1

Design of Elementary Components

1.1. Introduction

An electronic circuit is composed of various types of components. Some of these components are termed as *active components* because they take part in the transformation of the energy while other components, which only dissipate or store energy, are called as *passive elements*. The vaccum tubes, rectifier, transistors are some of the common active elements while the resistances, which dissipate the power and energy storing elements such as capacitances and inductances are known as passive elements. The transformers may be regarded as a matching device. The success of any electronic circuit depends not only on proper selection of the active elements but on the passive and matching elements too. The proper function of an active devices is decided by the proper values of these passive elements. Hence the selection of these elements such as resistances, inductances, capacitance, and transformers not only require the proper attention, but also decide the proper function of the active devices as well as the circuit as a whole.

1.2. Resistances

As stated above, the resistance are heat dissipating elements and in the electronic circuits they are mostly used for either controlling the current in the circuit or devolping a voltage drop across it, which could be utilized for some application. There are various types of resistances which can be classified according to a number of factors depending upon.

(*i*) Material used for fabricating a resistance (*ii*) Wattage and physical size. (*iii*) Intended applications. (*iv*) Ambient temperature rating and (*v*) Cost.

The most common classification is according to the intended application of the resistors which can be further sub-divided in' tolerance, semi-precision, and precision application. It is usual that when the precision increases, the cost and environmental performance requirements becomes more stringent. The equipment manufacturers who use these resistances have their own internal specifications as a result there are many different specifications available. Since the manufacturing of the electronic circuits is a highly competitive business, therefore, the cost is reduced by lowering down the performance index hence the lowest priced resistors. For these uses, are the so called fixed carbon composition resistor of the same physical size and wattage will have essentially the same temperature rise when a given power is applied, although variation in materials may effect this. For this reason, the choice of material becomes an important factor.

Basically the resistor can be splitted into the following four parts with the construction view-point :

(*i*) Base. (*ii*) Resistive element.

(*iii*) Terminals. (*iv*) Protective means.

1.2.1. The Base

The chasis is the base on which the resistive element is mounted, replaced attached or applied. The terminals, which are used to make on electric connection to the resistive element, are usually anchored to the chasis. The whole assembly is protected by means of a protective coating against the environmental effect which increases the mechanical strength of the whole assembly.

The glass, ceramics, plastics, cloths derivatives and combination of such insulating materials are commonly used as a base material. The base materials should be a good insulator and should have high insulation resistance over the expected temperature range. It should be impervious, to moistrue and should not have any ionic conduction which may lead to electrolysis and corrosion in the parts of the resistor. The base material should also have good mechanical properties and it should be easily shaped into required geometry. When a resistor is to be designed for some particular application, some special considerations may become of first order importance. The base material should also be capable of withstanding thermal shock, within the high and low temperature limit, without physical or electrical damage. The thermal expansion coefficient of the base material should be of the same order as that of the resistive material.

1.2.2. Resistive Elements

Metal alloys, carbon and graphite used with binders etc. are the usual resistive materials. The alloys used as resistance wire usually have higher specific resistances than the base metals and have lower temperature coefficient of resistance. The three most common types of resistance wire used are nickel-copper, nickel-chromium-aluminium and nickel-chromium.

Carbon and graphites are used as the basic resistance materials when they are mixed and heated with proper variety of resin binders. These types of resistances are generally known as composition carbon types resistors. The resistive element may be either in the form of a film or a solid slug, which consists of a number of conducting particles held together by resin. In the film type the base materials may be glass, ceramic and plastics.

In pyrolytic deposition of carbon resistors the carbon containing gases are fed into a container at high temperature, into which a refractory base material is placed, metallic films are formed by the decomposition of metallic compounds at high temperature or by evaporating or sputtering the metals on a proper base material. The most common materials used to produce these films are noble metals and alloys such as a gold, tin, chromium, nickel and nichrome. Conductive oxide films are formed by fusing combination such as tin and antimony oxides on to a glass base.

1.2.3. Terminals

To provide the mechanical means by which the electrical resistive element may be connected to the circuit, the terminals are used. The terminals also maintain the exact value of resistance. The wire leads, metallic lugs and metallic ferrules are the most common type of terminals. The leads may be either radial or axial but generally axial leads are preferred. Lug type terminals are usually made with tinned alloys and are used on power wound resistors, variable resistors and resistors for the automobile industry. The lugs have a hole for attaching the wire. Ferrules are used only for limited applications. They are designed to insert into standard clips which are similar to the standard cylindrical fuse clips. The ferrules are used on large size power wire wound resistors. Fig. 1.1 shows various types of resistors for common applications.

1.2.4. Protective Means

The protective covering on a resistance should provide the mechanical, environmental as well as electrical protection. This can be achieved in either of the three ways : (*i*) a coating applied in liquid form (*ii*) moulding (*iii*) enclosure usually of ceramic or glass. The cement mixed with organic binder, vitreous enamel or special silicons is mostly used for coating. This can withstand nearly 900°C

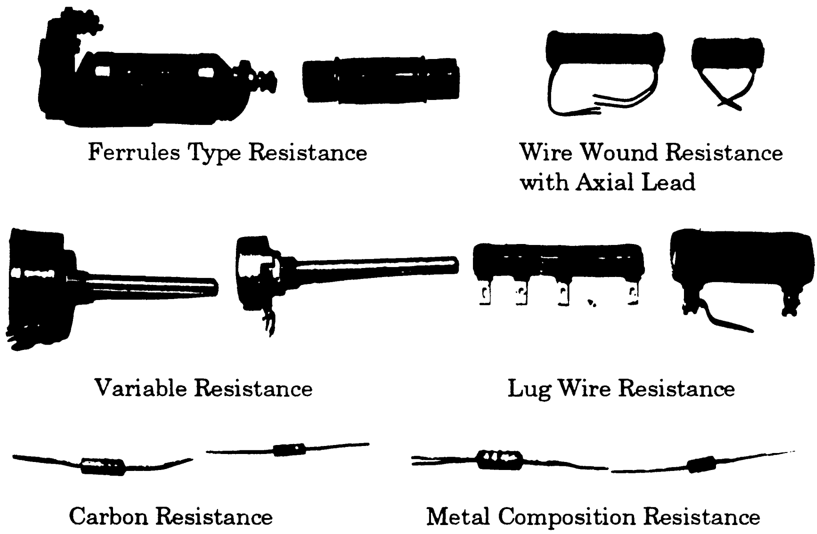


Fig. 1.1. A photograph to show : (1) Carbon resistance. (2) Wire wound resistance with axial lead. (3) Ferrules type resistance. (4) Lug type resistance. (5) Metal composition resistance.

without deterioration. The resistive element is moulded in a cylindrical form and the axial leads are provided. But the method of encapsulation is preferred over moulding. The sub-assembly *i.e.* base resistive material and terminals, are placed in a teflon plastic metal mould and then liquid epoxy is poured to fill up the voids between the sub-assembly and the mold. The "solder sealed resistors, are made by providing a ceramic or glass tube as an enclosure and closing the ends by soldering between the noble metal bands at the ends of the ceramic tube and the leads of the resistor sub-assembly. Resistors protected by sealing are safe until the temperature limit of the materials used for the resistance construction is not over come. The glass hermetically sealed resistor units usually require a care in their handling because they are fragile.

1.3. Characteristics of Resistors

The following characteristics are inherent in all resistance and may be controlled by design considerations and choice of material.

(*a*) **Temperature coefficient.** It is well known that the resistance changes with change in temperature. The temperature coefficient of resistance is defined as the percentage change in resistance per degree change in temperature and denoted by α.

where, $\alpha = \dfrac{R_{T_2} - R_{T_1}}{(T_2 - T_1)R_{T_1}}$ ohms per ohm per degree centigrade ...(1.1)

where, $R_{T_1} \longrightarrow$ the resistance in ohms at initial temp. T_1°C

$R_{T_2} \longrightarrow$ the resistance in ohms at final temp T_2°C

$\alpha \longrightarrow$ temperature coefficient of resistance

The change in the resistance depends upon the material and dimensions of the resistance. The temperature coefficient may be positive or negative depending upon whether the resistance increases or decreases with the rise of temperature.

Usually the pure metals have positive resistance temperature coefficient while carbon and graphite resistance have negative resistance temperature coefficient. But with the choice of binder, certain carbon resistance may have positive resistance temperature coefficient. The property of positive and negative resistance temperature coefficient may be used to precure temperature compensated resistors by using a series combination of two resistances having opposite resistance temperature coefficients. The value of α is not linear between two test temperatures, so it is necessary to plot the temperature coefficient as the resistance change against temperature for a number of incremental temperatures. The temperature coefficient characteristics of a resistor are important to an electronic circuit designer so as to have a margin for the change with might occur in his circuit when exposed to the expected temperature range.

(*b*) **Voltage coefficient of resistances.** The resistances, particularly fixed carbon composition resistances, show a marked change in their value with applied voltage. This factor is expressed as voltage coefficient of the resistances and is defined as the percentage change in the value of resistance per volt of applied voltage *i.e.*,

$$\text{Voltage coefficient} = \frac{R_{V_1} - R_{V_2}}{R_{V_1}(V_1 - V_2)} \quad ...(1.2)$$

where, R_{V_1} = value of resistance in ohms at voltage V_1 volts

R_{V_2} = value of resistance in ohms at voltage V_2 volts

The voltage coefficient depends on the geometry and the material of the resistance. For a given mixture of carbon and resin the voltage cofficient will decrease with decreasing resistance value and will also reduce with increase in body length of resistance.

(c) **High frequency characteristics.** At high frequency the resistances show change in their a.c. resistance due to (*i*) inter-turn or distributed capacitance (*ii*) skin effect (*iii*) inter-turn inductance. Out of the above, the (*i*) inter-turn capacitance (*ii*) skin effect (*iii*) inter-turn inductance is present in the wire wound resistance while distributed capacitance effect is present in carbon and film resistors.

Fig. 1.2 shows the effect of frequency on the resistance value of wire wound resistors, which can be represented by the equation (1.3).

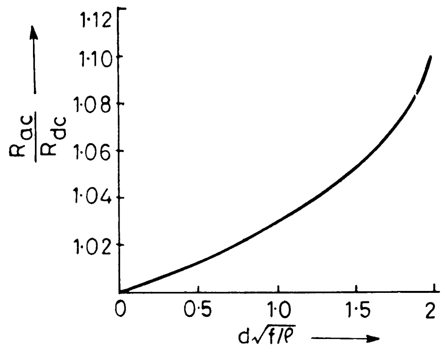


Fig. 1.2. Effect of frequency on the resistance value of wire wound resistances.

$$\frac{Rac}{Rdc} = F - d\sqrt{\left(\frac{f}{\rho}\right)} \qquad ...(1.3)$$

where, F = Some factor

f = frequency in Hz

ρ = Resistivity ohm per mm metres

d = diameter of resistance wire in mm

The inductance arises because of the magnetic field produced due to the flow of current in a conductor. The capacitance is invariably present because of capacitance between terminals and between the parts of resistors. The result is that at high frequency both the magnitude and the phase angle of impedance observed across the terminals of resistors very with frequency.

Any resistance, at high frequency, may be represented by Fig. 1.3. where R = the actual resistance taking into account the skin effect.

L = the inductance resulting from magnetic flux.

C = capacitance effect associated with the resistor.

The resistance represented by Fig. 1.3 may be reduced to the

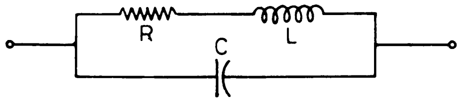


Fig. 1.3. Representation of resistance at high frequency.

series or parallel equivalent circuits as shown in Fig. 1.4 (*a*) and 1.4 (*b*) respectively.

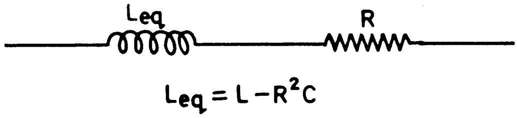


Fig. 1.4 (*a*) Equivalent circuit for a resistance.

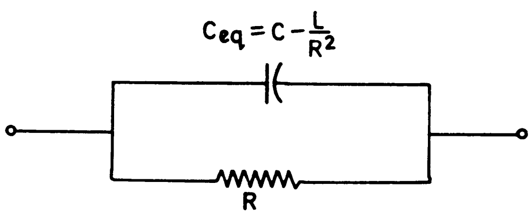


Fig. 1.4 (*b*) Equivalent circuit for a resistance.

where $$L_{eq} = L - R^2C \qquad \text{...(1.4)}$$

and $$C_{eq} = C - \frac{L}{R^2}$$

The wire wound resistances can be designed to have low reactive (inductive and capacitive) effect. In order to keep minimum inductance.the following points are to be observed.

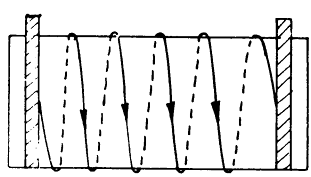


Fig. 1.5. Card Type.

1. The area of cross-section should be minimum.

2. The length of the resistance should be small.

3. The direction of current in the adjacent arms of a resistor should be in opposition to one another.

4. The resistance wire should have high specific résistance so as to have more resistance per unit length.

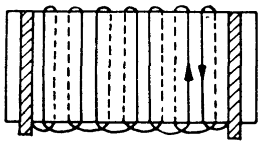


Fig. 1.6. Ayrton Perry.

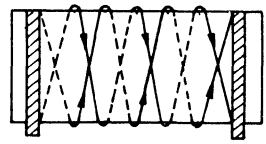


Fig. 1.7. Reversed Loop.

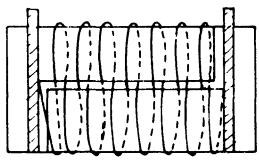


Fig. 1.8. Figure eight (8).

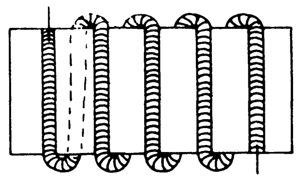


Fig. 1.9. Fish Line.

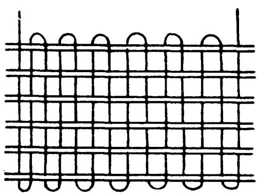


Fig. 1.10. Woven Tape.

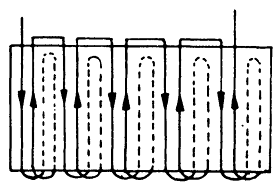


Fig. 1.11. Bifilar Series.

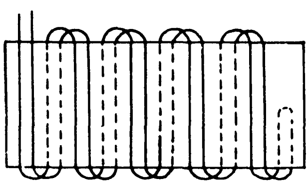


Fig. 1.12. Bifilar.

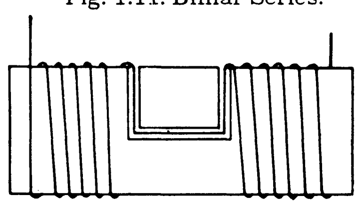


Fig. 1.13. Slotted Form.

The inter-turn capacitive effect may be reduced by

1. keeping the potential difference between the two adjacent turns to minimum.
2. by keeping the windings far apart.

The types of windings costly used to reduce the high frequency effects are shown in Figs. 1.5 to 1.13.

(*d*) **Electrical Noise.** When a d.c. voltage is applied to any type of resistance, there exist some fluctuations of small amplitudes which may resemble the a.c. voltage. These disturbances are called **noise.** In case of wire wound resistances these electrical disturbances are absent if the terminals are secured tightly. But in case of carbon resistances these are caused by the electrical contacts between the conducting particles which are held together by the binder. The precision film resistors have extremely low electrical noise. Noise is a function of applied voltage, physical dimensions of resistors and material used in its construction. Noise is usually measured by applying d.c. voltage to the resistors and through a capacitive coupling feeding output to the special high gain amplifier as shown in Fig. 1.14.

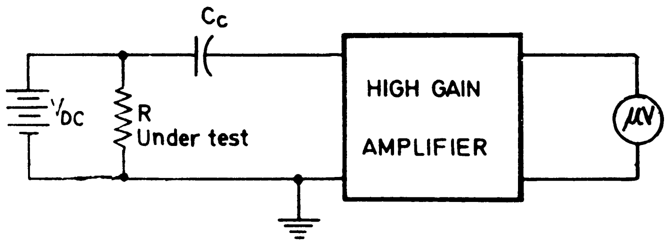


Fig. 1.14. Schematic diagram for noise measurement.

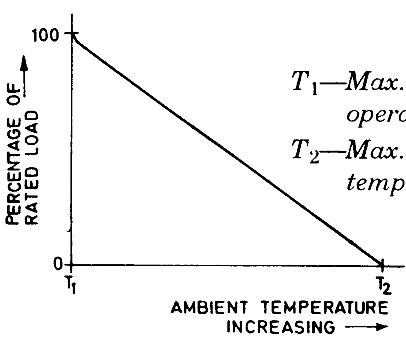
(*e*) **Power rating and de-rating.** The maximum amount of heat dissipated by a resistor at maximum specified temperature, without damage to the resistor, when expressed in wattage is called the power rating of a resistor. The po.wer rating depends upon.

(*i*) The choice of material.

(*ii*) The maximun specified temperature.

(*iii*) The physical size of heat dissipating surface of a resistor.

A resistor may be run at full load (rated value) at any ambient temperatuce equal to or less than the specified temperature. It may be over loaded for a short time when ambient temperature is less than the maximum rated temperature. The resistances may also be operated at temperatures above their full load rated load temperature. This can be done with the help of power derating curve. This is a straight line. The two extremities are the maximum safe operating temperatures corresponding to 100% load and no load. This is shown in Fig. 1.15.



T_1—*Max. full load safe operating temperature*

T_2—*Max. no load safe operating temperature*

Fig. 1.15. Power derating curve of a resistance.

(*f*) **Voltage rating of Resistors.** The maximum voltage stresses that may be applied to a resistor, without damage is known as the voltage rating of resistor. The voltage rating depends on.

(*i*) The material used.

(*ii*) The performance requirement.

(*iii*) The physical dimensions.

For fixed values of power and voltage there will be one and only one value of resistance that will dissipate rated voltage. This is given by the equation (1.6)

$$V = \sqrt{PR} \qquad \text{...(1.6)}$$

where V and P have the usual practical units and R is termed as critical resistance.

The maximum voltage is never reached if the value of resistance is below the critical resistance. For values of resistance above the critical value the power dissipation is less than the rated value of power dissipation.

(*g*) **Tolerance.** The tolerance is the change of resistance in plus and minus per cent from a nominal value. Various tolerances are available and they depend on the type of resistances. Fixed carbon resistances are available in tolerances of ±5.0%, ±10.0%, and ±20.0%. Pyrolytic carbon and metallic film resistors are produced in ±5.0%, ±2.0%, ±1.0%, ±0.5%, ±0.25%, and ±0.1% film while precision wire wound resistances are produced with initial tolerances as low as ±0.05% and still lower than ± 0.01% under special cases. Initial tolerance on variable resistances vary from ± 30% to ± 5.0% or even less for some precision applications.

1.4. Classification of Resistance

As stated earlier the resistances may be of three types, *i.e.*

(*i*) Fixed resistances

(*ii*) Semi variable resistances

(*iii*) Variable resistances

The fixed resistances are those whose value cannot be changed. In case of semi variable types of resistances their values can be changed with the help of screw driver. Semi variable type resistances are known as presets. In case of the variable resistances their values can be changed from zero to maximum with the help of a movable arm.

1.4.1. Fixed resistance

The fixed resistances are further divided into four main categories.

(*i*) Carbon composition resistance

(*ii*) Metal film resistance

(*iii*) Carbon film

(*iv*) Wire wound resistances.

1.4.1.1. Carbon composition resistances. The carbon composition resistances are available in resistance values from 1 ohm to 100 mega ohm with typical power rating of 1/2 Watt to 2 Watts. Their cost is low, but their temperature coefficient is little high *i.e.* more than 500 RPM per degree centigrade.

Fig. 1.16 shows the cross-sectional view of the carbon resistance. The resistance material is one of the form of the carbon such as graphite, which is mixed with a binder. Slug type structure of the resistance is obtained by simultaneous moulding of the resistance material, insulation material and the leads under high pressure and temperature.

Fig. 1.16. Cut away view of carbon composition resistance.

The different resistance values are obtained by varying the composition of carbon and binder material.

1.4.1.2. Metal film resistances. Metal film resistances are available in the following form.

(*i*) Thin film type (*ii*) Thick film type

The thin film type resistances have the resistance in form a film of metal of the thickness of one millionth of an inch. The film is deposited on a suitable ceramic base by high vacuum deposition technique. The thin film resistances are available from 10 ohm to 1 killo ohm with tolerance better than 0.005. They have low noise and the temperature coefficience of the order of 25 ppm/°C. They are available upto 5 Watts of power ratings.

The thick film resistances are of the following type.

(*a*) Tin oxide (*b*) Metal Glaze

(*c*) Carmet (*d*) Bulk film resistances

The thickness of the film is more than one millionth of an inch. The tin-oxide is usually deposited on a ceramic base under high temperature. The **tin oxide** thick film type resistances are available from few ohms to 2.5 mega ohms with tolerances better than 0.01

and temperature coefficient of the resistance is less than 200 ppm per degree centigrade and power rating upto 2W.

In case of metal glaze thick film type resistances the powdered glass and fine metal particle mixture is deposited on a ceramic base. The combination is fired at a high temperature of the order of 800°C. The values of the metal glaze thick film resistances are available from few ohms to 3.5 mega ohms, with tolerance lesser than 1% and temperature coefficients of the order of 20 ppm per degree centigrade and power rating upto 2 Watts.

The carmet type thick film resistances are manufactured by screening a mixture of precision metals and binder material on the ceramic base. The values of the carmet type resistance is available from 10 ohms to 10 mega ohms with tolerance less than 0.01 and temperature coefficient of the order of 100 ppm per °C. They are available upto 3 watts of power rating.

The bulk film type resistances are made by etching a metal film of glass substrate so that metal film is compressed due to unequal coefficient of expansion of glass and metal. Such compressed film has a negative temperature coefficient which cancells out the inherrent positive temperature coefficient of the film. As such these types of resistances have zero temperature coefficient of resistances. They are available upto the value of 30 ohm to 600 KΩ tolerance lower than 0.005 percent and wattage rating of 1 Watt.

1.4.1.3. Carbon film resistances. The carbon film resistances are available from 10 ohm to 10 mega ohm values with tolerance of 5 percent or greater. The temperature coefficient of the resistance is 150 ppm/°C and the power rating is upto 2 W. They are manufactured by depositing the film of carbon on the ceramic base.

1.4.1.4. Wire wound resistance. The wire wound resistors are avilable in wide spectrum of applications. Hence, they are available in various shapes and sizes, Fig. 1.5 to Fig 1.13 illustrate the types of windings for non-inductive resistances. The shape of the wire wound resistances is shown in Fig 1.17.

Power style wire wound resistances are made by winding a single layer length of special alloy wire in the form of a coil around an insulating core. The wire used may be nickel-chromium-aluminium (800 alloy) and nichrome (Nickel-Chromium-Iron). The core may be of ceramic steatite or vitreous material. Table 1.1 gives the typical characteristics of fixed resistances and Table 1.2 shows the commonly available various types of wire wound resistances.

