55 Mc provided the lead length is kept to a reasonable value. Measurements above this frequency indicate that very close coupling can be used, provided the leads do not become resonant.

The combination of the crystal oscillator and a good communications receiver will permit frequency measurements to an accuracy of 0.002% or better at frequencies up to 15 Mc. Here the limiting factor is not the oscillator stability, but the precision with which the receiver dial can be read. The best accuracy will be attainable with receivers having band-spread dials.

— ROBERT B. RICHMOND

SPECIFICATIONS

Frequency: 1 Mc, 100 kc, and 10 kc. The crystal has a temperature coefficient of one part per million per degree centigrade. Under normal operating conditions with a constant room temperature, a stability of approximately one part per million can be obtained for a day's operation.

Output: Greater than six volts for all three frequencies.

Harmonics Available: 1000, 250, and 25 Mc, respectively.

Controls: A ceramic wafer switch to select desired output frequencies.

Terminals: Jack-top binding posts provided with standard ¾ inch spacing.

Vacuum Tubes: Three 12AT7-type.

Power Supply: 300 volts dc, 120 ma; 6.3 volts, 1 ampere, ac.

Power Input: With 1203-A or 1204-A Power Supply, 15 to 31 watts, depending upon switch setting.

Accessories Supplied: One mating multipoint connector.

Mounting Black-crackle-finish panel and sides. Aluminum cover finished in clear lacquer.

Dimensions: (Width) 9⅞ x (height) 5¾ x (depth) 6¼ inches.

Net Weight: 3 lbs. 12 oz.

Type		*Code Word*	*Price*
1213-A	**Unit Crystal Oscillator***	REBEL	**$130.00**
1203-A	**Unit Power Supply**	ALIVE	**47.50**

*Licensed under patents of G. W. Pierce and of the Radio Corporation of America.

General Radio Unit Instruments are basic, general-purpose laboratory instruments, designed for high-quality performance at minimum price. Low cost is achieved through standardized cabinet and chassis construction and by simplified circuit design to use a minimum number of components.

Several other unit instruments will be described in forthcoming issues of the *Experimenter*, among them a null detector, an I-F amplifier, a pulse generator, and other oscillators.

In keeping with the trend toward miniaturized electronic equipment, these instruments have been designed to occupy as small a volume as is consistent with the ability to dissipate the heat developed.

A 1-MEGACYCLE SCHERING BRIDGE

Both commercial and military specifications on capacitors of 1000 $\mu\mu$f and less call for measurements of capacitance and dissipation factor at a frequency of one megacycle. Similarly, the grading of insulating materials is often based on the measured dielectric constant and loss factor at one megacycle. While the TYPE 916-A Radio-Frequency Bridge and the TYPE 821-A Twin-T are capable of making such measurements, neither instrument is ideal for the purpose. The TYPE 916 does not offer the desired accuracy for capacitance measurements while the Twin-T, *although entirely satisfactory for capacitance measurements,* in many instances does not have adequate resolution for the evaluation of the losses of low-loss materials or capacitors, particularly if the capacitance is small.

The Schering bridge circuit, exemplified by the General Radio TYPE 716, has been widely accepted at lower frequencies for capacitance and dissipation-factor measurements. By appropriate modification it is possible to obtain at one megacycle essentially the same performance as is obtained at lower frequencies with the standard model. Such a modification has been made at the request of leading capacitor manufacturers and is now offered on a semi-stock basis, designated as the Type 716-CS1.

Superficially, all that is required to obtain direct-reading operation at one megacycle is the installation of ratio arms of appropriate value to make the dissipation factor read correctly, but actually a number of other changes are necessary. The input transformer must be redesigned in order to obtain satisfactory transfer of energy at the higher frequency. It is also found that multiple sets of ratio arms, as provided in the standard model, produce serious errors caused presumably by the multiple current paths provided through capacitive coupling to the unused elements for any given setting. Accordingly, one set of equal ratio arms only is provided.

