ALL ABOUT ELECTRIC CAPACITORS

Part II—Varieties

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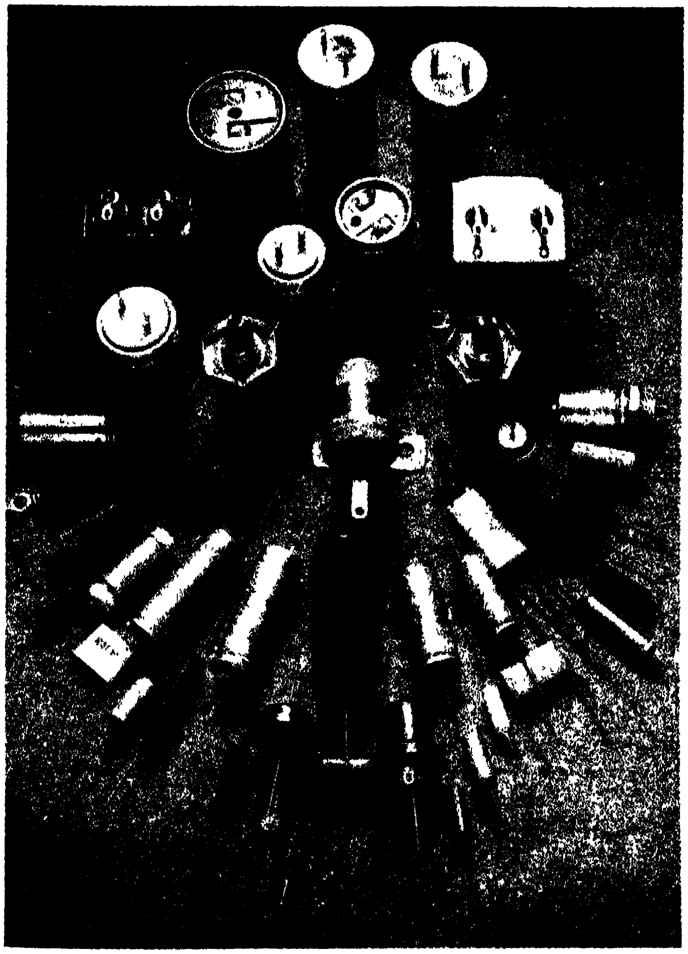

Capacitors may be classified based on the physical state of their dielectric. The dielectric may be either a gas (or vacuum), a liquid, a solid, or a combination of these. They may be further subdivided according to the specific dielectric used.

Capacitors are also classified as: fixed, adjustable, variable and trimmer.

Fixed capacitors. All single pieces of discrete capacitor components are included in this group. Their capacitance remains fixed and unchanged except for small variations caused by temperature etc.

Adjustable capacitors. The capacitance of these may be set in steps at any one of the several discrete values.

Variable capacitors. Their capacitance may be adjusted continuously and set at any value between the minimum and maximum limits fixed by its construction.

Trimmer capacitors. These are relatively small variable capacitors, used in parallel with large variable capacitors or fixed capacitors so as to permit exact adjustment of the capacitance in parallel combinations.

Capacitance range

Typical capacitance range of different types of capacitors is as given below:

Air Gas Vacuum	up to about 1000 pF
Mica Glass Low-k ceramics	few pF to few thousand pF
High-k ceramics:	a few hundred pF to a few μF
Paper:	Tens of pF to tens of μF
Plastic film:	Thousand pF to hundred μF
Electrolytic:	1 μF to 1 farad

Air/gas/vacuum capacitors

These are constructed with flat parallel metallic plates or cylindrical concentric plates with air, gas or vacuum as dielectric. Alternate plates are connected together (as shown in Fig. 3) and are supported by means of a solid insulating material such as glass, quartz, ceramic or plastic.

Gas capacitors are enclosed in a leak-proof case while vacuum capacitors are sealed in highly evacuated glass envelopes. Vacuum or gas under pressure increases the voltage breakdown value for a given plate spacing. Therefore gas and vacuum capacitors are used in high voltage circuits such as transmitters.