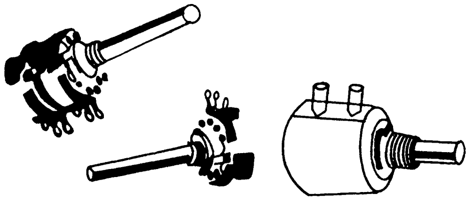


Fig. 1.17. (*a*) Various types of wire wound resistances (variable type).

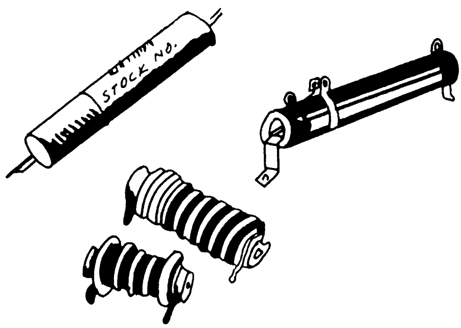


Fig. 1.17. (*b*) Various types of wire wound resistances. (fixed type).

1.4.2. Semi variable resistances

The semi variable resistances are 'set and forget me' type resistances. These are called trimmer pot or preset. Its rotational life is limited in comparison to other types of pot. These are available as single and multiple turn units. These range from few ohms to 5 mega ohms with tolerance ±10 of and power rating of 1 Watt.

These pots are shown in Fig. 1.18.

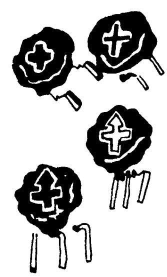


Fig. 1.18. Examples of trimmer pots.

1.4.3. Variable Resistances

The variable resistance are known as pots or potential deviders. In these resistances one may get different values of resistance by sliding a contact are over the resistance strip. These are of two types :

(*i*) Composition type (*ii*) Wire wound

(*iii*) Rheo state.

1.4.3.2. The composition type resistances are commonly used because they are cheap. Here a mixture of carbon and graphite is mixed with a resineous moulding powder and moulded on an insulating base.

The slider travels over the element giving various values. There are three terminals. The ends are used as start of finish ends and the centre one is used as movable point.

The composition type of pots are made by three materials :

(*i*) Carbon (*ii*) Carmet

(*iii*) Conductive Plastic.

In case of carbon pots the resistance element is made by spraying or brushing a carbon resistance compound on an insulating material such as laminated plastic.

Carbon-Ceramic and moulded carbon type pots show better characteristics. The carbon pot has a high temperature coefficient resistance and is succeptable to moisture and its maximum operating temperature is generally limited to 85°C.

Carmet type pot is made by mixture of precious metals and glass or ceramic powder screened on a ceramic substrate. The temperature coefficient of resistance is upto 30 ppm/°C and this operating temperature is 150°C.

Conductive Plastic Pots are made by spraying a special liquid suspension on plastic material under pressure. The suspension contains carbon, a solvent and a filler. The resistance value depends on the mix of carbon and filler.

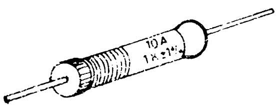
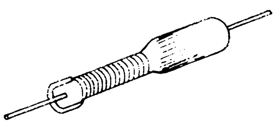
1.4.3.3. Wire Wound Pots. The wire wound variable resistances are prepared by winding a wire on a flat insulting material. The slider is in the form of a metal strip or wire bent at the end which moves on the winding wire. The slider moving over the exposed section of the winding comes in contact with next turn before it leaves the previous one thus maintaining the contact at all the time. This is covered with a protective container which has three tags, two at the ends and third one connected to the slider. The power rating of these resistors may vary 2 to 25 Watts and common values are available from 3 Kilo Ohms to 1 M Ohms. Because of its construction, the wire-wound pot has appreciable strong inductance and capacitance which may be a problem of high frequency operation.

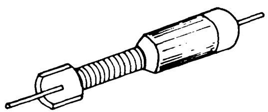
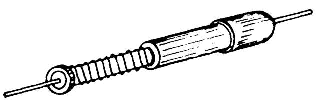
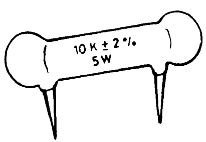
1.4.3.4. Rheostate. A wire wound pot that can dissipate 5 and more watts is often referred to as a rheostate. The resistance wire is wound on an open ring of ceramic which is covered with viterous enable, except for the track of the wiper arm. Rheostates are used to control motor speeds, X-ray tube voltages, welding current, ovens and many other high power applications.

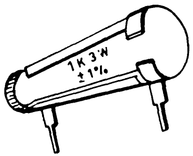
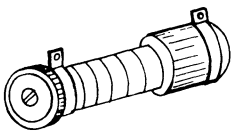
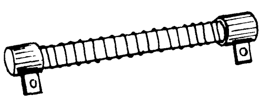
Table 1.1
Typical Characteristics of Commonly Used Resistances

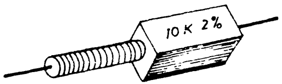
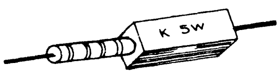
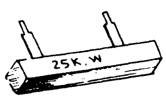
S. No.	*Type*	*Available values*	*Range Power*	*Tolerance percentage*	*Resistance Temperature Coefficient PPM/°C*	*Noice*	*Stability*	*Cost*
1.	**Fixed Resistors :**							
	(*a*) Carbon Composition	1Ω—100MΩ	½ W—2W	± 10	500	Low	Excel-lent	Low
	(*b*) Metal Film							
	(*i*) Thin Film	10Ω—1MΩ	Up to 5W	Better than 0.5	25	High		
	(*ii*) Thick Film							
	Tin Oxide	Up to 2.5MΩ	2W	1	200			
	Metal Glaze	10MΩ	2W	1	20		Good	
	Carmet	10Ω—10MΩ	3W	1	100		Good	
	Bulk Film	30Ω—600KΩ	1W	0.005	1	Low	Good	
	(*c*) Carbon Film	10Ω—10MΩ	2W	3 or more	150	Less	Good	Low
	(*d*) Wire Wound	10MΩ—	75W	± 10	20	High		
2.	**Trimmer Resistors**	5Ω	1W	± 10	High	High	Poor	Low
3.	**Variable Resistances**							
	(*a*) Carbon	1M	2W	± 10	High	Low	Poor	High
	(*b*) Carmet	2.2M	75W	± 10	50			
	Plastics	2.2M	125W	± 10				
	(*c*) Conductive							
	(*d*) Wire Wound	330K	50W	± 10	20	High	Good	High

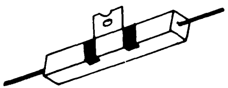
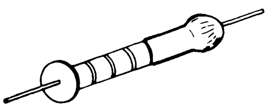
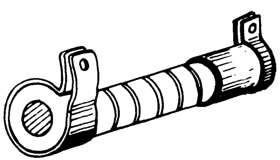
Table 1.2
Commonly Available Wire Wound Resistances

Style Construction HTR Series (1)	*Power Rating* (2)	*Resistance Range (Ohms)* (3)	*Tolerances Available* (4)	*Special Features* (5)
	SILICONE COATED TYPES			
Precision Axial type 	1W to 10W [125°C]	0.1 to 100 K ohms	10%, 5%, 3%, 1%, 0.5%, 0.25%, 0.1%,	Precision Non-inductive types available.
HI Temperature Axial Type 	0.75 to 12W [70°C]	0.1 to 100 K ohms	10%, 5%, 3%,	Flameproof thermocoat Industrial and telecommunication applications.

(1)	(2)	(3)	(4)	(5)
HI Precision Axial type 	0.25W to 2W [125°C]	0.1 to 100 K ohms	1%, 0.5% 0.1%, 0.05%,	High precision. TCR as low as 10 ppm/°C
Fibre glass Axial type 	1W to 10W [70° C]	0.1 to 11 K ohms	10%, 5%	Low cost. Commercial applications.
Power type PCB Mounting 	3W to 10W [25°C]	0.1 to 100 K ohms	10%, 5%, 2%	Designed for B/W and colour monitors. Adaptable to automated assembly.

(1)	(2)	(3)	(4)	(5)
Fibre-glass PCB Mounting 	3W to 9W [70°C]	0.4 to 11K ohms	10%, 5%	Low cost. Choice of terminal stand-off heights.
HI Power Radial Tag Termination 	5W to 400W [70°C]	0.25 to 330K ohms	10%, 5%, 2%	Applications which call for every high power dissipation. Non-inductive types available.
HI Power Edge Wound Redial Tag Termination 	120W to 500W	0.1 to 16 ohms	10%, 5% (on request)	Can withstand heavy overload surges. Used for controlling motors.

(1)	(2)	(3)	(4)	(5)
	CERAMIC ENCASED TYPES			
Power Axial and Vertical Mounting Type 	2W to 15W [70°C] 7W and 10W	0.1 to 13K ohms 0.5 to 11K ohms	10% and 5%	High insulation. Fireproof.
Semi Precision Axial type and Vertical Mounting Type 	4W to 17W [70°C]	0.25 to 90K ohms	10%, 5% 2%, 1%	Low surface temperature Fire proof.
Power type PCB mounting 	3W to 15W [70°C]	0.24 to 7.3K ohms	10% and 5%	Designed for B/W and colour TV applications. Choice of terminal stand-off heights.

(1)	*(2)*	*(3)*	*(4)*	*(5)*
HI-Power Lug Termination Bracket Mounting 	10W to 20W [25°C]	0.66 to 10K ohms	10% and 5%	Low surface temperature. Replaces old radial style.
		VITREOUS ENAMELLED TYPES		
Power Axial type 	2.5W to 12W [70°C]	0.2 to 12K ohms	10% and 5%	Tolerates high overload conditions. Resistant to hostile environment.
HI-Power Radial tag termination 	5W to 400W [70°C]	0.6 to 270K ohms	10% and 5%	Applications which call for very high dissipation and a hostile environment. Non-inductive types available.

1.5. Thermistors

A thermistor is a non-linear resistance made of semi-conductor material that is extremely sensitive to change in temperature. For a small change in body temperature of a thermistor, there is an appreciable change in its resistance, whereas most conductors have a positive-temperature coefficient, the thermistor can exhibit a positive or negative temperature coefficient (NTC). The thermistors are mostly negative temperature coefficient resistances. The resistances of thermistor decreases rapidly for increased temperature.

The thermistors are used in a wide a variety of applications. They can be used in measurement and control of temperatures, time delay, temperature compensation and liquid lavel indicators. The thermistors are available in the form of a disk, bead or bolted assembly packages.

Fig. 1.19 shows the temperature-resistance characteristics of thermistors.

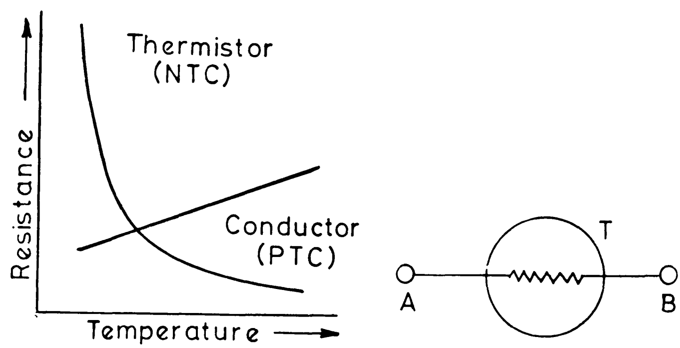


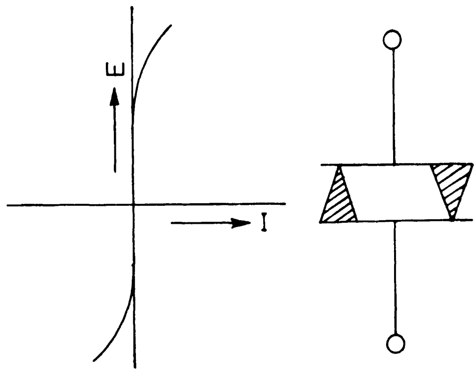
Fig. 1.19. Temperature-resistance Characteristics of Thermistors.

1.6. Varistors

These are voltage dependent resistances. They also fall under the category of non-linear resistors. According to the Ohm's Law the current is directly proportional to the impressed voltage but in case of varistors the current is proportional to the nth power of the impressed voltage *i.e.*

$$I \propto V^n$$

where I is the current in Amperes and V is the impressed voltage on the Varistors. Fig. 1.20 shows the V-I characteristics of the Varistors.



(Symbol)

Fig. 1.20. *V-I* Characteristics of varistors.

Application of the Varistor include voltage surge and protective circuits and the generation of non-sinusoidal waveform.

The varistors are made out of siliconcarbide and is available in the form of disk, rod or washers. They can withstand and d.c. voltage upto 10 kV or so.

1.7. Standard Values of Resistances

The electronic circuit designer is expected to know about the values of components, which may be available in the market. With the help of this, he can modify his design to a most practical design.

For resistances and capacitances the system proposed by Charls Renald is used to determine their value.

The system is based on the preferred numbers generated by a progression devised to repeat the succeeding decades.

The general relation used is given by

$$N = a \, . \, r^{n-1}$$

This is the geometric progression where a is the first term and r is the common ratio to give the nth term N.

If r is chosen to be the Kth root of 10 and the first term is unity then the nth term will be given by

$$N = K \, . \, (10)^{\frac{n-1}{K}}$$

where K is to be selected to provide a desired scale graduations.

In case of resistances and capacitances the standard decades are chosen to have 3, 6, 12, 24, 48 and 192 term.

The series so generated is called the E_3, E_6, E_{12}, E_{24}, etc. series and it will be clear from the above discussion that E_3 will have value of $K = 3$, E_6 will have $K = 6$ and so on.

The values of term in the few series are given as follows.

E_3 Series	1, 2.2, 4.7
E_6 Series	1, 1.5, 2.2, 3.3, 4.7, 6.8
E_{12} Series	1, 1.2, 1.5, 1.8, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, 8.2.
E_{24} Series	1, 1.1, 1.2, 1.3, 1.6, 1.5, 1.9, 1.8, 2, 2.2, 2.4, 2.7, 3.0, 3.3, 3.5, 3.9, 4.2, 4.7, 5.1, 5.6, 6.2, 6.8, 7.5, 8.2, 9.0

Different tolerances are standardised for different E series, for E_6 series component will have 20% tolerance, for E_{12} series 10% and E_{24} series 5%.

E-$_{12}$ series is most commonly used series hence the values of resistances in a decade will be as follows :

1.0, 1.2, 1.5, 1.5, 2.2, 2.7, 3.3, 3.9, 4.7, 5.6, 6.8, 8.2.

These may repeat for multiple of 10, 100, K, 10K, 100K, M, 10M etc.

Table 1.3

5% Carbon Film and 1% Metal Film Resistor Charts
5% Carbon Film Resistors

Table of Values in Ohms

1.0	5.6	33	160	820	3.9K	20K	100K	510K	2.7M
1.1	6.2	36	180	910	4.3K	22K	110K	560K	3M
1.2	6.8	39	200	1K	4.7K	24K	120K	620K	3.3M
1.3	7.5	43	220	1.1K	5.1K	27K	130K	680K	3.6M
1.5	8.2	47	240	1.2K	5.6K	30K	150K	750K	3.9M
1.6	9.1	51	270	1.3K	6.2K	33K	160K	820K	4.3M
1.8	10	56	300	1.5K	6.6K	36K	180K	910K	4.7M
2.0	11	62	330	1.6K	7.5K	39K	200K	1M	5.1M
2.2	12	68	360	1.8K	8.2K	43K	220K	1.1M	5.6M
2.4	13	75	390	2K	9.1K	47K	240K	1.2M	6.2M
2.7	15	82	430	2.2K	10K	51K	270K	1.3M	6.8M
3.0	16	91	470	2.4K	11K	56K	300K	1.5M	7.5M
3.3	18	100	510	2.7K	12K	62K	330K	1.6M	8.2M
3.6	20	110	560	3K	13K	68K	360K	1.8M	9.1M
3.9	22	120	620	3.2K	15K	75K	390K	2M	10M
4.3	24	130	680	3.3K	16K	82K	430K	2.2M	15M
4.7	27	150	750	3.6K	18K	91K	470K	2.4M	22M
5.1	30								

(Contd.)

1% Metal Film Resistors

Table of Values in Ohms

10	33	100	332	1K	3.32K	10.5K	34K	107K	357K
10.2	33.2	102	340	1.02K	3.4K	10.7K	34.8K	110K	360K
10.5	34	105	348	1.05K	3.48K	11K	35.7K	113K	365K
10.7	34.8	107	350	1.07K	3.57K	11.3K	36K	115K	374K
11	35.7	110	357	1.1K	3.6K	11.5K	36.5K	118K	383K
11.3	36	113	360	1.13K	3.65K	11.8K	37.4K	120K	390K
11.5	36.5	115	365	1.15K	3.74K	12K	38.3K	121K	392K
11.8	37.4	118	374	1.18K	3.83K	12.1K	39K	124K	402K
12	36.3	120	383	1.2K	3.9K	12.4K	39.2K	127K	412K
12.1	39	121	390	1.21K	3.92K	12.7K	40.2K	130K	422K
12.4	39.2	124	392	1.24K	4.02K	13K	41.2K	133K	430K
12.7	40.2	127	402	1.27K	4.12K	13.3K	42.2K	137K	432K
13	41.2	130	412	1.3K	4.22K	13.7K	43K	140K	442K
13.3	42.2	133	422	1.33K	4.32K	14K	43.2K	143K	453K
13.7	43	137	430	1.37K	4.42K	14.3K	44.2K	147K	464K
14	43.2	140	432	1.4K	4.53K	14.7K	45.3K	150K	470K
14.3	44.2	143	442	1.43K	4.64K	15K	46.4K	154K	475K
14.7	45.3	147	453	1.47K	4.7K	15.4K	47K	158K	487K
15	46.4	150	464	1.5K	4.75K	15.8K	47.5K	160K	499K
15.4	47	154	470	1.54K	4.87K	16K	48.7K	162K	511K
15.8	47.5	158	475	1.58K	4.99K	16.2K	49.9K	165K	523K
16	48.7	160	487	1.6K	5.1K	16.5K	51K	169K	536K
16.2	49.9	162	499	1.62K	5.11K	16.9K	51.1K	174K	549K
16.5	51	165	510	1.65K	5.23K	17.4K	52.3K	178K	560K
16.9	51.1	169	511	1.69K	5.36K	17.8K	53.6K	180K	562K
17.4	52.3	174	523	1.74K	5.49K	18K	54.9K	182K	576K
17.8	53.6	178	536	1.78K	5.6K	18.2K	56K	187K	590K
18	54.9	180	549	1.8K	5.62K	18.7K	56.2K	191K	604K
18.2	56	182	560	1.82K	5.76K	19.1K	57.6K	196K	619K
18.7	56.2	187	562	1.87K	5.9K	19.6K	59K	200K	620K
19.1	57.6	191	565	1.91K	6.04K	20K	60.4K	205K	634K
19.6	59	196	578	1.96K	6.19K	20.5K	61.9K	210K	649K
20	60.4	200	590	2K	6.2K	21K	62K	215K	665K
20.5	61.9	205	604	2.05K	6.34K	21.5K	63.4K	220K	680K
21	62	210	619	2.1K	6.49K	22K	64.9K	221K	681K
21.5	63.4	215	620	2.15K	6.65K	22.1K	66.5K	226K	698K
22	64.9	220	634	2.2K	6.8K	22.6K	68K	232K	715K
22.1	66.5	221	649	2.21K	6.81K	23.2K	68.1K	237K	732K
22.6	68	226	665	2.26K	6.98K	23.7K	69.8K	240K	750K
23.2	68.1	232	680	2.32K	7.15K	24K	71.5K	243K	768K
23.7	69.8	237	681	2.37K	7.32K	24.3K	73.2K	249K	787K
24	71.5	240	698	2.4K	7.5K	24.9K	75K	255K	806K
24.3	73.2	243	715	2.43K	7.68K	25.5K	76.8K	261K	820K

(Contd.)

1% Metal Film Resistors

Table of Values in Ohms

24.7	75	249	732	2.49K	7.87K	25.1K	78.7K	267K	825K
24.9	75.5	255	750	2.55K	8.06K	26.7K	80.6K	270K	845K
25.5	76.8	261	768	2.61K	8.2K	27K	82K	274K	866K
26.1	78.7	267	787	2.67K	8.25K	27.4K	82.5K	280K	887K
26.7	80.6	270	806	2.7K	8.45K	28K	84.5K	287K	909K
27	82	274	820	2.74K	8.66K	28.7K	86.6K	294K	910K
27.4	82.5	280	825	2.8K	8.8K	29.4K	88.7K	300K	931K
28	84.5	287	845	2.87K	8.87K	30K	90.9K	301K	953K
28.7	86.6	294	866	2.94K	9.09K	30.1K	91K	309K	976K
29.4	88.7	300	887	3.0K	9.1K	30.9K	93.1K	316K	1.0M
30	90.9	301	909	3.01K	9.31K	31.6K	95.3K	324K	1.5M
30.1	91	309	910	3.09K	9.53K	32.4K	97.6K	330K	2.2M
30.9	93.1	316	931	3.16K	9.76K	33K	100K	332K	
31.6	95.3	324	953	3.24K	10K	33.2K	102K	340K	
32.4	97.6	330	976	3.3K	10.2K	33.6K	105K	348K	

1.8. Colour Code for Resistances

The carbon resistances have different colour codes by which one can know the value of the particular resistance. The colour code for the resistance in Table 1.4.

1.8.1. Determination of the values from the colour code

There are two types of the carbon resistances :

1. Axial type. 2. Radial type.

Table 1.4

S. No.	*Colour Code*	*Colour value*	*Multiplying factor*	*Tolerances*
1	Black	0	$10^0 = 1$	—
2	Brown	1	$10^1 = 10$	—
3	Red	2	$10^2 = 100$	—
4	Orange	3	$10^3 = 1000$	—
5	Yellow	4	$10^4 = 10,000$	—
6	Green	5	$10^5 = 1,000,00$	—
7	Blue	6	$10^6 = 1,000,000$	—
8	Violet	7	$10^7 = 1,000,000,0$	—
9	Grey	8	$10^8 = 1,000,000,00$	—
10	White	9	$10^9 = 1,000,000,000$	—
11	Golden	—	$10^{-1} = 0.1$	± 5%
12	Silver	—	$10^{-2} = 0.01$	± 10%
13	No colour	—	—	± 20%

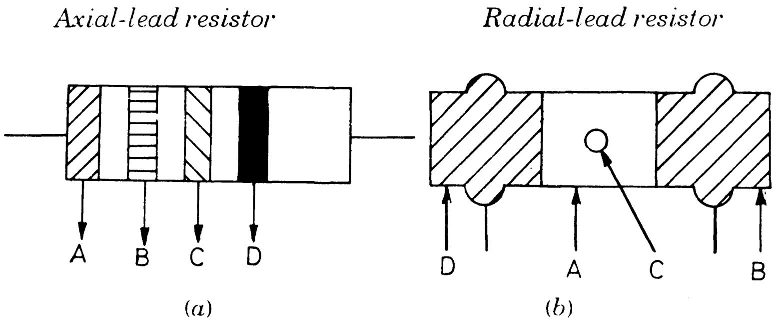


Fig. 1.21

For axial type as shown in Fig. 1.21 (*a*) : take the resistor in such a way that its end from which the colourband starts is on the left hand sides. Then the first and the second colour will indicate the most significant digits. The third colour will give you number of zeros or the multiplier and the last colour will indicate the tolerance. If the first colour (A) is yellow, the second colour (B) is blue and the third colour (C) is orange with fourth colour (D) as silver then the value of the resistances is given as 46,000 ohms or kilo-ohm with ± 10% tolerance.

