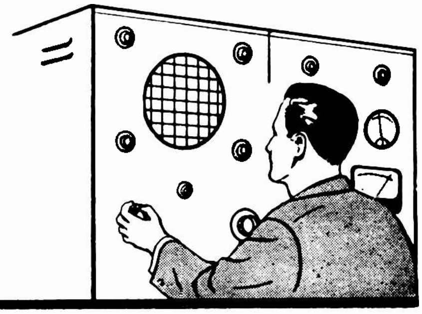
AEROVOX RESEARCH WORKER



The Aerovox Research Worker is edited and published by the Aerovox Corporation to bring to the Radio Experimenter and Engineer, authoritative, first hand information on capacitors and resistors for electrical and electronic application.

VOL. 34, NOS. 1-2-3 JAN.-FEB.-MARCH, 1964 Subscription By Application Only

Dielectric Constant:

Its Meaning & Measurement

By the Engineering Department, Aerovox Corporation

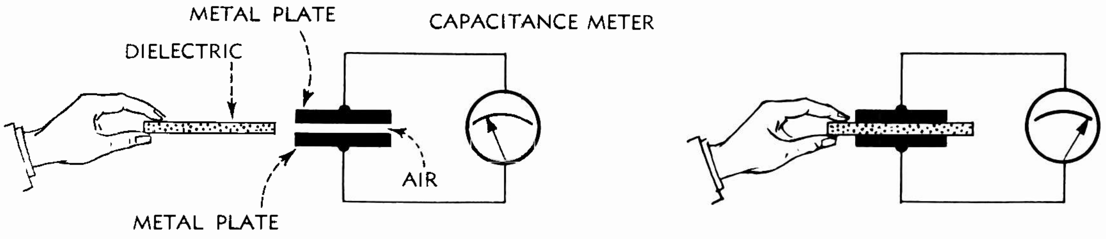
A dielectric material placed in an electrostatic field modifies the field flux in the region, one kind of material concentrating the lines of force in the area and another reducing them. Simplifying the mechanism, we can say it is as if the lines are accommodated more readily by some materials than by others. This effect resembles that accompanying the placement of metal in a magnetic field.

The attribute of a metal, which causes a modification of the magnetic field is described quantitatively as *permeability*, and that of a dielectric, which causes a similar effect on the electrostatic field as *permittivity*. The permeability of dry air is assumed as 1, and so is the permittivity.[1] For dielectrics and magnetic materials other than air, permittivity and permeability, respectively, are greater than 1 and are characteristic of the material.

Permittivity is known also as *specific inductive capacity* and *dielectric constant*, but the latter term (designated by the symbol *k*) is the most common in electronic engineering. Actually, dielectric constant is the ratio of the permittivity of a dielectric material (X) to the permittivity of air (A). That is, $K=E_x/E_a$. But since $E_a=1$, $K=E_x/1=E_x$. (The parallel with permeability is obvious: $\mu_x/\mu_a=\mu_x/1=\mu_x$.) These relationships assume that a constant electromo-

[1] Actually, this is the value for a vacuum. Permittivity of air is given as 1.00007 to 1.009.

Printed by Aerovox Corporation, New Bedford, Mass., U. S. A.



(A) LOW CAPACITANCE (B) HIGH CAPACITANCE

FIGURE 1. EFFECT OF DIELECTRIC CONSTANT

tive force is applied across the dielectric, and that a constant magnetomotive force acts upon the metal. Dielectric constant may also be expressed as the ratio of electrostatic flux density to field intensity.

