W. B. Webster

OPERATING INSTRUCTIONS

TYPE 1690-A

DIELECTRIC SAMPLE HOLDER

GENERAL RADIO COMPANY

E

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DIELECTRIC SAMPLE HOLDER

Form 1690-0110-E
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GENERAL RADIO COMPANY
WEST CONCORD, MASSACHUSETTS, USA

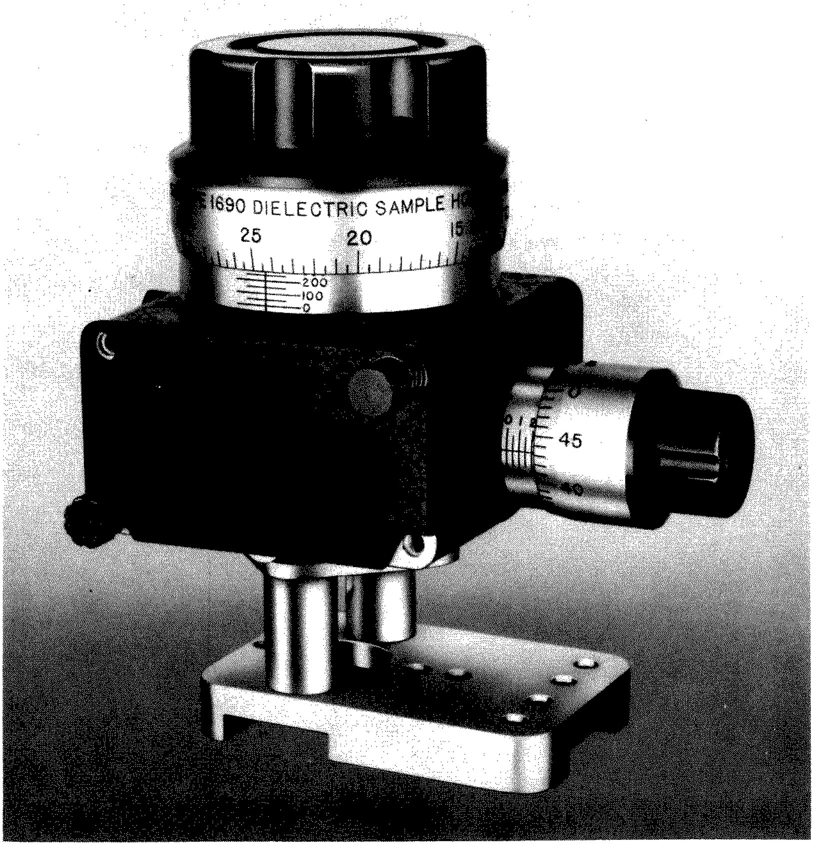

Figure 1. Type 1690-A Dielectric Sample Holder with the Type 1690-P1 Adaptor.

SPECIFICATIONS

Electrodes: Diameter, 2.000 inches ±0.0025. Surfaces are ground optically flat within a few wavelengths.

Electrode Spacing: Adjustable from zero to 0.3-inch indicated by the micrometer reading in mils.

Vernier: Incremental capacitance is 5$\mu\mu$f, nominal.

Calibration: For the main capacitor, a chart is provided giving the calculated air capacitance as a function of spacing. A correction curve is also provided with each holder, giving the measured deviations from calculated values over the range from 300 mils to 10 mils spacing. In accordance with recommended ASTM practice, this calibration is referred to the calculated geometric value at a spacing of 100 mils. Accuracy is ±0.2% ±0.1 mil.

For the vernier capacitor, a correction chart is provided from which capacitance differences can be determined to an accuracy of ±0.004 $\mu\mu$f.

Zero Capacitance: Approximately 11$\mu\mu$f with main capacitor set at 300 and vernier at 500.

U.S. Patent No. 2,548,457.

Frequency: No significant error occurs at frequencies below 100 Mc. At higher frequencies satisfactory results can be obtained for many types of measurements.

Accessories Supplied: TYPE 1690-P1 Adaptor Assembly for mounting to the TYPES 1615-A, 716-C, and -CS1 Capacitance Bridges. Hardware is supplied for mounting sample holder on TYPES 740-B, 1611-B, 1604-B, 544-B Bridges and TYPE 1862-B Megohm meter.

Accessories Available: TYPE 1690-P2 Adaptor Assembly for connecting to TYPE 874-LBA Slotted Line or TYPE 1602 Admittance Meter.

Mounting: Supplied with a wooden carrying case. A drawer in the case provides storage for hardware, and a spring clip holds the calibration charts.

Dimensions: Over-all, mounted on adaptor, 6¼ x 5¾ x 4½ inches.*

Net Weight: 3¾ pounds.**

* (160 x 150 x 155 mm)

** 1.8 kg

TYPE 1690-A
DIELECTRIC SAMPLE HOLDER

Section 1
INTRODUCTION

1.1 PURPOSE. The Type 1690-A Dielectric Sample Holder (Figure 1) is a micrometer-driven Hartshorn-type[1] sample holder, intended primarily for measurements of dielectric constant and dissipation factors of (ASTM)[2] standard two-inch-diameter specimens. It will accommodate any flat sample whose largest dimension is two inches or less and whose thickness is 0.3 in. or less. It can be used with resonant circuits for susceptance-variation or frequency-variation measurements, with the Types 1615-A, 716-C, or 716-CS1 Capacitance Bridge, Type 874-LBA Slotted Line, or the Type 1602-B Admittance Meter.

1.2 DESCRIPTION. Figure 2 is a cross-section drawing of the sample holder. The main micrometer capacitor is formed by the two electrodes (H) and (L). The surfaces of these electrodes are ground optically plane to within a few wavelengths. The lower electrode is supported by Vycor insulators (I). The upper electrode is positioned by the micrometer-type screw, with the spacing in mils indicated directly on the drum and barrel. The screw is shunted by the flexible copper tube or bellows (S) to insure low and constant resistance and inductance in the current path to the movable electrode. This electrode is designed so that when it contacts the specimen the spring-loaded drive disengages. This design feature (1) lets the movable electrode assume the plane of the top surface of the specimen assuring best possible contact even if the faces of the specimen are not exactly parallel; and (2) prevents straining of the micrometer screw, since the drive disengages at a predetermined pressure. About three-quarters of a turn beyond the disengage point, the micrometer screw bottoms inside the grounded electrode.

[1] L. Hartshorn and H. Ward, PROCEEDINGS, I.E.E. (London) Vol 79, pp. 597 to 609.

[2] ASTM Standard on Measurement Methods for Dielectric Constant and Loss of Electrical Insulating Materials, D150-54T.

CAUTION

Further rotation may damage the insulators and ruin the calibration. Use extra caution with soft or thin samples, which may mask the feel of the release point.

