PICKING THE PROPER INSULATION

safety factors are in order...

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It is generally recognized the primary function of electrical insulation is to guide current flow through desired paths and to separate electrical circuits and conductors which operate at different voltages. Furthermore, it is evident there are gross differences in the way insulations perform. For example, coils wound on polystyrene forms have a higher "Q" than those wound on molded mud forms; and certain circuits require the use of mica capacitors while in others cheaper paper capacitors will perform satisfactorily.

What are the electrical specifications by which the performance of insulation is measured? What considerations are involved in the selection of the proper insulation for a particular job? Some specifications (like power factor) are easily measured and known to a few percent. Others (like puncture strength) are very nebulous and must be used with a great deal of caution in any design application. Liquid and solid materials are broadly divided into classes according to their ability to conduct electricity. To be specific, when we measure the resistance of a number of liquid and solid materials between two metal plates each 1 inch square and separated by 1 inch (see Figure 1), we find most metals and acids are relatively good conductors of electricity while mineral oil, glass, wood, rubber and plastics are relatively poor conductors. The resistance of a sample having the aforementioned dimensions is called resistivity and is measured by a special unit called ohm-inches.

### TABLE I

<table>
<thead>
<tr>
<th>Material</th>
<th>Resistivity (ohm-in. at 30% rel. humidity or lower)</th>
<th>Dielectric Constant</th>
<th>Power Factor (% at 60 cy, 1 mc and 100 mc)</th>
<th>Puncture Strength (d-c or peak a-c V/mil)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>60 cy</td>
<td>1 mc</td>
</tr>
<tr>
<td>air</td>
<td>infinite</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>mica</td>
<td>$10^{-4}$</td>
<td>5-7</td>
<td>0.5</td>
<td>0.04</td>
</tr>
<tr>
<td>Mycalex</td>
<td>10^{-7}</td>
<td>7</td>
<td>0.64</td>
<td>0.21</td>
</tr>
<tr>
<td>stainless steel</td>
<td>10^{-6}</td>
<td>6</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>glass (Pyrex)</td>
<td>10^{-7}</td>
<td>5</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td>barium titanate</td>
<td>10^{-5}</td>
<td>1200</td>
<td>6.0</td>
<td>1.0</td>
</tr>
<tr>
<td>INORGANIC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teflon</td>
<td>$10^{-4}$</td>
<td>2.1</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>polyethylene</td>
<td>$10^{-4}$</td>
<td>2.2</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>polypropylene</td>
<td>$10^{-4}$</td>
<td>2.6</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>black Bakelite</td>
<td>$10^{-4}$</td>
<td>3</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>Lucite Plexiglas</td>
<td>$10^{-3}$</td>
<td>3</td>
<td>6.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Kel-F fluorocarbon</td>
<td>$10^{-3}$</td>
<td>2.5</td>
<td>3.0</td>
<td>0.9</td>
</tr>
<tr>
<td>hard rubber</td>
<td>$10^{-3}$</td>
<td>3</td>
<td>0.4</td>
<td>6.0</td>
</tr>
<tr>
<td>paper</td>
<td>—</td>
<td>4</td>
<td>1.0</td>
<td>4.0</td>
</tr>
<tr>
<td>ORGANIC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*A large number of the values quoted here taken from the Massachusetts Institute of Technology "Tables of Dielectric Materials."
The measurement of such large resistances is not easy, but by using thin samples and 500 volts or more applied to large electrodes, values up to about 10^10 ohm-inches can be measured accurately. The values quoted in Table I were measured at a relative humidity of 30% or lower. Moisture absorbed within or on the surfaces of high resistivity insulation can seriously lower the values measured.

Consider next the currents that flow through the block of insulation shown in Figure 1 when voltage V is suddenly applied by closing the switch. If V is a d-c voltage, there is a rush of charging current which gradually decays to some steady value determined by the resistivity of the material and the applied voltage. However, when a-e voltage is applied, although most of the current leads the voltage by 90° (\(V_{\text{rms}}\)), a small but measurable current component is in phase with the voltage (\(I_{\text{rms}}\)). The vector diagram of Figure 2 represents these two currents.

Now the ohmic current alone produces heat. The amount of heat is determined by the d-c resistivity of the insulation in conjunction with some extra heat generated when the molecules of the insulation rub against each other as they move under the influence of the a-c voltage.

Thus the cube of the insulation could be represented circuit-wise by a resistance shunted across a capacitance that, in turn, is a capacitor in series with a reactance that, when the circuit contains both resistance and reactance, the ratio of the heat-producing current (\(I_{\text{heating}}\)) to the no-load-producing current (\(I_{\text{heating}}\)) is called the power factor of the insulation.

In other words, the power factor is the number by which the "apparent" or "root-mean-square"* power of a capacitor-resistor combination must be multiplied to obtain the actual watts of heat developed. The power factor is a number (usually expressed as a percentage) which can vary from 0% for a perfect inductor such as air to 100% for a perfect conductor.