Air capacitors are used in high voltage or, and high frequency circuits. They are mainly used as variable capacitors in sizes up to about 1000 pF. They are commonly employed in radio receivers etc for frequency tuning. The shape of electrodes determines whether the angle of rotation gives linear change of capacitance or tuned frequency. Miniature air trimmers are used in RF, VHF and microwave applications, frequency tuning, impedance trimming, etc. Tiny giga hertz trimmers are also available, which provide a beautifully straightforward technique to fine tune RF hybrid and microwave circuits into proper behaviour. Air capacitors provide high Q and low losses. Both fixed and variable capacitors of special design are used as laboratory standards also.

Liquid dielectric capacitors

The plate assemblies of these capacitors are mounted in a tank filled with a suitable oil or liquid dielectric. External connections are made with insulators or bushing.

Dielectric constant of liquid dielectric ranges from 1.5 to 100. In non-polar liquids, whose dielectric constant is substantially independent of frequency, it ranges from about two to five. It is possible to increase capacitance by filling the plate space with a non-polar liquid such as mineral oil, which gives low losses at high frequencies.

The dielectric constant of mineral oil is 2.2, that of castor oil is 4.7 and of silicone oil is 2.6. It is essential to ensure that oils used for this purpose are carefully purified, clean and free from moisture. Silicone oils have a wider range of operational temperature and much higher flash point. Provision has to be made for the expansion and contraction of the liquid during temperature changes.

Oil-filled capacitors are generally used for high voltage applications like transmitter capacitors. Transmitter capacitors have to operate at several kilovolts. They must work at high voltages, high powers and high frequencies. For example, broadcasting transmitters have several hundred kilowatts of power. The main problems in such applications are those of spark-over, adequate spacing of vanes consistent with resonable size and losses at high frequencies due to insulation. Appreciable rise in temperature of insulation occurs due to dielectric heating. Generally four main types of transmitter capacitors are used - air-filled, pressurised or gas-filled, vacuum and oil-filled. Oil-filled types give high capacitance in a smaller package.

The main disadvantage of liquid-filled capacitors is that they cannot be kept in any position other than upright, which is most inconvenient in general usage.

Solid dielectric capacitors

These capacitors use solid dielectrics such as paper, mica, glass, quartz, ceramic, plastic films etc. Alternate plates of metal or metallic foil are stacked with the dielectric layer.

So far only the oldest forms of capacitors — air- and oil-filled capacitors have been discussed. Air capacitors are available for low values only, as due to unity dielectric constant, realising higher values is not possible. Therefore, they are essentially high frequency components. Although oil-filled capacitors are smaller than air capacitors, they are not very convenient for general purpose. They are specialised capacitors for high voltage application. It remains for the solid dielectric capacitors to serve as the general purpose circuit components.

Since there were very few solid type capacitors in the earlier times, the choice between them was comparatively easy. In fact, there were only three basic types—electrolytic, paper and mica. Electrolytic types offered large and cheap capacitors with comparatively poorer electrical characteristics. They were used for power supply filtering, and other low frequency applications. Caution of proper DC voltage polarity should be taken.

Mica capacitors were the most superior capacitors, used for high frequency and high quality circuits. The main problem of mica was that only small values of it was available.

The middle ground was taken by the impregnated paper capacitors which combined the good characteristics of both mica and electrolytic types to make it suitable for more varied usages in electrical circuits than any other type. Paper capacitors were the cheapest and most popular as well as most widely used AC capacitors. The superior mica capacitor was used only when the paper capacitor was not found satisfactory.

At present, the things are altogether quite different and complex, with many additional varieties of capacitors. The electrolytic capacitors are still used but improvements have been done by way of dry electrolytics, introduction of solid types, miniaturisation etc. The popular paper capacitors have been mostly replaced by film capacitors. Polyester capacitor has become the commonly used AC capacitor. Ceramic and polystyrene types are taking the place of mica even though it possesses unsurpassed qualities. Ceramics are inexpensive and ideal for printed circuits and are widely used in RF applications in general. Polystyrene capacitors are precision capacitors.

Fig. 3: Multiplate capacitor.