The micrometer screw (V) projects into a hole in the insulated electrode, forming a cylindrical vernier capacitor. Ten turns of this screw provide a capacitance increment of 5 $\mu\mu$f. This micrometer carries a 500-division scale, each division corresponding very closely to 0.01 $\mu\mu$f. The vernier is useful in susceptance-variation measurements to tune the system to the half-power points on either side of resonance. (Refer to ASTM Spec. D-150 for procedure.) It is also valuable when the micrometer balance with the sample out occurs at a very close electrode spacing. The vernier may be used to obtain a more precise capacitance balance, and thus permit a better resistive balance. It may also be used in measurements of components (refer to paragraph 4.6).

Bosses (A and B, Figure 2) permit use of either Type 874 Coaxial Connectors or banana plugs for connection to the electrodes. By means of duplicate connection facilities, the electrodes may be kept horizontal whether the holder is attached to a vertical or horizontal surface.

CAUTION

Do not use a wrench to tighten center pin connector.

The electrode shielding is completed by two aluminum side panels, which can be swung open to provide access to the electrodes from both sides. The two bottom holes are drilled completely through the casting to accommodate dial-type thermometers.

1.3 ACCESSORIES. Table 1 on page 4 lists accessories for use with the Type 1690-A Dielectric Sample Holder. All except the Type 1690-P2 Adaptor group (A, Figure 3, page 5) are supplied with the sample holder.

In addition to the items listed above, other equipment incidental to the particular type of measurement may be required. Thus, for instance, in some measurements with the Type 716-C Capacitance Bridge, a small parallel capacitor may be necessary (refer to paragraph 4.1c).

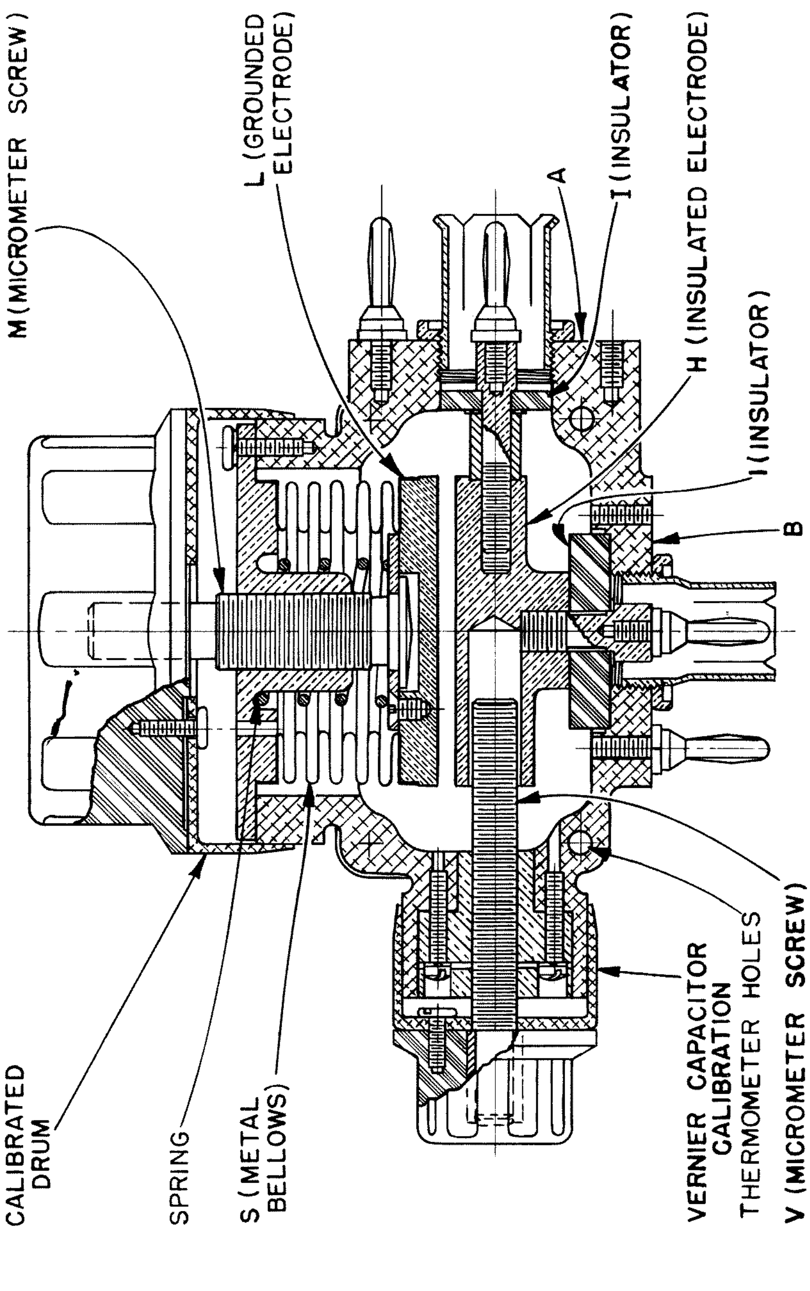

Figure 2. Cross-Section View of the Type 1690-A Dielectric Sample Holder.

TABLE 1. ACCESSORIES

Figure 3 Reference	Quantity Supplied	Item	Part No.	Use
A	1 1 1	Adaptor Coaxial ell } * Outer connector	1690-0270 874-EL 0874-0603	Attach to Types 1602 Admittance Meter and 874-LBA Slotted Line (plus 1 plug from E).
B	2 1 2	Posts Screw, 1 1/4 in. Spacers	1690-6010 7270-4300 1690-6020	Attach sample holder to Types 1615-A, 716-C, or 716-CS1 Capacitance Bridge (use with D and E).
C	1 1 1 2	Outer connector Outer shell Lock nut Binding post and spacer assemblies	0874-0603 0774-6122 0874-6013 0874-2120	Attach sample holder to VTVM for susceptance-variation measurements.
D	1 2 2	Adaptor Screws, 5/16 in. Nuts	1690-P1 7070-1100 1690-6070	Adapts sample holder for mounting on Types 1615-A, 716-C, or 716-CS1.
E	4	Banana plugs	0274-3640	Connect to extended binding posts of Type 716-C and 716-CS1 (use 2) and Type 1615-A (use 1).
F	4	Screws	7270-4000	Provide better bonding between cover plates and main casting, for vhf measurements.
G	4 4 2	Terminals Screws, 3/8 in. Spacers	7930-1800 7080-1000 7770-1200	Spacers screw into fixed electrode to supply high connection in same plane as face of main casting. Screws and terminals provide connections for components
H	1 3 3	Bushing Spacers, 1-1/4 in. Studs, 5/8 in.	4150-3200 7710-0400 7830-0500	Supports for use with Types 1611 Capacitance Bridge, 1862 Megohmmeter, etc, and binding post extension.

*Available as 1690-P2 but not supplied with sample holder.