For radial type. In the case of the radial type resistance as shown in Fig. 1.21 (*b*) the sequence is body, tip and dot for the colour codes. Body colour indicates the Ist digit, the tip colour indicates the 2nd digit and dot colour indicates the number of the zeros or the multiplier and the other tip indicates tolerance if any.

If the colour (A) of the body is white, that of the tip (B) is green and the dot (C) is yellow and the other tip is golden, then the val ıe of the resistance is given as 950,000 ohms or 950 kilo-ohms with ± 5 % tolerance.

To remember the colour code a sentence can be used "*B.B. Ray G.B.V.G. Washing*", *i.e.* B.B. Roy is a person having degree G.B.V.G. from Washington. Each character of this sentence represents the colour, *i.e.* B—Black, B—Brown, R—Red, O—Orange, Y—Yellow, G—Green, B—Blue, V—Violet G—Grey and W—White.

1.9. Application Notes

There are several factors which are essential to be considered in making a choise of resistance for particular applications. The factors may be summarized as

(*i*) **Long time stabilities** *i.e.* change of resistance value of a resistor over an extended period of time when it is not subjected to use.

(*ii*) **Load life** *i.e.* the change of resistance value of a resistor over a particular time when the resistor is subjected to rated load.

(*iii*) **Effect of humidity** *i.e.* the ability of resistor to absorb moisture and of the consequent effect on the resistive element.

(*iv*) **Shock, acceleration and vibration.** The composition type resistance should not have any voids. The resistor protection means should have sufficient mechanical strength to overcome shock, and vibration.

(*v*) **High altitude operation** *i.e.* the material used in the construction of resistors are not affected by reduced pressures.

(*vi*) **Low and high temperature storage.** The resistors are designed and specified to operate within certain temperature limits. It is always desirable to know the change of the resistance value when used at low and high temperatures.

(*vii*) **Thermal shock and temperature cycle.** The variation of the resistance value of a resistor with sudden change in temperature occurs if the coefficient of thermal expansion of the different parts of the resistance (*i.e.* body terminals, protective covers etc) are not the same.

(*viii*) **Pulse rating.** When a resistor is subjected to a pulse the power dissipated by it is a function of integral of the voltage-current relationship. It is difficult to measure this power when a pulse is applied but we can determine the average power dissipated by measuring the temperature rise and comparing this with the temperature rise curve for d.c. operation. Table 1.5 gives the guidelines for selection of resistance for different types of application.

Table 1.5
Section of Resistance

S. No.	*Class of Resistor*	*Type of Resistance*	*General Application Field*
1.	General purpose low power fixed resistors. (Non wire-wound).	Fixed carbon composition film type carbon resistances.	Mostly used in commercial and military equipments, computers, monitoring equipments.
2.	General purpose low power fixed resistors wire-wound).	Wire wound resistors wound on a flexible core of cord or glass fibre.	$\frac{1}{2}$ W to 2W resistors are used in meters and analyzers. As cathode bias resistor in TV circuits, low range bridge circuit, high stability oscillator low power ignition circuit, spark suppression etc.

S. No.	*Class of Resistor*	*Type of Resistance*	*General Application Field*
3.	Low and medium power high frequency resistances.	Composition film type and precision film type resistances. Length to dia ratio varies from 4 : 1 to 10 : 1.	Radar pulse equipment, r.f. probes, r.f. wide-band amplifiers, rhombic antenna, terminating devices, dummy-load, TV side-band filters, surge generators, high frequency measuring equipments.
4.	High voltage resistances.	Composition carbon film type and precision film type.	High voltage meter multiplier, photo electric cell applications, protective devices for h.v. circuits, T.V. high voltage circuits, high voltage bleeders, CR tube circuits, X-ray equipments and ionization chamber.
5.	Special purpose low power and medium power wire-wound resistors.	Metal wire wound on glass fibre core mostly heating elements.	Automotive industry such as horns, voltage regulators, ignition ballast resistors, wind shield wipers. Food mixer, coffee pots, electric range deep freezer and electric blanket.
6.	Precision wire wound resistors.	Tolerance ± 0.1% to ± 1.2%.	Bridge circuits, voltage divider circuits or calibrating resistors.
7.	Precision pyrolytic film (fixed resistors).	Pyrolytic film resistors. Coated, moulded and ceramic sealed.	Used in circuits where high order of stability is required such as measuring circuit and metering circuits, coated types are particularly used at high frequency, moulded and sealed types are used against the risk of mechanical damage or maximum moisture protection.

S. No.	*Class of Resistor*	*Type of Resistance*	*General Application Field*
8.	Precision metal film resistors.	Cylindrical or rectangular type.	Where they are used in input circuits of high gain amplifiers. Bridge voltage divider circuits and as a calibrating resistors.
9.	High temperature resistances.	Carbon alloy film type resistances.	All high ambient temperature and higher power rating at low ambient temperature applications.

Example 1.1. *A shunt of manganin plates 1.2 mm thick is required to be designed so as to give a voltage drop of 240 mV at 1200 Amps. The shunt has seven plates and the heat dissipated from the surface of the plates is 2400 watts per* m^2. *Find the length and width of plates. Specific resistance of manganin = 0.42* μ *ohm meter.*

Solution.

Let l can be the length and b cm be the width of each plate.

Thus area of cross-section of each plate

$$a = \text{Thickness} \times \text{Width}$$

$$= 1.2 \times 10^{-3} \times b \times 10^{-2}\ \text{m}^2 = 1.2\, b \times 10^{-5}\ \text{m}^2$$

Area of cross-section of 7 plates

$$A = 7 \times 1.2\, b \times 10^{-5} = 84 \times 10^{-5}\, b\ \text{m}^2$$

Resistance of total assembly

$$\frac{0.42 \times 10^{-6} \times l \times 10^{-2}}{7 \times 1.2 \times b \times 10^{-5}} = \frac{3.5 \times 10^{-4}}{7} \frac{l}{b}\ \text{ohm}$$

$$= 0.5 \times 10^{-4} \frac{l}{b}\ \text{ohm} \qquad ...(i)$$

Also the resistance of the total shunt

$$= \frac{V}{I} = \frac{240 \times 10^{-3}}{1200} = 2 \times 10^{-4}\ \Omega \qquad ...(ii)$$

Thus $0.5 \times 10^{-4} \frac{l}{b} = 2 \times 10^{-4}$ or $\frac{l}{b} = 4$ ...(*iii*)

The total heat dissipation area

$$= \text{Total surface area}$$

$$= 2 \times 7 \times lb \times 10^{-4}\ \text{m}^2 \qquad ...(iv)$$

Thus total heat dissipated $= 2400 \times 14\, lb \times 10^{-4}$ watts

and losses in shunt $= 240 \times 10^{-2} \times 1200$

$= 288$ watts ...(*v*)

Thus $2400 \times 14\, lb \times 10^{-4} = 288$

Which gives, $$lb = \frac{1.2 \times 10^3}{14} \quad ...(vi)$$

From (*iii*) and (*vi*), $l^2 = \frac{2.4}{7} \times 10^3 = 3.34 \times 10^2$

Thus, $l = 18.5$ cm and $b = 4.62$ cm.

Example 1.2. *How much series inductance is required to render a 10,000 ohm resistance coil with a shunt capacitance of 20 pF practically non-reactive over a reasonable range of frequency.*

Solution.

In order to make the coil non-reactive

$$L_1 = CR^2 = 20 \times 10^{-12} \times 10^8$$
$$= 2 \times 10^{-3} \text{ H} = 2 \text{ mH}.$$

Example 1.3. *A wire has a resistance of 300 ohms. What is the resistance of another wire which has one half the length of the first and three quarter its cross-section.*

Solution.

Resistance of wire length, $\propto \frac{\text{Length}}{\text{Area}}$

Resistance of new wire $= \text{Resistance of original wire} \times \frac{1}{2} \times \frac{4}{3}$

$$= 300 \times \frac{1}{2} \times \frac{4}{3} = 200 \text{ ohms}.$$

Example 1.4. *One wire has a resistance of 740 ohms. Calculate the resistance of the second wire having seven-eights the length of the first, four-fifths its resistivity and three-sixteenths its sectional area.*

Solution.

Let the length, resistive and cross-section of wire be $l\rho$, and a respectively.

$$R_1 = 750 = \frac{\rho l}{a}$$

$$R_2 = \frac{\frac{4}{5}\rho \cdot \frac{7}{8} l}{\frac{3}{16} a} = \frac{4}{5} \times \frac{7}{8} \times \frac{16}{3} \times \frac{\rho l}{a}$$

$$= \frac{5}{5} \times \frac{7}{8} \times \frac{16}{3} \times 750 = 2800\ \Omega.$$

Example 1.5. *A liquid resistance with parallel plate electrodes is to be designed to absorb 72 kW at 600 V. The 5% soda solution is used which has the resistivity of 25 ohm-cm. Allowing a current density on electrodes of 0.30 amp per cm^2. Find the distance between the electrodes.*

Solution.

Current through the electrodes

$$= \frac{72 \times 10^3}{600} = 120 \text{ Amp.}$$

The area of the electrodes

$$= \frac{125}{(0.30)} \text{ cm}^2 = 400 \text{ cm}^2$$

Resistance of the soda solution between electrodes

$$= \frac{600}{120} = 5 \text{ ohm.}$$

Thus distance between plates

$$d = \frac{Ra}{\rho} = \frac{5 \times 400}{25} \text{ cm} = 80 \text{ cm.} \quad \textbf{Ans.}$$

Example 1.6. *A regulating resistance is wound with 50 mt. of 1.2 mm dia wire of resistivity 12 × 10^{-6} ohm cm. Design a new resistance wire of resistivity 48 × 10^{-6} ohm cm to replace the original. Assuming the same conditions of emissivity and cooling.*

Solution.

Area of cross-section of original wire

$$= \frac{\pi}{4} (1.2)^3 \times 10^{-2} \text{ cm}^2$$

Let d mm be the diameter and l metres be the length of the new wire in cm units. Since the resistances of both the wires must be equal

$$\text{Thus} \quad \frac{12 \times 10^{-6} \times 50 \times 10^2}{\frac{\pi}{4} (1.2)^2 \times 10^{-2}} = \frac{48 \times 10^{-6}\, l \times 10^{-2}}{\frac{\pi}{4} \cdot d^2 \times 10^{-2}}$$

$$\therefore \quad \frac{l}{d^2} = 8.68 \qquad \ldots(i)$$

The heat dissipation area of the new wire should be equal to that of old wire.

$$\pi\, l \times 10^2 \times d \times 10^{-1} = \pi \times 50 \times 10^{2} \times 1.2 \times 10^{-1}$$

$$ld = 60 \qquad \ldots(ii)$$

Thus from equations (*i*) and (*ii*)

$$d^3 = \frac{60}{8.68} = 6.912$$

$$d = 1.90 \text{ mm}$$

$$l = 31.4 \text{ m.}$$

Example 1.7. *A porcelain cylinder 5 cm in diameter is wound with bare high resistance wire having a resistance of 1 ohm per metre length and 1 mm² cross-section. The distance between consecutive turns equals the diameter d of the wire. If the external surfaces of the cylinder (excluding the ends) can dissipate 0.32 W/cm² at the permitted temperature rise, find the length of cylinder and the diameter and the length of wire for a loading of 100 W and a current of 1 A.*

Solution.

Let d mm be the diameter of the wire and n be the number of turns of the wire on the cylinder.

Then length of the porcelain cylinder will be $2nd$ mm.

The heat dissipating surface of the cylinder is πDL cm² where D (cm) is dia of cylinder and L (cm) is the length of the cylinder.

Thus heat dissipating surface = $2nd \times 10^{-1} \times 5\pi = \pi\, nd$ cm²

The total heat to be dissipated = $0.32 \times \pi nd$ watts

This should be equal to the loading on wire.

Thus $\quad 0.32\, \pi nd = 100$

$$nd = \frac{100}{0.32 \times \pi} = 100 \qquad ...(i)$$

Also length of wire required

$$= \pi \times 5 \times n \text{ cm} = 5\pi n \text{ cm.} \qquad ...(ii)$$

$$\text{Resistance of wire } = \frac{5\pi n \times 10^{-2}}{\frac{\pi}{4} d^2} \times 1 \text{ ohm}$$

$$= 20 \times 10^{-2} \frac{n}{d^2} \text{ ohm} \qquad ...(iii)$$

The active resistance of wire can be calculated from power requirement. Thus

$$W = I^2 R$$

$$100 = (1)^2 . R$$

or

$$R = 100 \text{ ohm} \qquad ...(iv)$$

Equation (*iii*) and (*iv*)

$$20 \times 10^{-2} \times \frac{n}{d^2} = 100 \quad \text{or} \quad \frac{n}{d^2} = 500 \qquad ...(v)$$

Dividing (*i*) by (*v*), $d^3 = \frac{100}{500} = 0.2$

$d = 0.585$ mm

and $n = \frac{100}{0.585} = 171$

Length of wire $= n \times$ length of mean turn

$= 171 \times \pi(5 + 0.0585)$ cm

$= 2700$ cm $= 27$ m.

Length of porcelain cylinder $= 2nd$

$= 2 \times 171 \times 0.585 \times 10^{-1} = 20$ cm.

Example 1.8. *A tapped voltage divider is to be connected across a 200 V supply to provide outputs at*

(*a*) *20 mA at 100 volts and* (*b*) *30 mA at 150 volts.*

Find the resistance of each section of the divider, the total resistance and the dissipation in volts of each section, if the bleeder current passed by the divider is to be 50 mA on load.

Solution.

Voltage across $R_1 = 50$ V which is carrying a current of 100 mA

Thus $R_1 = \frac{50}{100 \times 10^{-3}} = 500\ \Omega$

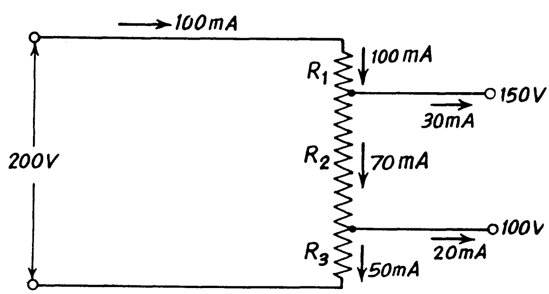


Fig. for example 1.8.

The power dissipation for $R_1 = V \cdot I$

$= 50 \times 100 \times 10^{-3} = 5$ W

Thus $R_1 = 500\ \Omega$, 5 W

The voltage across $R_2 = 150 - 100 = 50$ V

The current through $R_3 = 70$ mA

Thus resistance $R_2 = \frac{50 \times 10^3}{70} = 714$ ohm

The power dissipation for $R_2 = 50 \times 70 \times 10^{-3} = 3.5$ W
The voltage across $R_3 = 100$ V
The current through $R_3 = 50$ mA
Thus the value of resistance $R_2 = \dfrac{100}{50 \times 10^{-3}} = 2\ \text{K}\Omega$
The power dissipation for $R_3 = 100 \times 50 \times 10^{-3} = 5$ W
The total resistance $= 500 + 714 + 2000 = 3214\ \Omega$.

1.10. Design of Capacitance

The fundamental relation for the capacitance between two flat plates separated by a dielectric material is given by

$$C = \frac{0.08854\, KA}{d} \qquad \ldots(1.7)$$

where, C = capacitance, p.f.
K = dielectric constant
A = Area per plate in square cm.
d = Distance between two plates in cm.

when more than one plates are used the value will be increased by a factor $(N-1)$, where N is the number of plates.

Owing to the **edge and fringe** effects, the capacitance calculated by formula (1.7) becomes slightly lower. So the following corrections should be applied to the plate dimensions.

1. For straight edge add 0.44 d to the sides.

2. For circular edge and 0.11 d to the sides. To achieve higher capacitance to volume ratio the dielectric material with higher values of K should be used.

The equivalent circuit of a capacitor may be represented as shown in Fig. 1.22 (a).

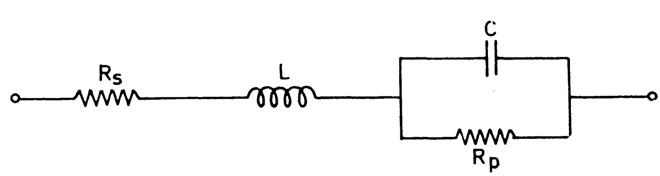


Fig. 1.22. (a) Equivalent representation of a capacitor.

In Fig. 1.22 (a) C represents the capacitance of the capacitor as calculated by the geometrical dimensions with the help of equation (1.7) R_s the series resistance, is the representation of the resistance due to leads, plates and contacts (1) R_p is the parallel resistance due to the dielectric and case material and L is the inductance due to leads and plates of the capacitor.

Design of capacitor is connected with the relation of the proper dielectric material for particular type of application. The dielectric materials used for capacitors may be grouped in the various classes. The dielectric coverage for different value of capacitors is shown in Fig. 1.22 (*b*).

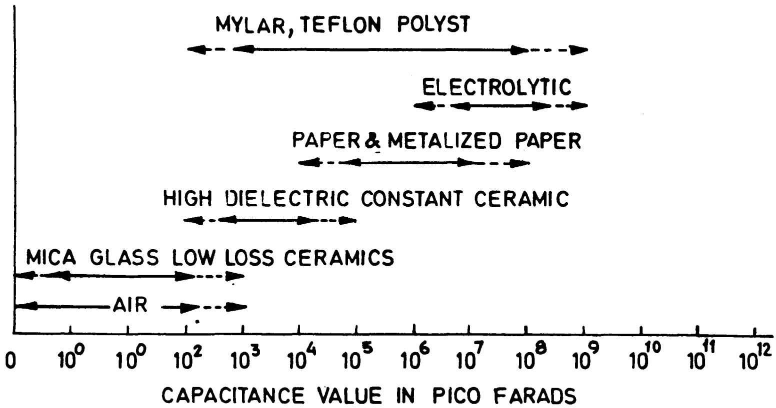


Fig. 1.22. (*b*) Different types of dielectric coverage for different values of capacitor.

The value of capacitance never remains constant except under certain fixed conditions. It changes with temperature, frequency and ageing. The capacitance value marked on the capacitor strictly applies only at specified room-temperature and at low frequencies. The behaviour of the capacitor at various frequencies may be grouped into the following seven classes :

(1) Mica, glass, air and low loss ceramic capacitors are used from few kHz to few hundreds MHz.

(2) Paper and metallized paper capacitor cover the frequency range of few Hz to few hundred kHz.

(3) High dielectric constant ceramic capacitors can only be used between the frequency range from few kHz to few, hundred of kHz however, they can find use from very low frequency to 1000 MHz.

(4) Aluminium electrolytic capacitor can find used at power-frequency from 10 Hz to 1000 Hz but can be used up to 10 kHz.

(5) Tantalum electrolytic capacitor may be used from d.c. to few hundred Hz.

(6) Polyethylene, tere-phthalate. (**Mylar**), cellulose acetate capacitors may find use from few hundred Hz to few MHz.

(7) Polystyrene, polyethylene, polytetrafluoroethylene (**Teflon**) capacitors are used from d.c. to 1000, MHz range. They are reported to give satisfactory performance even at higher frequencies.

1.11. Characteristics of Different Capacitors and their Selection Factors

(*a*) **Impregnated paper capacitor.** Impregnated paper capacitor, are most general purpose capacitors. They are cheaper in cost. They are constructed by rolling two or more sheets of paper or dielectric material between two metal foils and filling the voids with an impregnant. The characteristics of the paper capacitors may be summarised as follow.

(*i*) Cost—relatively cheaper.

(*ii*) Power factor—upto 0.01 at 25°C, measured at 1 KHz and 0.005 to 0.04 at – 55°C.

(*iii*) High capacitance to volume ratio.

(*iv*) Usually manufactured with tolerance of ± 10% or larger but ± 5% of tolerance is also possible.

(*v*) The life of such a capacitor depends on the working voltage. It is inversely proportional to the 5th power of the operating voltage upto 85°C ambient. Thus maximum permissible d.c. voltage depends on the ambient temperature for such type of capacitors.

The impregnated paper capacitors are used for application such as :

(1) Blocking, (2) Buffer, (3) By-passing, (4) Coupling
(5) Filtering.

(*b*) **Metallized paper capacitor.** In paper capacitors certain voids are left between paper and foil. So one side of the paper is metallized before rolling hence metallized paper capacitors become smaller than ordinary impregnated paper capacitors having safe voltage rating upto 600 volts. Then type of capacitors have **self-healing** properties, if a minor short circuit occurs during the operation the very thin metal quickly evaporates in the area of the puncture and prevents the permanent short circuits. The insulation resistance of these type of capacitors is nearly 50 to 100 times less than that of the impregnated type.

The metallized paper capacitors may be used for all such applications as foil or paper impregnated. Paper capacitors are used except that they are not recommended for coupling. They should be used with care on alternating current. The d.c. voltage rating cannot be simply translated into an a.c. rating. A.c. rating cannot be based upon foil types because of the poor heat conductivity of the metallized winding. However, the a.c. 50 Hz or 400 Hz peak voltage should never exceed the d.c. voltage rating. Metallized paper capacitors should never be used where the surges over the normal working voltage are likely to occur. This will reduce the performance of capacitance in respect of power factor, insulation resistance and capacitance value. If two capacitors are used in parallel, a resistance of the value of 1 KΩ is usually connected in series with each of them to prevent any transient surges which may occur if one capacitor fails.

(*c*) **Mica-dielectric capacitors.** Mica capacitors are constructed by the methods.

(1) Foil types in which very thin sheets of mica are alternately stacked between the layers of metal foils.

(2) Silver mica capacitors in which the conductive layer of silver is deposited on the surface of the mica dielectric sheet, in both cases the stacks are clamped, terminations are made and then mould or dip coating is applied for mechanical and environmental protections.

Mica and ceramic capacitors have excellent characters.

Mica capacitors are superior in some characteristics *e.g.* mica capacitors of excellent tolerance (0.1%) can be manufactured. They are more stable (0.1% change in 10 years). They heave good characteristics upto GHz frequencies, can be used at high temperatures (300°C) and high voltage. However ceramic capacitors are inexpensive, smaller in size and available in variety of types.

The following are the characteristics of the mica capacitors.

(*a*) Cost : a little more than paper dielectric type.

(*b*) Power factor : 0.001 at one kHz and 25°C.

(*c*) High Q, of the order of 100 to 1000 at MHz range.

(*d*) Low capacitance to volume ratio as compared to paper type capacitors.

(*e*) High d.c. working voltage is possible.

(*f*) The capacitance tolerance upto 0.25% can be achieved.

The silver mica capacitors find applications where low power factor, high voltage operation and low capacitance drift *i.e.* stability are the main requirements by they are unsuitable for heavy current duty. They may be used at following places.

(1) As blocking capacitor.

(2) As by-pass capacitor.

(3) As buffer capacitor.

(4) As coupling capacitor.

(5) For light frequency filtering.

(6) For high voltage, high frequency fixed turning.

(7) In the resonance circuits of an oscillator.

