L7

Practical Capacitors

① You can buy capacitors made with a variety of dielectrics. Each dielectric lends itself to certain construction techniques. There are many trade-offs with regard to cost, breakdown-voltage rating and size. Some dielectric materials are less effective at higher ② operating frequencies, so you want to avoid those for radio-frequency circuits. Operating-temperature changes have ③ a significant effect on the capacitance value of some capacitor types.

Selecting the proper capacitor for a specific job isn't difficult. You do have to understand the effects of some trade-offs, however. For example, an inexpensive ceramic capacitor may do fine as an audio-bypass capacitor. You would not use a normal ceramic capacitor in a radio-frequency oscillator circuit.

This section describes the common capacitor construction methods and dielectric materials. The information serves as an introduction. It will help you understand ④ why a 10 microfarad paper capacitor may not be a good substitute for a 10 microfarad tantalum capacitor.

2×V max You may see the breakdown-voltage rating given as working-volts dc (WVDC). This is the highest direct voltage you can safely connect to the capacitor. Select a capacitor with a breakdown voltage at least two times larger than the highest voltage you expect it to endure. This provides a safety margin.

⑤ *Mica capacitors* consist of metal-foil strips separated by thin mica layers. Figure 1 shows this construction. Alternate plates connect to each electrode. A plastic or ceramic coating seals the capacitor.

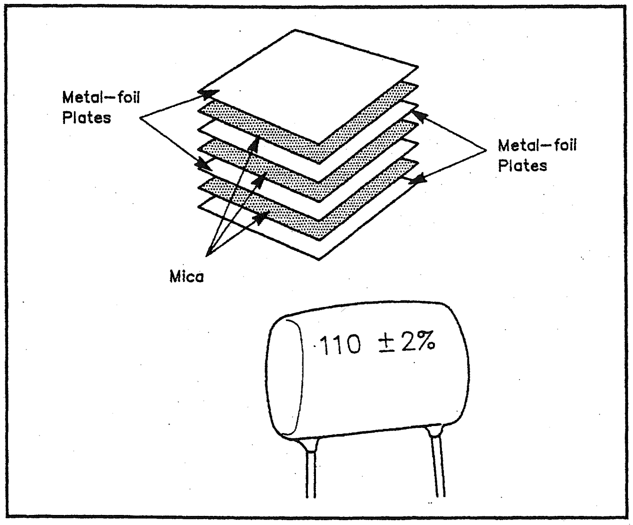

Figure 1—Mica capacitors have thin sheets of mica separating metal-foil capacitor plates. Alternate foil layers connect to the capacitor leads. A ceramic coating protects the assembly from dirt and moisture.

Mica has a breakdown-voltage rating between 3800 and 5600 volts per mil. This is why we use mica capacitors in transmitters and high-power amplifiers. Their ability to withstand high voltages is important.

Mica capacitors have good temperature stability. Their capacitance does not change much as the temperature changes.

Typical capacitance values for mica capacitors range from 1 picofarad to 0.1 microfarad. Breakdown-voltage ratings as high as 35,000 are possible.

II *Ceramic capacitors* have a metal film on both sides of a thin ceramic disc. Wire leads attach to the metal film. Figure 2 shows this construction. The capacitor has a protective plastic or ceramic covering.

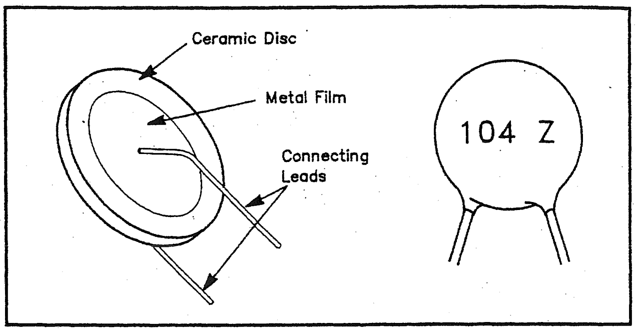

Figure 2—This drawing shows the construction of a disc ceramic capacitor. A metal film deposited on both sides of a small ceramic disc forms the electrodes. Wires attach to the metal, and the assembly gets a protective plastic or ceramic coating.

Ceramic capacitors are inexpensive and easy to make. Many electronics circuits use ceramic capacitors. You can't use them in every application, however.

The capacitance of ordinary ceramic capacitors changes when the temperature changes. You can't use them in a circuit requiring a capacitance that doesn't change with temperature.

Some capacitors have a *negative temperature coefficient*. This means their value decreases when the temperature goes up. Others have a *positive temperature coefficient*. Their capacitance increases when the temperature goes up.

There are special ceramic capacitors that don't change value with temperature changes. These *NP0 capacitors* have a zero temperature coefficient. The NP0 stands for "negative-positive zero." An NP0 capacitor has neither a negative temperature coefficient nor a positive one. The capacitance of an NP0 capacitor remains nearly unchanged over a wide temperature range.

You can buy ceramic capacitors with values from 1 picofarad (1 pF) to 0.1 microfarad (0.1 μF). Ceramic

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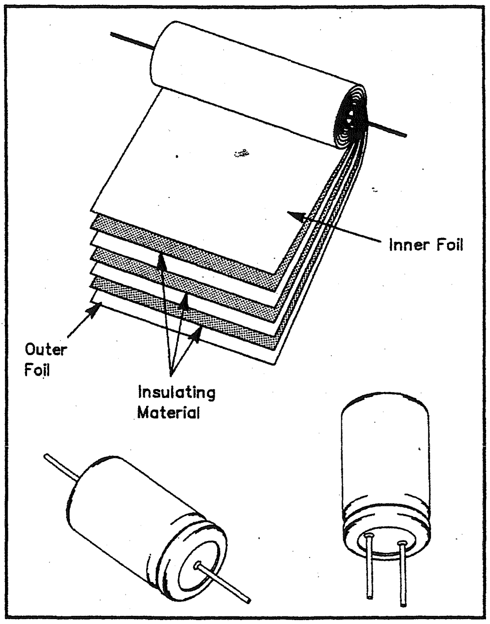


Figure 3—Several capacitor types use the same construction method as the paper capacitor. An insulating material between metal-foil plates forms the capacitor. Roll the assembly into a cylinder and finish it with a protective coating. Paper capacitors use an insulating paper as the dielectric. Plastic-film capacitors use mylar or polystyrene. Chemical-soaked paper goes between the aluminum-foil layers of an aluminum electrolytic capacitor.

capacitors with breakdown-voltage ratings up to 1000 volts are common.

