RESISTOR COMBINATIONS

- When we do not get specific resistor values we have to either use variable resistors such as potentiometers or presets to obtain such precise values. Pots are too expensive to use for every case.
- Another scheme is to combine two or more resistors to obtain the necessary precise values. Such resistor combinations can cost as little as 50p or so only.
- Then the question arises as to how one should combine these resistors, because, they can be combined in two different ways.
- These are called “Series” and “Parallel” combinations.

**Series Combination**

\[ R_{\text{Total}} = R_1 + R_2 \]

- Calculating values for two or more resistors in series is simple, add all the values up.
- The connection ensures that the SAME current flows through all resistors.
- In this type of connection \( R_{\text{TOTAL}} \) will always be GREATER than any of the included resistors.
Even if we have more than two resistors the total resistance is the sum of all the resistors connected in series:

\[ R_{\text{Total}} = R_1 + R_2 + R_3 + \cdots \cdots \]

**RESISTORS IN SERIES**

- The total applied voltage is divided by the two resistors.
- The current in the circuit is:
  \[ I = \frac{V}{R_1 + R_2} \]
- The voltages across \( R_1 \) and \( R_2 \) are (from Ohm's law):
  \[ V_1 = I.R_1 = \frac{V}{R_1 + R_2}.R_1 \]
  \[ V_2 = I.R_2 = \frac{V}{R_1 + R_2}.R_2 \]
- The total voltage is:
  \[ V = V_1 + V_2 = \frac{V}{R_1 + R_2}.R_1 + \frac{V}{R_1 + R_2}.R_2 \]
- If for example, \( V=6V \) and the two resistors are 1k each, then the current in the circuits is \( (6V/2k)=3mA \).
- The voltage across each is 3mA.1k = 3V.
- Instead, if the two resistors are 1k and 2k then the current is \( (6V/3k)=2mA \). The voltage across 1k is 2V and that across 2k is 4V.
• Thus the series connection is characterized by:

1. The same current flows through all the resistors connected in series, and
2. The resultant resistor is the SUM of all resistors in series and
3. Series resistors divide the total applied voltage proportional to their magnitude.

RESISTORS IN PARALLEL
PARALLEL COMBINATION:

• There are two paths available for Current.
• Hence current divides.
• But voltage across the resistors are the same.

• If the two resistors are equal the current will divide equally and the $R_{TOTAL}$ will be exactly half of either resistor or exactly one third if there are three equal resistors.

• In general,

$$\frac{1}{R_{TOTAL}} = \frac{1}{R_1} + \frac{1}{R_2} + \ldots.$$ 

$$R_{TOTAL} = \frac{R_1 \cdot R_2}{R_1 + R_2}$$
• Let us try a numerical example:

Let the voltage be 6V as usual, and the resistors be 1k each.

The current through each resistor will be \( \frac{6V}{1k} = 6mA \). Hence the total current is

\( (6mA + 6mA =) 12mA \).

6V will generate 12mA only when 0.5k is in the circuit.

• Hence the effective resistance when two 1k resistors are connected in parallel is 0.5k.

• This is also true by the formula we saw:

\[
R_{\text{TOTAL}} = \frac{R_1 \cdot R_2}{R_1 + R_2}
\]

\[
R = \frac{(1 \times 1/1+1)k}{1/2} = 0.5k
\]

• Now if two different resistors are used the current will still split, but not equally.

• More current will take the path of least resistance and less current will take the path of higher resistance.

• The total current is still always less than would be for either resistor alone.
Thus the parallel connection is characterized by:

1. The same voltage exists across all the resistors connected in parallel, and
2. The reciprocal of resultant resistor is the sum of reciprocals of all resistors in parallel, and
3. Parallel resistors divide the total current in an inverse proportion to their magnitude.

- When a set of resistors are connected in parallel, the effective resistance is always smaller than the smallest in the set.
- For example: 1k and 10k are parallel (say). Then the resultant is \((10/11)=0.9k\) which is smaller than 1k (the smallest).
- When 1k and 100k are used, then resultant is \((100/101)k=0.99k\) which is smaller than 1k.

**POTENTIAL DIVIDER**

Since series resistors divide voltage, this idea can be used to get smaller voltage from a power supply output. For example, we have a power supply with 10V fixed output. But we want only 5V from it. How to get it?

\[
V_{\text{out}} = V_{\text{in}} \left( \frac{R_2}{R_1 + R_2} \right)
\]
\[ I = \frac{V_{in}}{R_1 + R_2} \]

- Since the current \( I \) flows through \( R_2 \), the voltage developed across it from Ohm's law is
  \[ V_0 = I \times R_2 = \frac{V_{in}}{R_1 + R_2} \times R_2 \]
  \[ V_0 = \frac{R_2}{R_1 + R_2} \times V_{in} \]

- If \( R_1 = R_2 \), then \( V_0 = \frac{V_{in}}{2} \)
- But \( R_1 \) & \( R_2 \) can be 100kΩ each or 100Ω Ohms each!
- Which is to be used?
- Observe, the current \( I \) flowing through the Load will also pass through \( R_1 \).
• Hence $R_1$ will have to be chosen carefully. If we need more current through load $R_L$, then $R_1$ must be small.

