FREQUENCY DISCRIMINATION

Somewhat related to the coupling function of the capacitor is the characteristics of a capacitor that allows an engineer to discriminate between AC signals of different frequencies. In general, the greater the capacitance of a unit, the greater the current will be at any given frequency; and for a given capacitance, the higher the frequency, the more current will pass (up to the resonant frequency of the capacitor — the point of maximum current transfer). By utilizing this characteristic, an engineer can distinguish between AC currents of different frequencies. Again, as in the coupling application, the dissipation factor (heat producer under AC applications) can be critical.

TIMING

This function is really a control on the "speed of response" of the charging and discharging time for a capacitor and its associated circuitry. The rate at which charge flows in and out of the capacitor is directly controlled by the capacitance (C) and series resistance (R) of the circuit. Therefore, the "timing" or speed of response of a circuit can be controlled by using various RC combinations. This combination of R and C is known as the "TC" or "time constant". Usually, the most critical parameter to be considered in a "timing" applicaation is that of capacitance change with temperature (temperature coefficient). The variance of capacitance with time, and the retrace capabilites of the capacitance after temperature excursions can also be critical in certain circuit applications.

TRANSIENT VOLTAGE SUPPRESSION

This characteristic of a capacitor is widely used to provide "voltage stabilization." Most unregulated power supplies are subject to transient peaks of voltage surges which can cause malfunction in the circuit. By utilizing capacitors, these transient peaks are absorbed or stored by the capacitor and a steady voltage signal is supplied to the circuit. This same principle is used to reduce AC ripple voltages in rectified power supplies. Parameter behavior of the various kinds of capacitors is usually of no critical importance for this application.

ENERGY STORAGE

By using the capacitor to store energy over a long period of time and then discharging this total energy in a very short time, high currents can be made available to perform welding, photo-flash, heating, and other similar jobs. For the case of fairly high pulsing service, the dissipation factor may be of concern from a heating consideration. The most critical factor here is the current-carrying capabilites of the unit, leads, and connections.

ARC SUPPRESSION

"Make-break" type circuits, whereby mechanical relays or similar devices are used to periodically interrupt a current flow, causes arcing at the contact points. This results in a "noise" signal that can interfere with nearby radio and television reception. The use of capacitor-resistor and/or inductor combinations will reduce or eliminate this interference and prolong the life of the contacts by absorbing the voltage pulse resulting from this current interruption.

POWER FACTOR CORRECTION

Part of the total power generated by, or supplied to a circuit must be used to energize or activate certain components within the circuit. This power is effectively lost within the circuit and therefore not available for other uses. By using capacitors, this percent loss of power can be and is reduced, thus "correcting" or "improving" the power factor of the circuit. The immediate benefit from this "corrected" power factor is the reduction in lost power from the original total power generated, or the ability to increase the total power generated without additional equipment.

Specialized jobs such as voltage and frequency doubling, commutating, etc., are really combinations of the basic functions already described.

The selection of the "right capacitor for a specific job is really a matter of matching the capabilites of the capacitor to the requirements of the job.

TECHNICAL BULLETIN NO. 03

CAPACITORS...CAPACITANCE CHANGES —WHY?

In our circuit applications, the capacitor can be and is subjected to various electrical, mechanical, and environmental stresses. One of the most noticeable effects of these stresses is the phenomena of capacitance variation.

Now, the fact that the capacitance does vary will come as no surprise to most design engineers. Further, the fact that different kinds of capacitors will vary in different ways is also fairly common knowledge to those concerned. Our purpose in this article is to examine what causes this variation, determine why the capacitance changes, and compare the extent of the variation for the common capacitor dielectrics.

First, let's analyze our basic formula for capacitance:

$$C = \frac{KA}{d}$$

Where: C = Capacitance
K = Dielectric Constant
A = Effective Area
d = Distance between electrodes

We note that C varies directly with A and K, and inversely with d. Any change in C must come as a result of some change or combination of changes in A, K, or d.