Paper capacitors consist of alternate layers of metal foil and insulating paper. Wire leads attach to the two sets of metal-foil plates. Then the manufacturer rolls the layers into a cylinder, as Figure 3 shows.

The capacitor may have a plastic covering, or it may have a wax coating. This outer layer protects the capacitor from dirt and moisture.

The capacitor may have a stripe around one end. This shows the lead that attaches to the outer metal-foil plate. You can connect this end to the circuit ground, so the outer foil shields the capacitor from radio-frequency energy.

Capacitance values of paper capacitors range from about 500 pF to about 50 µF. They come with voltage ratings up to about 600 WVDC.

Paper capacitors are generally inexpensive. They have a larger size for a given value than other capacitor types, and this makes them impractical for some uses.

Plastic-film capacitors are similar in construction to paper capacitors. Thin sheets of mylar or polystyrene serve as the insulating layers. The plastic material gives the capacitors a high voltage rating in a physically small package. Mylar and polystyrene capacitors have good temperature stability. Typical values range from 5 pF to 0.47 µF.

Aluminum electrolytic capacitors also use a similar construction technique. Sheets of aluminum foil have a layer of paper soaked in a chemical solution between them. The rolled assembly goes into a protective casing, usually a metal can.

The chemical causes a reaction when you apply electricity, so we call the chemical an *electrolyte*. This is where we get the name *electrolytic*.

When you apply a voltage to the capacitor it causes a chemical reaction on the positive plate surface. This produces a thin aluminum-oxide layer, which forms the capacitor dielectric. Electrolytic capacitors have a high capacitance value in a small package because of this thin dielectric layer.

One lead of an electrolytic capacitor always has a + or a – sign clearly marked. You must observe this polarity when you connect the capacitor into a circuit. If you connect an aluminum electrolytic capacitor with the wrong polarity, a gas will form inside the capacitor. This may cause the capacitor to explode. At the very least, you will destroy an electrolytic capacitor by connecting it with reverse polarity.

Electrolytic capacitors are available in capacitance values from 1 µF to 100,000 µF (0.1 farad). Some of them have voltage ratings of 400 V or more. Electrolytic capacitors with high capacitance values and/or high voltage ratings are physically large.

Tantalum capacitors are another form of electrolytic capacitor. These are much smaller than aluminum electrolytic capacitors for a given value. They usually have the shape of a water drop.

The *anode*, or positive capacitor plate, is a small tantalum pellet. A layer of manganese dioxide forms the solid electrolyte, or chemical, which produces an oxide layer on the outside of the tantalum pellet. This oxide layer serves as the dielectric. Layers of carbon and silver form the *cathode* or negative capacitor plate.

An epoxy coating gives the capacitor its characteristic shape. This is why we often call them "tear-drop capacitors." Figure 4 shows the construction of a tantalum electrolytic capacitor.

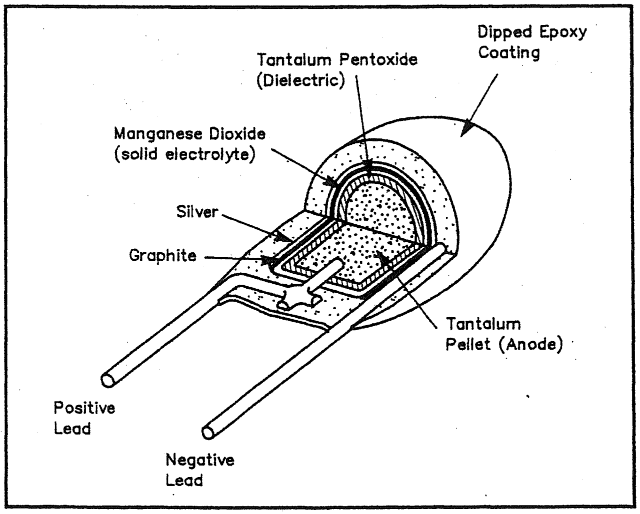
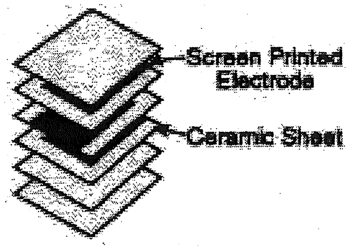


Figure 4—Tantalum capacitors, sometimes called "tear-drop capacitors" use a small tantalum pellet as the positive plate. This drawing shows the construction of these capacitors.

compressed and then fired. During firing, the ceramic sinters together into one homogeneous structure from which we get the name "monolithic." A much more complete description of the construction and the characteristics produced will be available in the program on ceramic capacitors.



Expanded Monolithic

Basic to the ceramic capacitor are the properties of the dielectric materials. There are many formulations in use to achieve the special characteristics of finished capacitors. In general, stability of capacitance with respect to temperature and voltage are sacrificed when large values of K are sought. While many special formulations are sold, the industry is concentrating on three general areas. We may call them stable, semi-stable, and general purpose. The COG (which is called NPO by almost everybody but specification writers) is highly stable with respect to temperature and also with respect to voltage and frequency. The others begin to develop wilder and wilder deviations in capacitance versus temperature as the value of K goes up. Nevertheless, they are very useful in applications where temperature changes little.

	Stable	Semi-stable	General Purpose
Symbols	COG or NPO	X7R	Z5U
K	60	1500	5000
Temperature Characteristics	0 ±30 ppm/°C	±15% ΔC -55 to 125°C	+22, -56% ΔC 10 to 85°C

The volumetric efficiency of ceramics comes from the high values of K which are possible. This result is in contrast with tantalums and other electrolytics which gain efficiency primarily from very close spacing of electrodes. A 50-volt ceramic dielectric, for example, would be about 60 times as thick as a 50-volt tantalum oxide dielectric.