Dielectric constant is significant in capacitor practice because capacitance is directly proportional to it. That is, a capacitor having fixed plate size and separation, and constant applied voltage will exhibit a different capacitance for each kind of dielectric material inserted between its plates. Thus, where K is the dielectric constant of the material, the capacitance of the capacitor $C_x = K(C_a)$, where C_a is the capacitance when the capacitor has dry air as its dielectric. The straightforward arithmetic relationship is easily demonstrated experimentally: a simple 2-plate capacitor across which a constant voltage is applied and which has a certain grade of mica as the dielectric between its plates will accumulate eight times the charge it accumulates when only air is between the plates separated by the same distance (See Figure 1). Since the charge is directly proportional to voltage and capacitance ($Q=CE$), the capacitance ($C=Q/E$), which is easily measured, will show this 8:1 ratio. The dielectric constant of that mica, then, is 8, since $C_m=8C_a$, where C_m is the capacitance with mica dielectric, and C_a the capacitance with air dielectric ($K_{air}=1$).

While K is called dielectric *constant*, it is not constant in the sense of being completely nonvarying. For a given material of specified purity, texture, and dimensions, K may have the same value, or very closely so, for all samples. But it can in some materials vary with applied voltage, temperature, frequency, and humidity. Conventional capacitor dielectrics are processed for a K that is as stable as practicable; some special materials (the nonlinear dielectrics), on the contrary, are processed for large, controllable variation of K with applied d-c voltage, and are not used in conventional capacitors.

Table 1 shows approximate values of dielectric constant for some common insulants.

Dielectric Constant of Some Common Materials

Air	1.0
Alcohol (methyl)	35.4
Barium Titanate	1000 - 10,000
Castor Oil	4.3 - 4.7
Glass	4 - 10
Lucite	2.8
Mica	4 - 8
Paper (Dry)	1.5 - 3
Paraffin	2 - 3
Phenolic (yellow)	2.8
Polyethylene	2.2
Polystyrene	2.4 - 2.9
Porcelain	6 - 7
Quartz	4.5
Steatite	6.1
Titanium Dioxide	90 - 170
Water (distilled)	81
Wood (dry)	3 - 6

TABLE 1.

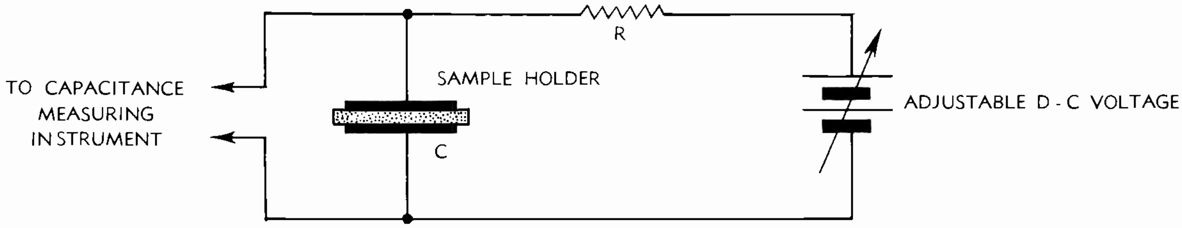


FIGURE 4. ARRANGEMENT FOR APPLYING D C

Checking With Applied D-C Voltage.

In order to study the effect of voltage upon dielectric constant of a given material, an adjustable pure d-c voltage may be applied to the test capacitor unit, as shown in Figure 4. When the dielectric sample has high leakage resistance, the direct current flow will be practically zero, and an isolating resistor R, of 1 megohm or higher, may be used. If there is appreciable leakage current, however, the resistor must be replaced with a low-resistance choke having high inductive reactance at the test frequency. The amplitude of any signal voltage generated by the capacitance-measuring instrument and impressed across the test capacitor must be very low compared to the d-c voltage, in order to prevent k-shift due to that source.

Measure the capacitance at each d-c voltage of interest, and calculate k by means of Equation (3), (4), or (5), whichever applies, for each voltage level. (The air capacitance need be measured or calculated only once.) From these data, a k-vs.-E curve may be plotted.

Checking at Different Temperatures. To study the variation of dielectric constant with temperature, enclose the sample and its holder inside an adjustable-temperature oven, and check the capacitance at each desired temperature. Calculate the k corresponding to each of these capacitances. (The air capacitance need be measured or calculated only once.)

To insure full heat-soak of the dielectric material, maintain the oven temperature at each new level for at least twenty-five minutes before making a measurement. Temperature/k tests may be made with or without applied d-c voltage and at as many frequencies as desired.

