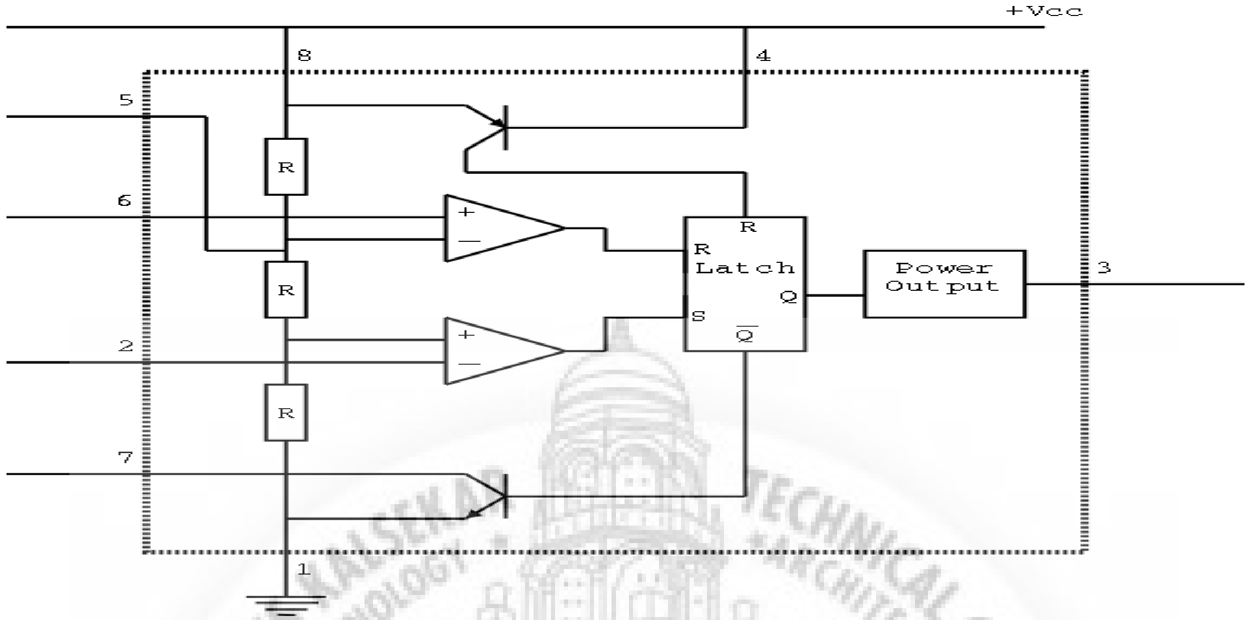


FIG 3.7 (f): OPERATION OF 555TIMER

- The resistors are arranged across the power supply to form a potential divider. The voltages at the junctions of the potential divider are 2/3 Vcc and 1/3 Vcc. They are connected to the inputs to a pair of comparators.
- One comparator, switching at 2/3 Vcc is controlled via the threshold input.
- The voltage at which the threshold comparator switches can be changed from 2/3 Vcc by applying a voltage to the control pin. This pin is usually decoupled to ground via a 10nF capacitor and, in this case, the comparator switches at 2/3 Vcc as expected.
- One comparator, switching at 1/3 Vcc is controlled via the triggerinput.
- The outputs from the two comparators control a set-reset flip flop (bistable).
- The reset pin of the 555 (not of the bistable) is usually held high. Taking this pin momentarily low applies a voltage to the reset pin of the flip flop and the output falls to zero.
- The output of the flip flop is connected to the output pin via a power amplifier circuit which includes short circuit protection etc.
- The output goes high when the trigger input is less than 1/3 Vcc.
- The output then remains high until the threshold input rises above 2/3 Vcc.

3.10 DC REGULATED POWER SUPPLY

Regulated DC power supplies provide accurate DC voltage, which are derived from AC mains. These DC supplies are cheaper in nature than the DC sources from battery. Such supplies provide constant voltage irrespective of load variations for which they are designed. DC power supplies are used extensively in various electronics laboratories, industries and communication departments to feed DC voltage to the electronic modules, R and D sections, institutions and colleges to impart practical training etc. Present range of electronic equipment produced in the country makes use of transistors and integrated circuits. These IC's are designed to work on fixed regulated DC voltages. Therefore, such supplies have become the part and parcel of such equipment and are:

1. Preset Power supplies (single or dual supply type)
2. Variable power supplies Preset Power Supplies (Single or Dual supply type)

These power supplies are generally customs made and preset for fixed voltages like 5V/10V/15 Volts etc. These supply units are normally mounted on/ integrated into the electronic equipment.

As such these power supplies are not fitted with any cabinets. These power supplies are used in computers. Variable Power Supplies Variable power supplies are supplies in which the voltage can be varied continuously with the knob as per requirement. They are generally available in the range of 5 to 30 volts in 0.5 to 10 amps capacities. These supplies are generally used in research institutions, colleges, practical training centers and electronic industries, etc.

3.10 DC REGULATED POWER SUPPLY

3.11 MAX232

The MAX232 is an integrated circuit that converts signals from an RS-232 serial port to signals suitable for use in TTL compatible digital logic circuits. The MAX232 is a dual driver/receiver and typically converts the RX, TX, CTS and RTS signals.

The drivers provide RS-232 voltage level outputs (approx. ± 7.5 V) from a single + 5 V supply via on-chip charge pumps and external capacitors. This makes it useful for implementing RS-232 in devices that otherwise do not need any voltages outside the 0 V to + 5 V range, as power supply design does not need to be made more complicated just for driving the RS-232 in this case. The receivers reduce RS-232 inputs (which may be as high as ± 25 V), to standard 5 V TTL levels. These receivers have a typical threshold of 1.3 V, and a typical hysteresis of 0.5 V.

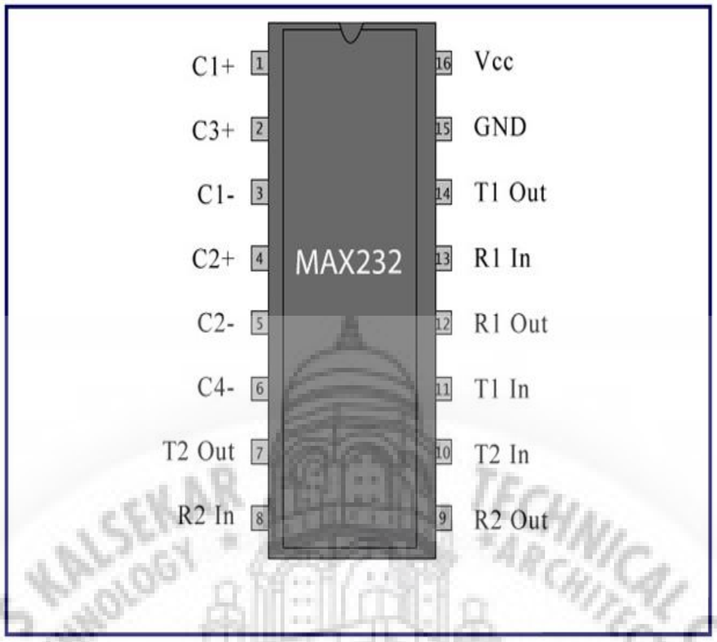
The later MAX232A is backwards compatible with the original MAX232 but may operate at higher baud rates and can use smaller external capacitors (0.1 μF) in place of the 1.0 μF capacitors used with the original device. The newer MAX3232 is also backwards compatible, but operates at a broader voltage range, from 3 to 5.5V.

Voltage levels:

It is helpful to understand what occurs to the voltage levels. When a MAX232 IC receives a TTL level to convert, it changes a TTL Logic 0 to between +3 and +15V, and changes TTL Logic 1 to between -3 to -15V, and vice versa for converting from RS232 to TTL.

This can be confusing when you realize that the RS232 Data Transmission voltages at a certain logic state are opposite from the RS232 Control Line voltages at the same logic state. To clarify the matter, see the table below. For more information see RS-232 Voltage Levels.