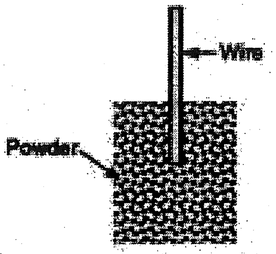
Now on to the next major class of electrodes. The solid tantalum capacitor is generally included in the class of "electrolytic" capacitors, although it doesn't belong there. An electrolytic capacitor is one which uses an electrolyte for at least one of the electrodes. An electrolyte must generally be made of some chemically ionizable compound dissolved in a liquid. The solid tantalum capacitor (also sometimes called a dry tantalum capacitor) uses manganese dioxide, rather than a liquid electrolyte, as an electrode. Because of similar characteristics and historical development, the manganese dioxide came to be called a solid electrolyte, but it really is not; it falls generally into the class of semi-conducting solids.

The basis of the solid tantalum capacitor is tantalum. Tantalum is an element with certain properties that produce the characteristics found so desirable in finished capacitors. Foremost, of course, is the fact that it is a "valve" metal (aluminum is another) upon which one may grow very uniform and stable oxides with good dielectric properties. The dielectric constant of tantalum oxide (at 26) is relatively high. To form a high quality oxide film requires very high purity of the metal substrate. Tantalum melts at 3000°C and can be worked above 2000°C in vacuum. Under these conditions, most impurities can be evaporated and pumped away. Finally, tantalum is relatively easy to work mechanically. It can be ground to powder, rolled to sheet, drawn to wire, bent and formed without great difficulty at room temperature.

Characteristics of Tantalum

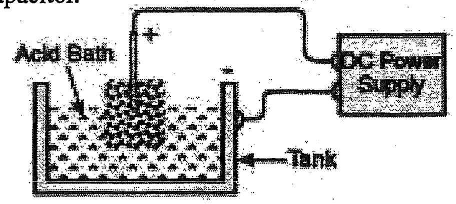
Valve metal
Excellent dielectric properties of oxide
Excellent purification process available
(high vacuum at 2000°C)
Easily worked mechanically

To make capacitors from this material, tantalum powder and tantalum wire are needed. These two are pressed together, usually with some form of organic binder which is later removed. The pressed form is normally cylindrical for leaded capacitors and is usually rectangular for surface mount types. While it is also possible to press only the powder and weld on the wire later, the pressed in wire-and-powder assembly shown here is by far the most popular method. These pellets are sintered in vacuum furnaces. Sintering is a process of slow fusion between adjacent surfaces, so that when the pellets emerge from the furnace they are strong mechanically and have shrunk somewhat from their original size. About half the volume of the sintered powder remains as void space.



Pressed and Sintered Tantalum

The pellets are then immersed in an acid bath and connected to the positive terminal of a DC power supply. The flow of current causes a layer of tantalum pentoxide, Ta_2O_5, to grow on all exposed surfaces of the tantalum. The exposed surface includes the wire and both external and internal surfaces of the sintered powder. The internal surface is over 100 times the apparent external area. The oxide layer later will become the dielectric of the capacitor. One electrode of the parallel-plate model is the tantalum metal; the second electrode will be applied in subsequent processing steps. The effective area of the capacitor becomes the entire surface of the tantalum pentoxide dielectric which can be contacted by the second separation between electrodes is the thickness of the oxide layer. This thickness is controlled by the voltage applied from the power supply. The higher the voltage, the thicker the oxide layer grows. Greater separation between electrodes means lower capacitance, of course, but it also means a higher voltage rating for the finished capacitor.

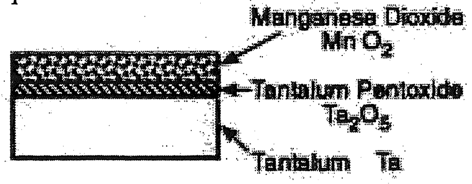


Anodizing

The second electrode is the semi-conducting manganese dioxide, MnO_2. To apply this material, the porous pellet is dipped into a manganous nitrate solution which wets all surfaces and fills up the pores. When the pellets are later heated, the water from this solution is evaporated and then the nitrate decomposes to form the oxide according to this chemical equation. The MnO_2 layer covers nearly all the internal surfaces and extends part way up the wire.

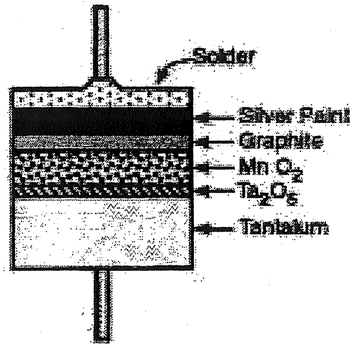
$$Mn(NO_3)_2 \xrightarrow{Heat} MnO_2 + 2NO_2\ (Gas)$$

Look at one small portion of the pellet at this point, and see the tantalum substrate, the tantalum pentoxide grown upon the substrate, and, finally, the manganese dioxide deposited upon the tantalum pentoxide. It begins to look familiar as a parallel-plate capacitor.



Tantalum Pellet

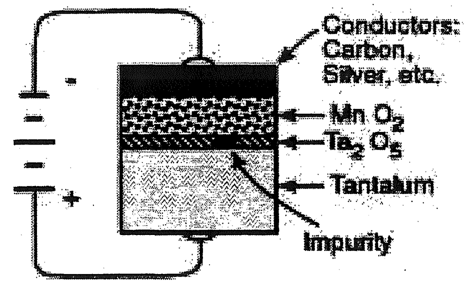
The rest of the processing is needed only to gain electronic contact to the electrodes. It is easy to weld an external lead wire to the stub of the tantalum wire, but contacting the MnO_2 is more difficult. To do this, the pellets are dipped into water containing a very finely divided carbon powder. After the water is evaporated, a layer of carbon (actually graphite) is left on all surfaces of the MnO_2. Resistivity of the graphite is much lower than that of MnO_2, and the fine particle size of the graphite enables this material to touch nearly all the very irregular MnO_2 surface. On top of the graphite, a silver-pigmented paint is applied. The sliver is held by an organic resin and presents a solderable surface to facilitate attachment of the second lead wire. Putting all the layers together gives us a section which looks like this, with two wires being shown as indicative of external connection:



All Tantalum Layers

The encapsulation of a solid tantalum capacitor can follow several courses. The original design was soldered inside a metal can closed with a glass-to-metal hermetic seal. The next commercial design used potting with an epoxy resin inside of a premolded plastic shell. Later can transfer molding with epoxy, and then dipping in liquid epoxy resin. The final step in evolution is the tantalum chip, which has been encapsulated in epoxy and has several innovations in terminal design to provide protection against the rigors of directly soldering onto ceramic or glass epoxy substrates.