(*d*) **Ceramic dielectric capacitors.** Ceramic capacitors are most popular of all due to their outstanding versatality in sizes, shapes and ratings. The dielectric (Ti_2 and other titanates) constant varies from about six to 10,000. Their merits include reliability, small size and are used in printed wiring boards. The stability of the capacitance value w.r.f. temperature is better for low *K* (dielectric constant) capacitors. Ceramic capacitors are available in disc, tubular, plate, ceramic barrier, layer, feed-through, stand-offs, multilayer chips, monoblock, monolithic and other forms. The disc and plate types are ideal for PCB's and need minimum space. The tubular form lends itself to efficient space utilisation. Ceramic capacitors are divided into low K (class I) and high—K (class II) types.

High *K* capacitors have dielectric constant of more than 3000. They are very small in size and are used in non critical applications such as by pass, coupling, filtering etc. They are available in a range from 0.001 μF to several μF. Their capacitance varies with temperature, voltage ε frequency. Low *K* ceramic capacitors have dielectric constant from 6 to 200 and thus have larger size for same value.

For greater stability with temperature low-*K*capacitors are used. They exhibit a capacitance change of about 5 to 15%. Temperature compensating capacitors exhibit controlled and predictable variation in cap. With change in temperature. They have high *Q*, linear TCC (temp. coefficient of capacity) and high stability with low losses. Ceramic capacitors and trimmers are used for critical circuit functions such as oscillators, filter circuits, crystal oscillators, *RF* amplifiers and variety of communication and test equipments. They are used from audio frequency to 500 MHz. They are much smaller than air trimmers. Ceramic and mica capacitors compete with each other. There are three types of ceramic capacitors :

(*i*) Low-loss, low-dielectric constant capacitor.

(*ii*) Temperature compensating, medium dielectric-constant capacitor.

(*iii*) High dielectric constant capacitor.

The low dielectric-constant ceramic capacitors are made of steatite or similar material. The dielectric constant of such material varies between 8 to 15.

Medium dielectric constant ceramic capacitors are generally temperature compensating capacitor and find their application as :

(1) Coupling (2) By pass (3) High frequency tunning :

But care has to be exercised that these capacitors should be used at such a place where the time temperature curve of the other parts of the circuit is similar to that for capacitor.

The high dielectric-constant ceramic capacitors provide high capacitance to volume ratio. The power factor and capacitance vary with temperature. These capacitors are subjected to hyteresis and are very much suitable only for a.c. voltage applications with very small voltages.

These capacitors are very much suitable for filtering and r.f. by-passing.

(*e*) **Glass dielectric capacitors.** Glass dielectric-constant capacitors are not very commonly used because of their comparatively high cost. These capacitors are manufactured by arranging alternate layers of glass ribbon and aluminium foils and fusing together to form a soild stack. The glass dielectric capacitors have higher dielectric constant and have high capacitance to volume ratio. They find their applications as (1) blocking, (2) tunning (3) coupling and (4) by passing.

(*f*) **Vitreous-enamel dielectric capacitors.** For excellent radio frequency characteristics vitreous enamel dielectric capacitors find their applications. They are manufactured by spraying vitreous enamal alternately on silver conductors. The stack so formed is fixed to a high temperature so as to form monolithic block. The other characteristics of these type of capacitors are :

(*i*) Capacitance drift is app. 5% over a wide temperature variation.

(*ii*) Have very high insulation resistance.

(*iii*) Low dissipation factor.

As stated above these types of capacitors are used at high frequency and find application as :

(1) blocking, (2) tunning (3) coupling and (4) by passing.

(*g*) **Plastic film capacitors.** The high dielectric constant and capacitance to voltage ratio may be achieved by using plastic dielectrics such as polystyrene, polyethylene, teraphthalate

(Mylar), polytetrafluorothylene (Teflon) etc. These capacitors have high operating temperature coefficients, low capacitance drift and high Q. They find their applications in (1) Precision timing circuits (2) Integrated circuits (3) High Q turned circuits and (4) Laboratory standards.

There are many types of plastic capacitors. They have higher capacitance density compared to glass or mica but lower than electrolytes. They are dry, non-polar show low loss, have excellent insulation resistance and low moisture absorption. Polyster ($K = 3.3$, Trade Name : Mylar, Melinex), Polystyrene ($K = 2.3$, T.N. : Styroflex, Styrofoil), Polycarbonate ($K = 3.2$, T.N. : Makrofol), PTFE ($K = 2.1$, TN L Teflon) are all plastic capacitors. They are not suitable at VHF/UHF frequency.

Polyester capacitors have high dielectric strength and can be used upto 150°C and 1000 volts. They have very high insulation resistance (greater than 50,000 Megaohms). They are most popular and cheap among plastic capacitors. Their only drawback is the higher TCC.

Polystyrene capacitors have excellent low and negative TCC., low losses and low dielectric absorption. The only drawback is they can be used only at room temperature, their maximum temperature rating is only 85°C. They are widely used in filter networks, as precision capacitors, in tuned circuit at radio frequency, computers and in timing applications. They are particularly suited in resonant circuit with ferrite coil with a corresponding positive TCC so that resonant frequency can be kept constant with change in temperature.

(*h*) **Electrolytic capacitors.** The very outstanding characteristic of this type capacitors is the very high capacitance to volume ratio specially at low working voltage. There are different types of electrolytic capacitors such as,

(*i*) Polarized aluminium electrolytic capacitors,

(*ii*) Non-polarized electrolytic capacitors,

(*iii*) Tantalum electrolytic capacitors.

Such type of capacitors are made by first forming a coating of aluminium oxide on both sides of an aluminium foil about 0.05 mm to 0.12 mm thick. The two strips of aluminium foil are separated by the layers of porous paper soaked with electrolyte. The formed foils act as the anode and plain foil as the contacting electrode for the electrolytic cathode.

Aluminium oxide (Al_2O_3) or tantalum oxide (Ta_2O_5) are used as electrolyte. When a voltage is applied, a thin film of (of few mils) dielectric is formed around one terminal due to electrolysis. They have large capacitance to volume ratio and light weight and low cost. Their values are normally from 1 μF to 1 Farad in small space. They are widely used in power supply filtering, by passing and coupling. They have very high tolerance (sometimes as high as (– 20 to 100%) and hence are not used for timing applications. They have high leakage current, which increases with applied voltage operating temperature and time. Their service life and reliability can be improved by reducing operating voltage and temperature. They may explode at higher temperature and hence should not be mounted in contact with heat producing elements like transformers, rectifier diodes etc. They are available in wet and dry (paste) types. They are available in polarized types and non polarized types.

Tantalum oxide has dielectric constant of 24 whereas Al_2O_3 has 8. The physical limit of field strength in both cases is not very different (approx. 5×10^8 and 7×10^8 volts/meter respectively). Tantalum capacitors are superior to aluminium capacitors in operating and storage temperature range, vibration shock resistance, leakage and size per μF (volumetric efficiency). They are used where high capacitance in small value is desired. However, their operating voltage range is limited are expansive and can fail oven in early stages of service life due to sudden breakdown failure (due to higher voltage spike).

Solid aluminium capacitors are slightly larger than comparable tantalums. They are low priced compared to tantalums but slightly more expensive than wet types. All these capacitors are used only upto 10 kHz due to higher inductance associated with them.

The electrical properties of aluminium electrolytic capacitors change widely under different conditions of use. There is a slight increase in capacitance value if the temperatures is raised from 25°C. to 85°C and a decrease as the temperature is reduced to – 20°C. At low temperature the rate of fall of capacitance is very fast similarly at high temperatures there is a marked decrease in p.f. and an increase in leakage current. These capacitors are to be reformed periodically if they are stored for a considerable length of time. The leakage current increases tremendously if they are stored, even at room temperature, for more than six months.

Aluminium electrolytic condensers find applications as :

(*i*) Bypassing. (*ii*) Filtering.

(*iii*) High energy pulse storage.

Non-polarized aluminium electrolytic capacitors are generally used as motor starting capacitors.

Tantalum electrolytic capacitors are used in the similar applications aluminium electrolytic capacitors but only where superior shelf life, greater operating temperature range and or smaller size are required. These capacitors have.

(*a*) Greater capacitance to volume ratio

(*b*) Longer shelf life.

(*c*) Greater operating temperature range.

(*d*) Low leakage current.

(*e*) Low power factor.

(*f*) Longer operating life.

(*i*) **NPO capacitors.** Special ceramic capacitors that remain stable with temperature are called negative-positive-zero (NPO) capacitors. They are even more stable than the silvered mica capacitors. They are used in many kinds of receivers. Their values are between 1 pF and several thousand pF.

The temperature coefficient of temperature compensated ceramic capacitors is denoted by a number prefixed by letter *P* and *N*, for example *P* 100, *N* 150, *N* 750 and so on. A commonly used temperature coefficient is *N* 750. Capacitors with this temperature coefficient have a *k* of about 90 N. 750 means that the decrease in capacitance will be 750 parts per million or 750 ppm per °C of temperature rise. In other words, the capacitance decreases by 0.075 percent for 1°C, increase or 1.5 percent for a 20°C increase. Thus, the prefix *N* means negative temperature coefficient of capacitor or negative TCC. Similarly *P* means positive TCC.

(*j*) **Quartz Capacitors.** They are unique in the fact that they can carry high *RF* current in amperes and withstand high *RF* voltages. Their *Q* is higher than that of glass.

(*k*) **Vacuum capacitor.** For very high voltage, vacuum is often used as the di-electrics. Vacuum capacitors range from 1 to 5000 pF and can operate at voltages as high as 60 kV.

(*l*) **Energy storage capacitors.** Energy storage capacitors store energy which can be discharged in a time interval from a fraction of a micro second to several hundreds of micro seconds. Specially prepared di-electric with impregnate kraft paper is used for such capacitors. These capacitors are available from 0.5 UF to 250 UF and voltage ratings upto 50 kV.

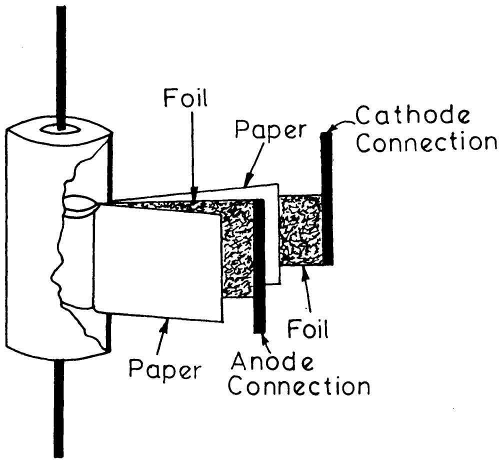


Fig. 1.23. Construction of an electrolytic capacitors.

A more detailed information about the important characteristics of fixed capacitors and dielectric materials may be obtained from table 1.6, to 1.9 for design and application purpose.

1.12. Characteristics of Variable Capacitors

Variable capacitors may be grouped in five general classes.

(*a*) Precision types

(*b*) General purpose types

(*c*) Transmitter type

(*d*) Trimmers

(*e*) Special types.

The important properties of variable capacitors are given in Table 1.10 and the various symbols of variable capacitors tabulated in Table 1.11.

Table 1.6. Typical Characteristics of Commonly used Fixed Capacitors

Type	*Capacitance Ranges*	*Maximum working voltage volts*	*Maximum operating temperature °C*	*Tolerance percentage*	*Insulation resistance M. Ohms*
Mica	1 pF—0.1 µF	50,000	150	± 0.25 to ± 5	
Silvered mica	1 pF—0.1 µF	75,000	125	± 1.0 to ± 20	More than 100,000
Paper	500 pF—50 µF	100,000	125	± 10 ± 20	1000
Polystyrene	500 pF—10 µF	1,000	85	± 0.5	100
Polycarbonate	0.001—1 µF	600	140	± 1	10,000
Polyester	5.000 pF—10 µF	600	125	± 10	10,000
Ceramic					10,000
Low grade	1 pF—0.001 µF	6,000	125	± 25 to ± 20	
High grade	100 pF—2.2 µF	100	85	± 100 to ± 20	1,000
Glass	10 pF—0.15 µF	6,000	125	± 1 to ± 20	100
Vacuum	1—5000 pF	60,000	85	± 5	More than 100,000
Energy storage	0.5—200 µF	50,000	100	± 10 to ± 20	More than 100,000
Electrolytic					100
Aluminium	1 µF—1 F	700	85	± 100 to – 20	
Tantalum	0.001 to 1000 uF	100	125	± 5 to ± 10	Less than 1
Chip Capacitors					More than 1
Ceramic	10 pF—3.5 µF	200		± 1 to ± 20	1,000
Tentalum	100 pF—100 µF	50		± 5 to ± 20	1,500
Porecelain	1—330 pF	50		± 1 to ± 10	100,000

Table 1.7. Properties of Some Capacitor Dielectric Materials

Material	*Power Factor*		*Dielectric constant 25° C 60 Hz*	*Capacitance at 85° C relative to 25° C*	*Insulation Resistance Mega ohms*		*Dielectric absorbtion 1 min ofter 2-sec discharge percentage*	*Operating Temp. range in degree C*
	60 Hz	*1 kHz*			*25°C*	*85°C*		
Proper (Kraft Cap tissue with :								
Mineral oil	0.002	0.0035	2.23	102	15,000	100	2.0	– 55 to 105
Caster oil	0.005	0.007	4.7	96	1,500	50	2.5	– 25 to 105
Silicon oil	0.003	0.0035	2.6	101	20,000	150	1.0	– 60 to 125
Polyisobutylene	0.002	0.003	2.2	101	20,000	150	1.0	– 55 to 125
Chlorinated napthalene	0.004	0.005	5.2	93	4,000	50	2.5	– 20 to 55
Chlorinated diphenyl	0.0025	0.003	4.9	96	10,000	100	2.2	– 55 to 85
Polythene terephthalate	0.0025	0.004	2.8	101	100,000	10,000	2.25	– 70 to 150
Above with silicon fluid	0.0025	0.0045	2.05	102	20,000	2,000	2.0	– 60 to 150
Polytetra-fluoro-ethylene (cast film)	0.001	0.0005	2.05	99	1,000,000	1,000,000	0.02	– 90 to 200
Above with silicon fluid	0.001	0.0005	2.1	98	20,000	20,000	2.5	– 60 to 200
Celulose acetate	0.009	0.015	3.8	105	15,000	200	1.5	– 70 to 125
Above with silicon fluid	0.01	0.016	3.8	104	8,000	100	2.5	– 60 to 125
Polystyrene	0.001	0.0005	2.6	99	1,000,000	100,000	0.02	– 70 to 85
Polystylene	0.001	0.0005	2.25	96	100,000	1,000	0.02	– 70 to 85
Mica (ruby)	0.0025	0.0006	5.5	100	100,000	1,000	0.7	– 60 to 160

Table 1.8. Properties of Some Capacitor Dielectric Materials

Material	*Limiting Frequency of Operation*		*Power Factor Loss Angle Tan δ*	*Dielectric Constant (Over operating Frequency Range)*	*Dielectric Strength Volts m*	*Temperature Limits*	
	Approx. Min.	*Approx. Max.*				*Approx. Min.*	*Approx Max.*
Glass (Soft Lead Soda)	200 Hz	10,000 MHz	0.001	6.5—6.8	< 500	no limit	+ 200
Glass (hard Borosilicate	100 Hz	10,000 MHz	0.001	4.0	< 500	—do—	+ 200
Quartz (fused)	100 Hz	710,000 MHz	0.0002	3.8	1,000	—do—	+ 300
Ceramic (Low dielectric constant type) Magnesium Silicate	100 Hz	10,000 MHz	0.001	5.4—7.0	200—300	—do—	+ 150
Ceramic dielectric constant Titania Oxide (TiO_2) (Medium dielectric constant type)	500 Hz	5,000 MHz	0.001	70—90	100—150	—do—	+ 125
Ceramic high dielectric constant type Titnate	1000 Hz	1,000 MHz	0.01	app. 1,000 over 7,000	100	– 100	+ 125

Table 1.9. Summary of Some of the Important Characteristics of Fixed Capacitors

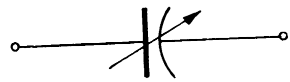
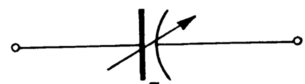
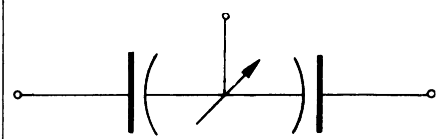
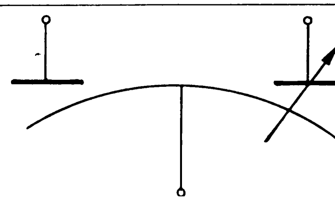
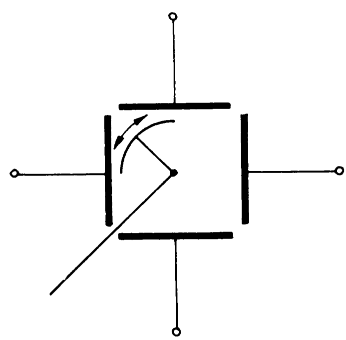
Type of capacitor (Military specifications (1)	*Closest tolerance in specifications* (2)	*Power factor at 1 kHz and 25°C or at 1 Hz and 25°C* (3)	*Temperature co-efficient (ppm / °C) characteristics where applicable* (4)	*Insulation Resistance (min at end of Life Test) megaohms* (5)	*Maximum capacitance variation after life Tests* (6)	*Maximum Operating temperature for longer Life* (7)
Impregnated Paper	± 10%	0.004—0.01	*	30% of original specified req.	10%	85°C or 125°C* depending on impregnant
Metullized Paper	± 10%	0.005—0.015	*	1/2 of original specified req.	10%	85°C or 124°C*
Moulded mica capacitors	± 2%	0.001—0.005	B—not specified C ± 200 ppm/°C D ± 100 ppm/°C E—100 ppm/°C + 20 ppm/°C F + 70 ppm/°C – 0 ppm/°C	75.00	3% or 0.5 pF whichever is greater	85°C 125°C to 150°C
Glass Dielectric	± 2%	0.001	140 ± 25 ppm/°C	10.000	2% or 1 pF whichever is greater	85°C or 125°C*
Vitreous enamel	*	0.001	114 + 25 ppm/°C	*	*	85°C
Ceramic temp. compensating	± 1%		+ 100—200 0—330 – 30—420 – 80—750 – 150	1.000	3% or 0.5 pF whichever is greater	85°C

(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Ceramic general purpose	± 100	0.01 to 0.03 varies with temp., etc.	– 1,500 varies non-linearly	3,000	*	86°C or 150°C
Mica, button types	± 2%	0.100—0.005	B—not specified D ± 100 ppm/°C	7,500 or 50,000 (depends on type of scale)	3% or 0.5 pF whichever is greater	85°C or 125°C
Polystyrene film	± 5%	*	– 120 ± 30 ppm/°C	60% of original specified req.	6% for values 0.05 pF 3% for values above 0.05 pF	65°C (85°C)
Polyterafluro ethylene	± 5%	*	*	60% of original specified req.	5%	170°C
Polyethelene terepthalate	± 5%	0.01 varies with temp. and freqn.	Varies with temperature	60% of original req.	5%	125°C
Tantalum electrolytic	± 2%	0.02—0.2	*	*	*	85°C, 122°C or
Tantalum solid electrolytic	± 10%	0.04—0.06	+ 600 ppm/°C	*	10%	85°C
Precision-type air dielectric	± 00.1	0.00001	+ 10	*	*	25°C

Table 1.10. Summary of Some of the Important Properties of Variable Capacitors

Type	*Approximate capacitance swing pF*	*Power factor at 1 kHz and 25°C*	*Q at 1 MHz and 25°C*	*Approximate operating voltage d.c. at sea-level pressure*	*Temp. coeff. ppm / °C*	*Max. oper. temp. for long life*
Single unit Precision	100—1,500	0.00001	—	1,000 volts	+ 10 (best)	—
Single unit, gen. purpose	15—100 and 350—550	0.001	—	750	+ 120	—
Multi gang, gen. purpose	—do—	0.001	—	750	+ 120	—
Multi gang, mini gen. purpose	300—350	0.001	—	500	+ 150	—
Trimmers, air diel. vane type	3.5—145	—	250 min	C_1 : 850 C_2 : 1,150 C_3 : 1,400	+ 150—150	85°C
Trimmers, glass diel. piston	0.5—30	—	500 min	500	± 100	125°C
type	7—45	—	500 min	500	—	—
Trimmers ceramic dielectric Trimmer, Mica Compression	7.5—80 1400—3605 Non-linear	0.001	—	250—500	poor	—

Table 1.11. Variable Capacitors Symbols

Types of Capacitor	*Symbol*
Adjustable or variable capacitor.	
Adjustable trimmer capacitor.	
Split stator capacitor (cap of both parts increases simultaneously.)	
Variable differential capacitor. Capacitance of one part increases as the capacitance of the other part decreases.	
Phase shifter capacitor.	

1.12.1. Standard Capacitance Values Available in the Market

pF range

10, 12 13, 15 18, 20, 22, 24, 27, 30, 33, 36
43, 47, 51, 56, 62, 68, 75, 82, 100, 110, 120, 130,

150, 180, 200, 220, 240, 270, 300, 330, 360, 390, 43,
470, 510, 560, 620, 680, 750, 820, 910.

μF range less than 0.1 μF

0.001,	0.0012,	0.0013,	0.0015,	0.0018,	0.002,
0.0022,	0.0033,	0.0047,	0.0068,	0.01,	0.015
0.022,	0.033,	0.047,	0.068		

μF range less than 10 μF

0.1,	0.15,	0.22,	0.33,	0.47,	0.68,
1.0,	1.5,	2.2,	3.3,	4.7,	6.8

μF range less than 100 μF

10,	15,	22,	25,	33,	47,
50,	68,	100,	220,	330,	470

μF range less than 1000 μF

1000,	2200,	3300,	4300,	6800,	10,000,
22,000,	47,000	82,000.			

1.13. Precision Variable Capacitors

These capacitors have been used for many years primarily as laboratory sub-standards of capacitance in bridge and resonant circuits. Various functions are available and capacitance upto 5000 p.f. can be obtained in one swing. Capacitance tolerance are of the order of one in ten-thousands. The following are the design requirement for a precision variable capacitors.

(*i*) The temperature coefficient of the rotor and stator assembly should be same.

(*ii*) The mechanical stresses in each part of the assembly should be minimised.

(*iii*) The temperature over whole unit must remain same.

(*iv*) High degree of mechanical stability and absence of residual stresses.

(*v*) The temperature coefficient of dielectric must be small.

(*vi*) The reduction of capacitance of solid dielectric with temperature should be minimum.

(*vii*) Small dielectric loss and high electric strength.

(*viii*) Accuracy of location of the insulator supporting the stator assembly.

(*ix*) Value of Mass × specific heat per unit area should be same for each part.

(*x*) Value of emissivity coefficient should be identical for each part.

(*xi*) The residual inductance should be low.

To achieve the maximum possible precision the frame, spacers, stator rod, rotor shaft, and plates are all constructed of the same aluminium alloy. To obtain accurate setting a worm device is issued. To insulate the stator assembly from the cast aluminium frame low loss steatite or quartz bars are used. The rotor shaft is supported on each end by a sealed salf-lubricating lightly stressed ball bearings. Electric connection to the rotor is made by means of a silver alloy brush making contact with a silver arm to assure a firm contact.