RS232 Line Type & Logic Level	RS232 Voltage	TTL Voltage to/from MAX232
Data Transmission (Rx/Tx) Logic 0	+3V to +15V	0V
Data Transmission (Rx/Tx) Logic 1	-3V to -15V	5V
Control Signals (RTS/CTS/DTR/DSR) Logic 0	-3V to -15V	5V
Control Signals (RTS/CTS/DTR/DSR) Logic 1	+3V to +15V	0V



3.11 PIN DIAGRAM

Pin No	Function	Name
1	Capacitor connection pins	Capacitor 1 +
2		Capacitor 3 +
3		Capacitor 1 -
4		Capacitor 2 +
5		Capacitor 2 -
6		Capacitor 4 -
7	Output pin; outputs the serially transmitted data at RS232 logic level; connected to receiver pin of PC serial port	T_2 Out
8	Input pin; receives serially transmitted data at RS 232 logic level; connected to transmitter pin of PC serial port	R_2 In
9	Output pin; outputs the serially transmitted data at TTL logic level; connected to receiver pin of controller.	R_2 Out
10	Input pins; receive the serial data at TTL logic level; connected to serial transmitter pin of controller.	T_2 In
11		T_1 In
12	Output pin; outputs the serially transmitted data at TTL logic level; connected to receiver pin of controller.	R_1 Out
13	Input pin; receives serially transmitted data at RS 232 logic level; connected to transmitter pin of PC serial port	R_1 In
14	Output pin; outputs the serially transmitted data at RS232 logic level; connected to receiver pin of PC serial port	T_1 Out
15	Ground (0V)	Ground
16	Supply voltage; 5V (4.5V – 5.5V)	Vcc

Application:

The MAX232 has two receivers (converts from RS-232 to TTL voltage levels) and two drivers (converts from TTL logic to RS-232 voltage levels). This means only two of the RS-232 signals can be converted in each direction.

Typically a pair of a driver/receiver of the MAX232 is used for

- TX and RX

And the second one for

- CTS and RTS.

There are not enough drivers/receivers in the MAX232 to also connect the DTR, DSR, and DCD signals. Usually these signals can be omitted when e.g. communicating with a PC's serial interface. If the DTE really requires these signals either a second MAX232 is needed, or some other IC from the MAX232 family can be used.

3.12 DB9 CONNECTOR

The DB9 (originally DE-9) connector is an analog 9-pin plug of the D-Sub miniature connector family (D-Sub or Sub-D). The DB9 connector is mainly used for serial connections, allowing for the asynchronous transmission of data as provided for by standard RS-232 (RS-232C).

3.12.1 DB9 CONNECTOR

Pins:

Pin number	Name
1	CD - Carrier Detect
2	RXD - Receive Data
3	TXD - Transmit Data
4	DTR - Data Terminal Ready
5	GND - Signal Ground
6	DSR - Data Set Ready
7	RTS - Request To Send
8	CTS - Clear To Send
9	RI - Ring Indicator
	Shield

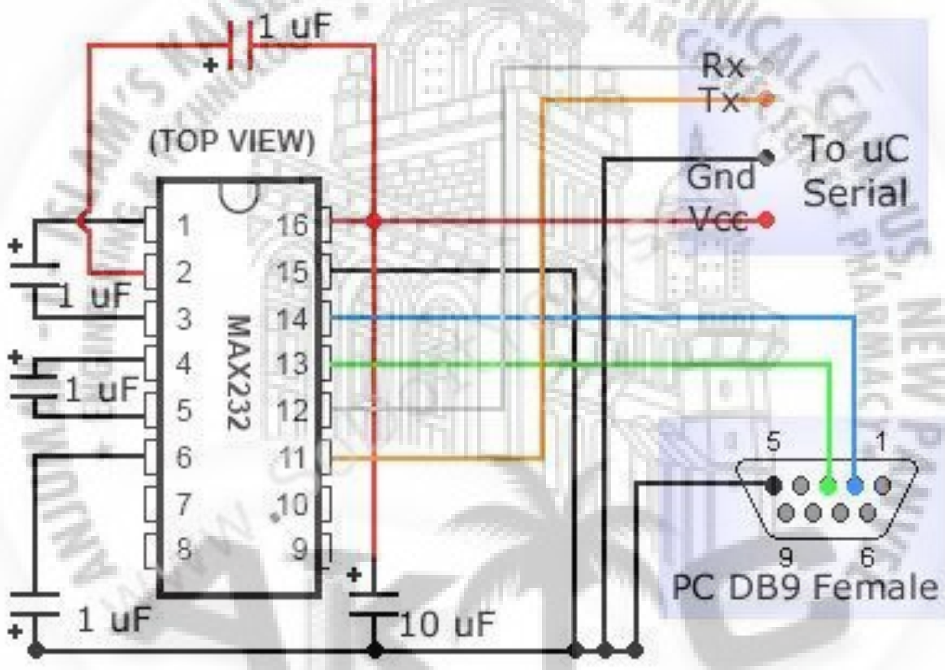
This is a common connector used in many computer, audio/video, and data applications. The official name is D-sub miniature, but many people call it "D-sub" or just "DB". The connector gets its name from its trapezoidal shape that resembles the letter "D". Most DB connectors have two rows of pins. Common types of D-sub connectors are DB9 and DB25, used on PCs for serial and parallel ports.

One special type of D-sub connectors is the High-Density DB style, which looks just like a regular DB connector, only with pins that are slightly smaller and placed closer together. This is typically referred to as an "HD" connector. HD connectors often have three rows of pins instead of two. The most common HD connector is the HD15, which is found on PC video cards and monitors. DB- and HD-connectors use thumbscrews to secure the connector in place.

Another type of D-sub is the MD, or Micro DB connector. This connector is slimmer than a standard D-sub, with pins even smaller than the ones used on HD connectors. The MD is also commonly called a "half-pitch" DB connector. These are often used in SCSI applications, and the most popular types are the MD50 and MD68 connections. MD-connectors can use latch clips or thumbscrews as anchoring mechanisms.

D-sub connectors are usually described by the total number of pins that they can hold. In some cases, a DB25 connector may only have 4 or 5 pins loaded into it; however, it is still called a "DB25" connector and not a "DB4" or "DB5". Another example is the HD15 connector used by monitors—most monitor cables only are loaded with 14 pins, but it is still called an HD15 connector.

Interfacing Between Microcontroller and Db9 Connector



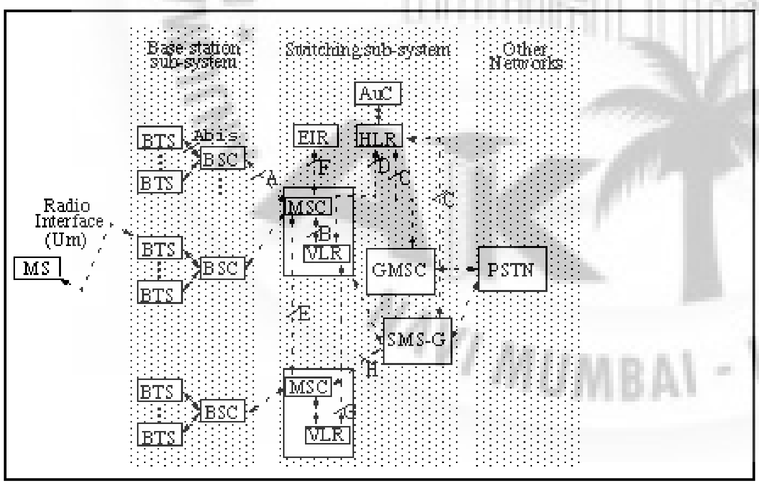
3.12.2 INTERFACING BETWEEN MICRO CONTROLLER DB9 CONNECTOR

3.13 GSM COMMUNICATION

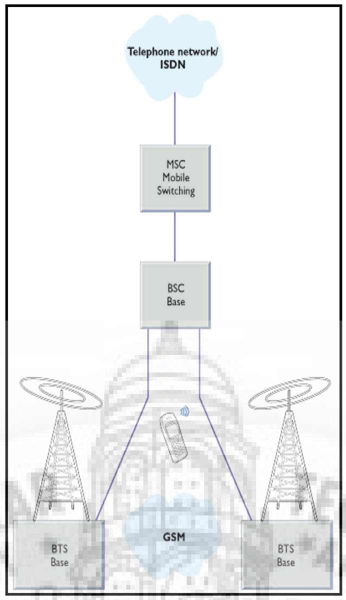
GSM for mobile system is increasingly popular and established throughout the world. The term GSM usually means the GSM standard and protocols in the frequency spectrum around 900MHz. There is also DCS1800 - GSM protocols but at different air frequencies around 1800 MHz - and in the United States, where spectrum for Personal Communication Services (PCS) was auctioned at around 1900MHz. As a result of this, the original and most widely-used GSM frequency implementation is known as GSM900, and DCS1800 is also known as GSM1800. Though the physical frequencies used are differed, the protocols and architecture remain the same. The following sections describe about the functional entities, the radio interface signaling protocol, the logical and physical channel structure and the TDMA structure based on GSM.

System architecture

The figure below shows the GSM system architecture, which consists of the switching system, the base station system and the user equipment. Functional entities are briefly explained as follows.