Paper capacitors

Paper capacitors are one of the oldest types. The first paper capacitor came into existence in 1876. Paper is the cheapest dielectric, therefore it yields the lowest cost capacitor. Saturation of paper with insulating oils increases its insulation resistance, temperature range and primarily its working voltage, since oil fills the air gaps which would otherwise produce corona. Such impregnated paper is used as a dielectric, with a dielectric constant of about three to five.

Although paper is cheap, it has the disadvantage of having a low dielectric strength. Usually two or more layers of paper are used. The probability of a point of weakness in one layer coinciding with another in the second layer is extremely small. With three layers one can count on having the strength of at least two layers.

Paper capacitors are usually constructed in the form of a roll, where bands of metal foil and the dielectric are rolled up until there is sufficient capacitance. The roll is then impregnated and may be mounted in an imperious case. The impregnation is for sealing as a protection against moisture. Otherwise, the hygroscopic paper can alter both the capacitance and the insulation with dampness and temperature.

Metallised paper capacitors

Metallised paper capacitors are an improved version of the normal paper capacitors, which appeared at the end of the 1940s. They differ from the paper capacitors only in that the conducting coating is formed by metallising directly on

Mica is a natural inorganic material which is mechanically extremely robust. Mica has excellent qualities as a dielectric, namely, a high dielectric constant, low losses, high dielectric strength and very good stability.

the paper. Thus, while the electrical properties are maintained, a considerable reduction in size is gained. Furthermore, a valuable new quality of 'self-healing' is acquired. The electric arc which arises with breakdown, evaporates the metal layer in the affected region, without impairing the dielectric. The breakdown ceases immediately, since the metal around the point of breakdown is burnt away. This interesting property made it possible to use a single layer of paper as dielectric. By applying a voltage twice the operating voltage after manufacture, critical points of weakness can be burnt away and paper's own dielectric strength can be better exploited. The capacitance decrease caused by the self-healing process is of a small proportion only.

Paper capacitors have low cost per unit capacitance and moderate capacitance-to-volume ratio. They have a good insulation resistance, fairly good stability and a capacity of operating up to a temperature of 125°C. They are useful over a frequency range of up to 10MHz or more. Paper capacitors were the only general purpose AC capacitors in use before the advent of plastic film capacitors. The nominal paper capacitor values are from tens of pF to tens of μF. A good capacitor can age up to two per cent of the original capacitance.

The life of paper capacitors depends on the working voltage and temperature. Thus the maximum permissible DC working voltage is dependent on the ambient temperature. The maximum voltage which may be applied instantaneously without destroying the capacitor is termed as the spark voltage. Maximum voltage should never be applied for more than a few seconds, as continuous sparking tends to destroy the capacitor.

Mica capacitors

Mica capacitors are also one of the oldest types. The first mica capacitor was made in 1845. In these thin sheets of high grade mica are used as dielectric with a dielectric constant in the range of six to eight. Various types of mica capacitors are as below:

Stack-foil mica capacitors. Consist of alternate layers of metal foils or deposited metal films and sheet-mica insulators which are stacked, compressed and then encapsulated.

Silvered mica capacitor. Has a silver electrode material screened on the mica stampings which are then assembled and encapsulated. Nowadays silvered mica capacitors are more common. Their capacitance value is varied by the number of stacked plates. Further alteration of the capacitance can occur by scraping away the silver layer.

Mica is a natural inorganic material which is mechanically extremely robust. Mica has excellent qualities as a dielectric, namely, a high dielectric constant, low losses, high dielectric strength and very good stability. Therefore, mica capacitors have inherent characteristics of high insulation resistance, low inductance, excellent stability, low dielectric losses even at high frequencies, good temperature, frequency and aging characteristics. These unique qualities make them well suited for high frequency applications and high quality circuits. Their temperature coefficient is low, lying between 0 and 70 ppm per°C. They can be manufactured with good tolerance of about one per cent in normal production. Even a closer tolerance of down to±0.1 per cent is not difficult. They are made with DC voltage ratings from a few hundred volts to several thousand volts. Their wide temperature extends up to 125°C and insulation resistance is

Fig. 4: Disc ceramic capacitor.

many thousands megohms. Silvered mica capacitors are available in moulded type, dip-coated type or wax-coated type in our country.