1.14. General Purpose Variable Capacitors

The change of capacitance with angular rotation of the rotor shaft is governed by the shape of fixed and moving plates of a capacitor. There can be many relationships depending on the specific requirements but the most common relationships are :

(*i*) Linear capacitance or straight line capacitance.

(*ii*) Linear frequency or inverse square-law capacitor which is known as straight line frequency (SLF).

(*iii*) Linear wavelength or square-law capacitance or straight line wevelength (SLW).

(*iv*) Logarithmic or exponential law of capacitance etc.

The design procedure for various type of capacitors are illustrated through examples.

Example 1.9. *Design the shape of plates for (1) Linear capacitance or (2) straight line capacitance suitable to be used in Bridge.*

Solution.

The law of linear capacitance as shown in Fig. 1.24 (*a*) may be stated as

$$C = m_1\theta + b_1$$

where, m_1 is constant determining the rate of cl ge of capacitance with angle θ *i.e.* tan α and b_1 is the constant determining the value of capacitance when the angle of rotation is zero *i.e.* residual capacitance.

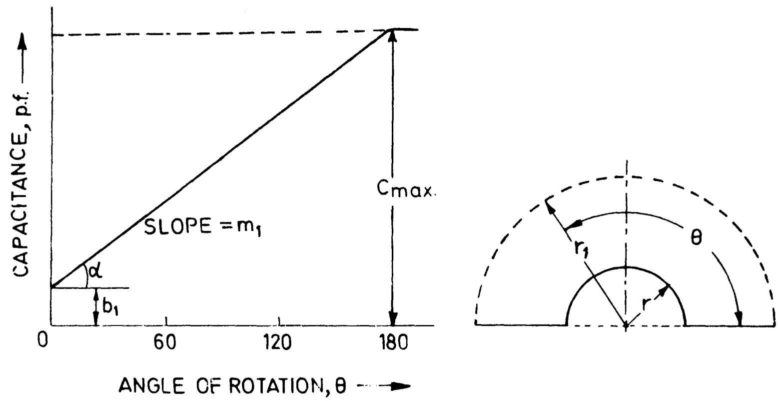
$$\tan \alpha = m_1 = \frac{\text{Max. cap. - Resi. cap.}}{\text{180 degrees}} = \frac{c_{max} - b_1}{\text{180 degrees}}$$

assuming full swing of 180° and b_1 = Residual capacitance

From Fig. 1.24 (*b*).

a = Area of lower semi-circular segment of radius r per unit degree of rotation.

$$a = \frac{\pi}{2 \times 180} \cdot r^2 = \frac{r^2}{114.6}$$



(*a*) Law of variation. (*b*) Shape of the plates.

Fig. 1.24. Straight line capacitance.

Let A be the rate of change of Area per unit capacitance

Then,
$$A = \frac{\text{Total plate area} - 180 \, . \, a}{\text{Max. capacitance} - \text{residual capacitance}}$$

Therefore, Plate Area for any angle θ

$$= A[m_1 \, \theta + b_1) - \text{residual cap.}] + \alpha \, . \, \theta$$

If r_1 is the external radius of the plate, then the area per unit degree of rotation will be given by

$$\frac{1}{2}\int_0^{\pi} \frac{r_1^2}{114.6} \, d\theta = \text{Area of the plate}$$

or
$$r_1 = \left(114.6 \frac{d}{d\theta} \text{Area}\right)^{1/2}$$

or
$$r_1^2 = 114.6 \, (Am_1 + a)$$

This will give a circle.

Example 1.10. *Design of straight line frequency capacitor suitable for use in the wave meter.*

Solution.

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

Hence,
$$f \propto \frac{1}{\sqrt{C}} \quad \text{or} \quad C \propto \frac{1}{f^2}$$

Let the law of f be $(m_2\theta + b_2)$ from Fig. 1.25 (a),

$$m_2 = \text{Slope of frequency } vs\ \theta \text{ curve}$$

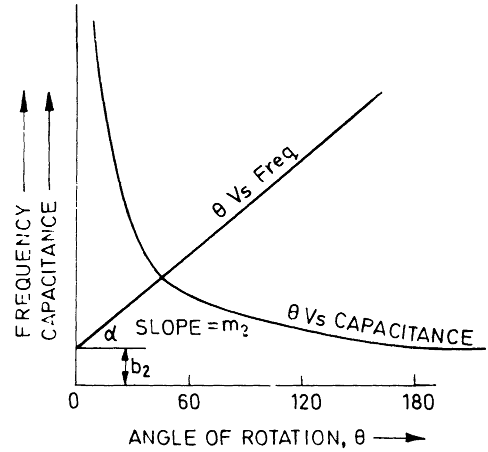


Fig. 1.25. (a) Law of variation of straight line frequency capacitance.

The law of capacitance will then be

$$C_2 = \frac{1}{(m_2\theta + b_2)^2}$$

Now, when $\theta = 0°$, C_2 will have max. capacitance, *i.e.*

$$b_2 = \frac{1}{\sqrt{\text{Max. capacitance}}}$$

When $\theta = 180°$

C_2 will have residual capacitance, therefore,

$$m_2 = \frac{1}{180°}\left\{\frac{1}{\sqrt{\text{Residual capacitance}}} - \frac{1}{\sqrt{\text{Max. capacitance}}}\right\}$$

Area of lower semi-circular segment per unit degree of rotation (from example 1.9)

$$a = \frac{r^2}{114.6},$$

Rate of change of area per unit capacitance

$$A = \frac{\text{Total plate area} - 180° \, . \, a}{\text{Residual capacitance} - \text{Max. capacitance}}$$

And plate Area for any angle θ

$$= A\left\{\text{Residual cap.} - \frac{1}{(m_2\theta + b_2)^2}\right\} + (180 - \theta)\,\alpha$$

External radius of plate (as in example 1.9)

$$r_2 = \sqrt{114.6} \left\{ \frac{2A \cdot m_2}{(m_2\theta + b_2)^3} + a \right\}^{1/2}$$

The shape of plates will be somewhat as shown in Fig. 1.25 (*b*).

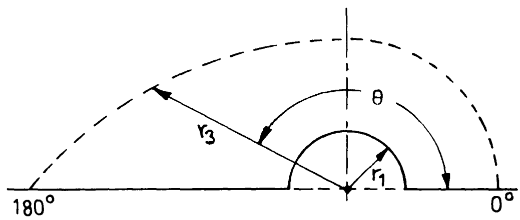


Fig. 1.25. (*b*) Shape of plates for straight line frequency capacitance.

Example 1.11. *Design of a straight line wavelength capacitor suitable for typical communication receiver.*

Solution.

Since, wavelength $\propto \frac{1}{\text{Frequency}}$

$\therefore$ Wavelength $\propto \sqrt{\text{Capacitance}}$

$\therefore$ Capacitance $\propto (\text{Wavelength})^2$

Let the law of wavelength be

$(m_3\theta + b_3)$ as shown in Fig. 1.26 (*a*).

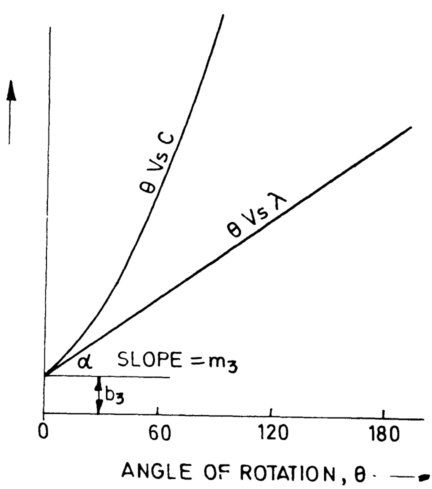


Fig. 1.26. (*a*) Straight line wavelength capacitor : Law of variation.

Capacitance = $(m_3\theta + b_3)^2$

$$b_2 = \sqrt{\text{Residual capacitance}}$$

Because it is the capacitance when θ is zero degree

$$m_3 = \frac{\sqrt{\text{Max. cap.}} - \sqrt{\text{Resi. cap.}}}{180^\circ}$$

The area of lower semi-circular segment per unit degree of rotation is,

$$a = \frac{r^2}{114.6} \qquad \text{(from example 1.9)}$$

The rate of change of area per unit capacitance

$$A = \frac{\text{Total plate area} - 180^\circ\, a}{\text{Max. cap.} - \text{Residual cap.}}$$

Thus Area of plate = $A[(m_3\,\theta + b_3)^2 - \text{Residual capacitance}] + a\theta$ External radius of plate,

$$r_2 = \sqrt{114.6}\;[2A\,.\,m_3(m_3\theta + b_3) + a)^{1/2}$$

The shape of the plate for such a capacitor will be somewhat similar to that shown in Fig. 1.26 (*b*).

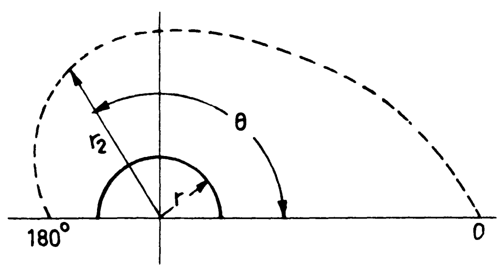


Fig. 1.26. (*b*) Straight line wavelength capacitor : Shape of plate.

Example 1.12. *Design the shape of the plates for a variable capacitor to follow the logarithmic law of capacitance for typical measurement applications.*

Solution.

The law of capacitance, as shown in Fig. 1.27 (*a*), can be given as

$$C = b_4\ \text{Exp.}\ (m_4\theta)$$

Now $\quad b_4$ = Residual capacitance, *i.e.* the capacitance where θ is zero degree.

$$m_4 = \frac{\text{Log}_{10}\,(\text{Max. cap.}) - \log_{10}\,(\text{Resid. cap.})}{78.14}$$

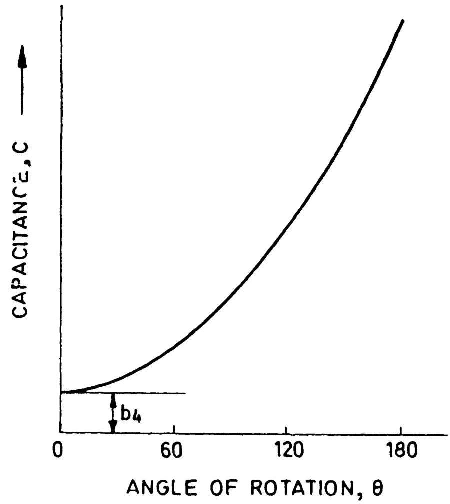


Fig. 1.27. (*a*) Logarithmic Law of variation : Angle of rotation.

The area of lower semi-circular segment per unit degree of rotation

$$a = \frac{r^2}{114.6}$$

The rate of change of area per unit of capacitor

$$A = \frac{\text{Total plate area} - 180\,a}{\text{Max. cap.} - \text{Resid. cap.}}$$

Thus, Plate area $= A\{b_4 \text{ Exp. } (m_4\theta) - \text{resid. cap.}\} + a\theta$

External Radius of the plate,

$$r_4 = \sqrt{114.6}\ \{Am_4b_4 \text{ Exp. } (m_4\theta) +\}^{1/2}$$

The shape of the plates will be somewhat as shown in Fig. 1.27 (*b*).

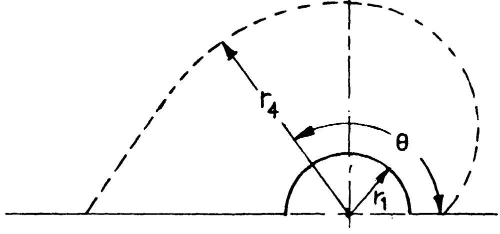


Fig. 1.27. (*b*) Shape of plates.

The shape of the plates of the type of law desired may be designed on the basis of the discussion in the above examples. Where ganged units are used it is necessary to trim the capacitances of the units so that they vary in steps. The radial slots are cut in the end plates so that an adjustment to balance any mismatch can be carried out. To achieve the frequency stability which is one of the main requirements in a broad-cast receiver variable capacitors, the change in vane spacing or dimensions of the frame should be minimised to zero. The vanes must be rigidly fixed and relieved of all the internal stress to prevent microphonics.

1.15. Transmitter Variable Capacitors

The transmitter capacitors are designed to operate at high voltages high powers and high frequencies. The main problems are of spark over, so adequate spacing of the vanes, with reasonable size, is necessary. The losses due to high frequency should be minimum. The heat loss due to insulation heating should be small.

1.15.1. Trimmer Capacitor

There are two uses to which trimmer capacitor can be put.

(*i*) For trimming, in which the capacitor is set to a given value.

(*ii*) For tunning in which continuous adjustment is necessary.

There are many types of trimmer capacitors :

(*i*) The moving vane
(*ii*) The concentric cylinder capacitors } 1.2 to 15 pf

(*iii*) Split stator trimmer

(*iv*) Temperature compensated air dielectric trimmer capacitors.

(*v*) Mica compression types 7.5 to 80 pf for smallest and 1400—3065 pf for largest.

(*vi*) Rotary type ceramic dielectric trimmers 5 to 7 pf for smallest and 7 to 45 pf for largest.

(*vii*) Glass piston type trimmer capacitor 0.5 to 12.0 pf.

(*viii*) Plastic dielectric trimmer capacitors 0.41 to 4.0 pf.

1.15.2. Special type variable capacitors

These capacitors are called on for special purposes and for some accurate measurements. Few of them are :

(*i*) Phase shift capacitors.

(*ii*) Sweep scanning capacitors.

(*iii*) Sine capacitor.

(*iv*) Semi Butterfly and Butterfly capacitors.

(*v*) Electrically variable gas dielectric capacitors.

(*vi*) Vari. cap. diodes—*i.e.* semiconductor diodes in reverse biasing.

1.15.3. Varactors (voltage variable capacitors)

When a *p-n* diode is reversed biased the depletion, region becomes devoid of free electrons and holes. Thus in such a situation the depletion layer may be considered to be a layer of dielectric while the *p* and *n* regions as the plates of capacitors.

When the reverse bias is increased the width of the depletion layer will increase, hence the capacitance will decrease. While with the reduction of reverse bias the capacitance will increase as shown in Fig. 1.28.

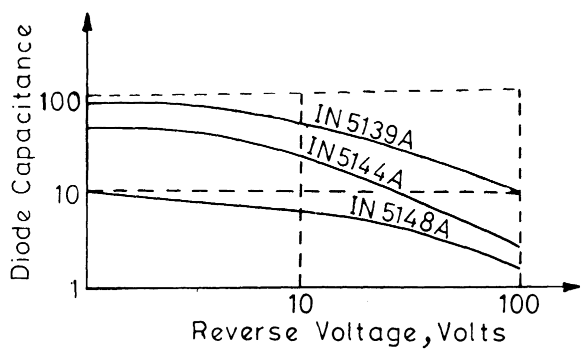


Fig. 1.28. Variation of capacitance with reverse voltage.

Such type of diodes are also known as voltage variable capacitors or varactors. The symbol of the varactor diode is shown in Fig. 1.29.

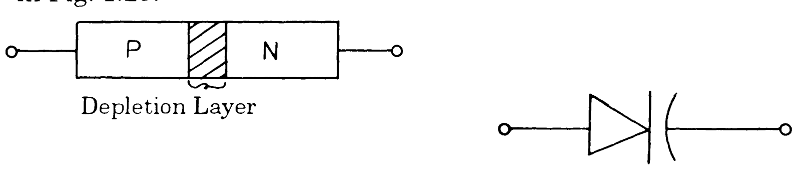


Fig. 1.29. Varactor diode.

1.16. Colour Coding for Capacitors

The values of capacitors is also given in terms of colour bands just in the same manner as in the case of resistances. This value is usually in micro micro or picofarads. The method of identifying the colour and their correspondence significance is also similar to resistance however the capacitors may have four additional bands or dots which signifies as follows :

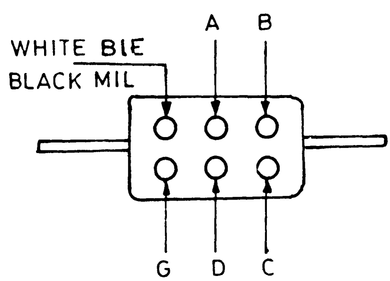
E—Third significant figure used in the same of the old type of system.

F—D.C. working voltage.

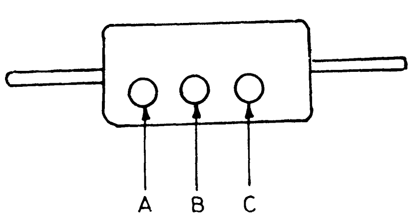
G—Classifications or operating characteristics.

H—Temperature coefficient.

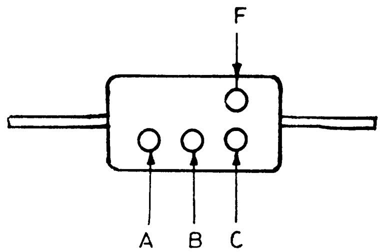
The different types of capacitors have different colour codes. Fig. 1.30 gives the scheme of colour dots on the moulded paper and moulded mica capacitors. Table 1.12 gives the corresponding colour coding informations.



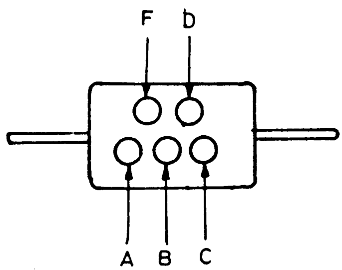
6—DOT Old Systems

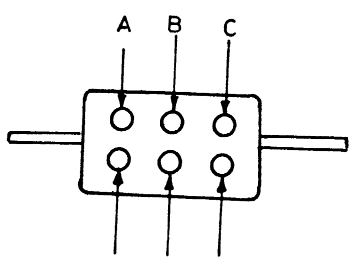


3-DOT

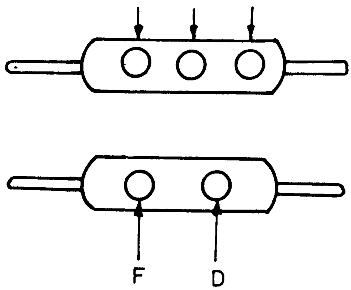


4—DOT

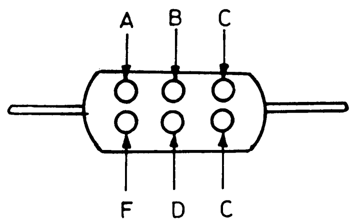




F Blank D
5—DOT



5—DOT



5—DOT

Fig. 1.30. Moulded Mica or Flat Paper Capacitors
(Present System)

Fig. 1.31 on next page gives colour scheme for ceramic capacitors and Table 1.13 gives the corresponding colour code information.

1.17. Design of Electronic Transformers

The transformers used in electronic circuits may be classified into three classes depending on their application.

(*i*) Power transformers used with power supplies.

(*ii*) Audio transformers cover the input and output transformers and isolation transformers.

(*iii*) Pulse transformers used in various types of pulse circuits.

The main difference between a transformer used in power system and electronic circuits are

(*i*) In the case of power system transformers there is no provision for d.c. to flow through windings while in case of the transformers used in electronic circuits they may be called on, for both a.c. and d.c. flowing in the windings.

Table 1.12

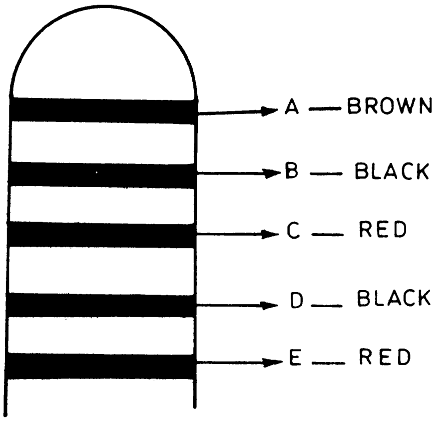
Identification of Moulded Paper and Moulded Mica Capacitors

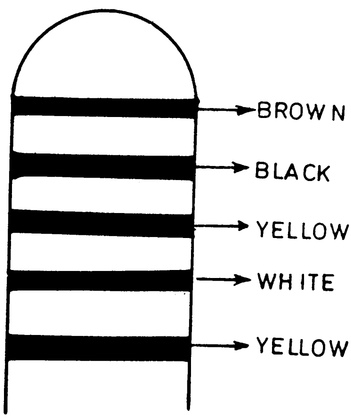
S. No.	*Colour of Bond or Dot*	*Ist. Sig. Fig. A*	*IInd Sig. Fig. B*	*C-Multiplication Factor*	*D-Tolerance*		*F-Working Voltage volts*
					Paper	*Mica*	
1.	Black	0	0	$10^0 = 1$	20	20	—
2.	Brown	1	1	$10^1 = 10$	—	—	100
3.	Red	2	2	$10^2 = 100$	—	2	200
4.	Orange	3	3	$10^3 = 1{,}000$	30	3	300
5.	Yellow	4	4	$10^4 = 10{,}000$	40	—	400
6.	Green	5	5	$10^5 = 100{,}000$	5	5	500
7.	Blue	6	6	$10^6 = 1{,}000{,}000$	—	—	600
8.	Violet	7	7	— —	—	—	700
9.	Grey	8	8	— —	—	—	800
10.	White	9	9	— —	10	—	900
11.	Gold	—	—	$10^{-1} = 0.1$	10	5	1000
12.	Silver	—	—	$10^{-2} = 0.01$	—	10	2000

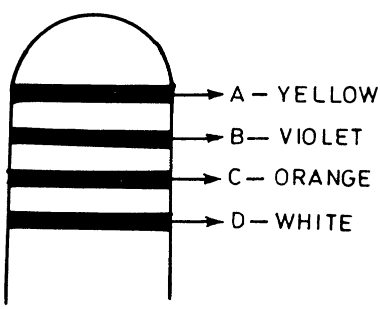
Table 1.13

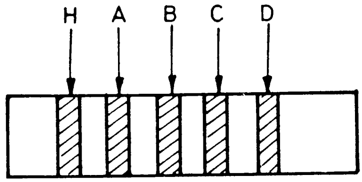
Identification of Ceramic Capacitors

S. No.	*Colour of Bonds and Dots*	*Ist. Sig. Fig. A*	*IInd Sig. Fig. B*	*C-Multiplication Factor*	*D-Tolerance*		*F-Working Voltage, Volts*
					Less than 10 P.F.	*More than 10 P.F.*	
1.	Black	0	0	$10^0 = 1$	2	20	—
2.	Brown	1	1	$10^1 = 10$	0.1	1	150
3.	Red	2	2	$10^2 = 100$	—	2	—
4.	Orange	3	3	$10^3 = 1{,}000$	—	2.5	350
5.	Yellow	4	4	$10^4 = 10{,}000$	—	—	—
6.	Green	5	5	$10^5 = 100{,}000$	0.5	5	500
7.	Blue	6	6	—	—	—	—
8.	Violet	7	7	—	—	—	—
9.	Grey	8	8	0.01	0.25	—	—
10.	White	9	9	0.1	1.0	10	—
11.	Gold	—	—	—	—	—	—
12.	Silver	—	—	—	—	—	—

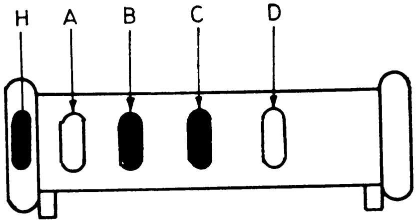

A — BROWN
B — BLACK
C — RED
D — BLACK
E — RED


BROWN
BLACK
YELLOW
WHITE
YELLOW

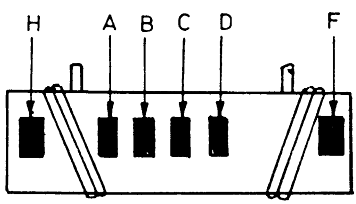

A — YELLOW
B — VIOLET
C — ORANGE
D — WHITE



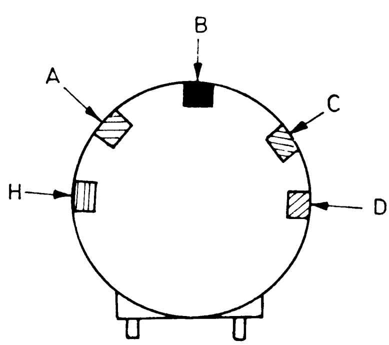
AXIAL-LEAD



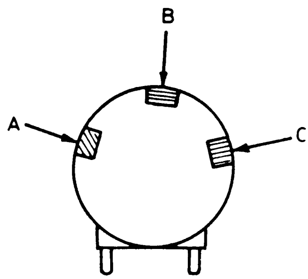
5—DOT-RADIAL



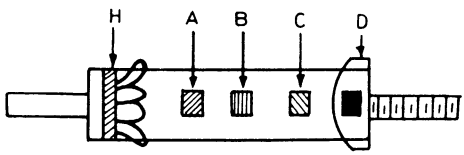
6—DOT-RADIAL



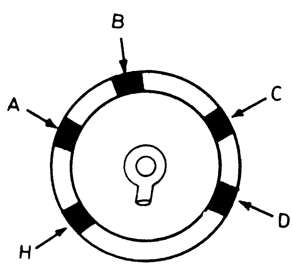
5—DOT-RISK



3—DOT-RISK



STAND OFF



BUTTON HEAD

Fig. 1.31. Ceramic Capacitors.

