the GENERAL RADIO Experimenter



Since 1915 – Manufacturers of Electronic Apparatus for Science and Industry

VOLUME 31 No. 2 JULY, 1956

# NEW DECADE CAPACITORS WITH POLYSTYRENE DIELECTRIC

*Also* IN THIS ISSUE



Mica, a natural material, has long been the outstanding dielectric for capacitors and, for many applications, has not been superseded. It is still used almost universally, for instance, for a-c standard capacitors and will undoubtedly continue to be used in this application for a long time. In many respects, however, some of the newer synthetic materials exhibit characteristics superior to those of mica.

Among the materials available in a form economically suited for capacitor manufacture is polystyrene. This material possesses very nearly the ideal characteristics: dielectric constant and low dissipation factor that are invariant with frequency. Measurements from dc to at least several hundred megacycles show substantially constant values of these parameters. Mica, on the other hand, exhibits marked polarizations at frequencies below the audio range. These are manifested by rising values of capacitance and dissipation factor at the low end of the audio range. The relaxation times of these polarizations

**Figure 1. View of the Type 980-A Decade Capacitor Unit.**

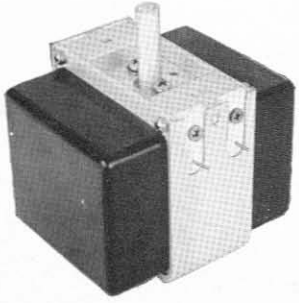


**Figure 2. View of the Type 1419-A Decade Capacitor**

correspond to frequencies in the tenths and hundredths of cycles per second and appear even in the millicycle and microcycle range. These polarizations are believed to be interfacial, resulting presumably from the laminar structure of the mica.

A thorough discussion of polarization in dielectrics is beyond the scope of this article. These phenomena can be described either in the frequency domain in terms of dielectric constant and loss factor (complex dielectric constant) or in the time domain in terms of the time variation of current resulting from changes in applied d-c voltage. The d-c response is often expressed in terms of "apparent resistance," and in fact most short term insulation-resistance measurements are actually nothing more than a measure of the charging current flowing into the low-frequency polarizations.

Terminology is as yet not well standardized. Terms such as "dielectric absorption," "soakage," "voltage recovery," and "d-c capacitance" have been used. The difficulty is that such terms can be relatively meaningless unless the method of measurement is specified. It is to be hoped that standardization on terminology, specifications, and method of measurement will soon be reached [1] in these areas, which appear to be of growing interest.

Capacitors carefully made of properly processed polystyrene can be shown to be about two orders of magnitude better than an equivalently carefully made mica capacitor. For example, Mr. R. F. Field reports [2] observations of high-quality, silvered-mica capacitors that show rises in capacitance as great as 30%, while similar measurements on the polystyrene units described later indicate rises of only a few tenths per cent. These measurements of discharge current vs. time were taken over a period of weeks and thus correspond, in the frequency domain, to measurements in the microcycle range.

### Early Applications

The potentialities of polystyrene as a capacitor dielectric were recognized in the late thirties, and since about 1940 General Radio has carried on a program of development, and manufacture for its own uses, of polystyrene capacitors. Our first commercial application was in tuning networks in the TYPE 762 Vibration Analyzer, in the frequency range down to 2.5 cycles. In this application other available capacitors were unsatisfactory. Mica was not only out of the question because of cost, size, and weight in the large capacitance values required, but the polarization mentioned above caused anomalous behavior at the low frequencies. Subsequent uses of such capacitors include the TYPE 1611-A Capacitance Test Bridge. In this instrument, a 1-$\mu$f polystyrene capacitor accurate to 0.25% is used as a standard. Field use in many hundreds of these bridges over a period of ten years has shown these capacitors to be entirely satisfactory from the points of view of stability and life expectancy. Capacitors of this type have thus demonstrated their performance and reliability and are now offered for sale in the form of decade units.

These polystyrene-dielectric capacitors, owing to their very low dielectric absorption, are particularly useful in research and development work on computor and integrator circuits, and on low-level a-c amplifiers. Because of their constancy of capacitance and dissipation factor with frequency, they

[1] Sections A and C, Subcommittee XII, ASTM Committee D-9 are interested in this work. The writer will welcome any comments or the participation of anyone interested.

[2] Unpublished data.

make excellent components for measuring circuits, filters, and tuned circuits. They are nearly ideal capacitors for d-c work, because of their high insulation resistance and low dielectric absorption.

## TYPE 980 DECADE CAPACITORS

Decades for assembly into other equipment are available in three capacitance ranges, with capacitance at maximum setting of 1.0, 0.1, and 0.01$\mu$f.

Each decade consists of four capacitors of magnitudes in the ratios 1–2–2–5. The switch selects parallel combinations to give increments over zero capacitance in all integral values from 1 to 10.