Since they have a low capacitance-to-volume or mass ratio, they are suitable for circuits requiring low values and good stability with respect to temperature, frequency and aging. Their disadvantge is that they are bulky and expensive.

Ceramic capacitors

Ceramic capacitors come in a variety of sizes, shapes and ratings. They are the most popular of all capacitors due to their outstanding versatility. The dielectric of the ceramic capacitors is a mixture of titanium oxide with other titanates. The dielectric constant varies extremely widely, from about six to 10,000 or even more, depending on the composition of the ceramic mixture. Ceramic capacitors have a very high capacitance-to-volume or mass ratio. Their distinct merits over other capacitors are their suitability for use in printed wiring boards, reliability and small size.

The stability of the dielectric constant with respect to temperature is an important feature. In general, the stability of the capacitance value with temperature variations depends on the low dielectric constant (k).

High-k or low-k

Ceramic capacitors are usually divided into low-k or class I ceramics and high-k or class II ceramics. High-k capacitors usually have a dielectric constant of more than 3000. They are extremely small sized for any given capacitance value and voltage rating. They are used mainly for bypass and coupling, and are usually in the range from 0.001μF to several μF. These are chiefly used for non-precision applications where appreciable capacitance change is tolerable. Typical non-critical applications are bypass, coupling, filtering etc. Their capacitance varies with temperature, electric field intensity, applied frequency and self-aging.

For greater stability with temperature, semi-stable and temperature-stable, low-k capacitors are used. They exhibit a capacitance change of about five to 15 per cent. Temperature compensating capacitors exhibit controlled and predictable variations in capacitance with change of temperature. They have dielectric constant in the range of six to 200, signifying a larger capacitor size for a given value. They have

The disc and plate types are ideal for printed circuit wiring and need minimum space. The hard inflexible tube of the tubular type acts as a support for the electrodes and leads, in addition to providing dielectric. The tubular form lends itself to efficient space utilisation.

high Q, which is required for critical circuit functions, such as in oscillator and filter circuits. They have linear TCC (temperature coefficient of capacitor) and high stability with low losses.

NP0 capacitors

Special ceramic capacitors that remain stable with temperature are called negative-positive-zero (NP0) 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 or N, for example, P100, N150, N750 and so on. A commonly used temperature coefficient is N750. Capacitors with this temperature coefficient have a k of about 90. N750 means that the decrease in capacitance will be 750 parts per million or 750 ppm per°C of temperature rise. In other

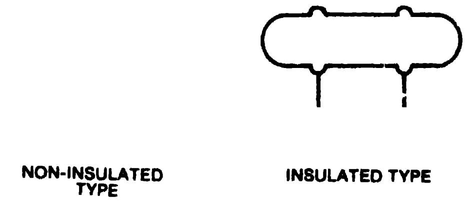

Fig. 5: Tubular ceramic capacitor.

words, the capacitance decreases by 0.075 per cent for 1°C increase or 1.5 per cent for a 20°C increase. Thus, the prefix N means negative temperature coefficient of capacitor or negative TCC. Similarly, P means positive TCC.

Construction type ceramic capacitors

Several construction type capacitors are also currently in use—disc, tubular, plate, ceramic barrier layer, feed-through, stand-offs, multilayer chips, mono-block, monolithic and so on.

Their electrodes usually consist of silver or some other good electrical conductor. For multilayer capacitors palladium or platinum is used, since the electrodes are applied before the ceramic is fired at a temperature at which silver would oxidise.

The raw materials are finely grinded and carefully mixed. After calcining, the resultant mass is reground and then mixed with, for instance, water and binding matter. The various shapes are obtained by extruding or rolling. After drying, the capacitor bodies are fired at high temperatures. Normally, the leads are soldered to the electrodes of the capacitor body with a high melting-point solder.

Disc capacitors. Consist of a ceramic disc with both sides metallised and provided with connecting leads (Fig. 4).

Tubular capacitors. Consist of a ceramic tube fully metallised internally and partially outside with two tangential leads. Both insulated and non-insulated tubular versions are available (as shown in Fig. 5).

Miniature ceramic plate capacitor. Consists of a thin rectangular ceramic plate, metallised on both sides and provided with leads (Fig. 6).