From the capacitance measurements, calculate the k corresponding to each of the capacitances, and plot a k-vs.-°C curve.

Checking at Microwave Frequencies.

Robertson and von Hippel have developed a method for measuring k at microwave frequencies.[6] The dielectric sample fills a section of slotted line, and k is determined from measurements of the standing wave maxima and minima along the air-filled and dielectric-filled portions of the line.

A commercial line designed for measurements by this method affords accuracy of ±2% for dielectric constant values between 1 and 10 checked at frequencies between 200 and 5000 Mc.

[6] S. Robertson and A. von Hippel, *Journal of Applied Physics*, 17, 610, 1946.

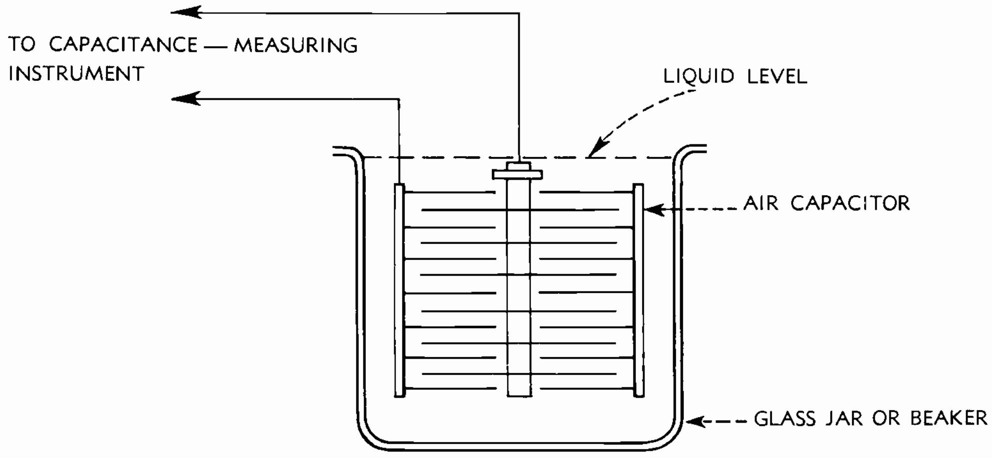


FIGURE 3. LIQUID - DIELECTRIC TEST CELL

K IN NONLINEAR DIELECTRICS

Experimental applications have been suggested for ceramic dielectrics in which k varies significantly and reproducibly with applied d-c voltage.[3] Such applications, including amplification, flip-flop action, memory storage, d-c tuning of tank circuits and filters, and automatic frequency control, have been proved in the laboratory but have not been commercially exploited chiefly because of the poor temperature coefficient of the high-k ceramic materials required.

An example of a nonlinear dielectric material of this kind is a barium titanate doped with strontium and having a k of 6000. Application of a d-c voltage of 50 v/mil will change the k to -70 percent of its value at zero voltage.

MEASURING DIELECTRIC CONSTANT

Solid Dielectric. Obtain a wafer or disc of the material, measure its thickness carefully, and make a 2-plate capacitor by applying a clean, flat, metal plate to each face of the dielectric. The plates must be exactly parallel, of the same size, and opposite each other. Attach a wire lead to each. Make the plates smaller than the dielectric, so that their edges will be well inside those of the dielectric; provide a guard ring when possible. Measure the area of one plate.

The capacitor sandwich must be flat so that no air pockets form between the plates and the dielectric.[4] This sometimes is difficult to accomplish when the dielectric is a hard material, such as plastic or ceramic. In such instances, it is desirable to metallize the opposite faces of the sample, either by silver painting or by vacuum evaporation or sputtering.[5]

Measure the capacitance of the test unit, using an a-c bridge at 60, 120, 400, or 1000 cps for the low-frequency k-value, or a Q-meter, substitution circuit, or r-f bridge at 1 Mc or higher for the high-frequency k-value. Record this measured capacitance as C_x.