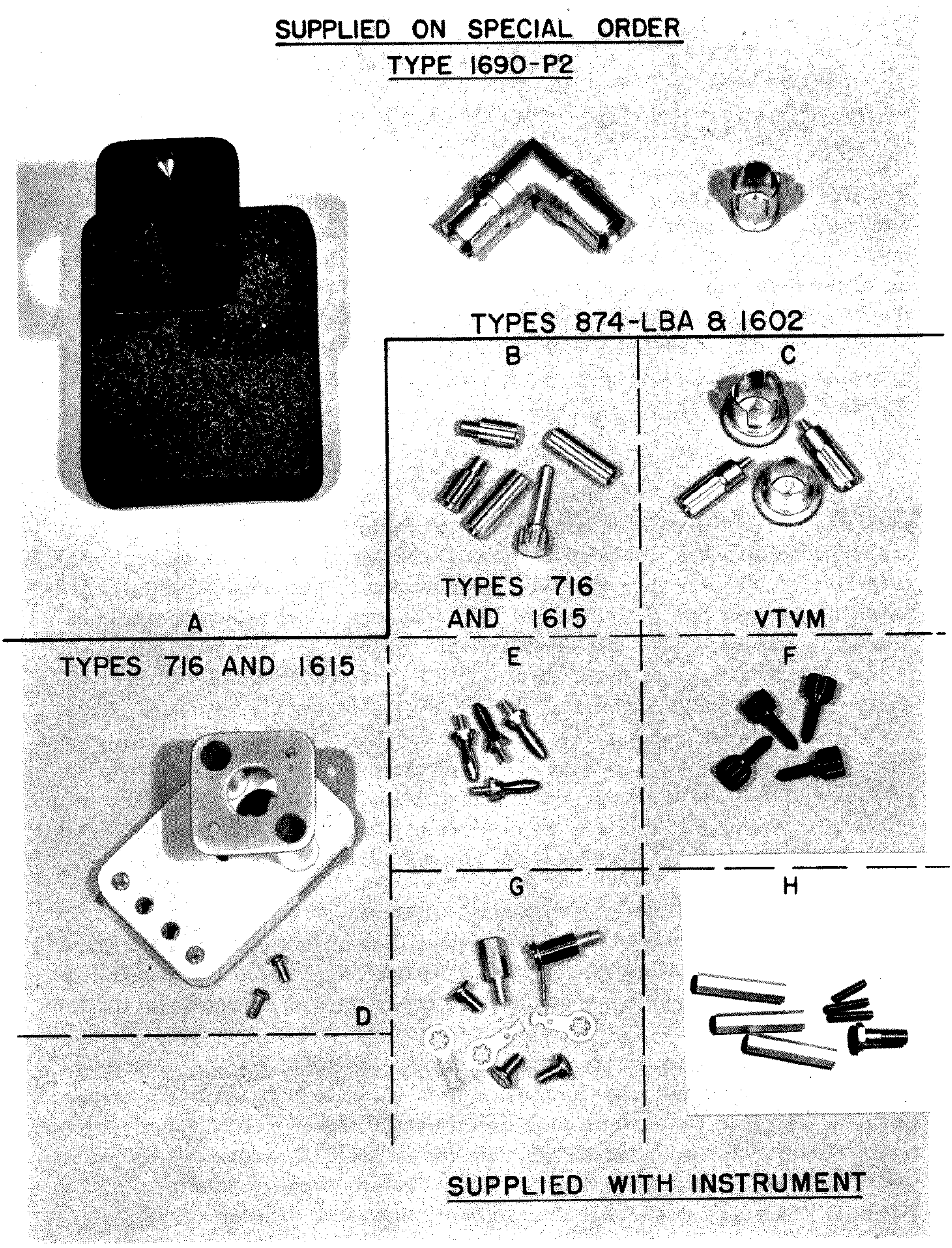

Figure 3. Accessories Used With Sample Holder.
(Refer to Table 1.)

Section 2
PRINCIPLES OF MEASUREMENT

2.1 GENERAL. The accepted method of evaluating the dielectric constant and dissipation factor of a solid dielectric material is to place the material between metallic electrodes and measure the capacitance and dissipation factor of the resulting capacitor. If the configuration of the electrode is such that the distribution of the electric field is accurately known, the constants of the material can be determined. One of the simplest electrode systems is a pair of circular parallel plates, of the type used in the Type 1690-A Dielectric Sample Holder.

2.2 MICROMETER-TYPE ELECTRODE. The micrometer-capacitor type of holder is recognized as the most satisfactory method of holding specimens of solid dielectric material for measurement at radio frequencies. Such holders are recommended in ASTM Specifications D-150 for use in the frequency range from 20 c to 500 Mc. The excellent high-frequency performance is largely a result of the fact that the effects of lead inductance and resistance are substantially eliminated from the measurement. Because of this fact the sample holder should always be used above 10 Mc. Another advantage of this type holder is that, properly calibrated, it virtually eliminates the errors from fringing fields and stray capacitance. Also, in studies of constants of a material over a wide frequency range, it is of considerable advantage to be able to use the same holder and the same specimen with the several different measuring circuits or instruments that may be employed. Accordingly, the sample holder is designed for use with low-frequency bridges as well as with high-frequency measuring circuits.

2.3 DIELECTRIC CONSTANT. The relative dielectric constant is the ratio of the equivalent parallel capacitance of a capacitor in which the material is a dielectric to the capacitance of the same capacitor with a vacuum as the dielectric.

Note: The dielectric constant of dry air is 1.00053 at 23°C and 760 millimeters of mercury. The divergence from unity, K-1, is inversely proportional to absolute temperature and directly proportional to atmospheric pressure. The increase in dielectric constant for air at 23°C saturated with water vapor is 0.00025 and varies approximately linearly with temperature in °C. For most practical purposes, the capacitance measured with air as the dielectric can be assumed to be equal to the capacitance with a vacuum as the dielectric.

2.4 EDGE CORRECTION AND STRAY CAPACITANCE.

It is easy to calculate the capacitance between parallel electrodes if it is assumed that the field distribution between them is uniform, with the lines of force perpendicular to the electrodes. However, the actual capacitance differs from that calculated on this basis because the electrostatic field is not confined to the region between electrodes. The total capacitance can be considered to consist of three parts, using the nomenclature of ASTM Specifications D-150:

C_A, the "geometric" capacitance, represented by the perpendicular flux lines between electrodes.

C_E, the "edge" capacitance, represented by the curved lines passing directly from electrode to electrode, but outside the edges.

C_G, the "stray" capacitance, contributed by the lines of force from the insulated electrode to the shield.

The edge capacitance varies with the spacing of the electrodes, while the stray capacitance is assumed to be constant. Stated otherwise, the stray capacitance may be defined as that component of capacitance that does not vary with spacing.