• But too small a value will cause energy drain on the power supply.

• More interesting results can be achieved if one (or both) of the resistors are replaced with a variable resistor.

**Power Dissipation:**

• It is also worth noting that when two resistors are in parallel then their overall power rating is increased.

• If both resistors are the same value and same power rating, then the total power rating is doubled.

• If parallel resistances are not equal, then the resistors with smaller values will be required to handle more power.

**RESISTORS**

• Four identical 0.25W resistors can be wired in parallel to give a resistor with one fourth the value in ohms, but four times the power rating. (1.0W)

• This is most useful when we require higher power handling, but don't want to go out and buy more expensive (and physically larger) resistors.

\[ P = V \times I \]
• We have already seen earlier, that the power (in watts) can be calculated by multiplying voltage by current.

• By using ohms law, the parallel or series resistor formulas and the above formula, a minimum power rating for a certain resistor can be calculated.

• If this is exceeded the resistor is likely to get hot and hopefully quietly breakdown. It could even start a fire.

**CAPACITOR**

The function of the capacitor is to store electric charge or in effect electrical energy. It is very useful as a filter, and for passing AC and blocking DC. The symbol is

![Capacitor Symbol]

• It consists of two metal plates separated by a dielectric in between.

\[
C = \frac{\varepsilon_0 \varepsilon r A}{d}
\]
Where $A$ is the area of the plates, $d$ is the spacing between them, $\varepsilon_0$ is called the permittivity in free space and $\varepsilon_r$ is the dielectric constant (relative permittivity).

- When a DC voltage is applied to a capacitor, it gets charged.
- Just as the charges get accumulated on the plates there is a current flowing in the circuit. But as the capacitor gets charged the current gets reduced and when it is fully charged, the current becomes zero.
- When we measure the resistance between the leads of a capacitor it will show infinite resistance.
- Hence a capacitor will block DC current.
- However, when AC voltage or current is applied it will pass. The reactance offered by a capacitance is

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

The unit for capacitance is Farad (F) for some capacitors and they are called as “Super Capacitors”.

- Since the value of capacitance is very small, units such as microfarad ($10^{-6}$F), nanofarad ($10^{-9}$F) and picofarad ($10^{-12}$F) are generally used.
- Sometimes, a three-digit code is used to indicate the value of a capacitor. There are two ways of writing it - one by using letters and numbers, the other by using only numbers depending on the manufacturer.
CAPACITORS IN SERIES

• When capacitors are connected in series the resultant is given by:

\[ \frac{1}{C_{\text{Total}}} = \frac{1}{C_1} + \frac{1}{C_2} \]

• OR

\[ C_{\text{Total}} = \frac{C_1 C_2}{C_1 + C_2} \]

CAPACITORS IN PARALLEL

• When capacitors are connected in parallel the resultant is given by:

\[ C_{\text{Total}} = C_1 + C_2 \]

BREAKDOWN VOLTAGE

The maximum voltage which can be applied across a capacitor – breakdown voltage. The breakdown voltage is the voltage that when exceeded will cause the dielectric (insulator) inside the capacitor to break down and conduct. It depends on the kind of capacitor being used. The failure can be catastrophic.
ELECTROLYTIC CAPACITORS

The important characteristic of electrolytic capacitors is that they have polarity. They have a positive and a negative electrode. Aluminum is used for the electrodes by using a thin oxidization membrane. Electrolytic capacitors range in value from about 1µF to thousands of µF. Mainly this type of capacitor is used as a ripple filter in a power supply circuit, or as a filter to bypass low frequency signals, etc.

CAPACITORS
When a circuit tester, such as an analog meter set to measure resistance, is connected to a 10 microfarad (µF) electrolytic capacitor, a current will flow, but only for a moment.

When we connect the meter's probes to the capacitor in reverse, we will note that current once again flows for a moment.

Once again, when the capacitor has fully charged, the current stops flowing.

So the capacitor can be used as a filter that blocks DC current.

**TANTALUM CAPACITORS**

- Tantalum Capacitors are electrolytic capacitors that use a material called tantalum for the electrodes.
- They are superior to aluminum electrolytic capacitors in temperature and frequency characteristics and therefore expensive.
- They are used for circuits which demand high stability in the capacitance values.
- They are mainly used in analog signal systems.

0.33 µF (35V), 0.47 µF (35V), 10 µF (35V)
CERAMIC CAPACITORS
Ceramic capacitors are constructed with materials such as titanium and barium used as the dielectric. Internally, these capacitors are not constructed as a coil, so they can be used in high frequency applications.

• Typically, they are used in circuits which bypass high frequency signals to ground.
• These capacitors have the shape of a disk.
• Their capacitance is comparatively small.
• They have no polarity.
• They should not be used for analog circuits, because they can distort the signal.