The individual capacitor units are non-inductively wound and carefully heat treated. The tape used is cast of purified high-molecular-weight polystyrene, pre-stretched only in the direction of winding. During heat treatment the units are carried beyond the transition temperature of the polystyrene, and the shrinkage of the tape produces an extremely firm, stable unit, which is insensitive to pressure, and which is stable in retrace capacitance value for temperatures up to 65° C.

The units are hermetically sealed in black-finished brass cans, having Teflon feed-through insulators to assure high resistance even under adverse humidity conditions. No impregnant, which might jeopardize the low-frequency performance, is used.

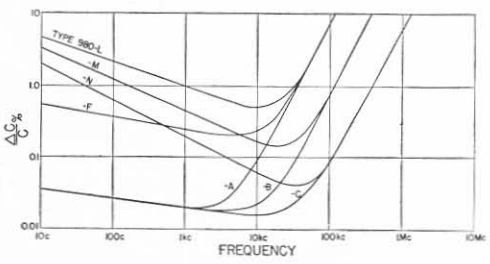
The cased units are mounted to a newly developed cam-type decade switch. The supporting dielectric material of the switch, including the shaft, is heat-resistant cross-linked polystyrene, and Teflon spacers support the rigid-wire leads.

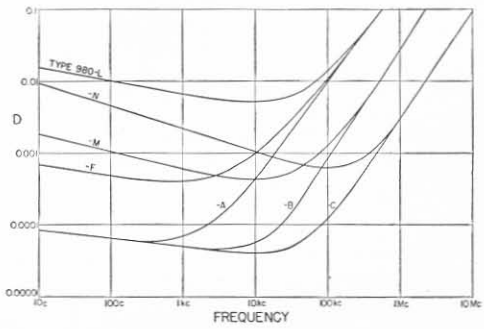
### Low-Frequency Performance

The resulting decade capacitor assembly has an insulation resistance greater than $10^{12}$ ohms under standard laboratory conditions (23° C, 50% RH) when measured at 100 volts. Dissipation factor is typically of the order of 0.0001 in the audio frequency range, and is specified not to exceed .0002 at frequencies down to 100 cycles. A slight rise occurs as frequency approaches zero, as shown in the plot of Fig. 3. Theory [3] indicates that the maximum value of dissipation factor (from dielectric loss) cannot be greater than one-half the value of the rise in capacitance. Measurements indicate that this maximum value is of the order of 0.0005.

[3] The "circular-arc" theory proposed by Cole and Cole.

**Figure 3. Typical plots of change in capacitance and dissipation factor as a function of frequency for Type 980 Decade Capacitor Units. Types 980-A, -B, and -C are polystyrene units; Types 980-L, -M, -N, and -F are paper and mica units. Capacitors are adjusted to their rated accuracy at 1 kc.**



In addition, at some sufficiently low frequency, the leakage resistance becomes significant in determining dissipation factor. At $10^{-4}$ cycles, the $10^{12}$ ohms resistance of one microfarad produces a dissipation factor of 0.001.

One of the most convenient means of measuring d-c performance is by the voltage-recovery method. If a capacitor is charged for a given period of time and then short-circuited through a protective resistor for a period long enough to discharge the high-frequency capacitance, the charges in the long-time polarizations remain. These charges gradually transfer to the high-frequency capacitance and appear as a measurable potential at the terminals. If these capacitors are charged for one hour and then discharged for 10 seconds, the ultimate recovered voltage is 0.1% or less of the original charging voltage. In contrast, even a good mica capacitor may recover 10% or more, while some impregnated paper capacitors may show recoveries approaching the charging voltage.

In terms of frequency characteristic the above performance is equivalent to an increase in capacitance of 0.1% at a frequency of the order of $10^{-4}$ cycles.

### High-Frequency Performance

At frequencies above a few hundred cycles, the dissipation factor of the material seems to reach a "floor" and remains constant, as does the dielectric constant. The terminal values of capacitance and dissipation factor, however, are modified by the residual inductance and series resistance of the capacitors, switch structure, and leads. The capacitance change increases as the square of the frequency, while the dissipation factor change varies as the 3/2 power of frequency. Representative plots of these variations are shown in Fig 3.

## SPECIFICATIONS

**Accuracy:** Capacitance increments are within ± 1% from zero position when measured at 1 kc. The units are checked with the switch mechanism high, electrically, and the common lead and case grounded. The zero capacitance is 10 μμf and must be added to the switch settings to give the total capacitance.