3.13.1 DETAILED ARCHITECTURE OF GSM



3.13.2 BASIC GSM NETWORK

DESCRIPTION OF MODULES IN GSM ARCHITECTURE

MS - Mobile Station:

The MS is the physical equipment used by a subscriber, most often a normal hand-held cellular telephone.

BTS -Base Transceiver Station:

The BTS comprises the radio transmission and reception devices, and also manages the signal processing related to the air interface.

TRAU -The Transcoder Rate Adaptor Unit:

The TRAU functionally belongs to the BTS. The TRAU enables the use of lower rates (32, 16 or 8 kbps) over the A-bits interface instead of the 64 kbps ISDN rate for which the MSC is designed. The TRAU can be located at the BTS, the BSC, or (immediately in front of) the MSC.

BSC- Base Station Controller:

The BSC manages the radio interface, mainly through the allocation, release and handover of radio channels.

BSS -Base Station System:

The BSS consists of a BSC and one or more BTS's.

MSC

-Mobile Switching Centre:

The MSC is basically an ISDN-switch, coordinating and setting up calls to and from MS's. An Inter-Working Function (IWF) may be required to adapt.

VLR -Visitor Location Register:

The VLR contains all the subscriber data, both permanent and temporary, which are necessary to control a MS in the MSCs coverage area. The VLR is commonly realized as an integral part of the MSC, rather than a separate entity.

AuC -Authentication Centre:

The AuC database contains the subscriber authentication keys and the algorithm required to calculate the authentication parameters to be transferred to the HLR.

HLR- Home Location Register:

The HLR database is used to store permanent and semi-permanent subscriber data; as such, the HLR will always know in which location area the MS is (assuming the MS is in a coverage area), and this data is used to locate an MS in the event of a MS terminating call set-up.

EIR -Equipment Identity Register:

The EIR database contains information on the MS and its capabilities. The IMEI (International Mobile Subscriber Identity) is used to interrogate the EIR.

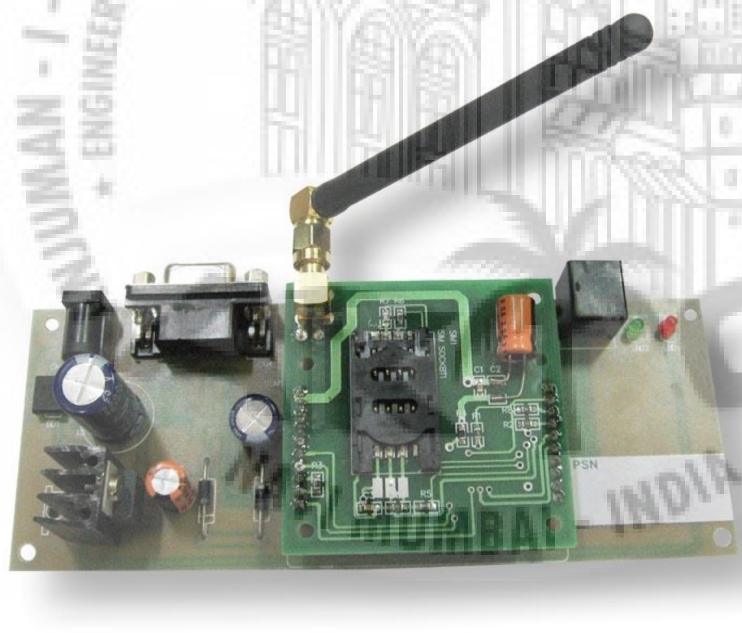
GMSC -Gateway Mobile Switching Centre:

The GMSC is the point to which a MS terminating call is initially routed, without any knowledge of the MS's location. The GMSC is thus in charge of obtaining the MSRN (Mobile Station Roaming Number) from the HLR based on the MSISDN (Mobile Station ISDN number, the "directory number" of a MS) and routing the call to the correct visited MSC. The "MSC" part of the term GMSC is misleading, since the gateway operation does not require any linking to a MSC.

SMSG: This is the term used to collectively describe the two Short Message Services Gateways described in the GSM recommendations. The SMS-GMSC (Short Message Service Gateway Mobile Switching Centre) is for mobile terminating short messages and SMS-IWMSC (Short Message Service Inter-Working Mobile Switching Centre) for mobile originating short messages. The SMS-GMSC role is similar to that of the GMSC, whereas the SMS-IWMSC provides a fixed access point to the Short Message Service Centre.

3.14 GSM MODEM

A **GSM modem** is a specialized type of modem which accepts a SIM card, and operates over a subscription to a mobile operator, just like a mobile phone. From the mobile operator perspective, a GSM modem looks just like a mobile phone.



3.14 GSM MODEM

When a GSM modem is connected to a computer, this allows the computer to use the GSM modem to communicate over the mobile network. While these GSM modems are most frequently used to provide mobile internet connectivity, many of them can also be used for sending and receiving SMS and MMS messages.

A GSM modem can be a dedicated modem device with a serial, USB or Bluetooth connection, or it can be a mobile phone that provides GSM modem capabilities.

For the purpose of this document, the term GSM modem is used as a generic term to refer to any modem that supports one or more of the protocols in the GSM evolutionary family, including the 2.5G technologies GPRS and EDGE, as well as the 3G technologies WCDMA, UMTS, HSDPA and HSUPA.

A GSM modem exposes an interface that allows applications such as SMS to send and receive messages over the modem interface. The mobile operator charges for this message sending and receiving as if it was performed directly on a mobile phone. To perform these tasks, a GSM modem must support an “extended AT command set” for sending/receiving SMS messages, as defined in the ETSI GSM 07.05 and 3GPP TS 27.005 specifications.

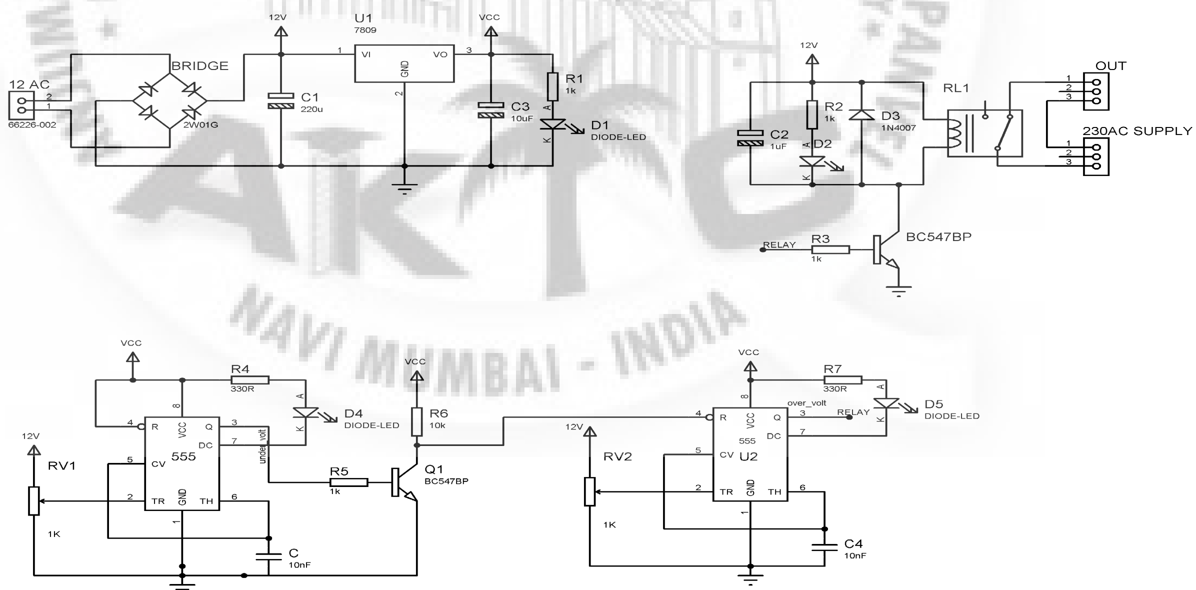
GSM modems can be a quick and efficient way to get started with SMS, because a special subscription to an SMS service provider is not required. In most parts of the world, GSM modems are a cost effective solution for receiving SMS messages, because the sender is paying for the message delivery.

A GSM modem can be a dedicated modem device with a serial, USB or Bluetooth connection, such as the Falcom Samba 75. (Other manufacturers of dedicated GSM modem devices include Wavecom, Multitech and iTegno. We’ve also reviewed a number of modems on our technical support blog.) To begin, insert a GSM SIM card into the modem and connect it to an available USB port on your computer.