2.5 CALIBRATION.

2.5.1 MICROMETER CAPACITOR. The calibration provided for the micrometer electrodes includes the variation of edge capacitance with spacing, and takes into account any mechanical imperfections in the screw thread and any lack of parallelism in the electrodes.

Since capacitance differences only are used in measurements, the absolute level of the calibration is unimportant. As suggested in ASTM Specifications D-150, the correction chart is referred to a spacing of 100 mils; i.e., the correction is arbitrarily considered to be zero for the 100-mil setting. The actual nominal value of the geometric capacitance at any spacing is expressed by:

$$C_A = 0.2249 \frac{A}{t} \quad (\mu\mu f,\ in.) \quad = 0.1766 \frac{d^2}{t} \qquad (1)$$

where A is the area of the electrode, t is the spacing, and d is the diameter.

For the 2-inch electrodes of the sample holder, this becomes:

$$C_A = \frac{706.4}{t} \quad (\mu\mu f,\ mils) \qquad (2)$$

The values of C_A as a function of t are given in Table 2, page 18. To obtain the capacitance difference between two settings, add to each value of capacitance taken from the table the correction taken from the correction chart. The difference between the two totals is the true capacitance difference.

This method of calibration and use completely eliminates edge correction errors, subject only to the assumption that the fringing flux in air is unaltered by the presence of the dielectric between the electrodes. Any error involved in this assumption appears to be so small as to be negligible.

Note: Investigations show that the error caused by the edge flux when a dielectric is present is significant only when the most accurate measurements are to be made. This error can be practically eliminated if a sample having a diameter less than that of the electrodes is used and reasonably well centered when inserted. The sample diameter should be smaller than the 2-inch electrode by at least five times the sample thickness.

2.5.2 VERNIER CAPACITOR. This is a worm calibration of the 5-$\mu\mu$f precision cylindrical capacitor (in capacitance removed). A chart is supplied, giving the correction at each 0.1-$\mu\mu$f setting.

Section 3
INSTALLATION

3.1 MOUNTING PROCEDURE. The Type 1690-P1 Adaptor Assembly supplied is designed to attach the sample holder to the Types 1615-A, 716-C, or 716-CS1 Capacitance Bridge. Figure 1 shows the manner in which the adaptor is attached to the sample holder for connection to the UNKNOWN DIRECT binding posts of the Types 716-C and 716-CS1 when the bridge panel is horizontal. Rotate the adaptor counterclockwise 90° for Type 1615-A with horizontal panel.

The Type 1690-P2 Adaptor is available for attaching the sample holder to the Type 874-LBA Slotted Line and Type 1602-B Admittance Meter.

3.2 PREPARATION OF SAMPLE.

3.2.1 DIMENSIONS. Select the test sample, if possible, to yield a capacitance between 20 and 70 $\mu\mu$f (about 50$\mu\mu$f is optimum for most samples). The choice of thickness and diameter depends on frequency, as well as on the constants of the material. Generally, at low frequencies, the sample should be two inches or slightly less in diameter (refer to Note, paragraph 2.5.1), with a thickness between 30 and 100 mils. At higher frequencies, use smaller diameters and greater thicknesses. When the sample is to be studied over a wide frequency range, it should be dimensioned for the highest frequency desired.

The results are likely to be more consistent if the same sample is measured over the entire range. If the approximate dielectric constant is known, the thickness (t) in mils for 50 $\mu\mu$f and a two-inch diameter is 14.1 K.

The maximum capacitance that can be measured by the sample holder is about 100 $\mu\mu$f.

3.2.2 ELECTRODES.

3.2.2.1 General. Although the electrode surfaces of the sample holder are finished for optical flatness, it is seldom practical to finish the specimen to the same degree of flatness. Failure to make intimate contact between dielectric and electrode will introduce error in the determination of dielectric constant and dissipation factor. Metal-foil, sprayed-metal, metal paint, and similar techniques are commonly used to insure intimate contact with the dielectric.

3.2.2.2 Use of Foil. Tin foil less than ½-mil thick is recommended, and may be secured to the sample by a small amount of petrolatum. Carefully remove excess petrolatum and air bubbles. A small rubber roller is useful for this purpose. Trim excess foil so that the foil comes as close to the edge of the specimen as possible. Tin foil is convenient for samples to be measured under room conditions.

3.2.2.3 Silver Paint. Certain air-drying silver paints provide convenient means of obtaining positive contact. Silver paint is superior for studies of temperature and humidity effects on dielectrics, since it stays in place at elevated temperatures and is porous. Such paints are available from Electro-Chemical Department, E. I. DuPont; Hanovia Chemical Company; and others.

At frequencies above about 30 Mc, the use of foil, sprayed-metal, metal paint, or similar techniques can cause significant errors in dissipation factor measurements on low-loss materials. This error results from the concentration of current (and hence increase in effective resistance) caused by the electrodes making contact with the metal film at a number of points on the surface rather than making a uniform contact over the whole surface. Therefore, for most accurate measurements, the foil or other metallic film should be used for dielectric constant measurements, and the bare sample surface used for dissipation factor measurements.

Refer to ASTM Specifications D-150 for further suggestions regarding electrode materials and methods of application. Samples should be cleaned with a suitable solvent, and the solvent allowed to dry, before any of the above electrodes are applied.

The electrodes should completely cover the flat faces of the samples, and the edges should be kept bare and clean, especially when low-loss materials are measured. After the electrodes are applied the samples should be handled by their faces only.

Section 4

MEASUREMENT PROCEDURE

4.1 USE WITH TYPES 1615-A, 716-C, OR 716-CS1 CAPACITANCE BRIDGE (METHOD 1). Mount the sample holder on the UNKNOWN binding posts on the Type 1615-A; set the switch at 2 TERMINAL. With the Type 716 Bridges the preferred location for the sample holder is at the UNKNOWN DIRECT binding posts. This is especially important for low-loss samples, so that the total capacitance in the circuit (C_1') may be kept as close to the sample capacitance (C_X) as possible in order to give better resolution for dissipation factor (preferably at 100 $\mu\mu$f or less; all precision capacitors in Type 716-C Bridges are reasonably linear to 70 $\mu\mu$f).

If the bridge panel is horizontal, secure the sample holder to the Type 1690-P1 Adaptor as shown in Figure 1 for Type 716 Bridges, or turned 90° counterclockwise for Type 1615-A. Mount the adaptor on the other boss if the bridge is rack-mounted. In either instance the electrode surfaces should be horizontal for convenience in handling the sample.

a. For maximum accuracy, measure the sample thickness, t_1, and diameter, d_X, with a machinist's micrometer before any foil or film is applied. Use an average value obtained from measurements at several points on the disc.

b. Insert the sample in the holder and screw the top electrode down until it is firmly in contact, as indicated by the release of the drive mechanism.