(*ii*) Transformers used in power system are designed for fixed power frequency with a limited deviation. But the electronic transformers are subjected to wide frequency variations.

(*iii*) The current ratings for electronic transformers range from a few micro amperes to hundreds of amperes. Thus the magnatising current in such transformers should be negligibly small.

In addition to the above factors the service, life, size and weight are the other factors worth considering for design of electronic transformers.

1.18. Characteristics of Electronic Power Transformers

(*i*) Power transformers are usually designed to operate from a source of low impedance at a single frequency.

The most popular frequencies have been 50 Hz and 400 Hz.

(*ii*) It is required to be constructed with sufficient insulation of necessary dielectric strength.

(*iii*) The transformer ratings are expressed in volt amperes. The volt amperes for each secondary windings or winding are added for the total sec. V.A. To this are added no load losses.

(*iv*) The size and weight of electronic power transformer depends on the following factors. For fixed volt ampere rating.

(*a*) The size reduces with increase in frequency, use of core materials of high stauration flux densities and low losses and increased maximum operating temperature.

(*b*) The size increases with smaller load regulation limit, increased efficiency, increased ambient temperature for fixed insulation system, longer life requirements and better environmental perfections.

(*c*) Temperature rise of a transformer is decided on two well known factors, *i.e.* the losses in the transformer and the heat dissipating or cooling facilities provided on the unit.

1.19. Characteristics of Electronic Audio Transformers

(*i*) These are designed for applications in tube and transistor circuits which may be called upon to operate in the range of 50 to 3000 Hz or even more.

(*ii*) These are designed to have good transmission characteristics at lower end of the band. This requires high turns ratio as well as high inductances which can be achieved by using small cross-section of winding wire and high permeability of the core.

(*iii*) The d.c. plates current in the winding of triode output transformers greatly reduces the effective permeability of the core and hence a large cross-section of the core is needed to achieve the required inductance.

(*iv*) The transmission characteristics at high end is limited by the series inductance and winding capacitance. In case of triode and transistors the termination load is resistive and in case of pentode it is an infinite load. So the degree of shaping possible at high end is limited in case of triode resistive load but in case of pentode it can be accomplished by adjustment of inductance and winding capacitance.

(*v*) In case of transistor—transformers because of low impedance of emitter circuits the input (Driver) transformer would be a step-down transformer. However because of high collector impedance the d.c. in the transistor circuits is appreciably low and hence the variations in the core material permeability will be ineffective.

(*vi*) Good high frequency response of the electronic audio transformer can be achieved by larger magnitude or leakage inductance and distributed capacitance. But if the size is reduced both these parameters decrease and high frequency response becomes poor.

(*vii*) The low frequency response is dependent on the shunting inductance which depends upon many factors and related by the equation (1.8)

$$L_{sh} = \frac{N^2 A_c}{l_g + \dfrac{l_e}{\mu_{ac}}} \times 4\pi \times 10^{-7} \text{ Henries} \qquad \text{...(1.8)}$$

where L_{sh} = Shunting inductance

N = Number of turns

A_c = Area of cross-section in m^2

l_g = Effective air gap length (m)

l_c = Magnetic core length (m)

μ_{ac} = Incremental permeability

Thus to have good low frequency response the airgap length should be minimum to have large shunting inductance.

1.20. Design Features of Electronic Transformers

The e.m.f. equation of a transformer is given by

$$E = 4.44 f \phi_m \cdot T_{ph}. \qquad \text{...(1.9)}$$

where f = frequency in Hz.

ϕ_m = Maximum value of mutual flux in webers

T_{ph} = Turns on the primary or sec.

If B_m is the maximum flux density in wb/m^2 and A_i is area of cross-section of the core.

Then $$E = 4.44 f B_m A_i T \qquad \text{...(1.10)}$$

The volt-ampere rating

$$EI = 4.44\, f B_m A_i . I . T. \qquad ...(1.11)$$

Also if δ is current density and a is the cross-section of the conductor. Then

$$EI = 4.44\, f B_m A_i\, \delta\, a\, .\, T \qquad ...(1.12)$$

If K_w is the window space factor *i.e.*, the ratio of area occupied by the copper to the area of window.

Then $$aT = K_w . A_w \qquad ...(1.13)$$

where A_w is the area of window in sq m.

$$\therefore \quad EI = 4.44\, f B_m A_i\, .\, \delta\, .\, K_w\, .\, A_w \qquad ...(1.14)$$

Therefore, voltampere rating

$$EI = 4.44\, K_w A_i\, .\, A_w f\, .\, \delta\, .\, B_m.$$

In order to obtain maximum voltamperes it is desirable to use the largest possible window and core space factor, flux density and current density.

The maximum utilization of window space requires that the insulation cross-section should be minimised. The maximum utilization of iron cross-section is obtained by the choice of an optimum core material.

There may be two flux densities in an electronic transformer. One, due to flow of unbalanced d.c. is given by

$$B_{dc} = \frac{\mu_0 N\, .\, I_{dc}}{l_g + \dfrac{l_c}{\mu_{dc}}}\ \text{Wb/m}^2 \qquad ...(1.15)$$

where B_{dc} = d.c. flux density wb/m^2

I_d = unbalanced d.c. in amp.

μ_{dc} = d.c. permeability of the material.

Under signal conditions the density is increased by the a.c. flux swing which is given by

$$B_{ac} = \frac{E}{4.44 \times f\, .\, A_i\, .\, T}\ \text{wb/m}^3 \qquad ...(1.16)$$

The maximum allowable flux density is the sum of these two flux densities ($B_{dc} + B_{ac}$) and is limited by the associated core losses and exciting current because both contribute to increased heating. The maximum flux density is chosen on the basis of the copper losses at low frequency and iron losses at high frequencies and minimum of these two be considered.

Current Density

The maximum allowable current density is limited by the associated resistance and copper losses. It is normally desirable to limit it by the resistance so that it would result in a no load to full load regulation not to exceed by 15 per cent. In addition, the resistance is limited by the copper losses. The copper losses are limited by the temperature rise.

1.21. The Informations Required by Designer

The following informations must be available to the designer before he commences for the design of a transformer :

(*i*) Power output.

(*ii*) Operating voltage.

(*iii*) Frequency range.

(*iv*) Permissible operating temperature and temperature rise.

(*v*) Space constraints, if any.

(*vi*) Efficiency and regulation.

(*vii*) Life expectancy.

(*viii*) Maximum working voltage to ground for each winding.

1.21.1. Size of Core

Size of core is one of the first consideration in regard of weight and volume of the transformer. This depends on the type of core and winding configuration to be used. Assuming the space factor, current and flux densities to be optimum, the size of the transformer is determined by the required area product, *i.e.* $(A_w \cdot A_i)$. The problem then is to determine the core configuration and dimensions to furnish the required area product and at the same time over the best practical combination of minimum weight and volume. Generally two formulae are used to find the area,

$$A_i = \sqrt{\frac{W_p}{0.87}} \qquad \text{...(1.17)}$$

or

$$A_i = \sqrt{\frac{W_p}{0.97}} \qquad \text{...(1.18)}$$

where A_i, is the area of cross-section in sq. cm.

and W_p, is the primary wattage.

Generally 10% of the area should be added to the core to accommodate all the turns for *low iron losses and compact size the equation (1.18) is preferred.*

1.21.2. Turns per Volt

The turns per volt of transformer are given by the relation

$$\text{Turns/volts} = \frac{10{,}000}{4.44\, f B_m A_i} \qquad ...(1.19)$$

Here f is the frequency in Hz.

B_m is flux density in Wb/m^2

A_i is nett area of cross-section in cm^2.

Table 1.14 gives the value of turns per volt for 50 H frequency.

Table 1.14

Flux density Wb/m^2	1.14	1.01	0.91	0.83	0.76
Turns per volt	$\frac{40}{A_i}$	$\frac{45}{A_i}$	$\frac{50}{A_i}$	$\frac{55}{A_i}$	$\frac{60}{A_i}$

Generally, the lower the flux density better will be quality of transformer.

Hence, we can calculate the turns for primary, and the different secondary windings of the transformer.

1.21.3. Wire Size

As stated above the wire size is dependent upon the current to be carried out by the winding which depends upon the current density. The current density can be selected on the basis of the cooling facilities available. For small transformers one can safely use current density of 3.1 Amp/mm^2 (Nearly 2000 A/in^2). For less copper loss 1.6 Amp/mm^2 (1000 A/in^2) or 2.4 Amp/mm^2 (1500 A/in^2) may be used. Generally even size gauges of wires are used. Enamel wire is ordinarily used but biculex or paramex is better. The area of cross-section of core is generally given in circular mils. A circular mil is defined as the square of the diameter of the conductor expressed in mils (*i.e* one thousandth of an inch) and differs the area of the cross-section in square inches by a factor of $\pi/4$. As an example, if dia. of the conductor is 1 in when expressed in mils it becomes 1000 mils and its area in circular mils is 10^6. Accordingly the area in square inch $= \frac{\pi}{4} 10^{-6}$ circular mils.

After finding the area of cross-section of the conductor in circular mils from the table 1.15 the S.W.G. of the enamel copper conductor can be found.

1.21.4. Dimensions of Core

As the number of turns and the wire size for each winding have been found out.

Now from Table 1.16 the number of turns per square cm of window area are found for each type of wire. Thus the space of window occupied by each winding can be calculated. Due consideration should be given to the window space factor which is given by the relation

$$K_w = 0.08 \log 10\,(VA) + K' \qquad ...(1.20)$$

where K_w is window space factor

VA is the volt ampere rating of the sec.

K' depends on number of windings on the core and the peak working voltage. But it is constant below one kilo volt and changes as shown in Table 1.15 with number of windings.

Table 1.15

Number of winding	2	3	4	5	7	10
K'	0.15	0.12	0.10	0.08	0.06	0.04

Window space factor,

$$K_w = \frac{\text{Area of copper in the windings}}{\text{Window area}} \qquad ...(1.21)$$

Thus, assuming iron space factor to be 0.9, *i.e.* effective area of iron

$$A_i = 0.9 \times \text{Area of stack} \qquad ...(1.22)$$

After determining the area of the window, the proper size of stampings which suits the window area may be selected. From the Table 1.17 of the dimensions of the stampings and the other dimensions of the core stack may be found out.

By knowing the width of the core the thickness of stampings stack may be calculated from area of iron (A_i). Generally square cross-section of the core is preferred.

Knowing the dimension of the core the length of mean turn of the winding wire can be calculated. Thus the length of the wire required for each winding may be known. By knowing the resistance per metre of the wire (Table 1.16) the resistance of each winding may be calculated, which may further be used to know the copper losses and regulations.

Table 1.16

SWG No.	*Diameter*		*Area of cross-section*		*Turns per unit area of enamel wire*		*Resistance per metre in ohms*		*Meter per kg*		*Turns per Linear cm enamel*	*Current carrying capacity of the wire under current density*		
	mm	*mils*	*mm^2*	*Circular miles*	*cm^2*	*in^2*	*Cu wire*	*Aluminium wire*	*Cu wire*	*Aluminium wire*		*$310/cm^2$ ($2000/in^2$)*	*$240/cm^2$ ($1500/in^2$)*	*$160/cm^2$ ($1000/in^2$)*
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
10	3.2512	128	8.3019	16384	9	58	0.00162	0.00344	14.1	46.5	2.76	12.8	19.9	25.6
11	2.9464	116	6.4183	13456	11	69	0.00210	0.00452	17.2	56.8	3.07	10.1	15.15	20.2
12	2.6416	104	5.4805	10816	13	86	0.00256	0.00523	21.4	70.5	3.42	8.5	12.75	17.0
13	2.3368	92	4.2888	8464	16	108	0.00330	0.00667	27.3	90.5	3.7	6.7	10.05	13.4
14	2.0320	80	3.2429	6400	21	141	0.0044	0.0087	36.0	118.8	4.33	5.0	7.5	10.0
15	1.8288	72	2.6268	5184	27	175	0.0054	0.0092	44.5	146	4.82	4.1	6.15	8.2
16	1.6256	64	2.0755	4096	34	219	0.00685	0.0137	54.5	180	5.5	3.2	4.8	6.4
17	1.4224	56	1.5890	3136	44	285	0.00885	0.0181	73.5	243	6.3	2.5	3.75	5.0
18	1.2192	48	1.1675	2304	52	388	0.0122	0.0246	100.0	330	7.48	1.8	2.7	3.6
19	1.0160	40	0.8107	1600	85	550	0.0174	0.0353	144.0	475	8.66	1.26	1.89	2.52
20	0.9144	36	0.6567	1296	109	676	0.0216	0.0445	178.0	586	9.85	1.02	1.53	2.04
21	0.8128	32	0.5189	1024	131	852	0.0273	0.0552	227.0	750	11.0	0.80	1.2	1.9
22	0.7112	28	0.3973	784	168	1089	0.0356	0.0700	296.0	975	13.35	0.62	0.93	1.24
23	0.6096	24	0.9219	576	224	1513	0.0485	0.0980	400.0	1320	14.20	0.45	0.675	0.90
24	0.5088	22	0.2453	484	276	1789	5.0571	0.1165	480.0	1585	15.30	0.38	0.57	0.76
25	0.5080	20	0.2027	400	320	2070	0.0700	0.1410	577.0	1900	16.91	0.314	0.471	0.628

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
26	0.4572	18	0.16417	324	410	2650	0.0862	0.1745	715	2360	18.90	0.254	0.381	0.508
27	0.4166	16.4	0.13628	269	522	3390	0.104	0.2100	860	2835	20.80	0.212	0.318	0.424
28	0.3759	14.4	0.11099	219	602	3900	128	0.2600	1120	3696	22.80	1.72	0.258	0.344
29	0.3454	13.8	0.09372	185	702	4550	0.151	0.3070	1250	4125	24.80	0.145	0.2175	0.290
30	0.3150	12.4	0.67791	154	854	5550	0.183	0.3670	1510	4980	26.80	0.121	0.1815	0.242
31	0.2946	11.3	0.00818	135	975	6300	0.208	0.4200	1720	00050	28.80	0.106	0.154	0.212
32	0.2743	10.8	0.05910	117	1142	7300	0.240	0.4850	1990	67970	30.15	0.092	0.138	0.184
33	0.2540	10.0	0.05067	100	1300	8400	0.280	0.5650	2230	57350	33.40	0.079	0.1185	0.158
34	0.2337	9.2	0.04289	85	1545	10000	0.330	0.6680	2730	9100	36.60	0.067	0.1005	0.134
35	0.2134	8.4	0.03575	71	1852	12000	0.396	0.8000	3262	10780	39.70	0.056	0.0840	0.112
36	0.1930	7.6	0.02927	58	2220	14500	0.485	0.975	4000	13200	43.3	0.045	0.0675	0.090
37	0.1727	6.8	0.02343	46	2870	18200	0.605	1.22	5000	16500	48	0.036	0.540	0.072
38	0.1524	6.0	0.618241	36	3540	22900	0.775	1.57	6425	21200	53	0.028	0.042	0.056
39	0.1321	5.2	0.013701	27	2725	30600	1.103	2.04	8550	28200	62.5	0.021	0.0315	0.042
40	0.1219	4.8	0.011675	23	5500	35600	1.250	2.48	10000	33000	66.5	0.018	0.027	0.036
41	0.1117	4.4	0.009750	19.2	6650	43000	1.440	2.96	12000	39600	73.2	0.0152	0.0228	0.0304
42	0.1010	4.0	0.008107	16	7880	51000	1.742	3.56	14450	47700	79	0.0126	0.0189	0.0252
43	0.09144	3.6	0.00657	12.96	10000	65000	2.160	4.32	15780	52000	86.5	0.0102	0.0153	0.0204
44	0.08128	3.2	0.005189	10.24	12500	81000	2.722	5.55	22600	74500	96.5	0.008	0012	0.016
45	0.07112	2.8	0.003973	7.84	16080	104000	3.560	7.25	29600	97000	117	0.062	0.0093	0.0124
46	0.06096	2.4	0.002919	5.76	21880	142096	4.9	9.85	40250	133000	128	0.0045	0.0067	0.0090
47	0.05080	2.0	0.002027	4.00	30200	197000	7.02	14.2	57300	189000	157	0.0030	0.0045	0.0060

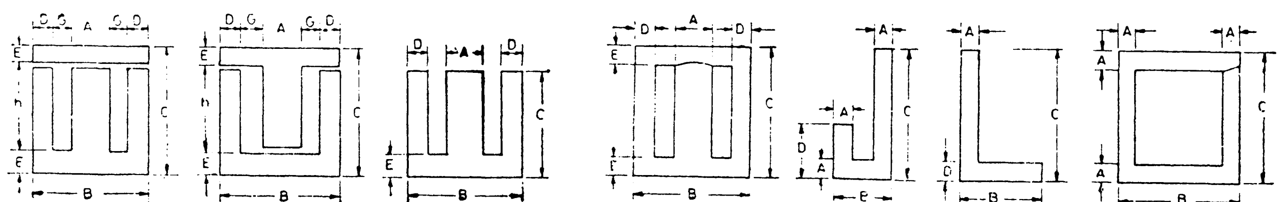
Table 1.17. Transformers and Choke Laminations
STANDARD TYPES*

Type No. Reference to Figure		*A*	*B*	*C*	*D*	*E*	*G*	*H*	*Window Area G × H* in^2	*Window Area G × H* mm^2	*Remarks*
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
17	1	1/2"	3/2"	5'4"	1/4"	1/4"	1/4"	3/4"	3/16		
12A	1	5/8"	15/8"	23/6"	5/16"	1/16"	5/16"	15/16"	75/256		18.9
12B	3	5/8"	15/8"	35/16"	5/16"	5/16"	5/16"	25/16"	125/256		31.5
12C	3	5/8"	$1\frac{1}{8}$	2"	5/16"	5/16"	5/16"	22/16"	110/256		27.7
21	1	5/8"	2"	17/8"	5/16"	3/8"	11/8"	11/8"	33/64		33.2
10	1	5/8"	$2\frac{3}{8}$"	17/8"	3/8"	3/8"	1/2"	11/8"	11/16	442	
10A	1	5/8"	$2\frac{3}{8}$"	$2\frac{1}{8}$	3/5"	3/8"	1/2"	11/8"	11/16	442	
1	1	21/32"	1(17/32")	$2\frac{1}{4}$	5/16"	8/10"	5/8"	1—5/8	65/64	655	4 bolts holes 1/8" dia
74	1	11/16	2(1/16")	1(23/32)	11/32"	11/32"	11/32'	33/32'	364/1024"	227	
23	1	3/4"	$2\frac{1}{4}$	$1\frac{7}{8}$	3/8"	3/8"	3/8"	9/8"	27/64	272	
11	1	3/4"	3"	$2\frac{1}{4}$	3/8"	3/8"	3/4"	3/2"	9/8"	726	
11A	1	3/4"	3"	21/8"	3/8"	3/8"	3/4"	15/8"	75/32	1510	
2	1	3/4"	3"	3"	3/8"	3/8"	3/4"	$2\frac{1}{4}$	27/16	1090	
30	1	20 mm	60 mm	50 mm	10 mm	10 mm	10 mm	30 mm	—	300 mm^2	
31	1	7/8"	2(5/8)	2(3/16)	7/16"	7/16"	7/16"	21/16"	147/256	370	4 bolts holes 5/32" dia
45	1	7/8"	2(5/8)	2(3/16)	7/16"	7/16"	7/16"	21/16"	147/256	370	4 bolts holes 0.156" dia

