Hall

OPERATING INSTRUCTIONS 1610-A

TYPE 1610-A CAPACITANCE MEASURING ASSEMBLY

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GENERAL RADIO COMPANY

CAMBRIDGE 39, MASSACHUSETTS, USA

OPERATING INSTRUCTIONS

TYPE 1610-A CAPACITANCE MEASURING ASSEMBLY

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THESE INSTRUCTIONS ARE INTENDED TO COVER THE OPERATION OF THE COMPONENT INSTRUMENTS AS A COMPLETE ASSEMBLY, AND ARE TO BE USED IN CONJUNCTION WITH THE OPERATING INSTRUCTIONS FOR THE INDIVIDUAL INSTRUMENTS.

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TYPE 1610-A

CAPACITANCE MEASURING ASSEMBLY

Section 1

INTRODUCTION

1.1 PURPOSE. The Type 1610-A Capacitance Measuring Assembly is a general purpose capacitance bridge combined in an integrated assembly with the necessary generator, detector and interconnecting cables. Also included is a guard circuit for certain specialized measurements. The assembly measures capacitance from zero to 1150 μμf and dissipation factor over a frequency range from 30 cycles to 100 kc. In the vicinity of 1 kc, the capacitance range extends to 1 μf. In addition to its use in capacitance measurement, the Capacitance Measuring Assembly finds wide application in evaluating the dielectric properties of insulating materials, not only for electrical applications but also in the fields of chemical and biological research and as a production control tool.

1.2 DESCRIPTION. The Type 1610-A Capacitance Measuring Assembly consists of the following instruments, relay-rack mounted and suitably interconnected:

a. The Type 716-C Capacitance Bridge, a Schering bridge which is direct reading in capacitance from 30 cycles to 300 kc, and in dissipation factor at 100 cycles, and 1, 10, and 100 kc.

b. The Type 716-P4 Guard Circuit, which permits three-terminal measurements to be made.

c. The Type 1302-A Oscillator, and R-C oscillator with a frequency range of 10 cycles to 100 kc, employing a Wein bridge circuit in the feedback path of a two-stage amplifier.

d. The Type 1231-B Amplifier and Null Detector, a combination high-gain amplifier and sensitive visual null detector. The Type 1261-A Power Supply, which is installed at the rear of the Type 1231-B Amplifier and Null Detector. This unit is both mechanically and electrically interchangeable with the Signal Corps Type BA48 battery.

e. The Type 1231-P5 Filter, consisting of a group of high-Q parallel resonant circuits. When connected in the grid circuit of the amplifier, the combination becomes a highly selective detector system, providing 30 to 45 db discrimination against unwanted signals and noise.

NOTE

The Type 1610-A2 Capacitance Measuring Assembly consists of the above units less the Type 716-P4 Guard Circuit.

1.3 ACCESSORIES. For measurements of dielectric properties of solid insulating materials, the Type 1690-A Dielectric Sample Holder is available. Provision is made for mounting this instrument directly onto the panel of the Type 716-C Capacitance Bridge.

Section 2

INSTALLATION

2.1 INITIAL ASSEMBLY. Mount the instruments in the rack unit as shown in Figure 1. For the Type 1610-A2 Capacitance Measuring Assembly, install the instruments as for the Type 1610-A except: Mount the blank panel at the top, the bridge at the bottom, and the amplifier directly above the bridge. Connect the amplifier INPUT to the bridge DETECTOR by means of the patch cord. The remaining connections are the same as for the Type 1610-A assembly.