Much work has gone into statistical treatment of failure rates of solid tantalum capacitors because these capacitors possess a unique "healing" mechanism which results in a failure rate apparently decreasing forever. The MnO_2 provides the healing mechanism. If a fault, perhaps some impurity, produces an imperfection in the dielectric layer, a heavy current will flow through that minute area when a DC potential is applied to the capacitor. The current also flows through the MnO_2 immediately adjacent to the fault. Resistance of the MnO_2 to this current flow causes localized heating. As the temperature of MnO_2 rises, this material is converted to a lower oxide of manganese, perhaps $Mn_2 O_3$, with much higher resistivity. The increase in resistance decreases the current flow. If this mechanism is successful, the current flow is reduced before localized heating goes too far, preventing a short circuit. Without this mechanism, the solid tantalum capacitor would never have gotten off the ground commercially.



PERFORMANCE OF STATE-OF-THE-ART AND ADVANCED CAPACITOR SYSTEMS

Capacitor System	kJ/kg Now / Future	kW/kg (average power) Now / Future	Rep-Rate Hz	Main Issues
Polymer Film	0.4 / 20	5 / 20 k	> 100 k	* New Polymer Films * Impregnants * Foils and Conductors * > 200 °C * >> 1 kJ/unit * Voltage Reversal * Pulse Duration * Repetition Rate
Ceramic	0.01 / 5	10 / 10 k	> 1000 k	* Ceramic Formulations * Electrodes * > 300 °C * 1 kJ/unit * Voltage Scaling * Fusing
Electrolytic	0.2 / 2	2 / 10 k	> 10 k	* Electrolytes * Separators * > 200 °C * 1 KJ/unit * Gassing * Hermetic Sealing * Voltage Reversal * Pulse Repetition Rate
Mica	0.005 / 0.05	5 / 50 k	> 100 MHz	* Electrodes * > 400 °C * 1 kJ/unit * Voltage Scaling/Reversa * Materials * Impregnants

The Role of Film Capacitors in the Replacement of Electrolytic Capacitor Assemblies

Table

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1. Abstract

This paper explores electrolytic capacitor limitations in terms of performance and lifetime. With the emergence of IGBT/GCT - based voltage fed inverters, the use of higher switching speeds makes a case for reduced minimum capacitance necessary to provide adequate smoothing, where electrolytics have previously been used for their current capabilities rather than their absolute capacitance value.

At higher voltages, where series connected electrolytics dictate the need for multiple assemblies, film dielectrics can often provide a convenient solution, particularly since improved metallisation techniques allow capacitor designs in smaller sizes than previously possible. The film solution offers reduced component count and ease of installation. The paper concludes with a case study where a successful design has been converted into a major contract and where over 2000 pieces of this generic design have now been sold worldwide.

2. The Present

Many equipment manufacturers are now experiencing problems after some 5 to 7 years of service where electrolytic capacitors suffer from drying out of the aqueous electrolyte. The subsequent short circuit is often catastrophic in nature. Whilst for some this is an opportunity for spares sales, others are looking at ways of designing around the problem for their new generations of IGBT and GCT based inverters and for increased reliability.

Capacitors for dc link applications for inverters comprise both electrolytic and polymer film types. For applications where the line voltage is less than 500V, there has been little that film capacitor manufacturers have been able to do to compete until recently, particularly with relatively low inverter switching speeds. For higher voltages, series arrangements of electrolytic capacitors have traditionally been used, together with the associated sharing resistors and multiple connections. This is an area where film capacitors can compete.

3. The Reasons for Change

A comparison of the characteristics of electrolytic and film capacitors can be summarised as follows:

Parameter	**Electrolytics**	**Metallised Polypropylene**
Lifetime	Up to 100k hours at 55°C, catastrophic failure	200k hours+ at 80°C, slow degradation of capacitance (<3%)
Ripple current capability	~15mA/µF at 450Vdc, 1kHz	~90mA/µF at 900Vdc, independent of frequency
Losses	Tan δ ~0.01 (100Hz)	Tan δ ~0.0002 (up to 1MHz)
Working voltage	500V max.	Up to 4kV typical
Voltage surge capability	+10% typical, short circuit	>2 x Un, self healing
Voltage reversal	1.5V max	100% capability
High voltage configuration	Series/parallel combinations, sharing resistors, multiple connections	Single unit, possibly two or three in parallel. Reduced component count

6. Case Study

A case study has been made at the request of the customer who had been experiencing electrolytic capacitor failures on older equipment and who had made the conscious decision to change to film capacitors for a new range of power conditioning equipment that he was contemplating. From the initial value of 32.4mF at 800V, made from 48 electrolytic capacitors, the designer had calculated that 5.4mF was still acceptable, providing he could have 900A ripple current capability. In addition, he wished to raise the line voltage. The following table shows a comparison of the relevant parameters:

Parameter	**Electrolytic**	**Metallised Polypropylene**
Capacitance value (original)	32.4mF	
Capacitance value (final)		5.4mF
Configuration	48 caps, 24 in // x 2 in series	3 units in parallel
Nominal dc voltage	480V x 2 (800V)	1000V
r.m.s. current	1000A at 2kHz	900A at 2kHz
Max. thermal rating		456A (x3) at 50°C
Max. operating temperature	50°C	50°C
Overall volume	86.4 litres	28.5 litres
Inductance		~20nH for 3 units in parallel
ESR (total)	2.1mΩ	0.1mΩ
Surge voltage	1.1 x Un	2 x Un
Price comparison (caps only)		95% of electrolytic solution

This particular design was a most convenient solution, optimising size, current capability, inductance and cost. Care had to be taken by the equipment designer to ensure correct current sharing for each inverter with multiple parallel connected inverters providing power to the load. The terminal assemblies are precisely located so that laminar busbars can be used and thereby keep inductance to a minimum. Unfortunately, due to commercial security, we are not able to show photographs. An important consideration was the reduction in component count, not just the number of capacitors, but also the removal of the sharing resistors. Assembly time was reduced and the reliability of the complete equipment was increased.