POLYSTYRENE FILM CAPACITORS
In these devices, polystyrene film is used as the dielectric. They are used well in filter circuits or timing circuits which run at several hundred kHz or less.

The component shown has a red color due to the copper leaf used for the electrode. The silver color is due to the use of aluminum foil as the electrode. These devices have no polarity.
ELECTRIC DOUBLE LAYER CAPACITORS

This is a “Super Capacitor” and the capacitance is 0.47 F (470,000 µF). The capacitor is more like a short circuit. A protection circuit needs to be set up. The size is small in spite of capacitance. Physically, the diameter is 21 mm, the height is 11 mm. Care is necessary, because these devices do have polarity.

POLYESTER FILM CAPACITORS

This capacitor uses thin polyester film as the dielectric. They are not high in tolerance, but they are cheap and handy. Their tolerance is about ±5% to ±10%.
POLYPROPYLENE CAPACITORS
This capacitor is used when a higher tolerance is necessary than polyester capacitors offer. Polypropylene film is used for the dielectric. There is no change of capacitance in these devices if they are used with frequencies of 100KHz or less. The pictured capacitors have a tolerance of ±1%.

MICA CAPACITORS
These capacitors use Mica for the dielectric. Mica capacitors have good stability because their temperature coefficient is small. Because their frequency characteristic is excellent, they are used for resonance circuits, and high frequency filters. They have very good insulation, and so can be utilized in high voltage circuits. It was often used for vacuum tube style radio transmitters, etc. Mica capacitors do not have high values of capacitance, and they can be relatively expensive. Pictures shown are "Dipped mica capacitors." These can handle up to 500 volts. These capacitors have no polarity.

47pF 220pF 1000pF
METALLIZED POLYESTER FILM CAPACITORS

These capacitors are a kind of a polyester film capacitor. Because their electrodes are thin, they can be miniaturized. These capacitors have no polarity.

0.001µF  0.22µF  2.2µF

VARIABLE CAPACITORS

Variable capacitors are used for adjustment of frequency mainly. The value of the capacitor can be affected by the capacitance of the screwdriver we use so we have to use a special screwdriver.

20pF  (3pF - 27pF)

There are different colors, as well.

Blue: 7pF (2 - 9), white: 10pF (3 - 15), green: 30pF (5 - 35), brown: 60pF (8 - 72).

These capacitors are used for radio tuners. The capacitance is varied by turning the spindle which changes the area between the plates.
COILS & INDUCTANCES

COILS

• A coil is copper wire wound in a spiral.

  The symbol

• Inductance value is designated in units called the Henry (H).

• The more turns the coil contains, the stronger its characteristics become.

• If a coil is wound around an iron rod, or ferrite core (strengthened with iron powder), the inductance of the coil will be greatly increased.

• Coils are sometimes called "inductors." Inductance is the measure of the strength of a coil.

• Self inductance is a measure of a coil's ability to establish an induced voltage as a result of a change in its current.

• Its symbol is "L". The unit of inductance is the Henry (H). Coils can have wide range of values from a few micro-henry (µH) to many henry (H).
CHARACTERISTIC OF COILS

CURRENT STABILIZATION CHARACTERISTIC:

• When current begins to flow in the coil, the coil resists the flow. When current decreases, the coil makes current continue to flow (briefly) at the previous rate. This is called "Lenz’s law". The direction of induced current in a coil is such that it opposes the change in the magnetic field that produced it.

USE AS RIPPLE FILTER CIRCUIT

• This characteristic is used for filtering the ripple voltage in a power supply where it transforms alternating current (AC) to direct current (DC).

TRANSFORMER

• The change in current of one coil affects the current and voltage in the second coil and this phenomenon is called Mutual inductance.

• Mutual inductance (inductance) is also measured in units of the Henry.
ELECTROMAGNET

When a current flows through a coil a magnetic field is produced in a direction of the axis of the coil.

So the coil acts as an ordinary magnet. Relays utilize this characteristic.

RESONANCE

When a coil and a capacitor are combined, the resulting circuit (tank circuit) has special characteristics.

The impedance (resistance to current flow) of the circuit changes with the frequency of the voltage. The tuning circuit that selects a particular radio station utilizes this characteristic.
COILS

Parallel resonance circuit

Series resonance circuit

\[ f_0 = \frac{1}{2\pi \sqrt{LC}} \]
Coils for high frequency resonance, or for detecting high frequency intermediate frequency (455KHz) high frequency transformers

**ADJUSTMENT OF THE INDUCTANCE VALUE**

The ferrite core of the coil is made like a screw. The core can be made to move in or out of the coil by turning it with a screwdriver. By moving the ferrite core in or out of the coil, the value of the coil's inductance can be changed. The value of inductance can also be changed by changing the number of turns of wire that comprise the coil. Eg. The tuner of an FM radio.
THE TOROIDAL COIL

The toroidal coil consists of copper wire wrapped around a cylindrical core.

It is possible to make it so that the magnetic flux which occurs within the coil doesn't leak out, the coil efficiency is good and that the magnetic flux has little influence on other components.