The multipoint plug, at the rear of the shielded cable that passes through a hole in the rack, connects to the rear of the Type 1302-A Oscillator. The shielded double plug at the other end of this cable connects to the GENERATOR terminals of the Type 716-C Capacitance Bridge. Connect the INPUT of the Type 1231-B Amplifier and Null Detector to the DETECTOR terminals of the Guard Circuit by means of the short Type 274-NEO special patch cord. The left-hand dress strip of the rack

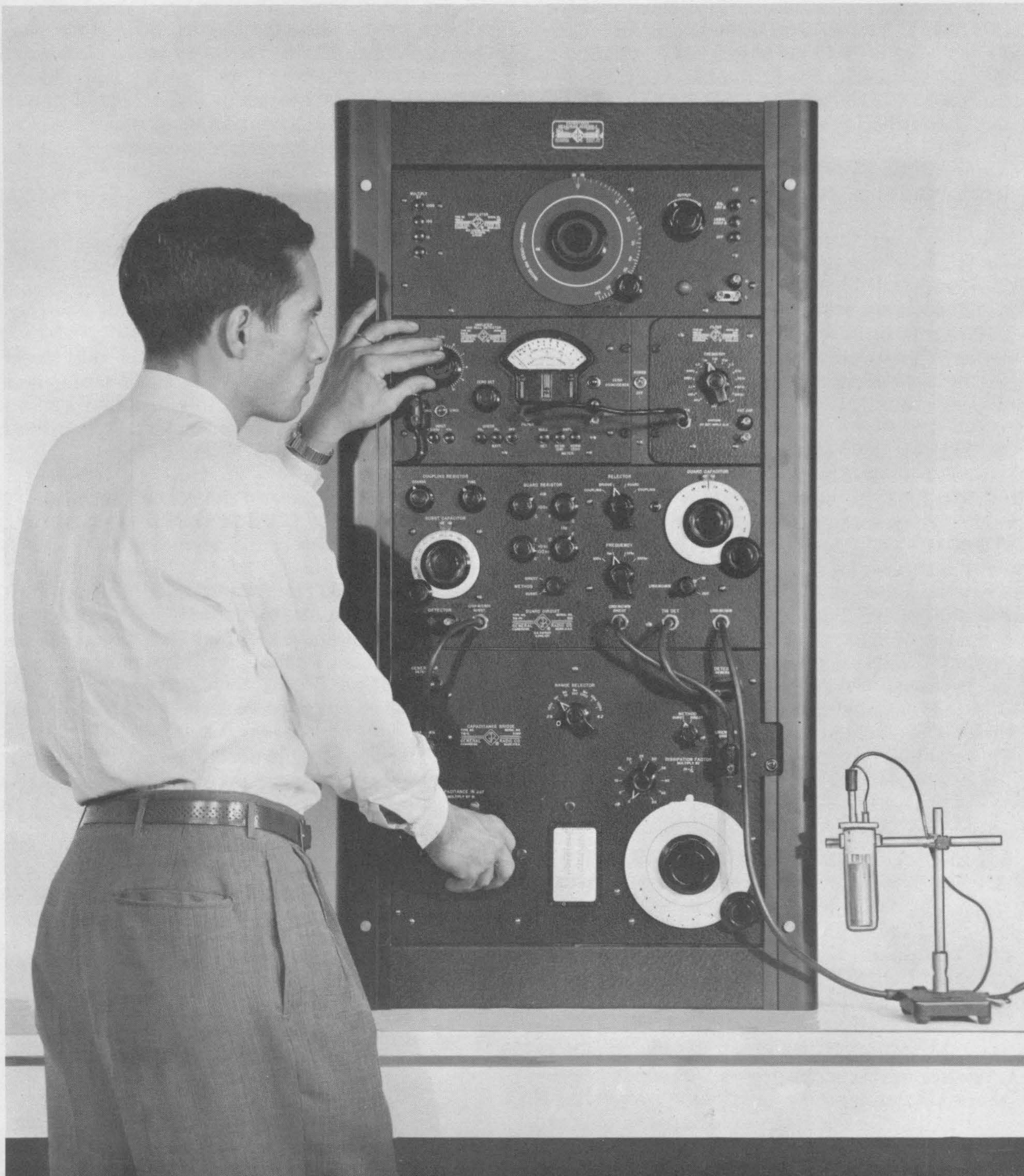


Figure 1.
The Type 1610-A Capacitance Measuring Assembly in Use Measuring
Liquid Dielectric Samples.

has three notches to accommodate these cables. BE SURE THAT ALL SHIELDED PLUGS ARE ORIENTED SO THAT THE GROUND SIDE (IDENTIFIED BY A "G" CAST IN THE METAL CASE) IS CONNECTED TO THE GROUNDED TERMINAL OF THE INSTRUMENT.