The disc and plate types are ideal for printed circuit wiring and need minimum space. The hard inflexible tube of the tubular type acts as a support for the electrodes and leads, in addition to providing dielectric. The tubular form lends itself to efficient space utilisation. An incidental advantge of this space is that it automatically provides separation between the leads, a valuable feature in high voltage usages.

Component package

Since the materials are comparatively non-hygroscopic, a complete coating of lacquer is usually sufficient for protection. The ceramic types do not always require the elaborate mounting or potting which are often so essential with other capacitors. Some ceramics rival mica in stability and loss and also have the added advantage that they can be moulded into a variety of useful shapes. Ceramic capacitors are available for use from kilohertz range to many megahertz range. Special types which work through gigahertz range are also available.

Ceramic trimmers are widely used from audio to 500 MHz. They provide an ideal low cost means of trimming circuits, such as crystal oscillators, RF amplifiers, all varieties of communication and test equipment. They are much smaller than air trimmers.

Ceramic and mica compete with each other.

Mica versus ceramic

Some manufacturers claim superiority of multilayer ceramics over mica. Mica manufacturers disagree. Modern mica capacitors are well developed. The initial tolerance, long term stability, high temperature operation, high-frequency performance, low losses—all seem to favour mica. Yet let us compare them:

Tolerance. Mica capacitors are manufactured with excellent tolerance of 0.1 per cent while ceramic types are much worse-off. A capacitor of 4765.5 pF can be made easily in mica but not in ceramics.

Stability. Mica capacitors are available with a 10 year stability of 0.1 per cent, which is not possible with the best ceramic ones in the world.

Performance. Ceramics rely on mixtures of oxides of rare earths. The manufacturers must not only struggle to maintain the purity of individual materials, but must vary the mixture to meet economic pressures. Changes in the mixtures may not affect the characteristics of the device at 250°C and at 1kHz test frequency, but it does effect at higher frequencies.

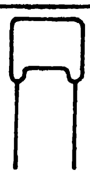

Fig. 6: Miniature ceramic plate type capacitor.

In contrast, mica capacitors retain good characteristics in the GHz range also. Often mica capacitors submitted for calibration caused the measuring bridge to show a negative power factor. It is a feature worth patenting! The fact is that the mica devices are of better quality than those used as standards in even the bridge.

High temperature. Devices are currently available for use of mica at 300°C. If larger values are required at high temperatures (125°C), mica can be fabricated into a paper and wound into larger units. These reconstituted mica capacitors are almost indestructible and find use in defence and aerospace projects. Temperature holds no danger for mica, since it existed even 4 million years ago, but it is not so for ceramics.

High voltage. Mica requires no voltage derating to 125°C, works at voltages over 60kV and has also survived the 100,000 g shock.

All the above points are quoted only to indicate the superior quality of mica capacitors. It also clearly establishes that the ceramics are definitely competing with mica because they compare favourably. Ceramic capacitors are inexpensive, smaller in size and a variety of types are available to meet every need in general. They are specially used in radio frequency circuits more than any other capacitor type.

Glass capacitors

Glass is used as dielectric in such capacitors. The dielectric constant of glass varies from four to 6.8, depending on the type of glass.

Glass capacitors consist of glass plates stacked in layers as dielectric, with metal foils as electrodes. Glass and metal are melted to a block at high temperature. The use of the same kind of glass for both the dielectric and the casing makes it feasible to create monolithic sealed capacitor.

The inorganic glass has a very good resistance against atomic and cosmic-ray radiation. Glass capacitors have high Q and low losses at radio frequencies, small and positive TCC, close tolerance of about one per cent, very high insulation figure, typically one million ohm farad, and are suitable for high voltage and high temperature operation. They are quite stable over wide temperatures and are protected against moisture. They can work with AC peak voltages equal to rated voltages even at the maximum temperature of 125°C.

The glass capacitors are used in RF and IF circuits. They are suitable for use as measuring and resonant circuit capacitors. The capacitance values are low, say, from about one pF to few thousand pF. They can resist aging, moisture, shock, vibration and can function under extremes of temperature. Glass trimmers are also used in high frequency circuits.