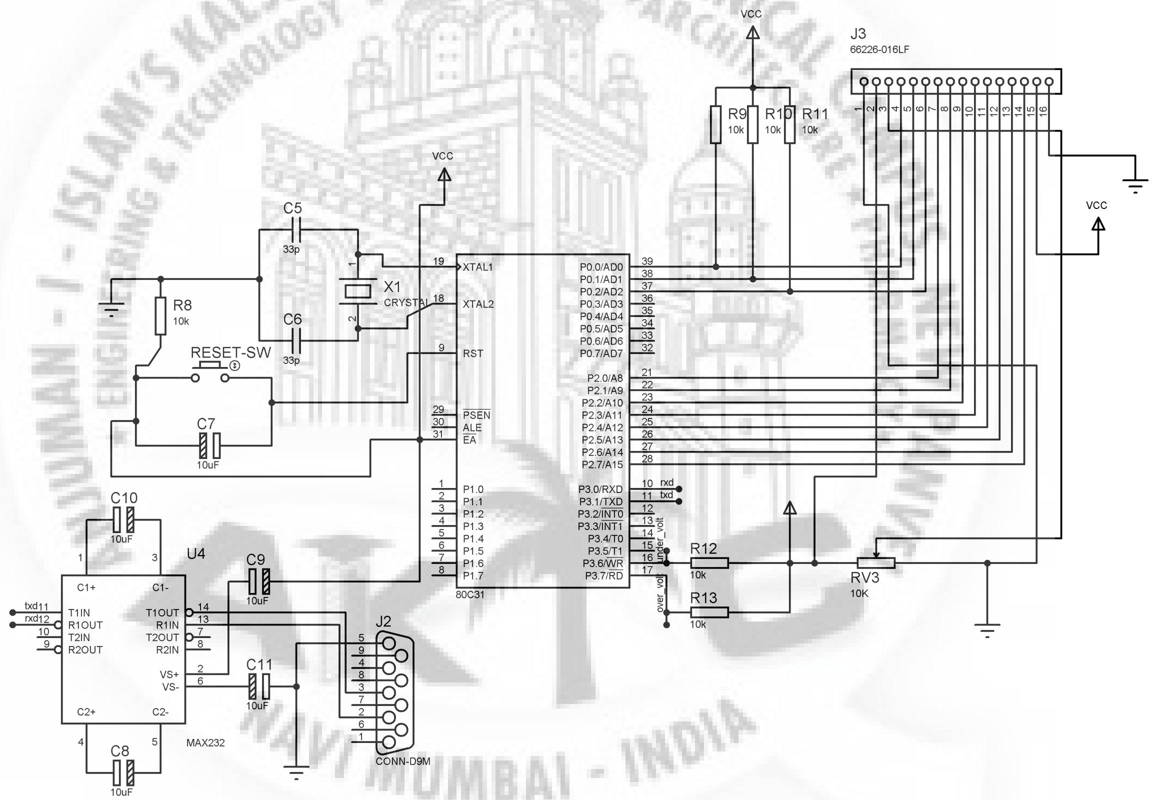
A GSM modem could also be a standard GSM mobile phone with the appropriate cable and software driver to connect to a serial port or USB port on your computer. Any phone that supports the “extended AT command set” for sending/receiving SMS messages, as defined in ETSI GSM 07.05 and/or 3GPP TS 27.005, can be supported by the Now SMS & MMS Gateway. Note that not all mobile phones support this modem interface.

Due to some compatibility issues that can exist with mobile phones, using a dedicated GSM modem is usually preferable to a GSM mobile phone. This is more of an issue with MMS messaging, where if you wish to be able to receive inbound MMS messages with the gateway, the modem interface on most GSM phones will only allow you to send MMS messages. This is because the mobile phone automatically processes received MMS message notifications without forwarding them via the modem interface.

It should also be noted that not all phones support the modem interface for sending and receiving SMS messages. In particular, most smart phones, including Blackberries, iPhone, and Windows Mobile devices, do not support this GSM modem interface for sending and receiving SMS messages at all at all. Additionally, Nokia phones that use the S60 (Series 60) interface, which is Symbian based, only support sending SMS messages via the modem interface, and do not support receiving SMS via the modem interface.



4. SCHEMATIC DIAGRAM



4.1 SCHEMATIC DIAGRAM

5. DESCRIPTION

5.1 CONNECTIONS:

In this project of OVER VOLTAGE OR UNDER VOLTAGE ALERT SYSTEM we are using one step down transformer from 230v 50hz to 12v. One bridge rectifier and voltage regulator of 7809 so that +9v can be obtained for the operation of the circuit. Here we are using 2 555 timer known as U2 &U3 8th pin of which is connected to 3rd pin of voltage regulator where 4th pin is shorted to 8th pin. 2nd pin of U2 is connected to RV1which is used for low voltage LV and pin 2 of U3 is used for high voltage HV. Where 5th pin and 6th pin of both U2 & U3 are shorted and connected to Gnd through capacitor C3 of 10n where 7th pin is connected to filter circuit through LED D6 and resistor R2 of 220R 3rd pin is connected to base of transistor Q1 &Q2 (BC547) through R3 of 1k. Emitter is connected to VCC where Q2 is connected to relay where RL1 consist of LOAD lamp and ac supply.

5.2 WORKING:

In this project of over voltage or under voltage alert system, the following three conditions are explained:

FOR NORMAL OPERATION

The pin2 of U2 is connected to a pot fixed at some point say 3.1Vand at pin2 of U3 is fixed at some point say 2.9V.This presetsare compared with 1/3rd voltage of supply 9V i.e., 3V at pin 5 of both 555 timers.In this condition the pin no.2 of U2 is high so the o/p at pin 3 of U2is low. Therefore,the transistor Q1 is not conducting.The o/p of transistor is high,given to pin4 of U3.So this timer is operating. Since the pin2 at U3 is less than 1/3rd voltage i.e., 3V the output is high. Thus the transistor conducts and the output low.Hencethe relay is ON, making the load turn ON.

FOR OVER VOLTAGE

Whenever there is any increase in power supply, the voltage at pin 3 is above 3.1V i.e., high.Therefore the output islow.The transistor Q1is not conducting,due to which high is given to pin4 of u3.Since the voltage at pin2 of U3 is also increased due to change in input supply,the pin2 voltage goes above 2.9V (say 2.3V).Hence the output at pin3 of U3 will be low .Thus the relay is off and hence the load is over voltagecondition.

FOR UNDER VOLTAGE

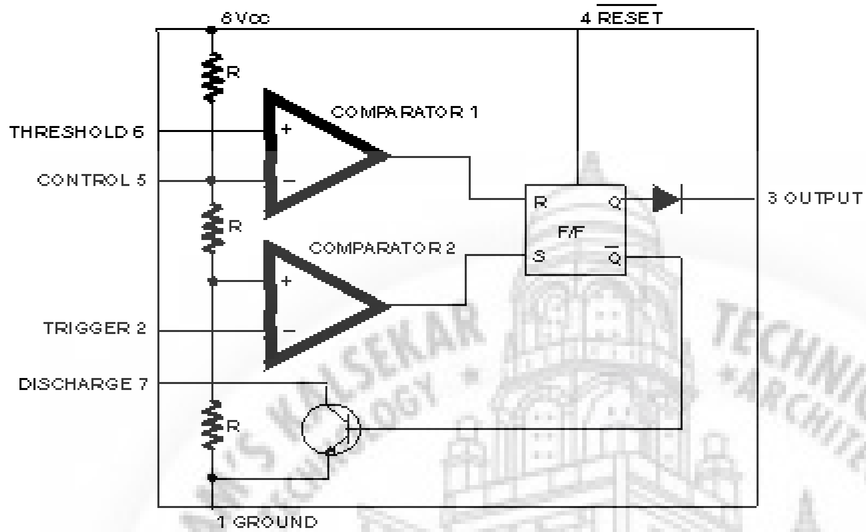
This condition occurs if there is any decrease in input supply.So thevoltage at pin2 of U2 will be less than 3.1V(say 2.8V)i.e., is low.Thus the output at pin3 of U2 is high.Now the transistor Q1 is conducting and load is given to pin4 of U3.Therefore the timer is not operating and the output will be low.So thetransistor Q2 is also not conducting.Now the relay is also OFF and theload is disconnected in case of undervoltage in powersupply.

NOTE: we can give over voltage or under voltage by using function generator/dc regulated power supply.

This over/under voltage cut-out will save your costly electrical and electronic appliances from the adverse effects of very high and very low mains voltages.