CAUTION

After the release of the drive mechanism, the knob can be rotated about three-quarters of a turn before the screw bottoms inside the grounded electrode. Further rotation may damage the insulators and ruin the calibration. Special care should be used with soft or warped samples since the release may be masked.

c. Balance the bridge (refer to Type 1615-A or 716-C Operating Instructions) and record its CAPACITANCE reading (C_1'), dissipation-factor reading (D_1), and the spacing between electrodes (t_1).[3] If the total capacitance of the sample is less than about 50$\mu\mu$f, it may be necessary to add a small capacitor in parallel to obtain an initial balance within the calibrated portion of the dial when using Type 716 Bridges. The Type 874-VC Variable Capacitor, a general-purpose tuning element, is very convenient for this purpose, since it is shielded and equipped with coaxial terminals. When using the Type 874-

[3] If the sample thickness without foil has been measured as indicated in step a, use the value of t_1 found in step a in all subsequent calculations. This value of t_1 is the most accurate since it does not include the foil thickness and is an average.

VC, set the bridge CAPACITANCE dial to a convenient low value (say 100 $\mu\mu f$), and then balance by adjusting the Type 874-VC and the DISSIPATION FACTOR dial. Slight adjustment of the CAPACITANCE dial may be necessary. Record readings as noted above, and continue on to step d. Do not disturb the setting of the Type 874-VC for the remainder of the measurement.

d. Remove the sample from the holder. Use a soft "pusher" for positioning and removing the sample, to avoid damaging the electrodes.

e. Rebalance the bridge by readjusting the micrometer capacitor (electrodes) and the DISSIPATION FACTOR dial. Do not disturb the bridge CAPACITANCE dial. Record the new spacing between electrodes (t_2) and the new DISSIPATION FACTOR (D_2).

f. Calculate the capacitance of the sample by the following formula:

$$C_X = C_{A2} + \Delta C_{A2} - \Delta C_{A1} - C_{A1}\left(1 - \frac{A_X}{A_E}\right) \quad (\mu\mu f) \qquad (3)$$

where

C_X = equivalent series capacitance of sample

C_{A2} = geometric air capacitance of electrodes at spacing t_2, from Table 2, page 18.

C_{A1} = geometric air capacitance of electrodes at spacing t_1, from Table 2, page 18.

ΔC_{A2} = correction for setting t_2, from chart supplied with sample holder.

ΔC_{A1} = correction for setting t_1, from chart supplied with sample holder.

A_X = area of specimen.

A_E = area of electrodes.

For a two-inch specimen the last term is zero and

$$C_X = C_{A2} + \Delta C_{A2} - \Delta C_{A1} \qquad (4)$$

g. Calculate dielectric constant by the formula:

$$K = \frac{C_X}{C_{A1}\left(\frac{A_X}{A_E}\right)} \qquad \left(\text{For a 2-inch specimen } K = \frac{C_X}{C_{A1}}\right) \qquad (5)$$

h. Calculate dissipation factor by the formula:

$$D_X = (D_1 - D_2)\,\frac{C_1'}{C_X} \qquad (6)$$

where C_1' = total capacitance in circuit.

i. With the measurement of a 1¾-inch disk of polyvinyl butyral as an example, the following data were obtained:

d_X = 1.738 inches (diameter of sample).

d_E = 2.000 inches (diameter of electrodes).

t_1 = 125.4 mils (averaged micrometer readings).

D_1 = 0.007 x 0.01

t_2 = 48.15 mils

C_1' = 78.0 $\mu\mu f$

D_2 = −0.088 x 0.01

From Table 2 and chart supplied with holder:

C_{A2} = 14.67 $\mu\mu f$

C_{A1} = 5.63 $\mu\mu f$

ΔC_{A2} = +0.18 $\mu\mu f$

ΔC_{A1} = −0.07 $\mu\mu f$

$$\frac{A_X}{A_E} = \left(\frac{d_X}{d_E}\right)^2 = \left(\frac{1.738}{2.000}\right)^2 = 0.756$$

$$\begin{aligned} C_X &= 14.67 + 0.18 - (+0.07) - 5.63(1 - 0.756) \\ &= 14.92 - 5.63(0.244) \\ &= 14.92 - 1.37 = 13.55\ \mu\mu f \end{aligned}$$

$$K = \frac{13.55}{5.63(0.756)} = 3.18$$

$$D_X = \left[0.007 - (-0.088)\right] \frac{78.0}{13.55} \times 0.01 = 0.00546$$

4.2 USE WITH TYPES 1615-A, 716-C, OR 716-CS1 CAPACITANCE BRIDGES (METHOD 2 for 2-inch specimens).

The constants of the sample can be computed directly from the readings C_1', D_1, D_2, and t_1, provided the total zero capacitance is known.

$$C_X = C_1' - C_O - C_{aux.} \tag{7}$$

where $C_{aux.}$ is added balancing capacitance (sometimes needed with the Type 716 Bridges, but not with the Type 1615-A) and C_O is the total capacitance of the holder and its connecting leads at the setting t_1, minus the air capacitance of the electrodes at that setting. This value can be determined for a particular holder and bridge and can be used as a constant.

Dissipation factor of the sample can be calculated by:

$$D_X = (D_1 - D_2)\,\frac{C_1'}{C_X} \qquad (8)$$

4.3 VOLUME RESISTIVITY MEASUREMENTS WITH TYPE 544-B MEGOHM BRIDGE.

To use the sample holder with the Type 544-B Megohm Bridge, first mount the three 1¼-inch spacers (J, Figure 3) on boss B, Figure 2. Plug in the sample holder and hold down firmly while unscrewing the ground binding post top until it supports the fourth corner of the boss. Use the binding-post extension if necessary. Measurement procedure is as follows:

a. With the sample in place, measure its d-c leakage resistance at the desired voltage (refer to Type 544-B Operating Instructions).

b. The d-c leakage resistance equals dial reading times multiplier setting. The volume resistivity, ρ_V. of the sample is given by:

$$\rho_V = \frac{RA}{t} \qquad (9)$$

where R = parallel resistance of sample in ohms
A = cross-sectional area in cm^2
t = thickness in cm

c. The contribution of the d-c leakage resistance to the dissipation factor at any frequency is:

$$D = \frac{1}{R\omega C_X} \quad \text{ohms, farads} \qquad (10)$$

when R = parallel d-c leakage resistance.

4.4 USE WITH OTHER GENERAL RADIO INSTRUMENTS.

The method outlined in paragraph 4.3 can be used to mount the sample holder on other General Radio instruments, such as:

- Type 740-B Capacitance Test Bridge
- Type 1611 Capacitance Test Bridge
- Type 1862 Megohmmeter (make sure that UNKNOWN + is connected to panel)

4.5 HIGH-FREQUENCY METHODS.

In the frequency range to 100 Mc, resonant-circuit methods are widely used. For a discussion of the resistance-variation, conductance-variation, susceptance-variation, and frequency-variation methods, refer to the current edition of ASTM Specification D-150.