A (effective area of electrodes) is set by design and once a capacitor is made, it is almost impossible for C to change due to a change in A. This, then, is not a normal factor in capacitance variation.
d (distance between the plates) is also set by design. Some small changes in d can occur on completed units due to external or internal pressure changes resulting in mechanical movement of the electrodes. This is not usually critical nor does it result in any large variations.

K (dielectric constant) is also initally set by design in the choice of dielectric material used to make the capacitor. Now, however, the complications begin — many factors will cause the K to change, and this change in K will vary for different materials. We see, then, that the major factor involved in why the capacitance changes is the fact that K does vary.

In order to clearly understand the various factors that cause K to change, and to what extent these changes take place for the common dielectrics, the following clarification is of interest.

The K (dielectric constant) in our basic formula is the effective dielectric constant of the total "space" between the electrodes. This "space" will consist of the dielectric material (or materials if a multiple dielectric design), air, impregnant (if an impregnated unit), and even moisture (if present). All of these dielectrics are effectively in series and therefore the resultant K_r would be:

$$K_r = \frac{1}{\frac{d_1}{d_t K_1} + \frac{d_2}{d_t K_2} + \frac{\ldots d_n}{d_t K_n}}$$

where: d_t = Total distance between electrodes
d_1 = Thickness of dielectric (1) with K_1
d_2 = Thickness of dielectric (2) with K_2
d_n = Thickness of dielectric (n) with K_n

or, for simplification:

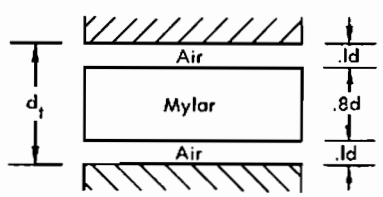
$$K_r = \frac{1}{\frac{\% d_1}{K_1} + \frac{\% d_2}{K_2} + \frac{\ldots \% d_n}{K_n}}$$

Where: d_t = 1 (100%) and d_1, d_2, ... d_n are expressed as % of d_t.

The major factors that will cause a change in K are moisture, voltage, frequency, and temperature.

MOISTURE

Whenever moisture vapor penetrates into the dielectric of a capacitor, the capacitance will increase somewhat depending on the amount and effectiveness of the penetration, the percent of the total distance between the electrodes that is represented by air, and the percent of the air that is saturated or, in effect, replaced by the moisture.
For illustration purposes, let us assume the following:



K_m (Mylar) = 3.0
K_a (Air) = 1.0
K_w (Water) = 80.0

Moisture replaces 50% of air.

Without moisture:

$$K_{m+a} = \frac{1}{\frac{\% d_m}{K_m} + \frac{\% d_a}{K_a}} = \frac{1}{\frac{.8}{3} + \frac{.2}{1}} = 2.14$$

With moisture:

$$K_{m+a+w} = \frac{1}{\frac{\% d_m}{K_m} + \frac{\% d_a}{K_a} + \frac{\% d_w}{K_w}} = \frac{1}{\frac{.8}{3} + \frac{.1}{1} + \frac{.1}{80}} = 2.72$$

For this illustration — we see approximately a 27% increase in capacitance due to the moisture.
Of course, you would not normally see this kind of gross moisture penetration, but — increases up to 5% are not uncommon on non-hermetically sealed commercial units when tested to the MIL-STD accelerated moisture tests.

VOLTAGE

With the exception of the General Purpose (high K) ceramics, voltage stress has only a very minor effect on the K of the standard dielectric materials.
In the case of the high K ceramics an AC voltage will cause the K to increase while a DC voltage will cause a decrease in K. The amount of charge will depend upon the original value of K for that particular ceramic mixture.

As an example, for a K = 1200 mix, it is not uncommon to see changes amounting to approximately +20% with 20 VAC (RMS) applied and −30% with 200 VDC applied.