The circuit features auto reset and utilizes easily available components. It makes use of the comparators available inside 555 timer ICs. Supply is tapped from different points of the power supply circuit for relay and control circuit operation to achieve reliability. The circuit utilizes comparator 2 for control while comparator 1 output (connected to reset pin R) is kept low by shorting pins 5 and 6 of 555 IC. The positive input pin of comparator 2 is at 1/3rd of Vcc voltage. Thus as long as negative input pin 2 is less positive than 1/3 Vcc, comparator 2 output is high and the internal flip-flop is set, i.e. its Q output (pin 3) is high. At the same time pin 7 is in high impedance state and LED6 connected to pin 7 is therefore off. The output (at pin 3) reverses (goes low) when pin 2 is taken more positive than 1/3 Vcc. At the same time pin 7 goes low (as Q output* of internal flip- flop is high) and the LED connected to pin 7 is lit. Both timers (u2 & u3) are configured to function in the same fashion. Preset RV1 is adjusted for under voltage (say 160 volts) cut-out by observing that LED6 just lights up when mains voltage is slightly greater than 160V AC. At this setting the output at pin 3 of u2 is low and transistor Q1 is in cut-off state. As a result RESET* pin 4 of u3 is held high since it is connected to Vcc via 10 kilo-ohm resistor R4. Preset RV2 is adjusted for over voltage (say 270V AC) cut-out by observing that LED7 just extinguishes when the mains voltage is slightly less than 270V AC. With RESET* pin 4 of u3 high, the output pin 3 is also high. As a result transistor Q2 conducts and energises relay RL1, connecting load to power supply via its N/O contacts. This is the situation as long as mains voltage is greater than 160V AC but less than 270V AC. When mains voltage goes beyond 270V AC, it causes output pin 3 of u3 to go low and cut-off transistor Q2 and de-energise relay RL1, in spite of RESET* pin 4 still being high. When mains voltage goes below 160V AC, u2 pin 3 goes high and LED6 is extinguished. The high output at pin 3 results in conduction of transistor Q1. As a result collector of transistor Q1 as also RESET* pin 4 of u3 are pulled low. Thus output of u3 goes low and transistor T2 does not conduct. As a result relay RL1 is de-energised, which causes load to be disconnected from the supply. When mains voltage again goes beyond 160V AC (but less than 270V AC) the relay again energises to connect the load to power supply

6. LAYOUT DIAGRAM



6.1 LAYOUT DIAGRAM

7. HARDWARE TESTING

7.1 CONTINUITY TEST:

In electronics, a continuity test is the checking of an electric circuit to see if current flows (that it is in fact a complete circuit). A continuity test is performed by placing a small voltage (wired in series with an LED or noise-producing component such as a piezoelectric speaker) across the chosen path. If electron flow is inhibited by broken conductors, damaged components, or excessive resistance, the circuit is "open".

Devices that can be used to perform continuity tests include multi meters which measure current and specialized continuity testers which are cheaper, more basic devices, generally with a simple light bulb that lights up when current flows.
An important application is the continuity test of a bundle of wires so as to find the two ends belonging to a particular one of these wires; there will be a negligible resistance between the "right" ends, and only between the "right" ends.

This test is the performed just after the hardware soldering and configuration has been completed. This test aims at finding any electrical open paths in the circuit after the soldering. Many a times, the electrical continuity in the circuit is lost due to improper soldering, wrong and rough handling of the PCB, improper usage of the soldering iron, component failures and presence of bugs in the circuit diagram. We use a multi meter to perform this test. We keep the multi meter in buzzer mode and connect the ground terminal of the multi meter to the ground. We connect both the terminals across the path that needs to be checked. If there is continuation then you will hear the beep sound.

7.2 POWER ON TEST:

This test is performed to check whether the voltage at different terminals is according to the requirement or not. We take a multi meter and put it in voltage mode. Remember that this test is performed without ICs. Firstly, if we are using a transformer we check the output of the transformer; whether we get the required 12V ACvoltage (depends on the transformer used in for the circuit). If we use a battery then we check if the battery is fully charged or not according to the specified voltage of the battery by using multimeter.

Then we apply this voltage to the power supply circuit. Note that we do this test without ICs because if there is any excessive voltage, this may lead to damaging the ICs. If a circuit consists of voltage regulator then we check for the input to the voltage regulator (like 7805, 7809, 7815, 7915 etc) i.e., are we getting an input of 12V and a required output depending on the regulator used in the circuit.

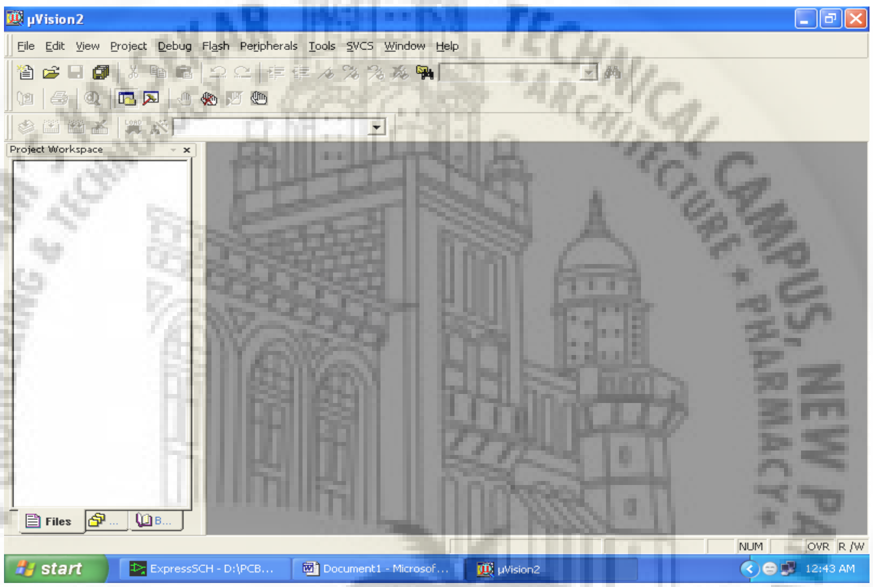
EX: if we are using 7805 we get output of 5V and if using 7809 we get 9V at output pin and so on.

This output from the voltage regulator is given to the power supply pin of specific ICs. Hence we check for the voltage level at those pins whether we are getting required voltage. Similarly, we check for the other terminals for the required voltage. In this way we can assure that the voltage at all the terminals is as per the requirement.

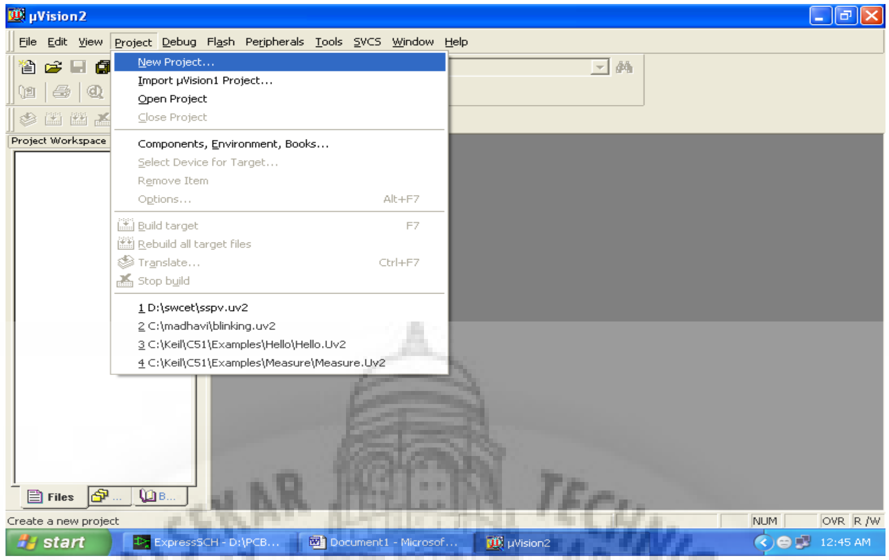
8.CODING

8.1 PROGRAM CODE

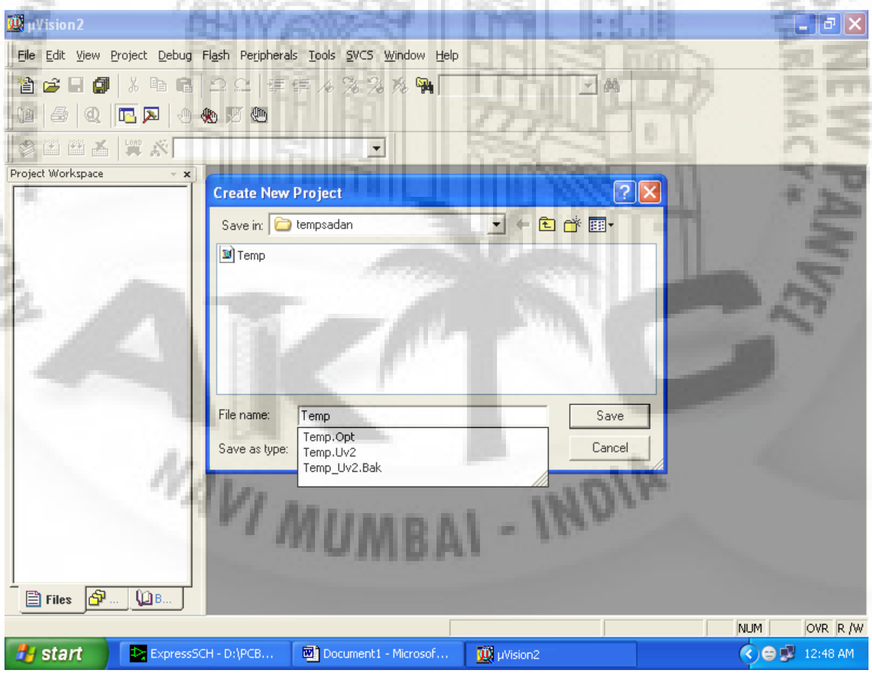
1. Click on the Keil Vision Icon on Desktop
2. The following fig will appear