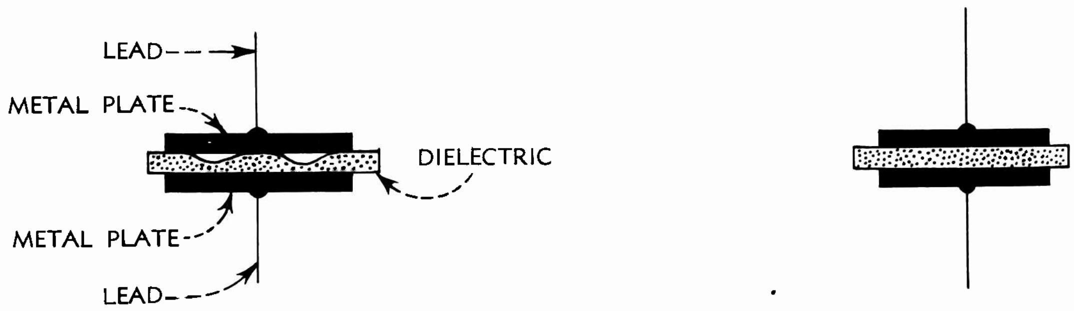
Calculate the dielectric constant by means of Equation (3), using the dielectric thickness (t) and plate are (A) measured above.

Liquid Dielectric. Pour the liquid into a clean, dry, glass beaker and stir it carefully to remove any air bubbles. Select an air capacitor (a small variable, with its plates completely enmeshed, and provided with wire leads will suffice) small enough to fit into the beaker of liquid dielectric. Carefully measure the capacitance of the capacitor alone, using a bridge, Q-meter, or substitution circuit, as explained under *Solid Dielectric,* and record this capacitance as C_a (i. e., the "air-dielectric capacitance"). Place the capacitor into the beaker of liquid (see Figure 3), stirring once again to destroy all air bubbles. Then, measure the capacitance again, and record this value as C_x. Calculate the dielectric constant from the ratio of the two capacitances:

(5) $k = C_x / C_a$
Where C_a and C_x both are in either pf or µfd

[4] One method is to "cement" the plates to the dielectric by means of an extremely thin film of petrolatum, rubbing to press out the surplus and to eliminate voids.

[5] Laboratory-type dielectric sample holders are available. An example is General Radio Type 1690-A which is equipped with a micrometer that shows plate separation accurately.



(A) AIR VOIDS IN DIELECTRIC

(B) FLAT DIELECTRIC, NO VOIDS

FIGURE 2. SOLID - DIELECTRIC TEST - SAMPLE CAPACITOR

k IN THE CAPACITOR

For a simple 2-plate capacitor, capacitance is related to dielectric constant, plate area, and plate separation in the following manner:

(1) $C = (kA)/4.45t$

Where C=capacitance (pf)

A=area of one identical plate (sq. in.)

t=separation between plates (in.)

For a capacitor having more than two plates,

(2) $$C = \frac{kA\ (n-1)}{4.45t}$$

Where C, A, and t are the same as in Equation (1), and n=number of plates

These simple formulas neglect the effects of fringing of the lines of force at plate edges, and assume that the dielectric is free of voids and completely fills the space between capacitor plates.

Equations (1) and (2) may be rewritten for dielectric constant:

(3) $$k = \frac{4.45tC}{A}$$

for the 2-plate capacitor

(4) $$k = \frac{4.45tC}{A\,(n-1)}$$

for the multiplate capacitor

From Table 1, it is seen that a suitable high capacitance-vs.-size ratio may be obtained by using the proper dielectric material in a capacitor. For example, a capacitor having C=1 pf with air dielectric becomes an 0.005 µfd capacitor with barium titanate (k=5000 variety) as the ceramic dielectric.