4.5.1 USE WITH TYPE 1602-B U-H-F ADMITTANCE METER.

The Type 1602-B U-H-F Admittance Meter can be used with the Type 1690-A Dielectric

Sample Holder at frequencies between 20 and $\frac{900}{\sqrt{K}}$ Mc where K is the dielectric constant of the sample. The dielectric constant of both low- and high-loss materials can be measured over this entire frequency range; however, dissipation-factor measurements can be made only on relatively high-loss materials. At 20 Mc, the dissipation-factor accuracy is approximately ±(5% + 0.03) for a 50-$\mu\mu$f sample and ±(5% ± 0.02) for a 100-$\mu\mu$f sample. At 100 Mc and above, a 20- to 50-$\mu\mu$f sample is recommended. The errors have not been thoroughly investigated at frequencies above 100 Mc, but it is believed that accuracies of the order of ±(5% + 0.02) should be obtainable in dissipation-factor measurements.

The possibility of the existence of higher-order resonant modes in the dielectric must be eliminated; therefore, the sample diameter, d_X, should be less than $d_X = \frac{10^4}{f_{MC}\sqrt{K}}$ where f_{MC} is the frequency in megacycles.

As pointed out in paragraph 3.2.2.3, the most accurate dielectric-constant measurements are made with foil or film applied to the sample surfaces. For dissipation-factor measurements, however, no foil or film should be used.

The measurement procedure is as follows:

a. Attach a banana pin and a Type 874-60-3 outer connector to the terminals at the base of the sample holder. Connect these terminals to the unknown terminals on the admittance meter directly or by means of a Type 874-E11.

b. Measure the sample thickness and diameter with a machinist's micrometer to obtain t_1 and d_X.

c. Insert the sample as outlined in paragraph 4.1b.

d. Balance the admittance meter using the lowest possible multiplier. Record the CONDUCTANCE, SUSCEPTANCE, and MULTIPLIER dial readings, G_1, B_1, M_1, as well as the frequency.

e. Remove the sample and rebalance the admittance meter using the CONDUCTANCE dial and the micrometer capacitor (electrodes). Record the new reading of the CONDUCTANCE dial, G_2.

f. Adjust the micrometer until the electrodes are in contact and again rebalance the admittance meter and record B_3 and M_3. (If only dielectric constant is desired, this step is unnecessary.)

g. Calculate the sample capacitance, C_X, and dielectric constant as in paragraph 4.1f.

h. If dissipation factor is desired, calculate the effective conductance G_E and susceptance B_E with the sample in place.

$$G_E = M_1(G_1 - G_2) \text{ millimhos} \quad (11)$$

$$B_E = M_1 B_1 \quad \text{millimhos} \tag{12}$$

i. In order to determine the effective conductance at the sample, the values measured by the admittance meter must be corrected for the effect of the length of 50-ohm line between the two instruments. The electrical length (θ) of this line can be calculated from the susceptance measurement with the electrodes shorted (paragraph 4.5.1).

$$\tan \theta = \frac{-Y_O}{M_3 B_3} \tag{13}$$

where Y_O is the characteristic admittance of the connecting line which is 20 millimhos.

j. The conductance, G_X, of the sample can then be calculated from the following equation:

$$G_X = \frac{G_E (1 + \tan^2 \theta)}{\left(1 + \frac{B_E}{Y_O} \tan \theta\right)^2 + \left(\frac{G_E}{Y_O} \tan \theta\right)^2} \tag{14}$$

The dissipation factor, D_X, is equal to:

$$D_X = \frac{G_X 10^3}{2\pi f_{MC} C_X} \qquad \frac{\text{millimhos}}{\text{Mc x } \mu\mu f} \tag{15}$$

The value of C_X is obtained from step g.

4.5.2 USE WITH TYPE 874-LBA SLOTTED LINE. At frequencies between about 100 Mc and $\frac{900}{\sqrt{K}}$ Mc, the dielectric constants of samples can be measured with the Type 874-LBA Slotted Line. The accuracy of dissipation-factor measurements has not been investigated thoroughly but preliminary results indicate that errors are present in measurements on low-loss materials.

The procedure for dielectric constant measurements is as follows:

a. Repeat steps a, b, and c in paragraph 4.5.1.

b. Locate position of a voltage minimum on slotted line. If adequate sensitivity is not obtained, increase the probe penetration on the slotted line.

c. With the probe left at the position found in paragraph 4.1g, remove the sample and adjust the micrometer until the output from the probe is a minimum. Then move the probe carriage slightly to both sides to make sure true voltage minimum is at the desired location. If it is not, readjust the micrometer slightly until the desired position is obtained.

d. Calculate the dielectric constant as described in paragraph 4.1f.

4.7 MEASUREMENT OF COMPONENTS. Besides its primary use in evaluating properties of materials, the sample holder may also be used for measurements of components. For this purpose, tapped holes are provided on the fixed electrode at a distance of ¾-inch from similar tapped holes in the casting for ground connection. This means of connection is in addition to those provided at the mounting bosses, and offers a somewhat lower inductance connection to the higher electrode. Accessories G, Figure 3, are provided for this purpose.

Representative measurements of components include capacitance and dissipation-factor measurements of capacitors (below 100 $\mu\mu$f) and shunt-capacitance measurements of resistors. Capacitance up to 5 $\mu\mu$f may be measured to 0.004 $\mu\mu$f by the worm calibrated vernier capacitor. The decrease in resistance of high-valued resistors with increase in frequency (Boella effect) may be studied by use of the holder with a susceptance-variation circuit. Refer to Type 1615-A or 716-C Operating Instructions for low-frequency methods.

Section 5

SERVICE AND MAINTENANCE

5.1 GENERAL. The two-year warranty given with every General Radio instrument attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible.

In case of difficulties that cannot be eliminated by the use of these service instructions, please write or phone our Service Department, giving full information of the trouble and of steps taken to remedy it. Be sure to mention the serial and type numbers of the instrument.

Before returning an instrument to General Radio for service, please write to our Service Department or nearest district office (see back cover), requesting a Returned Material Tag. Use of this tag will insure proper handling and identification. For instruments not covered by the warranty, a purchase order should be forwarded to avoid unnecessary delay.

5.2 MAINTENANCE.

5.2.1 ELECTRODE SURFACES. The electrode surfaces should be kept clean, especially when the sample's capacitance is high and dissipation factor is low. Usually a strip of clean paper pulled between the snug electrodes is sufficient.

5.2.2 SIDE PANELS. Keep the pivot corners of the side panels lubricated to prevent excessive wear.

TABLE 2. Calculated Capacitance in $\mu\mu f$ for 2-inch-diameter Electrodes.