3. Click on the Project menu from the title bar
4. Then Click on New Project



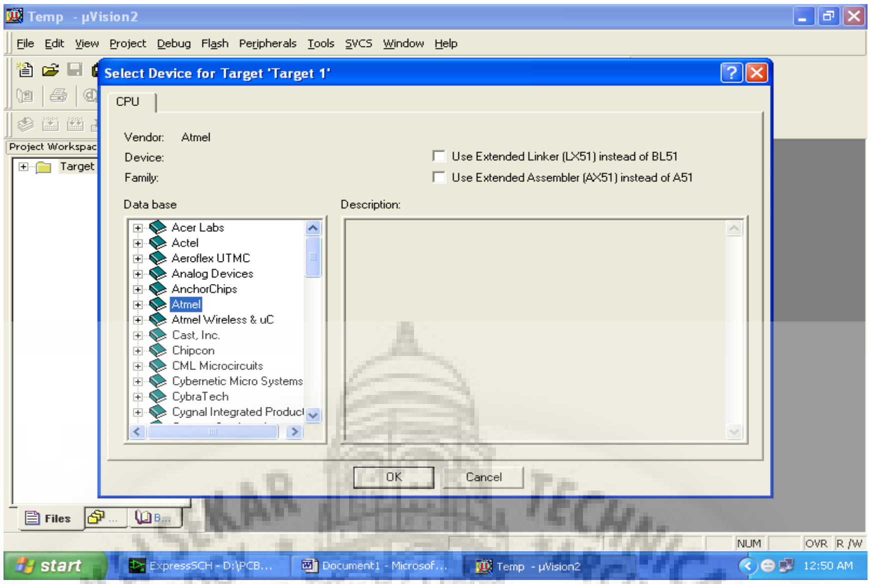
5. Save the Project by typing suitable project name with no extension in u r own folder sited in either C:\ or D:\



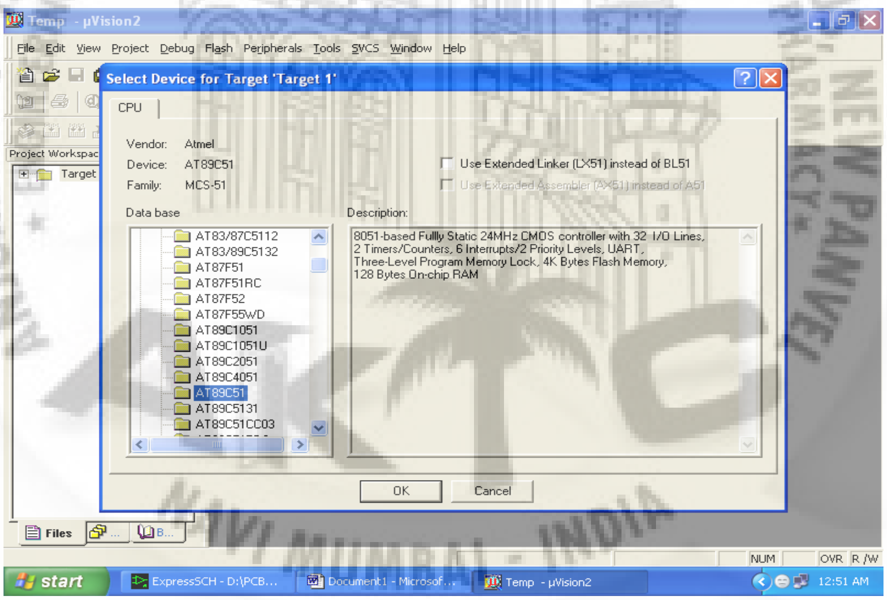
6. Then Click on Save button above.