7. Summary

Metallised polypropylene capacitors are playing an increasingly important role in the replacement of electrolytic capacitors, particularly where long life reliability is a major concern. For the replacement of series connected electrolytics in particular, the advantages of a single can solution can often outweigh the cost not only of the electrolytics, but also that of the associated resistors and hardware.

It is important to note, especially with IGBT/GCT based designs, where inductance and losses are critical, to involve the capacitor manufacturer at the earliest possible stage in the design process. Space constraints at a later date can lead to non-optimisation of these critical parameters. Finally, equipment designers should note that overspecifying parameters, particularly voltage, for 'safety' purposes, can result in an overdesigned, oversized and over-costly capacitor.

Tony Daykin
Norfolk Capacitors Ltd
Chicago, November 1999

References:

1. Say, M.G., "Electrical Engineers Reference Book," Newnes
2. Terman, F.E., "Radio Engineers Handbook," McGraw Hill
3. Maniscalco, P.S., Scaini, V., Veerkamp, W.E., "Specifying DC Chopper Systems for Electrochemical Applications," IEEE Publication PCIC-99-13

windings. This also reduces the losses due to skin effect which become increasingly apparent with the rise in switching frequency. There are design limits in A/m for both r.m.s. and peak current parameters. Of course there is always the downside - smaller windings mean extra winding and assembly time with the consequential increase in cost. However, the advantage is that the capacitor will achieve the performance within the space constraints given – you pay for what you get!

5.2 Terminations

Low resistance terminations are necessary at high r.m.s. currents. The use of brass is normally favoured due to the combination of mechanical strength and conductivity, but copper can also be used when losses are critical – copper has approximately five times better conductivity than brass in this respect. Of course copper is more expensive, but, as above, when applications are working close to the limit and space is at a premium, the extra cost involved may not necessarily be a consideration.

The hot spot of a polypropylene capacitor should not exceed 80°C for reliable long-term applications, 70°C is better. The use of better cooled busbars, whilst perhaps more intricate and costly, could have a beneficial effect on the filter capacitors which are often located directly onto them in as part of a stripline assembly. In general terms, a temperature rise of about 10C° could be expected for an IGBT filter capacitor with 150 to 200 A r.m.s. flowing through it. Busbar temperatures in excess of 70°C are not recommended in that the capacitor could act as a heat sink. Unwanted thermal transfer into the capacitor could cause premature failure by unacceptable loss of capacitance value, in exceptional circumstances even to the point of meltdown!

5.3 Internal Connections

The connections to the capacitor element are critical to satisfactory performance. Inadequate end spray methods, poorly rated connections and inefficient soldering techniques all give rise to increased losses which when operating a capacitor to its limits can often be catastrophic.

The materials traditionally used in the endspray process are tin and zinc. Tin tends to give improved solderability, whilst zinc has better adhesion to the metallised electrode. The importance of the correct selection, together with arc current and spray pressure is perhaps a matter for a technical paper in itself.

Equally important is the selection of the correct connection to the endspray of the windings and the internal connection to the termination. Stranded wire has little place with currents of the magnitude that modern IGBT filters demand. Braid connections do not allow the heat generated in the windings to be transferred effectively to the terminals. Copper strip is both effective and flexible in use. It allows for high currents and effective thermal transfer. However, with increasing frequencies encountered in IGBT filtering applications, due account has to be taken of skin effect.

5.4 Skin Effect

The classic formula of skin effect for a rectangular copper conductor is:

$$R' = K\frac{261\sqrt{f}}{2(a+c)} \times 10^{-9}$$

where: R' = effective resistance (Ω/cm)
K = the constant determined the ratio of the width and thickness of the conductor
a = width of the conductor (cm)
c = thickness of the conductor (cm)
f = frequency (Hz)

The K constant is determined by the following graph:

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f = frequency (Hz)

The K constant is determined by the following graph:

TUCAY Lecture 9

General information
Explanation of important terminology

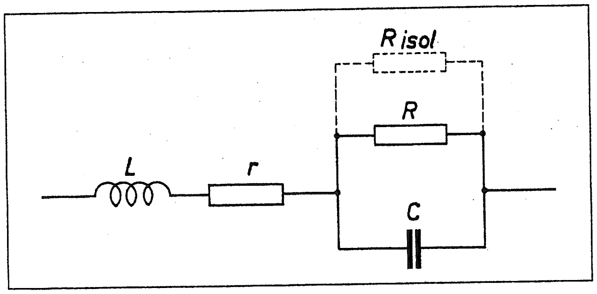
Rated capacitance
The rated capacitance of a capacitor is usually given in pF or µF.

Operating / rated voltage
Each capacitor is designed for a specified rated voltage in continuous operation.
This is usually only valid for ambient temperatures of ⩽ +85° C.
In the case of higher temperatures a derating factor must be applied to the rated voltage at 85° C.

In view of possible interference pulses, exclusively approved radio interference suppression capacitors are suited for continuous service on the mains.

Insulation resistance / time constant
The insulation resistance is normally expressed in megohms and is measured at a specified voltage after 1 minute.
The time constant defines the time in seconds, in which the voltage across the capacitor self-discharges to 37% of the fully charged state and it is expressed as $\tau = R_{is} \times C$.
The insulation resistance or time constant value denotes the quality of the dielectric insulation.

Dissipation factor
The dissipation factor tan δ is the quotient of the resistive and reactive parts of the impedance.
The a.c. dielectric losses are illustrated by R in the equivalent circuit diagram. The insulation resistance R_{is} is in parallel with R, and affects the tan δ only at very low frequencies.
The dissipation factor is also affected by the resistance of both electrodes and of the termination – electrode interface. This is represented by the series resistance r. L represents the remaining self-inductance.



Capacitance tolerance
The tolerance is the permissible actual capacitance relative to the nominal capacitance and it is defined in per cent. The tolerance is to be measured at 20° C and the permissible tolerance is only valid at the time of shipment.
The capacitance may change after long storage or long usage.
The tolerance, with the exception of ± 20% is usually marked on the capacitor body in clear symbols.