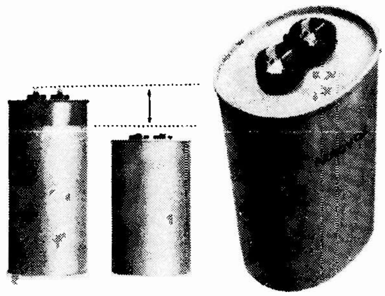
For a given thickness, a particular dielectric will not be entirely satisfactory, however, unless it has suitable dielectric strength, as well as dielectric constant. High k does not always go hand-in-hand with high voltage breakdown; Pyrex glass, for example, has a k of 4.2 - 4.9 compared to 1.5 - 3 for paper, but its dielectric strength is only 300 - 1000 volts/mil compared to 1250 for paper. A certain barium titanate ceramic has a k of 5750 but a dielectric strength of only 175 v/mil. The k of a dielectric material for conventional capacitor use must also be stable with temperature and voltage. Certain ceramics processed for controlled temperature coefficient of dielectric constant are used in compensating capacitors and in those having specified positive or negative temperature/capacitance coefficient.[2]

[2] See "Temperature Compensation", *Aerovox Research Worker*, April-May-June, 1962.

[3] See the following *Aerovox Research Worker* articles: "The Dielectric Amplifier," August, 1952; "Tubeless Amplifiers," July-August, 1956; "Voltage-Variable Capacitors" (Part 1, July-August-September, 1961; Part 2, October-November-December, 1961).

AEROVOX FEATURES MOTOR-RUN CAPACITORS WITH BOTH RELIABILITY AND LOW HEIGHT

PRODUCT NEWS FROM AEROVOX



Aerovox offers a savings in volume to meet your space savings requirements, with no sacrifice in long-life performance or reliability. All Aerovox motor-run capacitors feature Hyvol® F impregnant, a non-flammable synthetic liquid especially suited to AC capacitor design. Hermetically-sealed containers of drawn metal construction, and the double-lock seam are your assurance of maximum protection from distortion and damage from severe motor vibrations . . . and eliminate the inherent leakage problems of fabricated cans. These top-quality units have proven superior in performance and reliability in such demanding applications as air conditioning, refrigeration, heating, ventilating, business machines, pumps, power saws, and industrial controls . . . and generally wherever motor-run or small power-factor correction capacitors are required.

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Aerovox motor-run capacitors are available in a wide variety of case styles in a complete range of capacities and voltages. Standard ratings: capacity range 1 to 50 MFD; voltage range 165 to 660 VAC at 60 cps. Continuous engineering research and evaluation have resulted in minimum physical sizes consistent with safe ratings.

TERMINAL BUSHINGS

The molded cup employed on Aerovox motor-run capacitors prevents terminal rotation . . . the tapered bottom of the insulator permits cover finishing in compliance with Underwriter's Laboratories.

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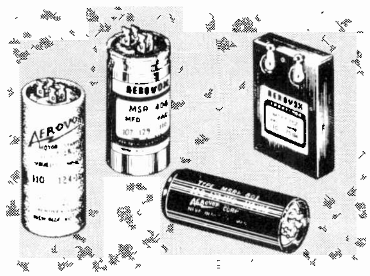
Weather-guard® 80-147 finish provides excellent corrosion resistance qualities. It is especially effective in outdoor environments where salt, fog and chemical conditions, combined with extreme temperatures and humidities, may be expected. Electro cad plate and electro zinc plate with Irridite finish also available.

SPECIAL CAPACITOR TYPES



If you have a special application requirement, qualified engineering service is available from Aerovox to develop and produce exactly what you need. As a pioneer and leader in capacitor design and manufacture, we offer years of experience and know-how for the discussion and analysis of your specific requirement.

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A complete line of top-quality motor-start capacitors is also available from Aerovox. Each unit features an exclusive electrolytic formula and special high-purity aluminum foil . . . your assurance of dependable performance and long service life in every application. Vibration protection against broken internal connections is assured by a special sealing compound used to imbed section in case. Positive seal guards against adverse environmental conditions. Phenolic and aluminum cases available with choice of terminals.

TECHNICAL DATA

See your Aerovox Representative or write direct today for Motor-Run Bulletin 171B1 and Motor-Start Bulletin 221B1.

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