**Dissipation Factor:** Less than 0.0002 at 1 kc and 23°C, 50% RH

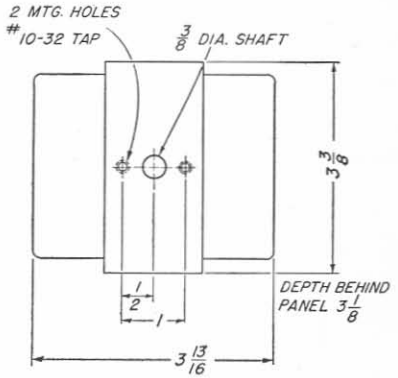
**Frequency Characteristics:** Figure 3.

**Maximum Voltage:** 500 volts d-c or peak at frequencies below the limiting frequencies tabulated below. At higher frequencies the allowable voltage decreases and is inversely proportional to the square root of the frequency. These limits correspond to a temperature rise of 40° Centigrade for a power dissipation of 3.5 watts.

**Mounting:** Machine screws for attaching the decade to a panel are supplied.

**Dimensions:** See accompanying sketch.

**Net Weight:** 2 pounds, 2 ounces.



980-A,-B,-C

| *Type* | *Capacitance* | *Dielectric* | *Frequency Limit in Kc-Max. Volt.* | *Code Word* | *Price* |
|---|---|---|---|---|---|
| **980-A** | **1.0 μf in 0.1 μf steps.....** | **Polystyrene** | **10** | AVAST | **$66.00** |
| **980-B** | **0.1 μf in 0.01 μf steps.....** | **Polystyrene** | **100** | AVERT | **51.00** |
| **980-C** | **0.01 μf in 0.001 μf steps.....** | **Polystyrene** | **1000** | AVOID | **57.00** |

## TYPE 1419-A DECADE CAPACITOR

A three-dial decade capacitor having a range from .001 μf to 1.11 μf in steps of .001 μf is also available. The individual TYPE 980 decades are mounted on an aluminum panel, in an aluminum cabinet, providing complete electrostatic shielding. A separate ground post is provided, so that the capacitor may be used in either two-terminal or three-terminal applications, with case grounded.

## SPECIFICATIONS

**Capacitance Range:** .001μf to 1.11μf in steps of .001μf. The three decades have steps of .001, .01, and .1μf respectively.
**Zero Capacitance:** Approximately 35μμf.
**Accuracy:** Individual capacitors are adjusted to an accuracy of ± 1%. The capacitance at the terminals, less the zero capacitance, is within ± 1% of indicated value for any setting
**Dissipation Factor:** Dissipation factor caused by dielectric loss is less than 0.0002 at all frequencies above 100 cycles. At high frequencies, series metallic resistance increases the dissipation factor as shown by the curves of Figure 3.
**Insulation Resistance:** Greater than 1 megamegohm ($10^{12}$ ohms), when measured at 100 volts, 23° C, and 50% RH.
**Maximum Voltage:** 500 volts d-c or peak.
**Frequency Characteristics:** The d-c capacitance is equal to the 1-kc value within 0.1%. At high frequencies, series inductance causes capacitance to increase as shown by the curves of Figure 3.
**Dielectric Absorption:** See Voltage Recovery.
**Voltage Recovery:** The voltage recovery at the terminals is less than 0.1% of the original charging voltage, after a charging period of one hour and a 10-second discharge through a resistance equal to one ohm per volt of charging.
**Mounting:** Aluminum panel and cabinet.
**Dimensions:** (Length) 13 x (width) 4 5/16 x (depth) 5 inches, over-all.
**Net Weight:** 8 3/8 pounds.

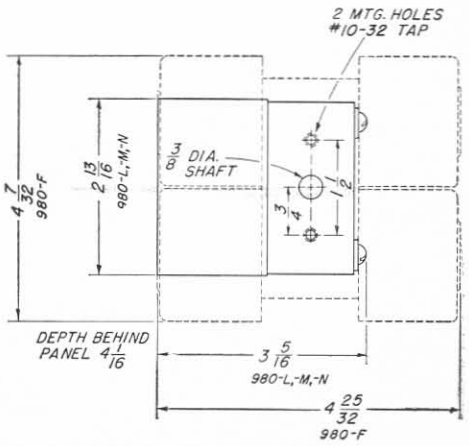
| *Type* | | *Code Word* | *Price* |
|---|---|---|---|
| **1419-A** | **Decade Capacitor.....** | BIGOT | **$195.00** |