FREQUENCY

For our primary area of application interest, we are concerned mainly with the low frequency band of 0 to 30K Hz. In this area. the K of mica, glass, teflon, polystyrene, and NPO type ceramic dielectrics, does not exhibit any measureable change. Polycarbonate film will show a slight decrease in K of about .4% at 30K Hz. Mylar will drop about 1.5 to 2.0%, high K (1200) ceramics approximately 2.0 to 2.5%, and paper-impregnated units between 3.0 to 6.0%, depending on the impregnant. Reference measurement frequency here is 1000 Hz.

TEMPERATURE

Temperature will have an effect on the K of all standard dielectric materials. This effect will be fairly small on some dielectrics and quite extensive on others.

The following charts compare the average curves of various dielectrics relative to the capacitance variations with temperature. Special processing and other factors can be used to alter these curves somewhat.

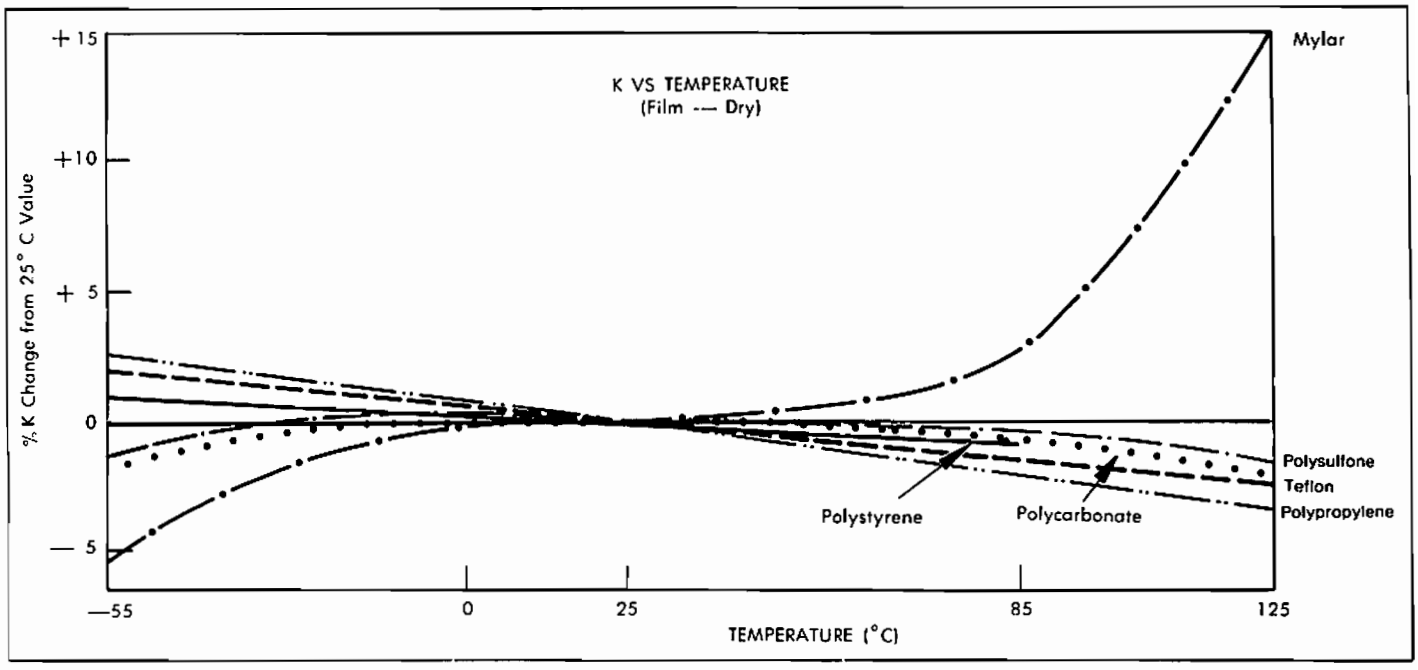


Figure 1

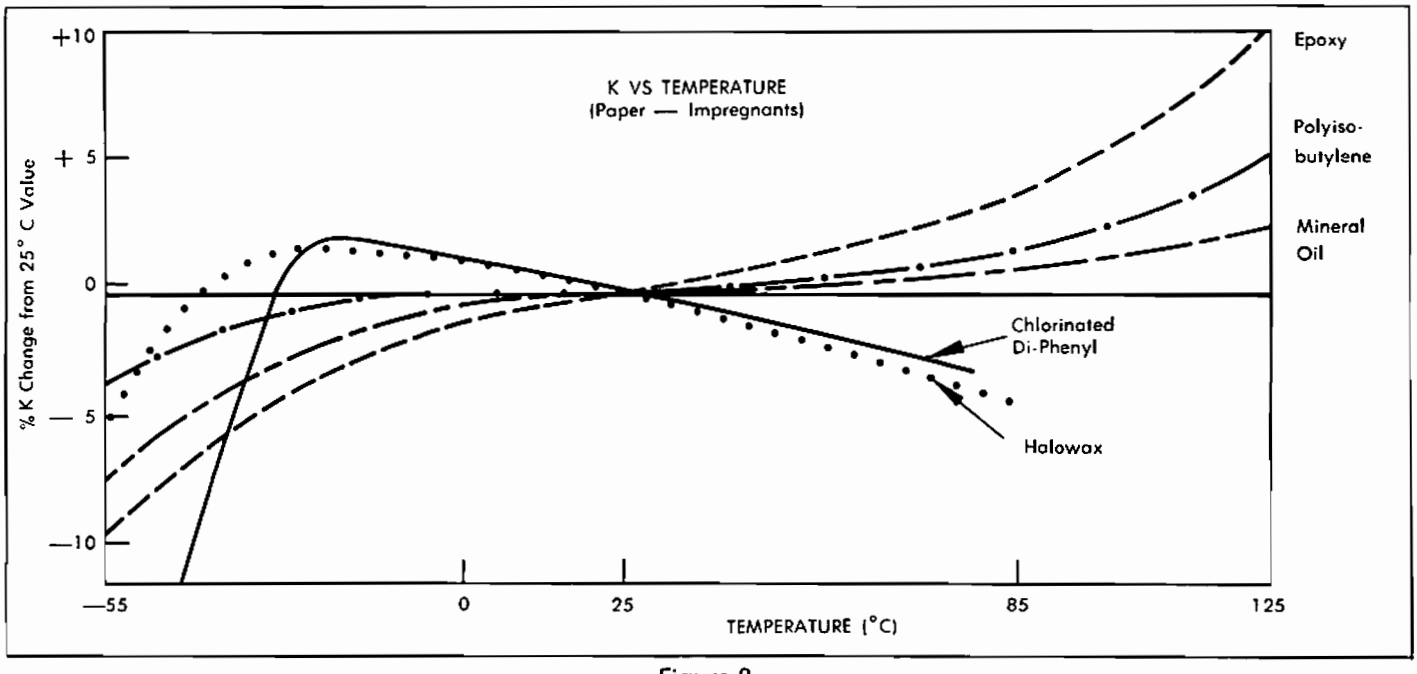


Figure 2

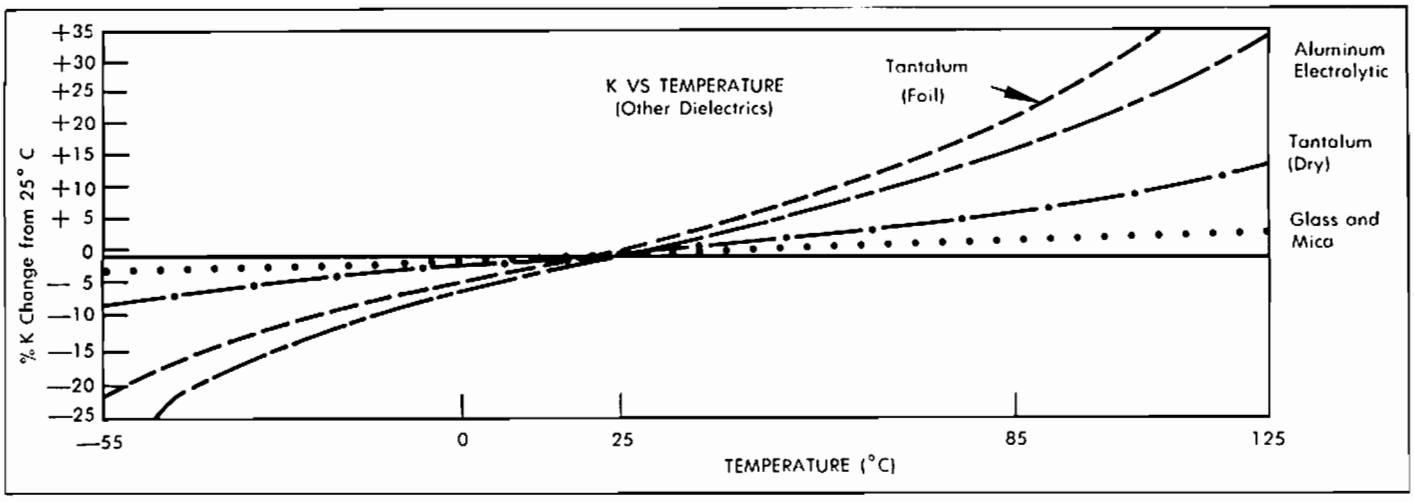


Figure 3

Figure 1 is based on "dry" type film units; that is, no impregnants have been used. Actually, the films will not impregnate, but the use of impregnants as a "filler" is quite common to achieve certain results. When this is done, some alterations in the curves will result.