Temperature coefficient of capacitance
The temperature coefficient α expresses the change in capacitance with temperature, relative to the capacitance at the reference temperature of + 20° C; it is usually expressed in ppm per °C.

$$C_T = C_{20} \times [1 + \alpha \times (T - 20°C)]$$

C_{20} = capacitance at + 20° C
C_T = capacitance at T° C
α may be positive or negative.

Pulse stressing
The ratings on pulse rise time are based on tests in accordance with DIN-IEC 60384 part 1.

The test voltage corresponds to the rated voltage and the test comprises 10 000 pulses with a repetition frequency of 1 Hz.

The catalogue ratings are in accordance with the CECC specifications which specify that the test pulse rise time shall be 10 times the catalogue rating.

It should also be noted that the pulse rise time (F) i.e. V / µs also provides the maximum current capability, as it can be determined from the following formula.

$$I = F \times C \times 1.6$$

C in µF
I in amps.

$i = c\frac{\partial v}{\partial t}$? 1.6 ?

The information on the pulse rise time refers to pulses equal to the rated voltage so that, at lower operating voltages, the permissible pulse rise times may be increased.

ISO 9000 Certification
ISO 9000 is an international basic standard of quality assurance systems for all branches of industry. The approval according to DIN EN ISO 9000 of our factories at Berlin, Aurich, Unna and Mannheim (all in Germany) by the VDE inspectorate certifies that organisation, equipment and monitoring of quality assurance in our factories correspond to internationally recognized standards.

All WIMA-components are shipped with constant quality standard which reduces to a minimum incoming inspection of the customer. A mere identity control will be suffice.
Even internal homologation is no longer necessary.

The CECC System
CECC is a European system for the quality assessment of electronic components that harmonizes with international IEC standards. All WIMA families are produced in conformity with the severe CECC specifications partly existing as new EN specifications. The characteristics of the components are laid down in the component detail specification.

The corresponding international test and requirement standard specifications are listed in the various chapters of the component ranges. The data mentioned in the catalogue may deviate, in a positive sense, from the contents of the mentioned component specifications.

dielectrics used

four P's

Polyester

For general applications e.g. decoupling, coupling and by-pass applications

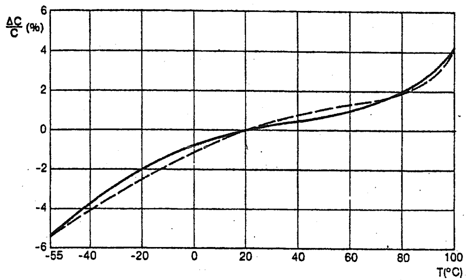
sputter thin film →

Metallized capacitors: SMD 1812 · SMD 2220-N · SMD 2824-N · SMD 2220 · SMD 2824 · SMD 7.3 · SMD 4036 · SMD 5045 · SMD 6560 · SMD 8067 · SMD 11580 · SMD 13595 · SMD MKS 10 · MKS 02 · MKS 022 · MKS 2 · MKS 2-i · MKS 22 · MKS 3 · MKS 4 · MKS 10

2 block →

Film/foil capacitors: FKS 02 · FKS 2 · FKS 3

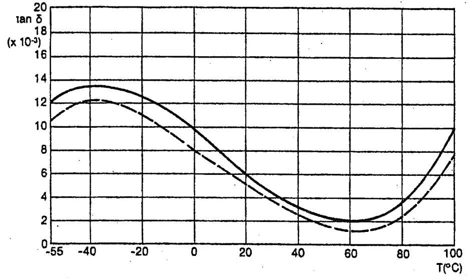
6% @ 100°C



Capacitance change with temperature (f = 1 kHz) (general guide)

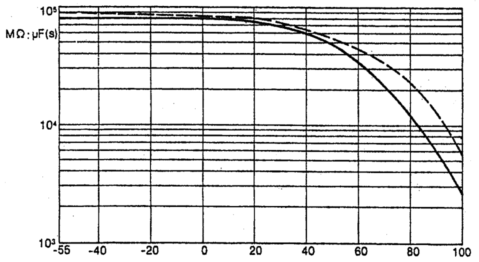
typically 10^{-2}

$\tan\delta = \frac{R}{1/\omega C} = R\omega C$



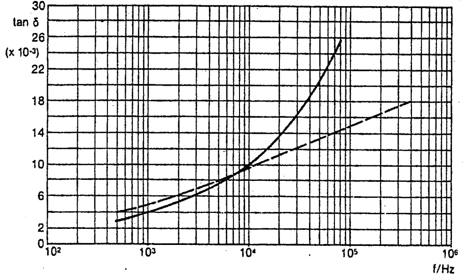
Dissipation factor change with temperature (f = 1 kHz) (general guide)

varies * 7



Insulation resistance change with temperature (general guide)

typically 10^{-2}

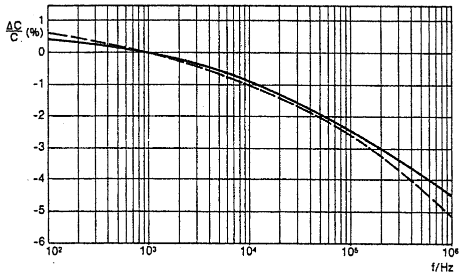


~~Dissipation factor~~ ~~change with~~ ~~frequency~~ (general guide)

tanδ ↑ with f

*10

6% @ 1MHz



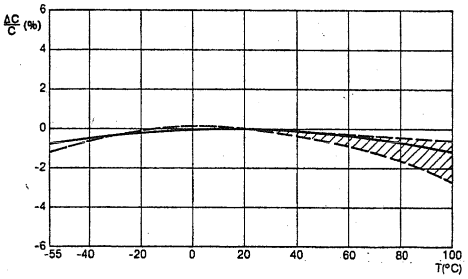
Capacitance change with frequency (general guide)