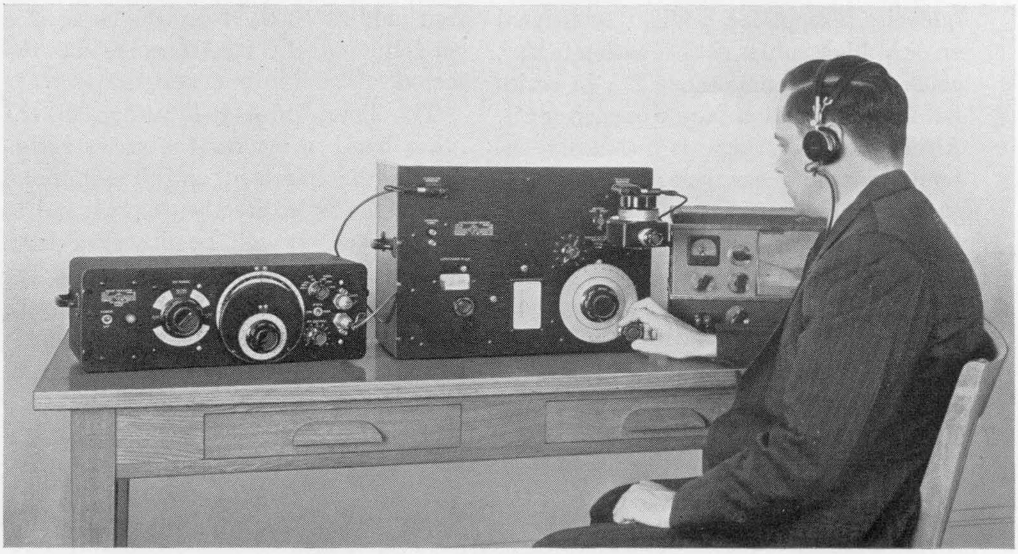
The construction of the precision capacitor used in the standard Type 716-C is not entirely satisfactory for use at one megacycle and higher, and a capacitor of the 722-N type is used. This capacitor, designed for *R-F* use, has lower inductance and lower and more nearly constant metallic resistance.

Finally, considerable attention must be given to the location of connecting leads and equalization of lead lengths in order to realize the desired accuracy.

Figure 2 shows the basic circuit bridge circuit, including the residual inductances that are significant in determining performance. Several adjustments are provided to equalize circuit impedances and to provide direct-reading operation.

In order that the static calibration of the capacitor C_N give directly the value of the capacitance C_X connected in the adjacent arm, it is necessary that L_N equal L_P. However, even if this condition is not met, C_N can alternatively be made direct reading for any given frequency by taking the difference of L_N and L_P into account. For a substitution measurement across the UNKNOWN, SUBST terminals, the inductance L'_N

Figure 1. Setup for one-megacycle dielectric measurements. Shown are the Type 716-CS1 Capacitance Bridge, Type 1690-A Dielectric Sample Holder, and Type 1330-A Bridge Oscillator.



introduces an error but in this case there is no opportunity for compensation in the adjacent arm. Actually C_N is calibrated to be direct reading for substitution measurements at 1 Mc, taking into account the inductance L'_N. The values of L_N, L'_N, and L_P are such that this calibration is also correct for direct measurements within the normal calibration accuracy.

The capacitance C_B is adjusted to compensate for the zero capacitance of the dissipation factor capacitor C_A. It also serves to equalize any differences in L_A and L_B, which behave approximately as a negative capacitance in shunt, independent of frequency. The ratio arm resistors themselves are adjusted to equality within ±.05%.

A third adjustment is provided by a differential capacitor connected between the primary shield of the transformer and the junction of the ratio arms. This compensates for any residual leakage capacitance between primary and secondary windings of the transformer[1] and also, in part, for induced voltages in the transformer shields.

With these adjustments properly made, the direct-reading accuracy for capacitance and dissipation factor at one megacycle is the same as at low frequencies, except for a slight additional error at high values of dissipation factor, caused by the inductance L'_A in series with the dissipation factor capacitor C_A. Although the bridge is primarily intended for one-megacycle use, it is useful to about 5 Mc.