Quartz capacitors

Dielectric constant of quartz is 3.8. Quartz capacitors are also high quality RF capacitors like glass capacitors. Quartz trimmers are especially used in RF applications. They are unique in the fact that they can carry high RF current in amperes and withstand high RF voltages. Their quality factor is higher than that of the glass types.

Plastic/film capacitors

Plastic or film capacitors is a collective name for several types of capacitors with different materials as dielectric. They are truly symmetrical or non-polar capacitors, well suited for AC application. Polymer films are available in thinner gauges and thus have higher capacitance density compared to glass or mica but lower than the electrolytics. These capacitors are dry, non-polar, show low loss, have excellent insulation resistance and low moisture absorption.

Polystyrene was the first plastic used in capacitors during the thirties. However, various types of material later came into use. The popular ones are polyester, polystyrene, polycarbonate and polytetra fuloro ethylene (PTFE).

Chemical name	Dielectric constant	Commercial name or trade name
Polyester	3.3	Mylar, Melinex
Polystyrene	2.5	Styroflex, Styrofoil
Polycarbonate	3.2	Makrofol
PTFE	2.1	Teflon

Plastic capacitors are manufactured in a similar way as paper capacitors, with plastic foils replacing the paper. They consist of alternate layers of metal foil and one or more layers of flexible plastic insulating material in ribbon form rolled up together and encapsulated. The metal foil is either aluminium or tin ribbon in foil-type capacitors, or a thin vapourised layer of metal deposited on the surface of the insulating materials in metallised dielectrics.

Metallised dielectrics

Metallised dielectrics are more popular. Through an evaporative process, a metal layer is deposited on a dielectric surface to form the metallised dielectric. The metal deposition then replaces the conventional metal foil conductive plate used in a standard film-foil capacitor.

Exhibiting the same basic electrical characteristics as the film-foil capacitors, the metallised series offer advantages in size and weight savings and have 'self-healing' properties, which prevent momentary voltage surges from effecting permanent capacitor breakdown. The breakdown ceases immediately because the metal burns away around the point of breakdown and a metal-free zone is built up. These advantages, coupled with only a slight increase in cost, are taking the metallised dielectrics towards dominance in the wound capacitor field.

After winding, such capacitor rolls are heat treated. This 'baking' causes the stretched plastic foils to shrink, thus sealing the capacitor and providing protection from moisture, without becoming a sealed construction. This also ensures that the roll becomes compact, and dimensionally stable. This capacitor roll can be used up to 70°C as the absorption of dampness is insignificant here. If sealed, the capacitor can be used at higher temperatures too.

These capacitors have very high insulation resistance quality. They absorb an insignificant amount of dampness and are thus comparable to mica and superior to paper. With regard to losses and stability, polystyrene and teflon are comparable to mica, while polyester and polycarbonate are more comparable to paper. Polystyrene, polycarbonate and teflon capacitors have excellent TCC characteristics Their capacitances range from about 0.001 μF to 100 μF.

Polyester capacitors

Polyester capacitors are the most popular and inexpensive among plastic capacitors. Their only drawback is the high TCC.

They are characterised by high dilectric strength and are suitable for operating temperatures up to 150°C. They have been in use since many years and have largely replaced paper as the standard capacitor dielectric for electronic applications. Polyester also allows for many special designs and applications. They can be used up to voltages of 1000 V. Their typical insulation resistance is greater than 50,000 megohms

Polystyrene capacitors

Polystyrene is a thermoplastic material with a melting point of just over 90°C. Thus, polystyrene capacitors have a maximum temperature rating of only 85°C.

They are characterised by extraordinarily low dielectric absorption and very high insulation resistance with an excellent low and linear negative TCC. This film yields relatively high capacitance density due to thinner guages.

Due to low dielectric absorption, low losses and constant negative TCC, this capacitor is particularly suitable for use as resonant circuit capacitor where ferrite coils with a corresponding positive TCC are used so that the resonant frequency can be kept constant and independent of temperature variations. Therefore, polystyrene capacitors are widely used in filter networks and as precision capacitors. They are ideally suited for computers, timing applications as well as tuned circuits and can work from audio to radio frequencies in a very high frequency range. **(To be continued)**