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
15	1	1"	3"	3/2"	1/2"	1/2"	1/2"	$1\frac{1}{2}''$	3/4	484	4 bolts holes 7/32" dia.
44	1	1"	3"	$2\frac{1}{2}''$	1/2"	1/2"	1/2"	$1\frac{1}{2}''$	3/4	484	4bolts holes 7/32" dia. 20
14	1	1"	3(5/16)"	$2\frac{5}{8}''$	17/32"	1/2"	5/8"	$1\frac{5}{8}$	65/65	655	notches 1/4" × 1/4"
4	1	1"	3(13/16")	3(13/16")	17/32"	1/2"	7/8"	2(13/16")	315/128	1580	4 bolts holes 7/32° dia. 4 bolts holes 7/32" dia.
33	1	28 mm	84 mm	70 mm	14 mm	14 mm	14 mm	56 mm	—	784	4 bolts holes 11/64" dia.
3	1	$1\frac{1}{4}''$	$3\frac{3}{4}''$	$3\frac{1}{8}''$	5/8"	5/8"	5/8"	$1\frac{7}{8}$	75/64	755	4 bolts holes 1/4° dia.
13	1	$1\frac{1}{4}''$	4"	$3\frac{1}{2}''$	1/2"	1/2"	7/8"	$2\frac{1}{2}''$	35/16	1410	4 bolts holes 7/32" dia.
4A	1	1(5/16")	$4\frac{1}{8}''$	3(7/16")	21/32"	21/32"	3/4"	$2\frac{1}{2}''$	51/32	1030	4 bolts holes 3/16" dia.
15	1	$1\frac{1}{2}''$	$4\frac{1}{2}''$	$3\frac{3}{4}''$	3/4"	3/4"	3/4"	$2\frac{1}{8}''$	27/16	1090	4 bolts holes 7/32" dia.
76	1	$1\frac{1}{2}''$	$4\frac{3}{4}''$	$4\frac{3}{4}''$	3/4"	3/4"	7/8"	$2\frac{1}{4}''$	63/32	1270	4 bolts holes 7/32" dia.
6	1	$1\frac{1}{2}$	5"	$4\frac{1}{2}''$	3/4"	3/4"	1"	3"	3	1940	4 bolts holes 9/32" dia.
7	1	2"	6"	5"	1"	1"	1"	2(1/16)	37/16	1492	4 bolts holes 17/64" dia.
43	1	2"	6"	5"	1"	1"	1"	3"	3"	1940	4 bollts holes 17/64" dia.
8	1	2"	$7\frac{1}{4}''$	$6\frac{3}{4}''$	1"	1"	$1\frac{5}{8}''$	$4\frac{3}{4}''$	247/32	4950	4 bolts holes 3/8 dia.
34	2	5/8"	$3\frac{1}{8}''$	$2\frac{1}{2}''$	1/2"	1/2"	3/4"	$1\frac{1}{2}''$	9/8	726	4 bolts holes 5/32" dia.
9	2	7/8"	$3\frac{1}{4}''$	$2\frac{1}{2}''$	7/16"	5/16"	3/4"	$1\frac{5}{8}''$	39/3"	785	4 bolts holes 7/32" dia.
9A	2	7/8"	$3\frac{1}{4}''$	$2\frac{1}{2}''$	7/16"	7/16"	3/4"	$1\frac{3}{8}''$	39/32	785	4 bolts holes 5/32" dia.
4A"	2	15/16"	3(9/16")	3(3/16")	7/16"	7/16"	7/8"	2(5/16")	259/128	1310	4 bolts holes 5/32" dia.
75	2	1"	4"	$3\frac{3}{8}''$	1/2"	1/2"	1"	$2\frac{3}{8}''$	19/8	1533	2 bolts holes 1/4" dia.
35A	2	$1\frac{1}{2}''$	$6\frac{1}{4}''$	$5\frac{1}{4}''$	3/4"	3/4"	4(5/2)	$3\frac{3}{4}''$	195/32	3930	4 bolts holes 5/32" dia. {used as a pair}

1	2	3	4	5	6	7	8	9	10	11	12
32	3	1/4"	1"	1/2"	1/8"	1/8"					7 bolts holes 3/32" dia. 4 bolts holes 3/32" dia.
	3	1/4"	1"	1/4"	1/8"	1/8"					1 bolts holes 3/32" dia.
41	3	0.79	3.090"	1.313	0.475"	0.475"					
	3	0.79	3.090"	0.585"	0.485"	0.475"					
20	3	5/8"	$2\frac{1}{8}$"	$1\frac{5}{8}$"	3/8"	3/8"					
22A	4	5/8"	$1\frac{7}{8}$"	2(7/16")	1"/64	3/8"					2 bolts holes 5/32" dia.
28	5	1/2"	3/2"	$2\frac{1}{8}$"	$1\frac{5}{8}$						
29	6	17/32"	0.974"	3(5/16")	1/2"						
38	6	0.593"	1.0625"	3.875"	0.593"						
36	6	5/8"	1(3/7")	$3\frac{1}{2}$"	5/8"						
37	6	5/8"	1(15/16")	$2\frac{7}{8}$"	5/8"						4 bolts holes 7/32" dia.
25	6	11/16"	2"	$3\frac{1}{2}$	16/16"						
26	6	11/16"	1—5/16"	45/16"	11/16"						2 bolts holes 7/32" dia.
24	7	1"	4"	4"							may be used as a pair.

(By courtesy of Guest-Keen, Williams, Limited)



Example 1.13. *A mains transformer is required to provide the following a.c. outputs : 6 A at 6.3 V for valve heaters. 2 A at 5 V for rectifier heaters. 100 mA at 500 V for full wave H.T. rectifiers. The mains voltage is 220 V and it is proposed to use primary winding of 2000 turns.*

(*a*) *How many secondary windings will be required. Calculate the number of turns on each.*

(*b*) *What power will the primary take mains neglecting transformer losses.*

Solution.

There will be secondary windings.

(*a*) For supplying 6.3 V.

The number of turns $= \frac{6.3}{220} \times 2000 = 50$ turns.

VA rating of this winding $= 6.3 \times 6 = 37.8$ VA.

(*b*) For supplying 5 V

The number of turns $= \frac{5}{220} \times 200 = 46$ Turns

VA rating of this winding $= 5 \times 2 = 10$ VA

(*c*) Centre tapped 500—0—500 winding.

With total number of turns

$$= \frac{2 \times 500}{220} \times 2000 = 2 \times 4545 \text{ turns.}$$

VA rating of this winding $= 100 \times 500 \times 10^{-3} = 50$ VA

Total VA to be supplied by primary $= 50 + 10 + 37.8$

$= 97.8 \text{ VA} \simeq 100 \text{ VA}$

Thus the primary current rating $= \frac{100}{220} = 455$ mA.

Example 1.14. *Design a power transformer to operate at 220 V, 50 Hz Ac. with the following requirements.*

(*a*) *6.3 V at 2.5 A* (*b*) *12 V at 1 A* (*c*) *500—0—500 at 150 mA.*

Solution.

There will be three secondary windings.

(*a*) For supplying 6.3 V at 2.5 A.

The VA rating of this winding $= 6.3 \times 2.5 = 15.75$ VA.

(*b*) For supplying 12 V at 1 amp, VA rating of the winding will be $= 12 \times 1 = 12$ VA.

(*c*) For supplying 500 V at 150 mA, the VA rating of the windings will be $= 500 \times 150 \times 10^{-3} = 75$ VA.

Thus total VA of primary winding will be

$$15.75 + 12.00 + 75.00 = 102.75 \text{ VA}$$

Allowing 10% for losses the transformer may be designed for 110 VA.

Assuming 0.9 p.f. the primary wattage of the transformer will be 100 W approximately.

Thus, Area of cross-section in cm. by Eq. (1.17) is

$$A_i = \sqrt{\frac{Wp}{0.87}} = \sqrt{\frac{100}{0.87}} = 11.5 \text{ cm}^2$$

Adding 10% more to accommodate the turns nicely

$$A = 12.5 \text{ cm}^2$$

For 50 Hz the turns per volt for 0.83 Wb/m^2 flux density from Table 1.14.

$$\text{Turns per volt} = \frac{55}{A_i} = \frac{55}{12.5} = 4.75$$

No. of turns for primary winding

$$= 4.75 \times 220 = 1050$$

No. of turns for 6.3 V winding

$$= 4.75 \times 6.3 = 30$$

No. of turns for 12 V winding

$$= 4.75 \times 12 = 57$$

No. of turns for 500 V—0—500 winding

$$= 2 \times 4.75 \times 500 = 2 \times 2375$$

Wire size using current density of 1.6 Amp/mm^2 or 1000 A/inch^2.

The area of cross-section for primary winding

$$= \frac{110}{220} \times \frac{1}{1.6} \text{ mm}^2 = 0.512 \text{ mm}^2$$

Area of cross-section for 6.3 V winding

$$= \frac{2.5}{1.6} \text{ mm}^2 = 1.56 \text{ mm}^2$$

Area of cross-section for 5 V winding

$$= \frac{1}{1.6} = 0.625 \text{ mm}^2$$

Area of cross-section for 500—0—500 winding

$$= \frac{150 \times 10^{-3}}{1.6 \times 0} = 0.09375 \text{ mm}^2$$

Using S.W.G. table the wire sizes are modified as :

Calculated wire size mm^2		*SWG*	*Actual wire size*	*Turns /per* cm^2	*Area occupied by different windings*
Primary winding	0.312	22	0.3973 mm^2	168	$\frac{1050}{168} = 6.25\ cm^2$
6.3 V winding	1.56	17	1.5890 mm^2	44	$\frac{30}{44} = 0.75\ cm^2$
5 V winding	0.625	20	0.6567 mm^2	109	$\frac{57}{109} = 0.52\ cm^2$
500—0—500 winding	0.09375	28	0.11099 mm^2	602	$\frac{2 \times 2375}{602} \simeq 7.2\ cm^2$

The total area occupied by the windings = 15.32 cm^2

Considering winding space factor to be equal to 0.6

The actual area occupied by the winding will be

$$= \frac{15.32}{0.6} \approx 25.6\ cm^2$$

Consulting Table 1.17, the stamping No. 3 Sanky type having window area 30.25 cm^2 will be suitable. The space left will be filled up by insulation and packings. The dimensions of the stamping are as follow :

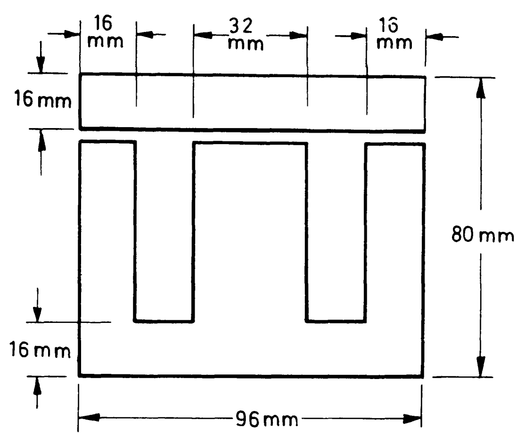


Fig. 1.32

Since iron area = 12.5 cm^2

The thickness of the core stack will be $\frac{12.5}{3.18}$ = 4 cm nearly.

Example 1.15. *Design a power transformer of the following specifications,—primary 220 V; secondary 3000—0—300 V at 80 mA, 6.3 V at amps. and 5 V at 2 amps.*

Solution.

1. The voltage of the secondary side

Power delivered by $S_1 = 300 \times 80 \times 10^{-3} = 24$ VA

by $S_2 = 6.3 \times 3 = 18.9$ VA

by $S_3 = 5 \times 2 = 10$ V

Total = 52.9 VA ≈ 53 VA

Assuming 80% efficiency and unity power factor. The actual VI input = 53/10.8 = 66.25 volt-amperes.

Thus primary current = 66.25/220 = 0.3 Amp.

2. The core area

By Eq. (1.17), $A_i = \sqrt{\frac{Wp}{0.87}} = \sqrt{\frac{66.25}{0.87}}$ = 9.87 sq cm^2

Adding 10% more to accommodate the turns nicely.

A_i = 10 sq cm.

3. Turns per volt

For 50 Hz the turns per volt for 0.91 Wb/m^2 from Table 1.14

Turns per volt $= \frac{50}{A_i} = \frac{50}{10}$ = 5 turns per volt.

Thus for primary winding $= 220 \times 5 = 1100$

Thus for S_1 winding $= 300 \times 5 = 1500$

Thus for S_2 winding $= 6.4 \times 5 = 32 \approx 35$

Thus for S_3 winding $= 5 \times 5 = 25 \approx 28$

Slightly more number of turns are recommended for S_2 and S_3, so at to give correct voltage at load.

Wire size

From Table 1.16 for 2.4 Amp/mm^2 current density the area of cross-section of the wires for four different windings will be as follows :

Winding	*Current*	*Area*	*SWG*	*Turns per sq. cm*	*Area occupied by different winding*
Primary	0.3 A	$\frac{0.3}{2.4} = 0.125\ mm^2$	28	602	$\frac{110}{602} = 1.831$ sq cm
S_1 (30 V)	80 mA	$\frac{80 \times 13^{-3}}{2.4} = 0.0033\ mm^2$	36	2220	$\frac{1500}{2220} = 0.672$ sq cm
S_2 (6.3 V)	3 A	$\frac{3}{2.4} = 1.25\ mm^2$	18	52	$\frac{35}{52} = 0.673$ sq cm
S_3 (5 V)	2 A	$\frac{2}{2.4} = 0.8333\ mm^2$	20	109	$\frac{28}{109} = 0.257$ sq cm

Total area required = 3.433 sq cm

Considering window space factor as 0.5

The actual area occupied by the windings will be

$$= \frac{3.433}{0.5} = 6.866 \text{ sq cm}$$

Thus consulting Table 1.17, No. 34 Sanky standard stamping having window area 726 sq mm will be suitable whose dimensions are given as follows :

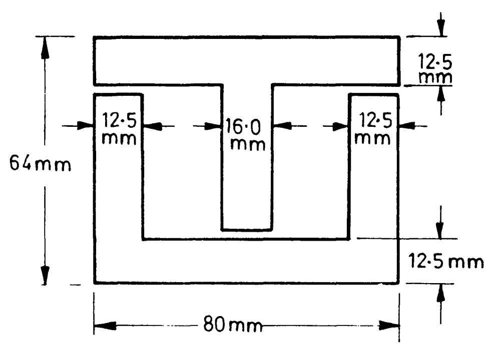


Fig. 1.33

The thickness of the core stack will be

$$= \frac{A_i}{\text{Width of core limb}} = \frac{10}{1.6} = 6.29 \text{ cm.}$$

1.22. Audio Transformers

Audio transformers find use either as the input transformers between source and an amplifier or as a coupling transformer to couple the output of one stage with the input of the next stage. In both the cases the impedance or the primary winding of the transformer should be equal to the output impedance of the device to which the primary winding is connected. The impedance of the secondary winding should be, similarly equal to the input impedance of the device to which the transformer is supplying power. This condition is called the *matching*. The matching is achieved by adjusting the turns ratio of the primary to the secondary winding.

The power transfer from input to the output is at very high efficiency.

Hence $$v_1 i_1 = v_2 i_2 \quad \text{...(1.23)}$$

v_1 and v_2 are primary and secondary voltages.

i_1 and i_2 are primary and secondary current rating.

But $$v_2 = \frac{N_2}{N_1} v_1 \quad \text{...(1.24)}$$

and $$i_2 = \frac{N_1}{N_2} i_1 \quad \text{...(1.25)}$$

But input resistance $$R_i = \frac{v_1}{i_1} = \left(\frac{N_1}{N_2}\right)^2 \frac{v_2}{i_2} \quad \text{...(1.26)}$$

$$R_i = \left(\frac{N_1}{N_2}\right)^2 R_2 \quad \text{...(1.27)}$$

Thus the impedance ratio R_1/R_2 will be function of the turns ratio $\left(\frac{N_1}{N_2}\right)$ and varies as the square of the turns ratio.

An exact impedance match is not required if one is prepared to accept a small power loss. If the impedances R_1 and R_2 are unequal by as much as a factor of 3, the power loss is only about 25% or 1 db. A 6 : 1 mismatch reduces the power output to only one half of the maximum.

1.23. Equivalent Circuit of an Audio Transformers

A transformer may be represented as an ideal transformer T in conjunction with the analog parameters to represent the various effects as shown in Fig. 1.34.

A finite inductance L_p, represents the inductance of the primary winding. The secondary winding will have a different value of inductance L_s. Because the inductance of an iron core winding is proportional to the square of the turns, the inductances are related by

$$L_s = \left(\frac{N_2}{N_1}\right)^2 L_p \qquad ...(1.28)$$

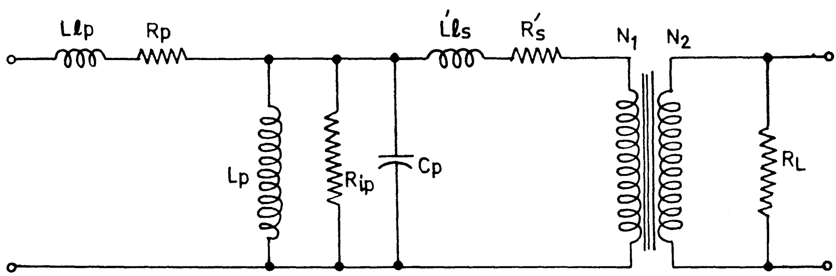


Fig. 1.34. Equivalent circuit of an audio transformer.

The reactance looking into the primary winding is ωL_p. The reactance, ωL_s is the reactance seen looking back into the secondary winding. Thus the inductance of the transformer can be represented either ωL_p on the primary side or ωL_s on the secondary side.

C_p is the equivalent shunt capacitance of the primary and secondary windings.

L_{lp} and L_{ls} are the primary and secondary leakage inductances. When L_{ls} is transformed to the primary side its value becomes equal to

$$L'_{ls} = \left(\frac{N_1}{N_2}\right)^2 L_{ls} \qquad ...(1.29)$$

R_p and R_s are the primary and secondary winding resistance and when R_s is transformed to the primary side its value becomes equal to

$$R'_s = \left(\frac{N_1}{N_2}\right)^2 R_s \qquad ...(1.30)$$

Rl_p represents the resistance to take into account the core losses in the transformer and it is represented by a shunt resistance.

1.23.1. Low frequency effect

At low frequency only L_p predominates being connected in shunt. If the reactance of L_p is equal to the source resistance R_G, *i.e.*

$$X_L = R_G \qquad ...(1.31)$$

or $$2\pi f_c \,.\, L_p = R_G$$

or $$f_c = \frac{R_G}{2\pi L_p} \qquad ...(1.32)$$

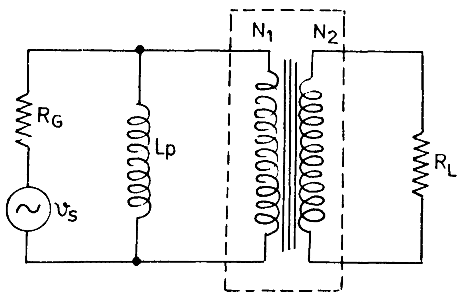


Fig. 1.35. Equivalent circuit at low frequency.

where, f_c is the cut-off frequency, but this condition is valid only when the input resistance of the transformer is infinite, *i.e.* the load impedance is infinite or R_L is open circuited.

However, if there is certain amount of load connected across the secondary terminals, then the input resistance as seen from the primary terminals of a transformer, R_{in}, and if the load is matched, *i.e.* $R_{in} = R_G$.

Then the cut off frequency will be given by

$$X_L = R_{in} \parallel R_G$$

$$f_c = \frac{R_{in} \parallel R_G}{2\pi L_p} \qquad ...(1.33)$$

which is just half of the value as given by equation (1.32).

Thus low frequency cut-off of a transformer depends on both the generator and the load impedance. Hence it is generally specified for a particular load impedance termination.

1.23.2. High frequency response

The shunt inductance and capacitances will have an open circuit effect at high frequencies. Thus they will have a negligible effect as shown in Fig. 1.36.

The high frequency cut-off f_h is approximately the frequency at which the series leakage reactance equals to the total series resistance seen by the primary signal. Thus,

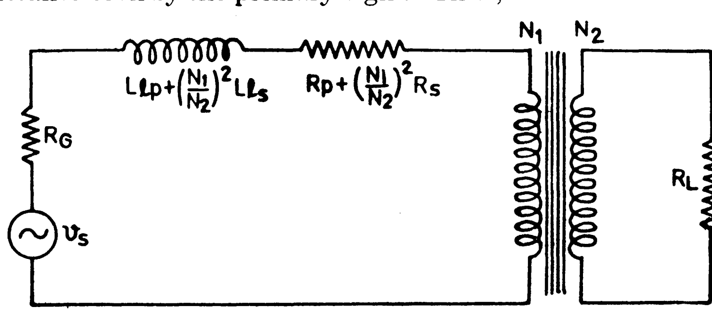


Fig. 1.36. Equivalent circuit at high frequency.

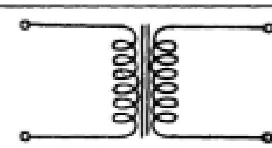
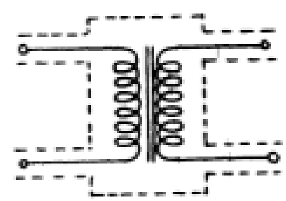
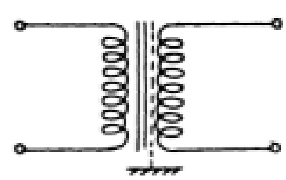
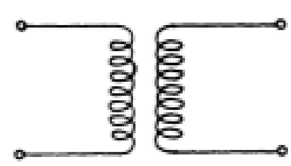
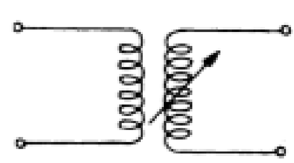
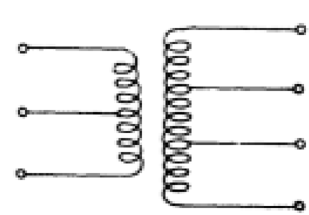
$$R_G + R_{in} = 2\pi(L_{ip} + L'_{is})f_h \qquad ...(1.34)$$

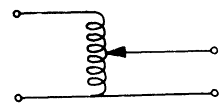
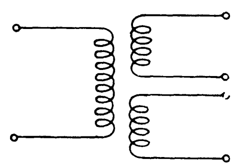
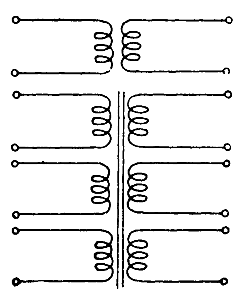
or

$$f_h = \frac{R_a + R_{in}}{2\pi(L_{lp} + L'_{ls})} \qquad ...(1.35)$$

At audio frequencies the winding resistance of a medium size (1 W) transformer will be about 5 per cent of the nominal impedance. Small transformers (0.1 W) have nominal impedances of about 5 times the d.c. resistance. Small transformers are generally designed for speech frequencies (200 to 3000 Hz) and upward.

Table 1.18. Transformer Symbols

S. No.	*Type*	*Symbol*
1.	Transformer with magnetic core	
2.	Shielded transformer with magnetic core	
3.	Magnetic core with a shield between windings	
4.	Air cored transformers	
5.	One winding transform with adjustable inductance	
6.	Transformer with tappings	

S. No.	*Type*	*Symbol*
7.	Auto-transformer	
8.	Single phase three winding transformers	
9.	Three phase with 1 phase two winding transformer	

1.24. Design of Inductors

Whenever there is change in the flux linkage across a coil an e.m.f. is induced. This induced e.m.f. is proportional to the rate of change of current in the coil *i.e.*

$$\text{Induced e.m.f.} = -L\frac{di}{dt} \quad \text{where } i \text{ is the current} \qquad ...(1.36)$$

The constant of proportionality, L, is known as the inductance of the coil.

The inductance depends on the physical characteristics of the conductor. The induced e.m.f. is also given by the rate of change of flux linkage, *i.e.*

$$\text{Induced e.m.f.} = N\frac{d\phi}{dt} \quad \text{where } \phi \text{ is the flux} \qquad ...(1.37)$$

From equations (1.36) and (1.37),

$$L\frac{di}{dt} = N\frac{d\phi}{dt} \quad i.e.\ L = N\frac{d\phi}{dt} \qquad ...(1.38)$$

But ϕ is given by the flux density β and area of cross-section of the coil as shown in Fig. 1.37.

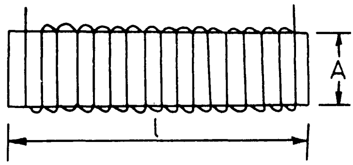


Fig. 1.37. Coil Dimensions used in Inductance Formula.

i.e. $$\phi = \beta A \qquad ...(1.39)$$

But β, the flux density is given by

$$\beta = \mu_0 \mu_r H \qquad ...(1.40)$$

where μ_r is the relative permeability of the material of the core.