$C = \frac{706.5}{t}$ (t in mils) (C = geometric air capacitance, C_{A1} or C_{A2})

Mils	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
5	141.30	138.53	135.87	133.30	130.84	128.46	126.16	123.95	121.81	119.75	117.75
6	117.75	115.82	113.95	112.14	110.39	108.69	107.05	105.45	103.90	102.39	100.93
7	100.93	99.51	98.13	96.78	95.47	94.20	92.96	91.76	90.58	89.43	88.31
8	88.31	87.22	86.16	85.12	84.11	83.12	82.15	81.21	80.29	79.38	78.50
9	78.50	77.64	76.80	75.97	75.16	74.37	73.60	72.84	72.09	71.36	70.65
10	70.65	69.95	69.27	68.59	67.93	67.29	66.65	66.03	65.42	64.82	64.23
11	64.23	63.65	63.08	62.52	61.97	61.44	60.91	60.39	59.87	59.37	58.88
12	58.88	58.39	57.91	57.44	56.98	56.52	56.07	55.63	55.20	54.77	54.35
13	54.35	53.93	53.52	53.12	52.72	52.33	51.95	51.57	51.20	50.83	50.47
14	50.47	50.11	49.75	49.41	49.06	48.73	48.39	48.06	47.74	47.42	47.10
15	47.10	46.79	46.48	46.18	45.88	45.58	45.29	45.00	44.72	44.43	44.16
16	44.16	43.88	43.61	43.34	43.08	42.82	42.56	42.31	42.05	41.81	41.56
17	41.56	41.32	41.08	40.84	40.60	40.37	40.14	39.92	39.69	39.47	39.25
18	39.25	39.03	38.82	38.61	38.40	38.19	37.98	37.78	37.58	37.38	37.18
19	37.18	36.99	36.80	36.61	36.42	36.23	36.05	35.86	35.68	35.50	35.33
20	35.33	35.15	34.98	34.80	34.63	34.46	34.30	34.13	33.97	33.80	33.64
21	33.64	33.48	33.33	33.17	33.01	32.86	32.71	32.56	32.41	32.26	32.11
22	32.11	31.97	31.82	31.68	31.54	31.40	31.26	31.12	30.99	30.85	30.72
23	30.72	30.58	30.45	30.32	30.19	30.06	29.94	29.81	29.69	29.56	29.44
24	29.44	29.32	29.19	29.07	28.96	28.84	28.72	28.60	28.49	28.37	28.26
25	28.26	28.15	28.04	27.93	27.82	27.71	27.60	27.49	27.38	27.28	27.17
26	27.17	27.07	26.97	26.86	26.76	26.66	26.56	26.46	26.36	26.26	26.17
27	26.17	26.07	25.97	25.88	25.79	25.69	25.60	25.51	25.41	25.32	25.23
28	25.23	25.14	25.05	24.97	24.88	24.79	24.70	24.62	24.53	24.45	24.36
29	24.36	24.28	24.20	24.11	24.03	23.95	23.87	23.79	23.71	23.63	23.55
30	23.55	23.47	23.39	23.32	23.24	23.16	23.09	23.01	22.94	22.86	22.79
31	22.79	22.72	22.64	22.57	22.50	22.43	22.36	22.29	22.22	22.15	22.08
32	22.08	22.01	21.94	21.87	21.81	21.74	21.67	21.61	21.54	21.47	21.41

TABLE 2. (Continued)

Mils	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	10
33	21.41	21.34	21.28	21.22	21.15	21.09	21.03	20.96	20.90	20.84	20.78
34	20.78	20.72	20.66	20.60	20.54	20.48	20.42	20.36	20.30	20.24	20.19
35	20.19	20.13	20.07	20.01	19.96	19.90	19.85	19.79	19.74	19.68	19.63
36	19.63	19.57	19.52	19.46	19.41	19.36	19.30	19.25	19.20	19.15	19.09
37	19.09	19.04	18.99	18.94	18.89	18.84	18.79	18.74	18.69	18.64	18.59
38	18.59	18.54	18.50	18.45	18.40	18.35	18.30	18.26	18.21	18.16	18.12
39	18.12	18.07	18.02	17.98	17.93	17.89	17.84	17.80	17.75	17.71	17.66
40	17.66	17.62	17.57	17.53	17.49	17.44	17.40	17.36	17.32	17.27	17.23
41	17.23	17.19	17.15	17.11	17.07	17.02	16.98	16.94	16.90	16.86	16.82
42	16.82	16.78	16.74	16.70	16.66	16.62	16.58	16.55	16.51	16.47	16.43
43	16.43	16.39	16.35	16.32	16.28	16.24	16.20	16.17	16.13	16.09	16.06
44	16.06	16.02	15.98	15.95	15.91	15.88	15.84	15.81	15.77	15.74	15.70
45	15.70	15.67	15.63	15.60	15.56	15.53	15.49	15.46	15.43	15.39	15.36
46	15.36	15.33	15.29	15.26	15.23	15.19	15.16	15.13	15.10	15.06	15.03
47	15.03	15.00	14.97	14.94	14.91	14.87	14.84	14.81	14.78	14.75	14.72
48	14.72	14.69	14.66	14.63	14.60	14.57	14.54	14.51	14.48	14.45	14.42
49	14.42	14.39	14.36	14.33	14.30	14.27	14.24	14.22	14.19	14.16	14.13
50	14.13	14.10	14.07	14.05	14.02	13.99	13.96	13.94	13.91	13.88	13.85
51	13.85	13.83	13.80	13.77	13.75	13.72	13.69	13.67	13.64	13.61	13.59
52	13.59	13.56	13.53	13.51	13.48	13.46	13.43	13.41	13.38	13.36	13.33
53	13.33	13.31	13.28	13.26	13.23	13.21	13.18	13.16	13.13	13.11	13.08
54	13.08	13.06	13.04	13.01	12.99	12.96	12.94	12.92	12.89	12.87	12.85
55	12.85	12.82	12.80	12.78	12.75	12.73	12.71	12.68	12.66	12.64	12.62
56	12.62	12.59	12.57	12.55	12.53	12.50	12.48	12.46	12.44	12.42	12.40
57	12.40	12.37	12.35	12.33	12.31	12.29	12.27	12.24	12.22	12.20	12.18
58	12.18	12.16	12.14	12.12	12.10	12.08	12.06	12.04	12.02	12.00	11.98
59	11.98	11.96	11.94	11.92	11.90	11.88	11.86	11.84	11.82	11.80	11.78
60	11.78	11.76	11.74	11.72	11.70	11.68	11.66	11.64	11.62	11.60	11.58
61	11.58	11.56	11.54	11.53	11.51	11.49	11.47	11.45	11.43	11.41	11.40
62	11.40	11.38	11.36	11.34	11.32	11.30	11.29	11.27	11.25	11.23	11.21
63	11.21	11.20	11.18	11.16	11.14	11.13	11.11	11.09	11.07	11.06	11.04
64	11.04	11.02	11.00	10.99	10.97	10.95	10.94	10.92	10.90	10.89	10.87