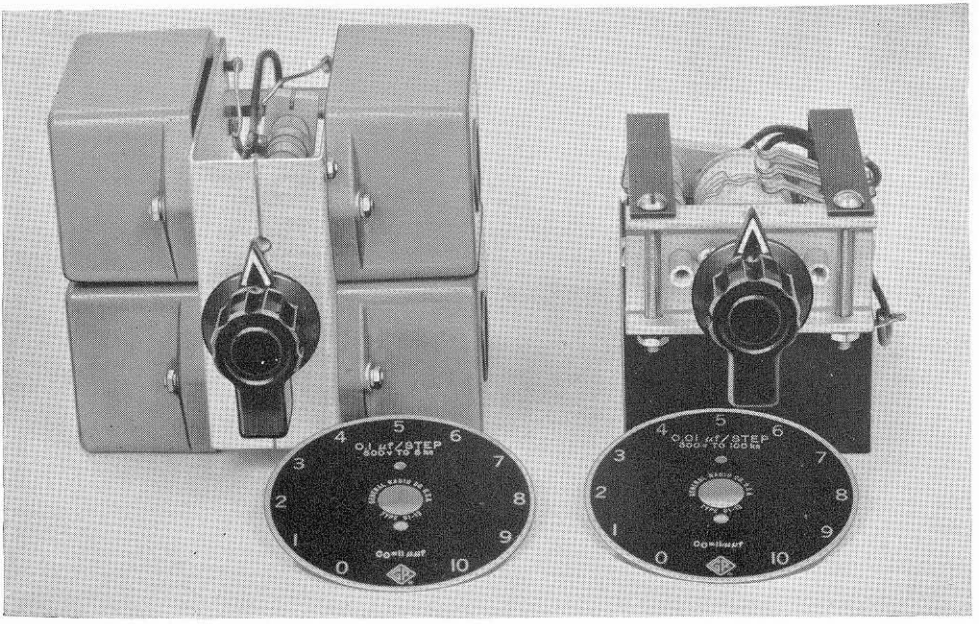
## DECADE CAPACITORS WITH MICA AND PAPER DIELECTRICS

The new decade switch is now also used for mica and paper decade capacitors. The new assemblies replace the former TYPE 380, with identical mounting dimensions. A listing of these units is given, with specifications, below. The low-loss switch, plus improvements in the mica capacitors themselves, result in lower dissipation factor than that specified for the superseded TYPE 380 Units.

## SPECIFICATIONS

**Accuracy:** Capacitance increments on all units are within ± 1% from zero position when measured at 1 kc except the TYPE 980-L, which is accurate within ±2%. The units are checked with the switch mechanism high, electrically, and the common lead and case grounded. The zero capacitance of all units is 10μμf and must be added to the switch settings to give the total capacitance.
**Dielectric:** See table.
**Dissipation Factor:** See table.
**Frequency Characteristics:** See Figure 3.
**Maximum Voltage:** 500 volts peak for all units (except 980-L which is rated at 300 volts) at frequencies below the limiting frequencies tabulated below. At higher frequencies the allowable voltage decreases and is inversely proportional to the square root of the frequency. These limits correspond to a temperature rise of 40° Centi-





**View of the Type 980-F (left) and Type 980-N (right) Decade Capacitor Units.**

grade for a power dissipation of 2.5 watts for the TYPE 980-F and 3.5 watts for all other units.
**Mounting:** Machine screws for attaching the decade to a panel are supplied.

**Dimensions:** See accompanying sketch.
**Net Weight:** TYPE 980-F, 3 pounds, 12 ounces; TYPE 980-L, 1 pound, 10 ounces; TYPES 980-M and -N, 1 pound, 8 ounces.

| *Type* | *Capacitance* | *Dielectric* | *Dissipation Factor at 1 kc and 23° C* | *Frequency Limit in Kc for Max. Voltage* | *Code Word* | *Price* |
|---|---|---|---|---|---|---|
| **980-F** | **1.0 μf in 0.1 μf steps** | **Mica** | **Less than 0.0003** | **5** | ACUTE | **$128.00** |
| **980-L** | **1.0 μf in 0.1 μf steps** | **Paper** | **Less than 0.010** | **1** | ADAGE | **28.00** |
| **980-M** | **0.1 μf in 0.01 μf steps** | **Mica** | **Less than 0.001** | **100** | ADDER | **42.00** |
| **980-N** | **0.01 μf in 0.001 μf steps** | **Mica** | **Less than 0.001** | **1000** | ADDLE | **26.00** |
| **980-PI** | **Switch only** | | | | SWITCHBIRD | **11.00** |

## WESCON 1956

The Western Electronic Show and Convention will be held in Los Angeles, August 21–24. Visit us in booths 918 and 919 to see the new GR instruments that you have been reading about in the *Experimenter*, including:

TYPE 1230-A D-C Amplifier and Electrometer
TYPE 1605-A Impedance Comparator
TYPE 1391-A Pulse, Sweep, and Time-Delay Generator
TYPE 1603-A Z-Y Bridge
TYPE 874-LBA Slotted Line, with TYPE 874-MD Motor Drive
TYPE 907-R and 908-R X-Y Dial Drives