Polycarbonate

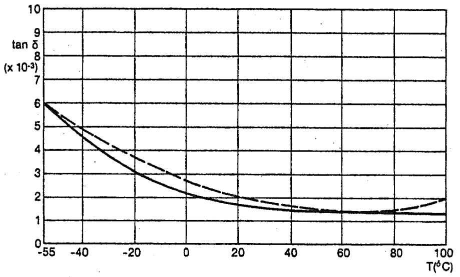
For special applications where an almost constant temperature effect is required: filters, memories, timers, balancing capacitors

Metallized capacitors: MKC 02 · MKC 2 · MKC 3 · MKC 4 · MKC 10

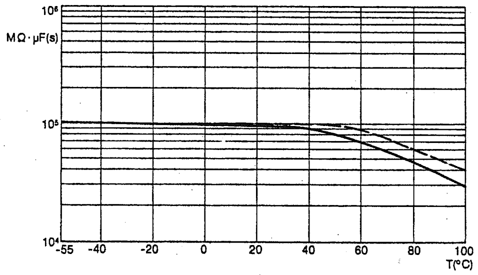
Film/foil capacitors: FKC 02 · FKC 2 · FKC 3



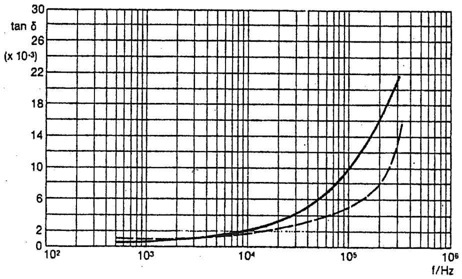
Capacitance change with temperature (f = 1 kHz) (general guide)



Dissipation factor change with temperature (f = 1 kHz) (general guide)



Insulation resistance change with temperature (general guide)



Dissipation factor change with frequency (general guide)

Annotation:

The full lines characterize the metallized versions

The broken lines show the film/foil types

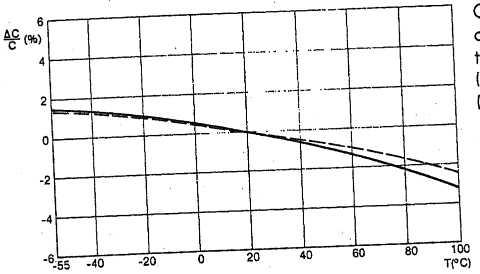
Typical graphs of the dielectrics used

Polypropylene

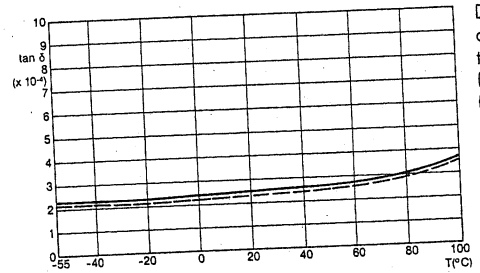
For high frequencies e.g. in power supplies, deflection systems, lighting and audio applications

Metallized capacitors:
MKP 2 **MKP 3** **MKP 4** **MKP 10** **Snubber MKP**

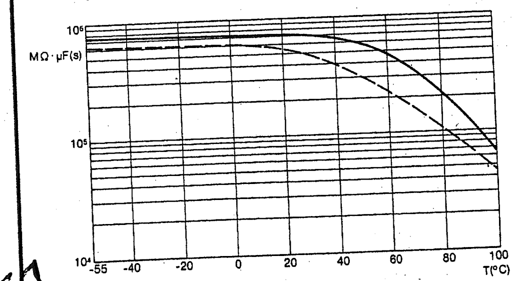
Film/foil capacitors:
FKP 02 **FKP 2** **FKP 3** **FKP 1** **Snubber FKP**



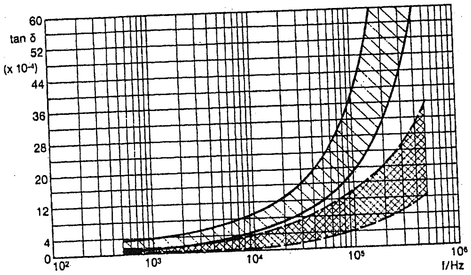
Capacitance change with temperature (f = 1 kHz) (general guide)



Dissipation factor change with temperature (f = 1 kHz) (general guide)



Insulation resistance change with temperature (general guide)



Dissipation factor change with frequency (general guide)

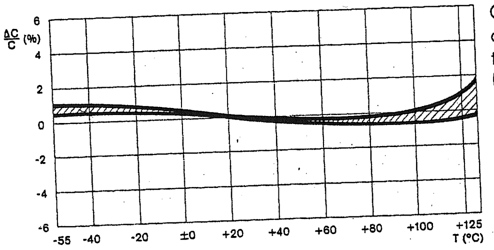
tanδ
2x2
+
±10

Polyphenylene-sulphide (PPS)

Special applications for high temperature stability and temperatures up to + 140° C

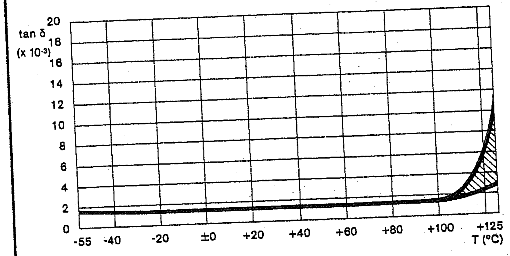
Metallized capacitors:
SMD 7.3 MKI **MKI 2**

Film/foil capacitors:
SMD 7.3 FKI **SMD FKI 3** **SMD FKI 1** **FKI 2**

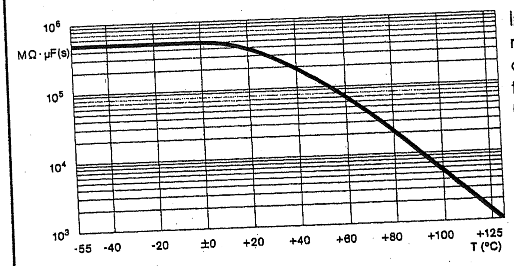


Capacitance change with temperature (f = 1 kHz) (general guide)