RANGE

The introductory paragraph mentioned briefly the Type 821-A Twin-T and the Type 916-A R-F Bridge. A more detailed comparison between these two and the Type 716-CS1 Capacitance Bridge is in order to point out the area of measurement in which the latter is particularly useful. In Figure 3 is reproduced a plot showing the smallest[2] measurable dissipation factor at one megacycle, as a function of capacitance over the range 1 to 1000 μμf.

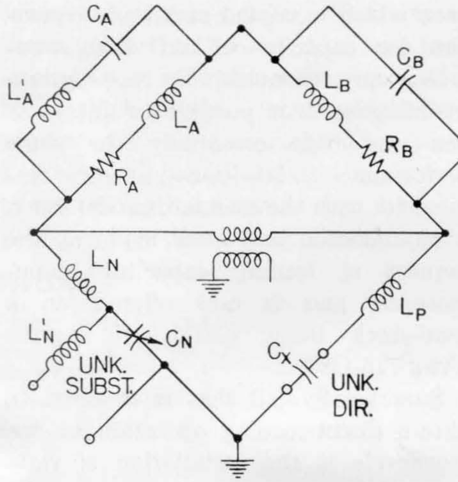


Figure 2. Simplified schematic diagram of Type 716-CS1, showing location of the more important residual inductances.

The Twin-T is calibrated in terms of conductance, hence the minimum detectable dissipation factor is an inverse function of capacitance. It will be noted that only at 1000 μμf can the losses of a capacitor in the 0.0002 range be detected.

The Type 916-A R-F Bridge, on the other hand, measures the series resistance of the unknown, and the minimum detectable D is directly proportional to capacitance. It will be observed from the plot that below about 500 μμf the Type 916-A R-F Bridge will theoretically measure lower losses, and this is possible, if corrections for residual pa-

[1] R. F. Field and I. G. Easton, "A Wide-Frequency-Range Capacitance Bridge," *General Radio Experimenter*, May, 1947.

[2] In terms of the smallest calibrated scale division. Actually about ⅕ of smallest division can be estimated in most instances.

rameters are established by measurement for the individual bridge used. The accuracy and precision of *capacitance* measurements, however, are not adequate for capacitor checking to close tolerances.

In the Schering bridge circuit, used in the Type 716-CS1, the dissipation factor reading is independent of capacitance. Over the direct-reading range of 100 to 1000 μμf, a value of D of .0001 can be observed.[2] When a substitution measurement is made, the dissipation factor, D, of the unknown capacitor is equal to the observed change in D multiplied by the ratio of circuit to unknown capacitance. This accounts for the increase in minimum dissipation factor shown by the curve labeled (SUBST).

The curves plotted in Figure 2 are based entirely on minimum calibration points with no consideration for such factors as balance sensitivity, ease of balance, and signal-to-noise ratio. When such factors are considered, the advantage of the Type 716-CS1 for the measurements in question becomes even more pronounced.

It should be pointed out here that the comparisons just made are for a particular measurement at a particular frequency. The Twin-T and the R-F Bridge are general purpose instruments of wide frequency range; the 716-CS1 is a specialized instrument of relatively limited frequency range.

DIELECTRIC MEASUREMENTS

In addition to its use for measuring capacitors, the Type 716-CS1 Capacitance Bridge will find application in measuring dielectrics at the ASTM test frequency of one megacycle, with the Type 1690-A Dielectric Sample Holder.[3]

[3] Ivan G. Easton, "A Sample Holder for Solid Dielectric Materials," *General Radio Experimenter*, August, 1951.