7. Select the component for u r project. i.e. Atmel……

8. Click on the + Symbol beside of Atmel

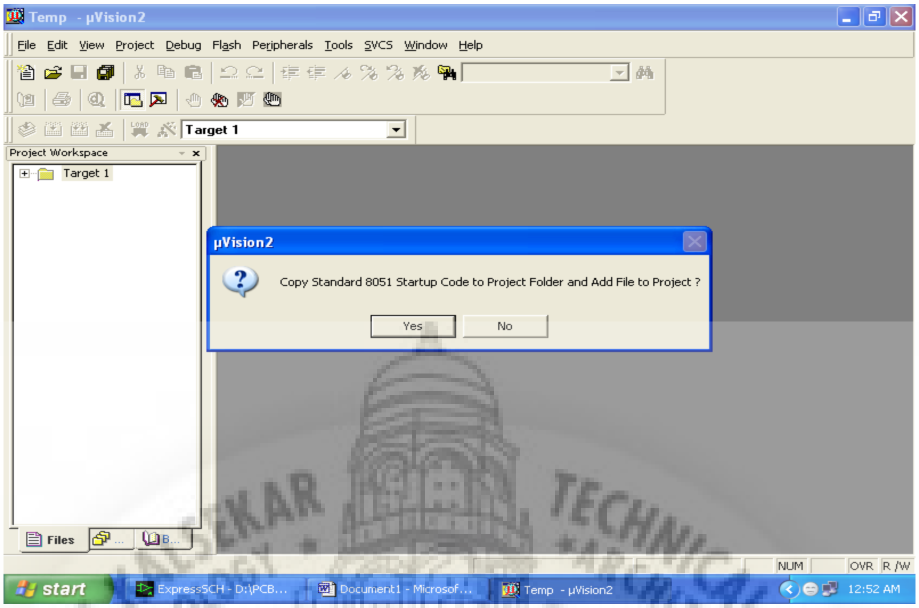


9. Select AT89C51 as shown below



10. Then Click on "OK"

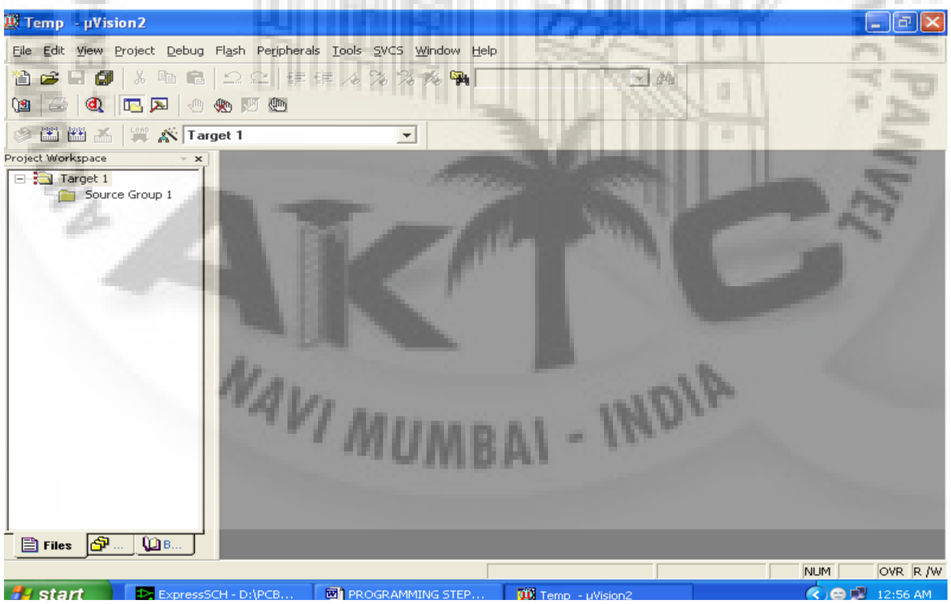
11. The Following fig will appear



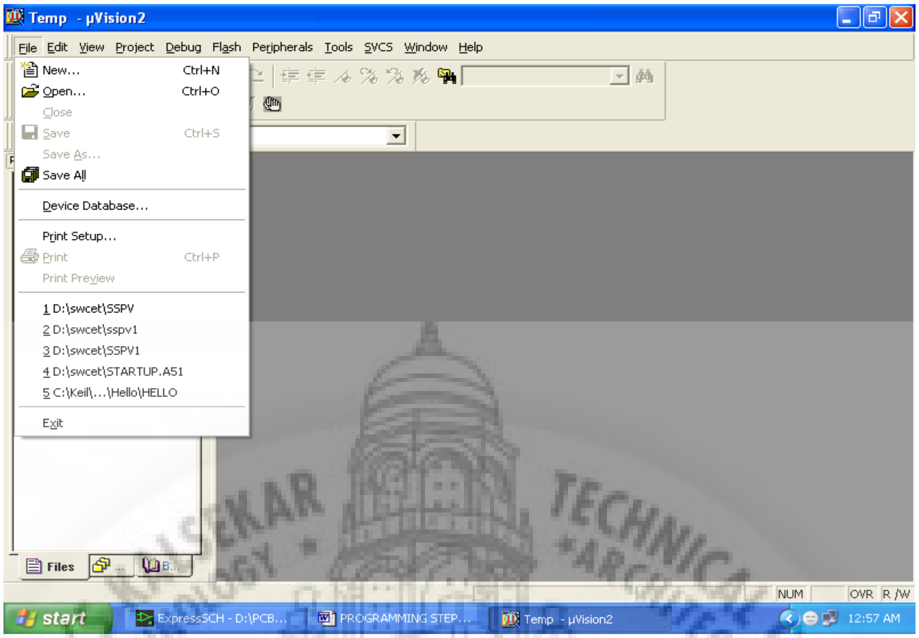
12. Then Click either YES or NO………mostly "NO".

13. Now your project is ready to USE.

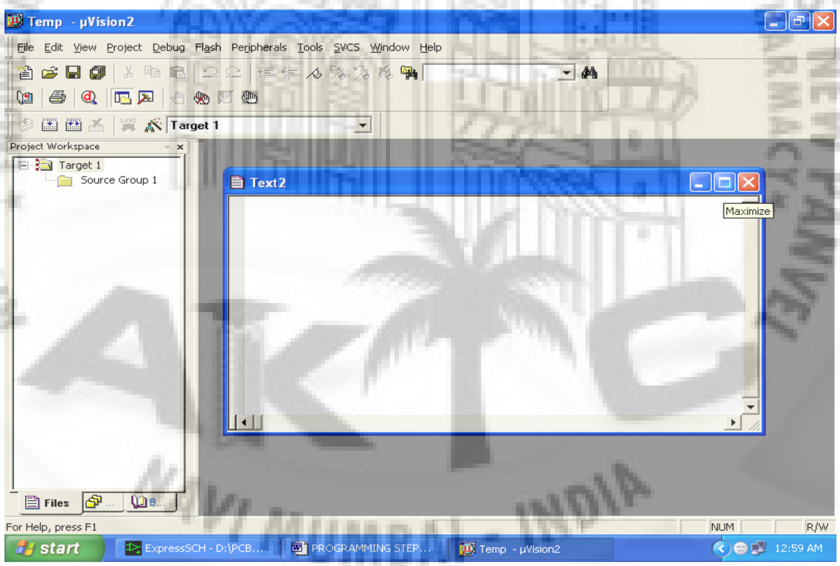
14. Now double click on the Target1, you would get another option "Source group 1" as shown in next page.



15. Click on the file option from menu bar and select "new".

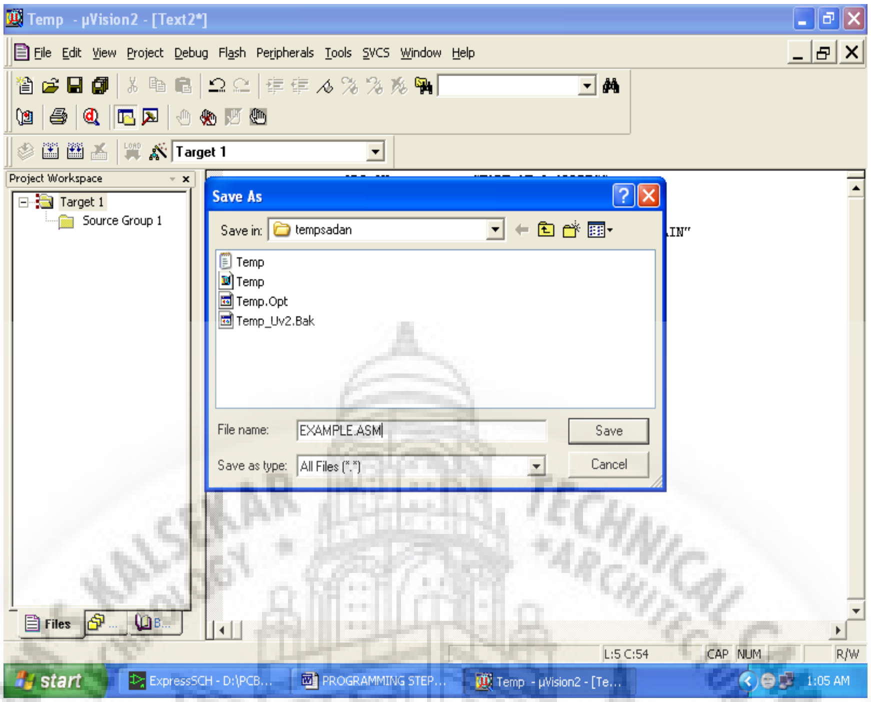


16. The next screen will be as shown in next page, and just maximize it by double clicking on its blue boarder.

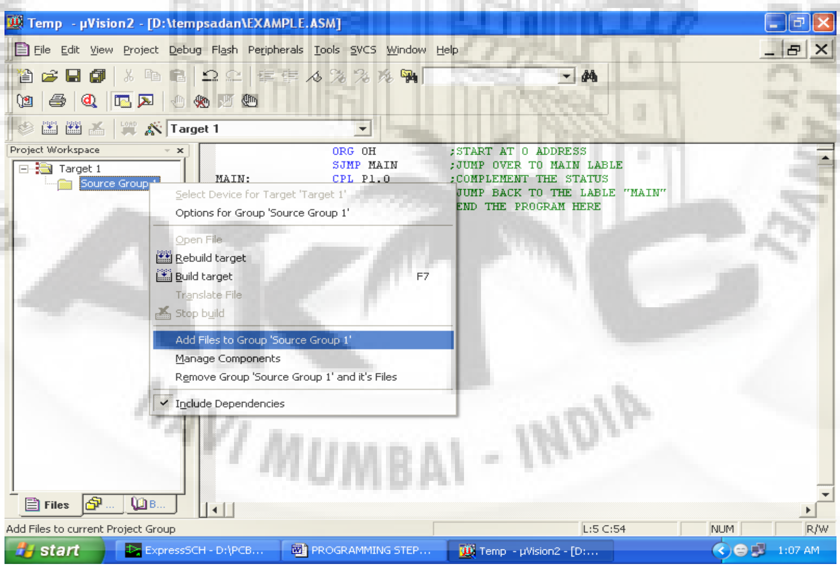


17. Now start writing program in either in “EMBEDDED C” or “ASM”.

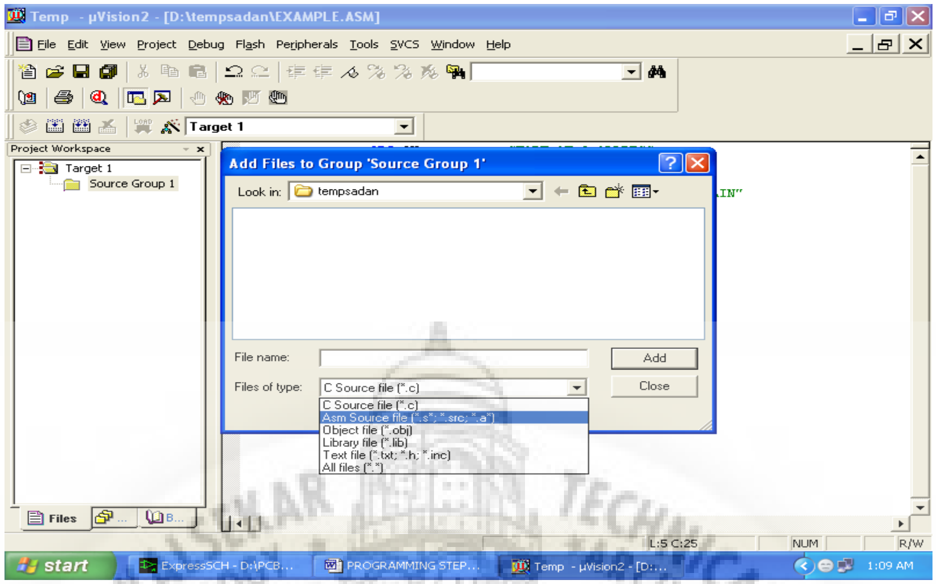
18. For a program written in Assembly, then save it with extension “. asm” and for “EMBEDDED C” based program save it with extension “ .C”