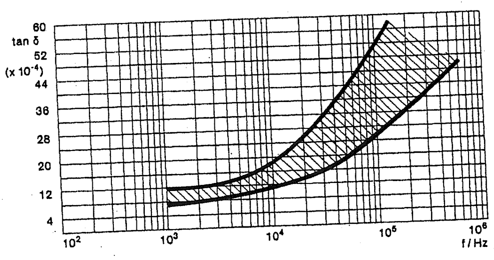
No Change with T



Dissipation factor change with temperature (f = 1 kHz) (general guide)



Insulation resistance change with temperature (general guide)



Dissipation factor change with frequency (general guide)

Characteristics of the plastic film dielectrics*

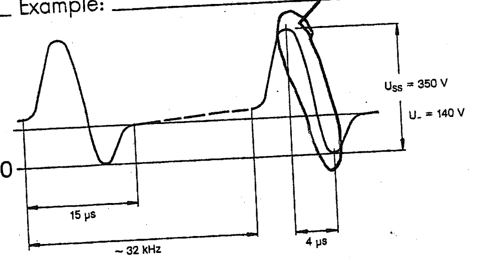
	Dielectric constant 1 kHz/23° C	Specific volume resistance Ω cm/23° C	Dielectric strength in V/µm at 23° C	Preferred temperature range	Dielectric absorption in % at 23° C
Polyester	3.3 (positive as temperature rises)	10^{18}	580 V–	–55…+100° C	0.20…0.25
Polycarbonate	2.8 (largely constant over temperature range)	2×10^{17}	535 V–	–55…+100° C	0.12…0.20
Polypropylene	2.2 (negative as temperature rises)	6×10^{18}	650 V–	–55…+100° C	0.05…0.10
	3.0 (very constant	5×10^{17}	470 V–	–55…+140° C	0.05…0.10

6

The selection of capacitors for pulse applications and graphs of WIMA FKP 1

worst case ∂V/∂t
∂t ~ 4 μs

Example:



Selected capacitor: WIMA FKP 1/0.22 μF

31 μs = T   1/T   T/4   ≈ 8 μs   2.8

Determination of the nominal voltage

$U_r \geqslant 2.5 \times 350$ V (k ≈ 0.4 for f = 32 kHz) see graph 1

Cap spec req'd → $U_r \geqslant 875$ V

$U_{rms} \sim 70$ V (referring to AC voltage share)

Selected nominal voltage: 1000 VDC/600 VAC

lead spacing 37.5 mm

Permissible voltage gradient

4 μs? Why not 8 μs

The voltage rise time is: $\frac{350\ \text{V}}{4\ \mu\text{sec.}} \cong 87.5\ \text{V}/\mu\text{sec.}$

Value from table "pulse rise time WIMA FKP 1" page 67: 2200 V/μsec.

The calculated voltage gradient is lower than the permissible value shown in the catalogue for this capacitor.

Not 1 cycle
1/2 cycle of 32 kHz
1/4 cycle 15 μs

Dissipation

Given: $U_{rms} = 70$ V
f = 32 kHz
C = 0.22 μF

The frequency determined from the steepest part of the pulse is:
Pulse width = 15 μsec. = 1 cycle

$$\text{Hence pulse frequency} = \frac{1}{15 \times 10^{-6}} \cong 66\ \text{kHz}$$

The tan δ of WIMA FKP 1 at 66 kHz ≅ 10×10^{-4} (graph 4 for FKP 1 on this page)

$P_d = 70^2 \times 2\,\pi \times 32 \times 10^3 \times 0.22 \times 10^{-6} \times 10 \times 10^{-4}$
≅ 0.217 Watts

The selected capacitor has a lead spacing of 37.5 mm (table 1) and the temperature rise due to self-heating is:

$$\text{Temperature rise} = \frac{0.217\ \text{Watts}}{0.03\ \text{Watts/K}} \cong +7\ \text{K}$$

The temperature rise plus the max. ambient temperature = max. permissible operating temperature (taking into account the voltage derating factor as detailed in the Technical Data). If the permissible temperature is exceeded, then select a capacitor with a higher voltage rating.

⑧

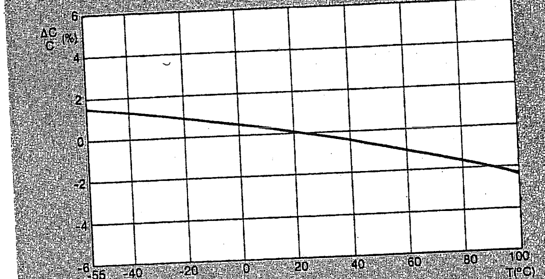
Alternatively, our engineers will submit their recommendations upon receipt of voltage and current oscillogrammes.

Questionnaire available on demand.

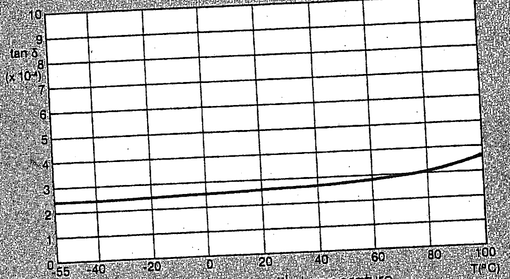
WIMA FKP 1

Capacitors for pulse applications for very high current ratings

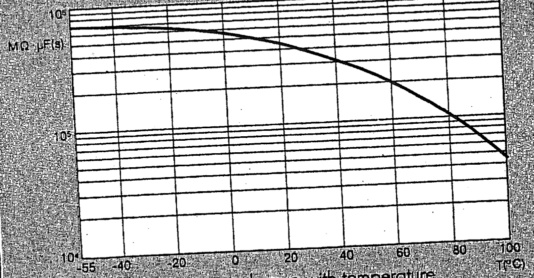
further data page 67.



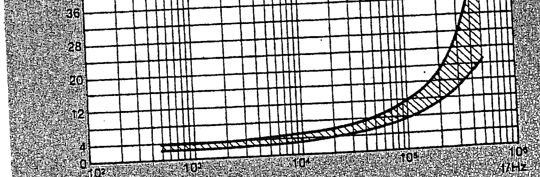
Capacitance change with temperature (f = 1 kHz) (general guide)



Dissipation factor change with temperature (f = 1 kHz) (general guide)



Insulation resistance change with temperature (general guide)



Dissipation factor change with frequency (general guide)