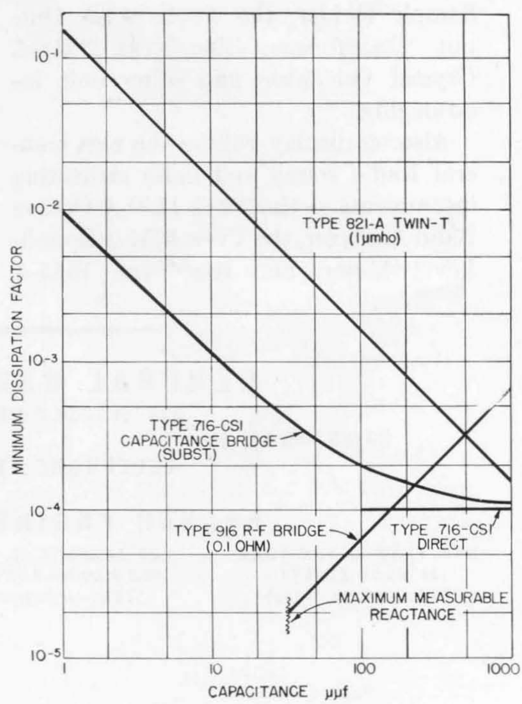
In Figure 3 is shown a sample holder mounted on the Type 716-CS1. A Type 1330-A Bridge Oscillator provides the test voltage and a commercial radio receiver is used as the null detector.

When the dielectric sample holder is used, the calibration of the precision capacitor in the bridge is not used. Consequently the balance may be made at its minimum setting of about 40 μμf. Under this condition the minimum measurable D is lower than that indicated by the curve of Figure 2. Also, about one fifth division on the D dial can be estimated, and, taking all these factors into account, the ultimate resolution is about 5×10^{-5}, with a 50 μμf low loss specimen.

— Ivan G. Easton

For Specifications, see page 8

Figure 3. Comparative theoretical minimum ranges of Types 716-CS1, 916-A, and 821-A.



SPECIFICATIONS FOR TYPE 716-CS1 CAPACITANCE BRIDGE

Capacitance Range: Direct Method, 100 to 1000 $\mu\mu$f; Substitution Method, 0.1 to 1000 $\mu\mu$f.

Dissipation Factor Range: Direct Method, 0.00002 to 0.56; Substitution Method, 0.00002 $\times \frac{C'}{C_X}$ to 0.56 $\times \frac{C'}{C_X}$, where C' is the capacitance of the standard capacitor and C_X that of the unknown.

Frequency Range: Calibrated for one megacycle, the bridge operates satisfactorily at frequencies between 0.5 and 3 megacycles.

Accuracy: At one megacycle, the bridge is adjusted to have the same accuracy as the standard Type 716-C at low frequencies (see the current General Radio catalog for details). This same accuracy can be obtained at other frequencies between 0.5 Mc and 3 Mc, if correction is made for the effects of residual inductance.

Other specifications are the same as those for the standard Type 716-C.

Type		*Code Word*	*Price*
716-CMS1	**Capacitance Bridge** (Mounted in Cabinet).....	BOGEY	**$610.00**
716-CRS1	**Capacitance Bridge** (For Relay-Rack Mounting)	BACON	**565.00**

1952 RADIO ENGINEERING SHOW

When you come to the 1952 Convention of the Institute of Radio Engineers, be sure to look in at Booths 92 and 93 (first floor) in the Radio Engineering Show. General Radio engineers will be glad to show you the new instruments that you have read about in this and other recent issues of the *Experimenter* — the Type 1390-A Random Noise Generator, the Type 1652-A Resistance-Limit Bridge, the Type 1862-A Megohmmeter, the Type 1690-A Dielectric Sample Holder, the Type 942-A Output Transformer, the Type 1213-A Crystal Oscillator, and other unit instruments.

Also on display will be the new General Radio sound and noise measuring instruments — the Type 1550-A Octave Band Analyzer, the Type 1551-A Sound-Level Meter, and the Type 1555-A Sound-Survey Meter. These instruments, embodying the latest circuit and design techniques, are rapidly increasing in importance to industry. An important new use for these basic measuring tools is determining the possibility of ear damage to factory employees from excessive noise levels.

For impedance measurements in the u-h-f and v-h-f ranges, the Type 1602-A Admittance Meter will be set up and operating, so that you can see how quickly and easily it measures, on direct-reading scales, the impedance of resistors, capacitors, inductors, lines, antennas, and cable. If you are working on u-h-f television circuits, this instrument will save you time and money. No calculations, no transmission line charts are necessary.

Don't miss it!

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