μ_0 is the absolute permeability of the free space *i.e.* $4\pi \times 10^{-7}$ H/m

H is the Ampere turns per meter length of the coil

i.e. $$H = \frac{NI}{L} \qquad ...(1.41)$$

Hence $$L = \frac{\mu_0 \mu_r NI}{l} \frac{NA.}{I} \qquad ...(1.42)$$

$$= \frac{N^2 \mu_0 \mu_r}{l} A$$

If the conductor is formed into a coil, its inductance will increase. A coil of many turns will have more inductance than one of few turns, if both coils are otherwise physically similar. Also, if a coil is placed around an iron core its inductance will be greater than it was without magnetic core.

1.24.1. Calculation of Inductance

The approximate inductance of single layer air core may be calculated from the simplified formula

$$L(\mu H) = \frac{2.54\, r^2 N^2}{9r + 10l} \qquad ...(1.43)$$

where r is the radius of coil in cms

l is the length of coil in cms

N is number of turns.

The relation given by equation (1.43) as applicable to the coils having length to radius ratio (l/r) is equal to greater than 0.8.

If the inductance is known then from Eq. (1.43) the number of turns N can be calculated by $N = \sqrt{\frac{L(\mu H) \,.\, 9 \,.\, r + 10l}{2.54\, r^2}}$ ...(1.44)

1.24.2. Inductance Chart

Most inductance formulas loose accuracy when applied to small coils (such as coils used in VHF work *e.g.*, low pass filters built for reducing harmonic interference to television because of the conductor thickness is no longer negligible in comparison to the coil.

The nomograph of Fig. 1.38 can be used for fast determination of the inductance of coils, their reactances, the amount of capacitance necessary for resonance and the capacitive reactance. The frequency range is from 1 to 1000 MHz.

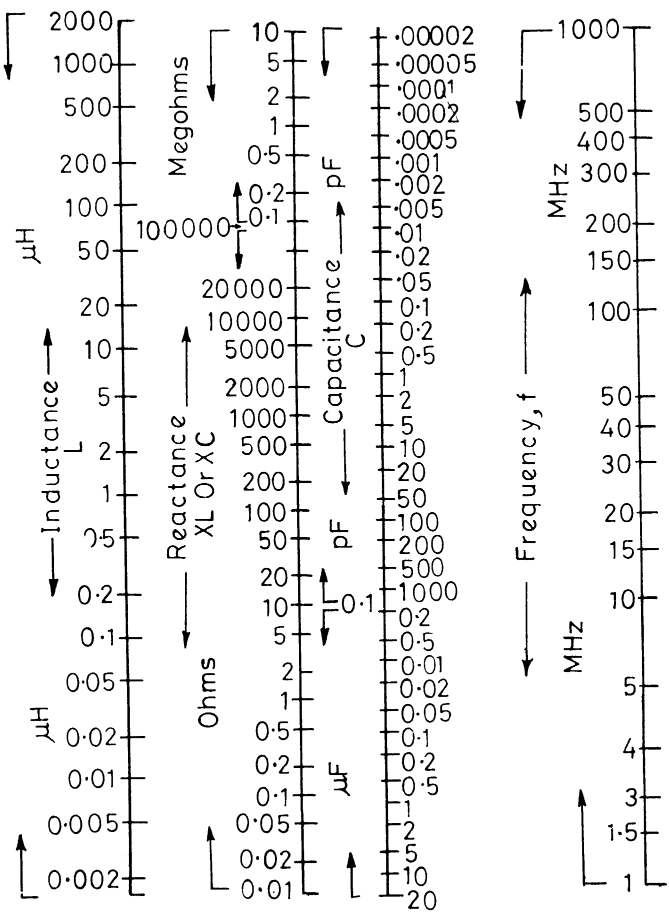
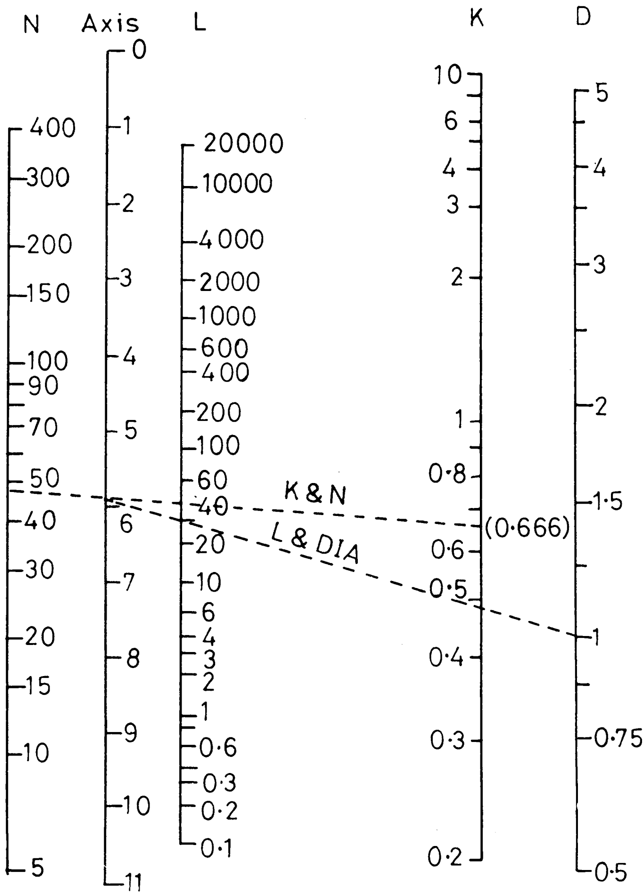


Fig. 1.38. Nomograph for inductance, capacitance and frequency.

If the coil diameter and winding length are known, the number of wire turns necessary for a specific inductance can be found in the monograph given in Fig. 1.39. This is applicable for single layer coils only.

Single-Layer wound coil chart



N = Total number of turns, L = Inductance μH
K = Ratio of (Diameter/Length), D = Diameter (inches)

Fig. 1.39. Nomograph for single layer inductance.

1.24.3. Value of Inductance

If the physical dimensions of the inductor coil are known then the value of inductance can be calculated by the following formula :

$$\text{Inductance } (L) = \frac{4\pi \times 10^{-7} \times K \times A \times N}{l} \quad ...(1.45)$$

where A is the area of coil in sq. meter

N is the number of turns

l is length of the coil in meter

K is the factor depending upon the ratio of diameter of length of coil.

The charts of Figs. 1.40 and 1.41 are useful for rapid determination of the inductance of the coils of the type commonly used in radio frequency circuits in the range of 3 to 30 MHz. They are of sufficient accuracy for most practical work. Given the coil length in cm (or inches) the curve shows the multiplying factor, K to be applied to inductance values given in Table 1.19 (for Fig. 1.40) and Table 1.20 (for Fig. 1.41).

Table 1.19
Value of Inductance for Various Coil Diameters and Number of Turns per Unit Length

Coil dia.		*Turns per unit length*		*Induction In μH*
mm	*Inches*	*Per cm*	*Per inch*	
30	1.25	1.6	4	2.75
		2.40	6	6.3
		3.00	8	11.2
		4.00	10	17.5
		6.00	16	42.5
40	1.5	1.6	4	3.9
		2.4	6	8.8
		3.0	8	15.6
		4.00	10	24.5
		6.00	16	63.00
45	1.75	1.6	4	5.2
		2.4	6	11.8
		3.00	8	21.00
		4.00	10	33.00
		6.00	16	85.00
50	2	1.6	4	6.6
		2.4	6	15.00
		3.00	8	26.5
		4.00	10	42.00
		6.00	16	108.00

Coil dia.		Turns per unit length		Induction In μH
mm	*Inches*	*Per cm*	*Per inch*	
60	2.5	1.6	4	10.2
		2.4	6	23.00
		3.00	8	41.00
		4.00	10	64.00
75	3	1.6	4	14.00
		2.4	6	31.5
		3.00	8	56.00
		4.00	10	89.00

Table 1.20
Value of Inductance for Various Coil Diameter and Number of Turns per Unit Length

Coil dia.		Turns per length		Induction In μH
mm	*Inches*	*Per cm*	*Per inch*	
10	0.5 (A)	1.6	4	0.18
		2.4	6	0.40
		3.0	8	0.72
		4.0	10	1.12
		6.0	16	2.9
		12.00	32	12.0
15	0.625 (A)	1.6	4	0.28
		2.4	6	0.62
		3.0	8	1.1
		4.0	10	1.7
		6.0	16	4.4
		12.0	32	18.00
20	0.75 (B)	1.6	4	0.6
		2.4	6	1.35
		3.0	8	2.4
		4.0	10	3.8
		6.0	16	9.9
		12.0	32	40.00
25	1 (B)	1.6	4	1.0
		2.4	6	3.3
		3.0	8	4.2
		4.0	10	6.6
		6.0	16	16.9
		12.0	32	68.00

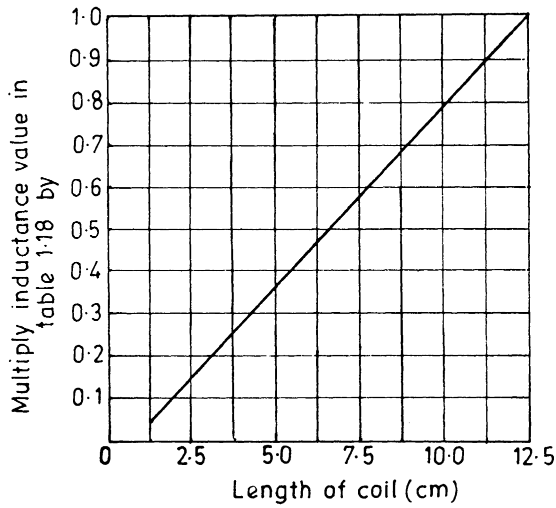


Fig. 1.40

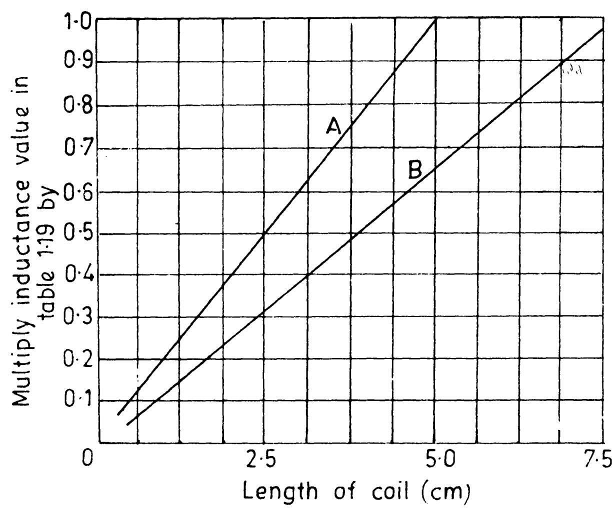


Fig. 1.41

Table 1.19 is to be used for finding out the inductance of coil upto the length of 12.5 cm. The value of K will be found from Fig. 1.40.

The Table 1.20 will be used for finding out the inductance of coil. The value of K has to be found from Fig. 14.1. Use curve A for coils marked A and curve B for coil marked B.

Thus using the Tables (1.19) and (1.20) and equation (1.42) to (1.45) the single layer or multilayer inductors can be used by using air core. These inductors will be useful at high frequencies.

1.25. Iron Core Inductances

The iron core inductances can be designed by using the relations as discussed in case of air cored inductances. The value of inductance will be μ_r times the value that obtained for air cored inductance.

If the flux density is more than it is possible for which the iron core may saturate where the value of μ_r may be become negligible. Hence, iron core inductors should have more diameter in comparison to air core inductors.

The following equations will be useful in designing the inductance. Table 1.21 gives the copper wire table giving various details about copper wire with American and Standard Wire Gauge.

$$L = 0.4606\ \mu \log_{10} \frac{(r_1)}{(r_2)}\, l_e N^2 \times 10^{-9} \text{ Heneries}$$

where $l_e = l - \dfrac{0.0675\, r^2}{r_1 - r_2}$ ...(1.46)

where L is the inductance in Heneries

l is core length in mm

l_e is the effective length of core before finish corrected for corner radii in mm

r is corner radius in mm

r_1 is outside radius in mm

r_2 is inside radius in mm

N is the Number of Turns.

The measured value of a large iron core inductor may change form its nominal value for several reasons such as change in the magnetic properties of the core material. The slop. of the B_H curve is one of the factor for the inductance of the coil. If the slope of B_H curve changes with different values of excitation current then the inductance will also change. Different steels have different slops hence will have different values of inductance for same value of H. The other factors which influence the value of inductance is the temperature, magnitude of the voltage applied frequency of the applied voltage etc.

1.26. Swinging Chokes

A Swinging Choke is designed as such that its inductance changes with the change of current. The value of inductance will decrease with the increase in the value of current.

The function of Choke is to keep the d.c. output voltage of power supply below the average value of the rectified a.c. input to the filter. The critical value of inductance required for this purpose increases as load current decreases and decreases as load current increases. Hence, if a Swinging Choke is used then the size of Choke will be smaller and less expensive.

1.27. True Inductance and Apparent Inductance

When inductance is measured at the test frequency which is at or near the self resonating frequency of the Coil, the results will be misleading. The self resonating frequency of a Coil is the frequency at which the inductance are at resonance. Since coil impedance rapidly decreases as the self resonating frequency of the Coil is approached, hence the results provided will be mis-leading. Any measured inductance at a frequency at or near the self resonating frequency of a coil is called the *apparent inductance*, to distinguish it from *true inductance*, which should always be measured at a frequency far below the self resonating frequency of the Coil.

Thus $$L_t = L_{app}\left\{1 - \left(\frac{f}{f_0}\right)^2\right\} \qquad ...(1.47)$$

where L_{app} is the apparent inductance

L_t is the true value of inductance

f test frequency *i.e.* at which the apparent inductance is measured

f_0 is the self resonating frequency.

1.28. Ferrite Core Inductors

Since all the undesirable effects such as the skin effect, eddy currents, dielectric losses and distributed capacitance in an inductor are function of the length of the wire in the coil. All these effects may be reduced to a large extend by use of powdered iron and ferrite cores.

The permeability of powdered iron and ferrite core materials is very much greater than the permeability of air. Their relative permeability may range from 40 to 3000.

Ferrite technically denotes the family of oxides containing trivalent iron ions Fe_3^+ called ferric ions. The chemical formula of a ferrite is $MoFe_2O_3$. Where Mo stands for an oxide of a divalent metal. When *M* is replaced by two or more metals ion, the result is mixed ferrite. In a ferrite oxygen and metallic ions are bonded ionically in a geometric pattern and ferrite are generally obtained in a sintered multi crystal form.

High electric resistivity, low specific gravity and flexibility with which it can be moulded into complex shapes of all sizes has rendered ferrite suitable for a wide variety of applications.

Due to low eddy current loses over a wide frequency range, high permeability and good temperature stability soft ferrites are ideally suitable for high frequency transformer filter coils and power supply transformers.

The ferrite cores are available in forms such as turning cores, toroids slug, beads and other special forms. Properties of ferrites are given in Table 1.22.

Thus the coils that are wound over such cores have a much higher inductance than air core coils of the same diameter and the same number of turns. Accordingly much less wire will be used to ferrite core inductors than the air core coils which have the same inductance and all undesirable effects and losses will be reduced to minimum.

Ferrite core materials are constantly being improved and some of the core material produce only few years ago is already absolute. Newest types of core material, more stable against the environmental changes and temperature changes are in market.

Table 1.22

Ferrite Core and Their Properties

Ferrite Toroids **A_L-Chart (mH per 1000 turns)**

Enameled Wire

Core Size	63-Mix $\mu = 40$	61-Mix $\mu = 40$	43-Mix $\mu = 950$	72-Mix $\mu = 2000$	75-Mix $\mu = 5000$
FT-23	7.9	24.8	189.0	396.0	990.0
FT-37	17.7	55.3	420.0	884.0	2210.0
FT-50	22.0	68.0	523.0	1100.0	2750.0
FT-83	23.4	73.3	557.0	1172.0	2930.0
FT-114	25.4	79.3	603.0	1268.0	3170.0

Number turns = $1000\sqrt{\text{desired } L(\text{mH}) + A_L \text{ value (above)}}$

Ferrite Magnetic Properties

Property	*Unit*	*63-Mix*	*61-Mix*	*43-Mix*	*72-Mix*	*75-Mix*
Initial Perm (μi)		40	125	950	2000	5000
Maximum Perm		125	450	3000	3500	8000
Saturation Flux Density @ 13 oer	Gauss	1850	2350	2750	3500	3900
Residual Flux Density	Gauss	750	1200	1200	1500	1250
Curie Temp.	°C	500	300	130	150	160
Vol. Resistivity	ohm/cm	1×10^8	1×10^8	1×10^5	1×10^2	5×10^2
Opt. Freq. Range	MHz	15—25	2—10	0.1—1	0.01—1	0.01—1
Specific Gravity		4.7	4.7	4.5	4.8	4.8
Loss-Factor	$\frac{1}{\mu O}$	9.0×10^{-5} @ 25 MHz	2.2×10^{-5} @ 2.0 MHz	2.5×10^{-5} @ .2 MHz	9.0×10^{-6} @ 1 MHz	5.0×10^{-6} @ 1 MHz
Coercive Force	Oer	2.40	1.60	0.30	0.18	0.18
Temp. Co-eff. of initial Perm	% /°C 20—70°C	0.10	0.10	0.20	0.60	

Ferrite Toroids **Physical Properties**

Core Size	*OD*	*ID*	*Height*	A_c	l_e	V_e	A_s	A_w
FT-23	0.230	0.120	0.060	0.00330	0.529	0.00174	0.1264	0.01121
FT-37	0.375	0.187	0.125	0.01175	0.846	0.00994	0.3860	0.02750
FT-50	0.500	0.281	0.188	0.02060	1.190	0.02450	0.7300	0.06200
FT-82	0.825	0.520	0.250	0.03810	2.070	0.07890	1.7000	0.21200
FT-114	1.142	0.748	0.295	0.05810	2.920	0.16950	2.9200	0.43900

OD-Outer diameter (inches)
ID-Inner diameter (inches)
Hgt-Height (inches)
A_w-Total window area $(in)^2$
Inches × 25.4 = mm.

A_e—Effective magnetic cross-sectional area $(in)^2$
l_e—Effective magnetic path length (inches)
V_e—Effective magnetic volume $(in)^3$
A_s—Surface area exposed for cooling $(in)^2$
Courtesy of Amidon Assoc. N Hollywood CA 91607

1.29. Electromagnetic Relays

The relays are the command elements which command the operation of a system to operate as per the desire of the human operator.

These are an intermediate means used to command the system operation. Relays have helped very much in the automisation of the various industries. There are various types of relays used for various purposes. They operate on various operating principles most common types of relays are :

(*i*) Mechanical relays

(*ii*) Pnumatic relays

(*iii*) Hydraulic relays

(*iv*) Thermal relays

(*v*) Electromagnetic relays

(*vi*) Electric relays

(*vii*) Programmable logic conditions.

The relays may be one of the following type :

(*i*) Normally open relays

(*ii*) Normally closed relays

(*iii*) Multi contact relays.

1.29.1. Electromagnetic relays

An electromagnetic relay consists of a switch contains which operates by a magnetic coil. The magnetic coil consists of an iron core which becomes an electromagnet when the current flows through this coil as shown in Fig. 1.42. The magnetic pull of the field of the electromagnetic attracts a flexible reed or switch contact when the reed is pulled of closes the actuating circuit. Open the voltage applied to two coil is removed then the reed is pulled back to its original position.

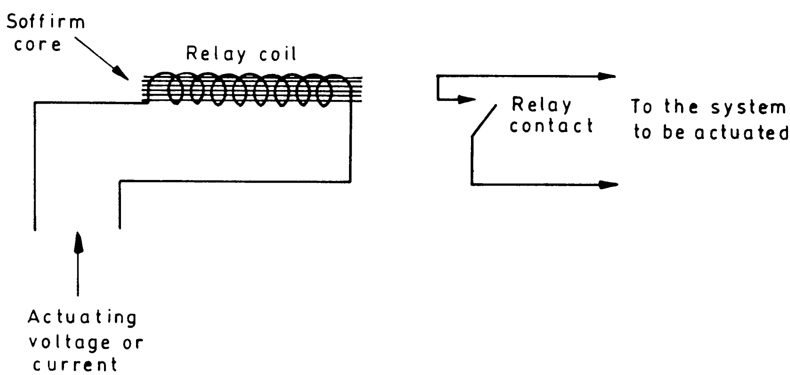


Fig. 1.42. Electromagnetic relays.

The switches may be either a simple single hole, single throw type or it may be single pole double throw or a double pole single throw type or even more complex. The symbols of the relays are shown in Fig. 1.43. In a normally open type relay the switch contacts as open when the relay is not energised. As the current flows through the relay coil, the coil is energised and the switch contacts which are normally open, come to the closed position

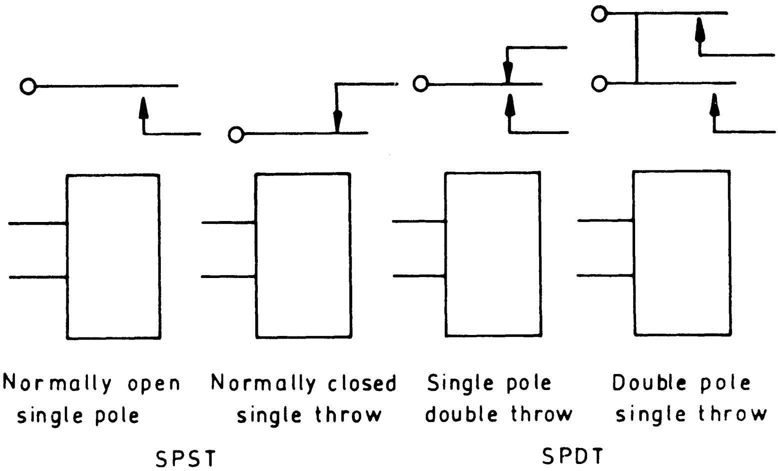


Fig. 1.43. Relay Symbols.

In the normally closed type relays when the coil is energised by passing a current through it, the normally closed contain becomes open.

The relays are extremely ragged desires which can operate very fast. The operating time may be less than 1 m sec or so. The relays have a life span of thousand millions of operation or about 40 years.

The relays are still used to some extent where a slow process is tolerable. In the off position, relays require no power of their open contacts effectively would to output from the input. In the on position the contacts can carry heavy current and the resistance across the contacts on almost zero. Since the contacts have to make and break the heavy current hence the problem of sparking may be there as such the contacts should be made from the highly conductive material such as silver.

The contacts are also shunted by a suitable values of the capacitance in order to suppress the sparking during the make and break of the contacts.

1.29.2. Specifications of the relays

The specifications of the relays are given by two types of currents :

(*i*) Pick up currents (*ii*) Release currents.

Pick up Current

When the current passes through the relay coil its core gets excited and develops a force of attraction and tries to pull the armature.

The maximum amount of relay current required to pull up the armature of the relay is called the pick up current.

Release Current

When the current through the relay coil is reduced it will try to release the armature when the force does not remain sufficient to keep it attracted.

The maximum amount of relay current which is insufficient to keep the armature affected is called the release current.

The value of the pick up current of the release current depends on the tension spring used with the relay. Normally the released current is less than the pick up current.