Figure 2 illustrates quite vividly the impact that the various impregnating materials have on the resultant K of the material between the electrodes. And, to further complicate the picture, the use of various additives to the impregnating material can alter even these curves considerably.

Figure 3 shows the relative curves for other common dielectrics.

For the case of ceramic capacitors, a plot of a "typical" capacitance vs. temperature curve is not feasible since these units can be made to exhibit almost any characteristic desired depending on the dielectric mixture used, processing, method of assembly, and stabilization techniques used following manufacture.

In this article, we have seen how external stresses applied to the capacitor causes the capacitance to vary. Future articles will discuss how these same stresses affect other parameters.

TECHNICAL BULLETIN NO. 04

CAPACITORS...INSULATION RESISTANCE CAN BE CONFUSING!

Confusing? Yes — it can be — but doesn't have to be! An understanding of the basic principles involved in this concept of "Insulation Resistance" should help to dispel this confusion.

When a capacitor is charged from a DC energy source, an initial high current flows from the energy source into the capacitor. This current flow rapidly decreases toward zero as the capacitor absorbs it. At the same time, the voltage charge on the capacitor starts from zero and rapidly increases toward the energy source voltage value (see Figure 1).

Once a steady state charge condition is reached, the current flow into the capacitor should be zero, and the capacitor has a voltage charge equal to the source voltage value. Now, if we had an "ideal" capacitor, no further current would flow in the circuit. Unfortunately, there is no "ideal" capacitor obtainable, and a very small "leakage current" does flow in the circuit. This "leakage current" is a result of electrons physically making their way through the capacitor. In a correctly designed and manufactured unit, the "leakage current" is composed of electrons that make their way through the dielectric itself, around the edges and across the surfaces of the dielectric, and between the leads. Usually, the flow of electrons through the dielectric is far greater than the total of the other paths, and therefore the other paths can be ignored.

This "leakage current" through the dielectric is usually converted to the expression "insulation resistance" by using Ohm's Law.

"Insulation Resistance" then, is a measure of the ability of the dielectric to withstand the passage of electrons through itself, and should not be confused with the inherent "series resistance" of the capacitor. For ease of identification, this "insulation resistance" is also referred to as the "parallel" or "shunt" resistance of the capacitor (see Figure 2).