19. Now right click on Source group 1 and click on "Add files to Group Source".



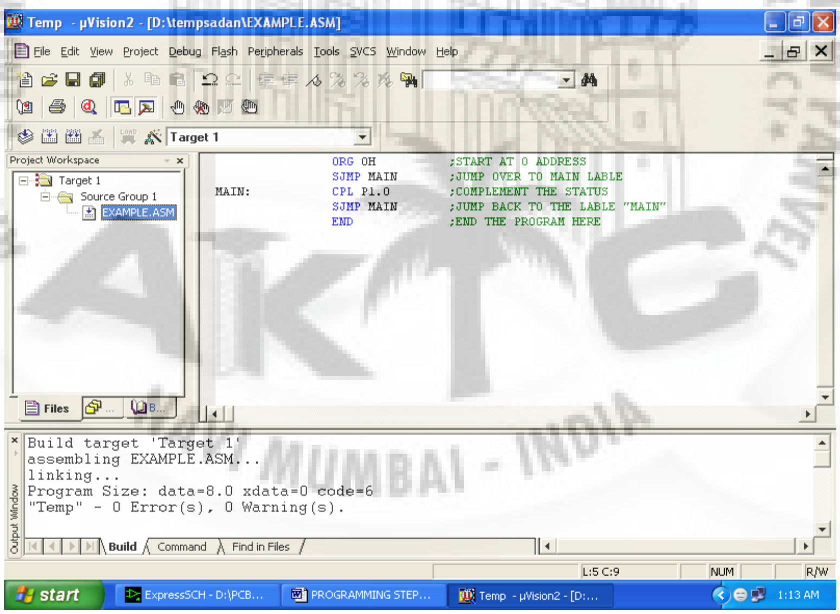
20. Now you will get another window, on which by default "EMBEDDED C" files will appear.



21. Now select as per your file extension given while saving the file

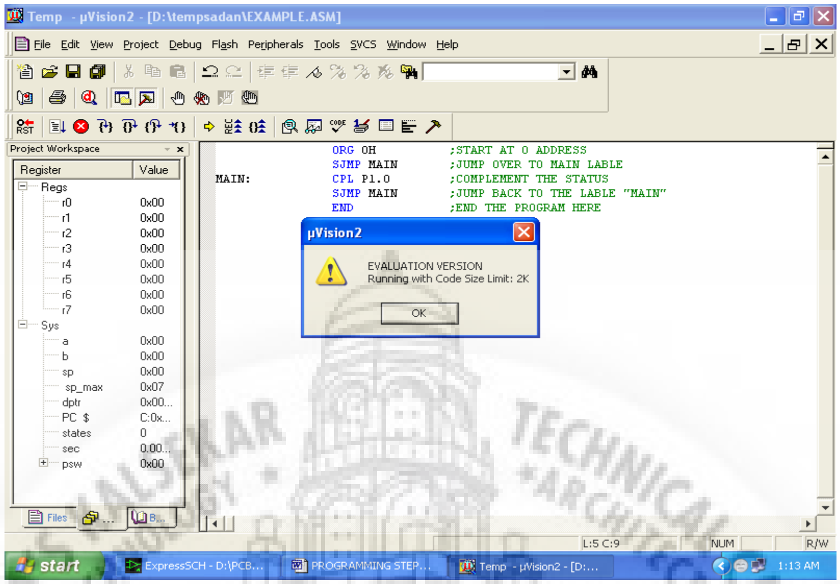
22. Click only one time on option "**ADD**".

23. Now Press function key F7 to compile. Any error will appear if so happen.



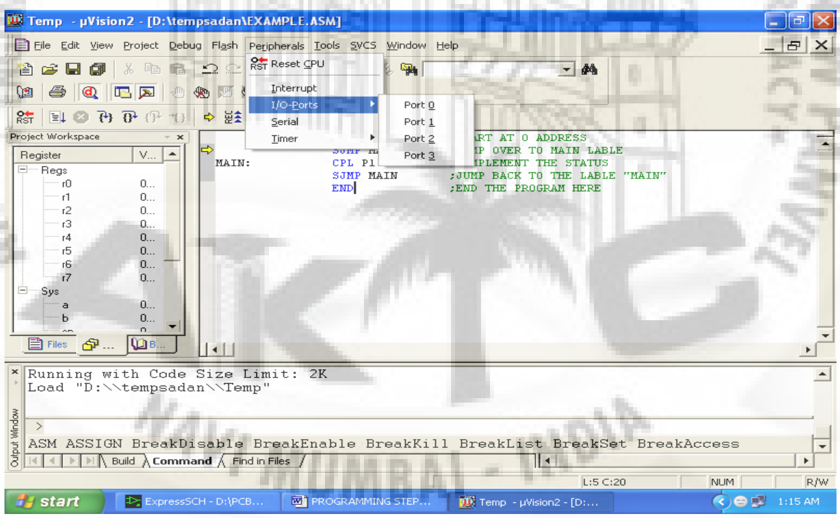
24. If the file contains no error, then press Control+F5 simultaneously.

25. The new window is as follows

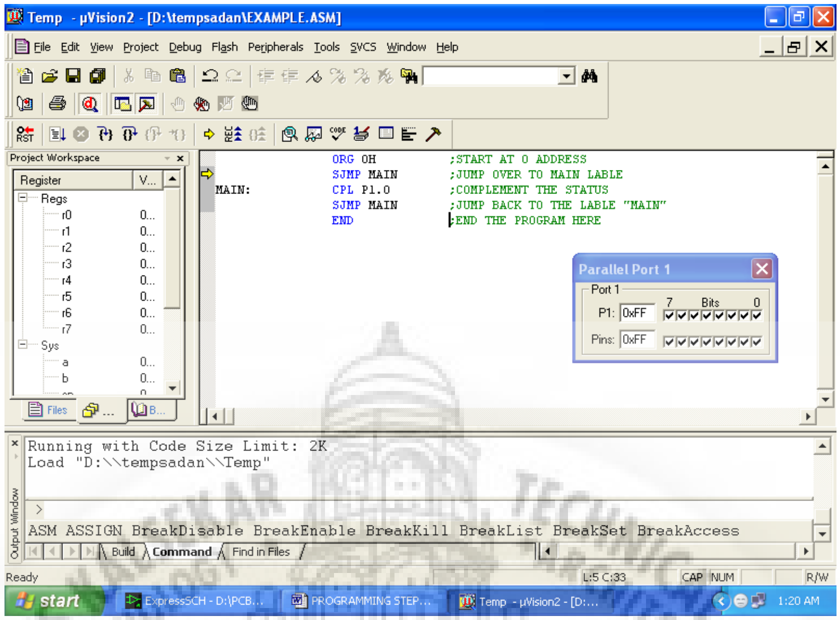


26. Then Click "OK".

27. Now click on the Peripherals from menu bar, and check your required port as shown in fig below.



28. Drag the port a side and click in the program file.



29. Now keep Pressing function key "F11" slowly and observe.

30. You are running your program successfully.

9. ADVANTAGES AND DISADVANTAGES

ADVANTAGES

- We can provide the protection for the home appliances during voltage fluctuation.
- We can set or change permissible limit of Voltage as per our requirements.
- We can monitor the condition of the load from the remote locations.
- We can use this device for the different load specification.
- We can get SMS Alert on every registered mobile number.

DISADVANTAGES

- The device requires additional DC supply for the operation.
- If there is a network issue in our mobile we cant get SMS Alert.
- To ensure the continuous operation of the device we required independent or backup power supply which may increase the cost.

10. CONCLUSION

- This project provides the protection against the Over Voltage and Under voltage.
- When the Voltage is above high permissible limit the circuit will be tripped and device will be isolated, In this project the higher permissible voltage is 240V.
- When the Voltage is below minimum permissible limit the circuit will be tripped and the device will be isolated, in this project the lower permissible Voltage 160V.
- In both the condition when the circuit will trip we will get a SMS Alert on the registered mobile number.
- We can observe the condition of the circuit on the LCD display.

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