TABLE 2. (Continued)

Mils	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	10
65	10.87	10.85	10.84	10.82	10.80	10.79	10.77	10.75	10.74	10.72	10.71
66	10.71	10.69	10.67	10.66	10.64	10.62	10.61	10.59	10.58	10.56	10.55
67	10.55	10.53	10.51	10.50	10.48	10.47	10.45	10.44	10.42	10.41	10.39
68	10.39	10.37	10.36	10.34	10.33	10.31	10.30	10.28	10.27	10.25	10.24
69	10.24	10.22	10.21	10.20	10.18	10.17	10.15	10.14	10.12	10.11	10.09
70	10.09	10.08	10.06	10.05	10.04	10.02	10.01	9.99	9.98	9.96	9.95
71	9.95	9.94	9.92	9.91	9.90	9.88	9.87	9.85	9.84	9.83	9.81
72	9.81	9.80	9.79	9.77	9.76	9.75	9.73	9.72	9.70	9.69	9.68
73	9.68	9.67	9.65	9.64	9.63	9.61	9.60	9.59	9.57	9.56	9.55
74	9.55	9.53	9.52	9.51	9.50	9.48	9.47	9.46	9.45	9.43	9.42
75	9.42	9.41	9.40	9.38	9.37	9.36	9.35	9.33	9.32	9.31	9.30
76	9.30	9.28	9.27	9.26	9.25	9.24	9.22	9.21	9.20	9.19	9.18
77	9.18	9.16	9.15	9.14	9.13	9.12	9.10	9.09	9.08	9.07	9.06
78	9.06	9.05	9.03	9.02	9.01	9.00	8.99	8.98	8.97	8.95	8.94
79	8.94	8.93	8.92	8.91	8.90	8.89	8.88	8.86	8.85	8.84	8.83
80	8.83	8.82	8.81	8.80	8.79	8.78	8.77	8.75	8.74	8.73	8.72
81	8.72	8.71	8.70	8.69	8.68	8.67	8.66	8.65	8.64	8.63	8.62
82	8.62	8.61	8.60	8.58	8.57	8.56	8.55	8.54	8.53	8.52	8.51
83	8.51	8.50	8.49	8.48	8.47	8.46	8.45	8.44	8.43	8.42	8.41
84	8.41	8.40	8.39	8.38	8.37	8.36	8.35	8.34	8.33	8.32	8.31
85	8.31	8.30	8.29	8.28	8.27	8.26	8.25	8.24	8.23	8.22	8.22
86	8.22	8.21	8.20	8.19	8.18	8.17	8.16	8.15	8.14	8.13	8.12
87	8.12	8.11	8.10	8.09	8.08	8.07	8.07	8.06	8.05	8.04	8.03
88	8.03	8.02	8.01	8.00	7.99	7.98	7.97	7.97	7.96	7.95	7.94
89	7.94	7.93	7.92	7.91	7.90	7.89	7.89	7.88	7.87	7.86	7.85
90	7.85	7.84	7.83	7.82	7.82	7.81	7.80	7.79	7.78	7.77	7.76
91	7.76	7.76	7.75	7.74	7.73	7.72	7.71	7.70	7.70	7.69	7.68
92	7.68	7.67	7.66	7.65	7.65	7.64	7.63	7.62	7.61	7.61	7.60
93	7.60	7.59	7.58	7.57	7.56	7.56	7.55	7.54	7.53	7.52	7.52
94	7.52	7.51	7.50	7.49	7.48	7.48	7.47	7.46	7.45	7.44	7.44
95	7.44	7.43	7.42	7.41	7.41	7.41	7.39	7.38	7.37	7.37	7.36

TABLE 2. (Continued)

Mils	0	.1	.2	.3	.4	.5	.6	.7	.8	.9	10
96	7.36	7.35	7.34	7.34	7.33	7.32	7.31	7.31	7.30	7.29	7.28
97	7.28	7.28	7.27	7.26	7.25	7.25	7.24	7.23	7.22	7.22	7.21
98	7.21	7.20	7.19	7.19	7.18	7.17	7.17	7.16	7.15	7.14	7.14
99	7.14	7.13	7.12	7.11	7.11	7.10	7.09	7.09	7.08	7.07	7.07

Mils	0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
100	7.07	7.00	6.93	6.86	6.79	6.73	6.67	6.60	6.54	6.48	6.42
110	6.42	6.37	6.31	6.25	6.20	6.14	6.09	6.04	5.99	5.94	5.89
120	5.89	5.84	5.79	5.74	5.70	5.65	5.61	5.56	5.52	5.48	5.44
130	5.44	5.39	5.35	5.31	5.27	5.23	5.20	5.16	5.12	5.08	5.05
140	5.05	5.01	4.98	4.94	4.91	4.87	4.84	4.81	4.77	4.74	4.71
150	4.71	4.68	4.65	4.62	4.59	4.56	4.53	4.50	4.47	4.44	4.42
160	4.42	4.39	4.36	4.33	4.31	4.28	4.26	4.23	4.21	4.18	4.16
170	4.16	4.13	4.11	4.08	4.06	4.04	4.01	3.99	3.97	3.95	3.93
180	3.93	3.90	3.88	3.86	3.84	3.82	3.80	3.78	3.76	3.74	3.72
190	3.72	3.70	3.68	3.66	3.64	3.62	3.61	3.59	3.57	3.55	3.53
200	3.53	3.52	3.50	3.48	3.46	3.45	3.43	3.42	3.40	3.38	3.36
210	3.36	3.35	3.33	3.32	3.30	3.29	3.27	3.26	3.24	3.23	3.21
220	3.21	3.20	3.18	3.17	3.15	3.14	3.13	3.11	3.10	3.09	3.07
230	3.07	3.06	3.05	3.03	3.02	3.01	2.99	2.98	2.97	2.96	2.94
240	2.94	2.93	2.92	2.91	2.90	2.88	2.87	2.86	2.85	2.84	2.83
250	2.83	2.82	2.80	2.79	2.78	2.77	2.76	2.75	2.74	2.73	2.72
260	2.72	2.71	2.70	2.69	2.68	2.67	2.66	2.65	2.64	2.63	2.62
270	2.62	2.61	2.60	2.59	2.58	2.57	2.56	2.55	2.54	2.53	2.52
280	2.52	2.51	2.51	2.50	2.49	2.48	2.47	2.46	2.45	2.45	2.44
290	2.44	2.43	2.42	2.41	2.40	2.40	2.39	2.38	2.37	2.36	2.36

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