For most commonly used insulators the power factor is less than 5%, and it may be as low as 0.2% for the very best insulators such as polystyrene or mica.

Now as indicated previously, the d-c resistivity of an insulator is in part determined by the movement of the molecules under the influence of the a-c voltage. The net result is to cause the power factor to change in a rather complicated manner with variations in the frequency of the measuring voltage. This is reflected in the power-factor columns in Table I which show it to be meaningless to quote a power factor without specifying the frequency at which the measurement was made.

This variation with frequency illustrates why it is of utmost importance in many applications to choose a coil form of suitable material when working with R-F circuits. For instance, a paper roll form would have a power factor of 1% at 60 cycles but 6.5% at 100 megacycles. And in comparing two different types of coil form material it is seen that the power factor of black Bakelite is 3.5% at 100 megacycles while polystyrene is 0.55% at the same frequency. Thus the efficiency and Q of an R-F circuit ran very well be quite dependent upon the type of insulation used.

* The "apparent power" or "root-mean-square" drawn in a circuit containing both inductance and resistance (a-c) is obtained by multiplying the voltage across the circuit by the total current drawn without regard to their relative phases. Actually, power is computed in the same way in d-c circuits, but here the current used is the steady value of the a-c component; it is the "apparent power." Therefore, we define the power factor as the ratio of the actual power consumed by the circuit (which appears as heat in the resistor of an R-F circuit) to the apparent power (volts times amperes) of the circuit.
1953 Edison Radio Amateur Award
J. Stan Surber
W9NZZ

These impartial judges picked W9NZZ as the radio amateur who performed the most outstanding public service during 1953:

E. ROLAND HARRISMAN
President, The American Red Cross

GEORGE E. STERLING
Commissioner, Federal Communications Commission

GODWIN H. DOLAND
President, American Radio Relay League

GARDNER COWLES
President and Editor, "Good" Magazine

His 20-meter beam stays pointed north to squirt CW to remote weather stations near the Pole, where crews are lucky to get more than twice a year. (Note Indiana sub-letter license plate.)

News of winning the Award came via 75-foot from K4AF (MARS) via W9CMT (left) as W9NZZ was on his 4 pm-to-midnight trick as CSO RR dispatcher.

The "helping hand" operating this ivory-handled bug (hand-caved from walrus tusk) belongs to W9NZZ, winner of General Electric's 1953 Edison Radio Amateur Award. Though he never tops the monthly BPL list, he'll count words with anyone.
Stan starts each day with early trip to post office to pick up mail for arctic weather men. In 1953 he kept regular skeds with arctic stations 353 days.

XYL, Louise serves lunch at the rig so he can keep two skeds with each station most days. She won a wrist watch from G.E. as a "Most Understanding Wife.

Louise works the same hours as the OM as PBX operator for C&O.

Stan loves to explain his hobby to neighbors (left) and gets many souvenirs from devoted friends he has never seen (above). Traffic piled up when Award ceremonies broke up skeds—but he reports operations now on a current basis again.
PICKING THE PROPER INSULATION

(Cont'd from page 2)

It is a familiar fact that the capacity of a condenser depends on the area and separation of the plates, but perhaps not nearly so well appreciated is the fact that capacity also depends on the kind of material between the plates. This has led to the use of the dimensionless quantity called "dielectric constant," which usually is denoted by the letter K.

In general, the capacity of the condenser of Figure 1 first with a solid insulation between the plates and then with just air between the plates. The capacitance obtained with the solid insulation divided by the capacitance obtained with air insulation gives us the dielectric constant of the material between the plates. This is always 1. The K of the so-called "high-K" materials may have a value of more than 1000 (see Table 1).

The principal effect of this number is to determine the capacitance per cubic inch that may be obtained in a capacitor. Thus a capacitor made with mica insulation could be made more compact than a paper-insulated capacitor of the same value since the dielectric constant of paper is 3. For the same reason, a mica-filled capacitor is much smaller than an oil-filled capacitor of the same value.

The last of the more important electrical ratings assigned to insulations is called the "puncture" or dielectric strength. This usually is expressed in volts per mil, and gives the measure of the amount of voltage necessary to puncture a piece of insulation. While the puncture strengths in Table 1 are quoted in volts per mil of insulation thickness, these values are not applicable over a wide range of thickness. The puncture strengths in Table 1 apply to measurements made with flat electrodes with carefully polished and rounded edges on insulation about 1/16 inch thick. This condition rarely is attained with practice with the result the strengths listed in Table 1 are all apt to be higher than would be encountered in practical situations. Thus safety factors of the order of 100% must be applied to any design based on these numbers.

Although such a listing of puncture strengths is qualitative at best, the following generalizations may be made regarding the effect of various materials on the puncture strength of the insulation. (a) Gases (like air) have very low puncture strengths of about 900 volts/mil, and the puncture strength of solids; and (b) solid insulators 34 to 5/8 inch thick have strengths of several hundred volts per mil. Hence, in case of mica and very thin plastic sheets (a few mils) which may have a puncture strength as large as 1000 volts/mil.

A fact worth noting is that breakdown usually culminates in a high-temperature arc. While this is of little consequence with air and ceramic insulators, organic insulation will be charred by the arc and the carbon traces left will then burn down at a much lower voltage than that which caused the initial failure. This fact may be of importance when selecting insulations for high voltage applications where arcing is expected. Often breakdowns occur in transformers where voltage taps are brought out from the windings. If the charred varnish surrounding the insulation is carefully cut away with a knife or razor blade, and the resulting void filled with plastic film such as Glyptal, the transformer may be saved sometimes.

Selection between two condensers in certain situations may be eliminated by inserting a sheet of solid insulation between them. A piece of mylar or thin sheet of plastic often will do the trick.

Since pressure and stress cause breakdown at lower voltages than will occur with smooth-surfaced conductors under otherwise equal conditions. Thus, care should be taken to polish capacitor plate edges, keep the plates dust-free and to round-off condenser in high-voltage circuits. Even paper plates of rather small size may have developed a few hundred volts/mil wire that have been cut with side cutters so that the breakdown voltage rating of the gap will be doubled.

A discussion of insulation would not be complete without mention of the effect of moisture. Moisture will lower the breakdown voltage of many kinds of insulations, especially the paper and cloth varieties. Thus, it is wise to allow ample "dry-out" time of high-voltage gear that has been stored in damp locations.

Furthermore, moisture absorbed on the surfaces of plastics will cause their power factors (and attenuation per foot) to rise. Almost every man who has operated in wet weather with twin conductors insulated with polyethylene has noticed this effect. By actual measurement at 300 megacycles, the attenuation per hundred feet of one variety of twin lead conductors increased from 1.3 decibels to 6.5 decibels when its surface was wet. The application of water-repellent materials like silicones to these surfaces often will improve performance of insulation under adverse moisture conditions. All the values quoted in Table 1 apply to measurements made at room temperature. Generally speaking, at higher temperatures the performance of insulating materials becomes poorer. As the operating temperature of a given insulation is raised, the resistivity, dielectric constant, and puncture voltage becomes lower while the power factor rises—W2UKL.
In Cardiff, Wales, a case of TVI was traced to the 42-inch predilection of a spring grandfather clock, and was remedied by grounding the metal works, according to "Sparkle," the Brandon, Manitoba, club bulletin.

The Al-Ski-Ben Club of Omaha, reports "Ham Ham," has started an annual award (a first-class communications receiver) for the member who will be adjudged as having done the most for amateur radio during 1954. . . the same bulletin reports 25 SSB stations in the Northeast Nebraska area where only 2 operated a year ago. . . the two widely separated local ham clubs bulletin which includes the pride and joy of, first, the most technical-minded hams and now the rag-chewers. But as equipment and circuits become more standardised and we find ways to tick the stability problem, we feel SSB has a future in traffic work.

Don't think for a moment that we mean the technical- nicness and rag-chewers are going to turn into traffic men in mass. Not at all. The biggest single factor in traffic sets are the operators—the guys and gals with a particular kind of intense perseverance and whose main objective in life is to get that message through. They're born, not made. And we feel sure that when they hatch into SSB communications, there'll be no stopping them. Of course, a complete change-over on an entire traffic set is a problem not wholly technical—a problem of economics. (How many lads can afford to lift SSB?)

You feel just as you do for the "murder car" drivers, in, effect, their life's blood to acquire? The transition will be slow. But we feel sure that it will come. . . the day is sure to come. . .

Don't think that with all this talk of four wave we're slighting good, reliable CW. We ask among our friends every once in a while about whether they prefer CW or SSB. We've found half and half as far as we can figure. Lots of fellows like to work both. Our editor himself feels that the worst man in the world—just the same he likes it best.

What to do for the QRP CW rigs. Inc. One of the best 30- to-radar CW rigs we know of is the "Electro" series described in G-E HAM NEWS, Volume 3, No. 5. It's a two-control, two-stage VFO job that's a delight to operate. It sells a 1614 (but a 166 works fine) and a GL-D21/4.125A. Be glad to send you one of these back copies directly.
The new "Service-Designed" GL-5U4-GA has slightly higher output voltage and current ratings than the old 5U4-G and a streamlined envelope and sturdier construction—all of which make it more adaptable to ham use. Here's the difference:

**OLD**

- **G-5U4-G**
  - Max. plate current: 675 ma
  - Max. plate voltage: 450 volts
  - Filter input capacitor: 10 mfd
  - DC output current: 225 ma
  - Tube voltage drop: 50 volts

**NEW**

- **GL-5U4-GA**
  - Max. plate current: 900 ma
  - Max. plate voltage: 450 volts
  - Filter input capacitor: 40 mfd
  - DC output current: 250 ma
  - Tube voltage drop: 44 volts

The envelope is shorter and narrower than the old model, and thus saves space. Note the mica support at bottom as well as top—which together with the new "button stem" construction makes a sturdier tube. Shock and vibration tests show the new 5U4-GA can withstand the hard usage of Field Day and portable operation.