Connect the Type 1231-P5 Filter to the FILTER jack of the amplifier.

Three power cords are located behind the power switch on the connecting panel between the Amplifier and Null Detector and the Type 1231-P5 Filter. The shortest cord connects to the Type 1261-A Power Supply at the rear of the amplifier. The medium-length cord connects to the oscillator. The longest cord connects to the power outlet at the bottom of the rack.

2.2 PRELIMINARY CONNECTIONS FOR TWO-TERMINAL MEASUREMENTS. Connect the cable marked 716 DET to the DETECTOR terminals of the bridge. The cables marked UNKNOWN SUBST., UNKNOWN DIRECT, and UNKNOWN remain unconnected. Knot these cables loosely together to keep them away from the exposed bridge terminals. When the assembly is used in this manner set the value of the guard circuit COUPLING RESISTOR high (maximum clockwise setting). The guard circuit may be bypassed by a direct connection between amplifier INPUT and capacitance bridge DETECTOR terminals. Connect the unknown directly to the UNKNOWN terminals on the bridge.

2.3 PRELIMINARY CONNECTIONS FOR THREE-TERMINAL MEASUREMENTS. Connect the guard circuit cables designated as UNKNOWN SUBST. and UNKNOWN DIRECT to the corresponding terminals on the panel of the Type 716-C Capacitance Bridge. The cable marked 716 DET is connected to the DETECTOR terminals of the bridge. The remaining cable, labeled UNKNOWN, provides means for connection to the component under measurement.

2.4 PRELIMINARY OPERATING TESTS. The following preliminary checks are recommended to ensure that the equipment is functioning properly. If unfamiliar with this general type of apparatus, read instrument instruction books and Sections 3, 4, and 5 of this manual before attempting any capacitance measurements.

2.4.1 TESTS WITH GUARD CIRCUIT DISCONNECTED.

2.4.1.1 Oscillator. Turn on the Type 1302-A Oscillator by pressing the UNBAL 5000 Ω button. Select any appropriate frequency (such as 1 kc). Advance OUTPUT control, and, with a suitable means of detection (headphones or Type 1231-B Amplifier and Null Detector) connected to the output terminals of the oscillator, note presence of output.

2.4.1.2 Amplifier and Filter Settings. Press NULL DET and INPUT < 1 v buttons on the Type 1231-B Amplifier and Null Detector. Advance the GAIN control. Check to see if meter reads. Vary the GAIN control of the Amplifier and Null Detector and the OUTPUT control of the oscillator to be sure that the meter reading varies. Set the Type 1231-P5 Filter to the same frequency as supplied by the oscillator. Note the meter reading on the null indicator. Change the setting of the filter and note a decrease (counterclockwise) in meter indication at other frequency settings.

2.4.1.3 Bridge Balance. Using the procedures outlined in Section 4.5, make a trial balance using a capacitor of known approximate value.

2.4.2 TESTS WITH THE GUARD CIRCUIT CONNECTED. Complete familiarity with the bridge and associated equipment should be acquired before measurements with the guard circuit are attempted. A reading of the Type 716-P4 Guard Circuit instruction book is recommended.

The following procedure will afford practice in three-terminal measurement technique and will also determine whether the guard circuit is functioning properly.

a. Measure by the two-terminal method the exact value of a mica capacitor whose marked value is about 500 μμf.

b. Connect this capacitor with two others (also about 500 μμf) to form a three-terminal network (see Figure 4a).

c. Prepare the measuring assembly for three-terminal measurements. Connect the three-terminal network to the UNKNOWN cable in the following manner: cable high connection to one side of the capacitor measured in step a, cable ground connection to the other side. The guard connection is made to the junction of the other two capacitors (see Figure 7).

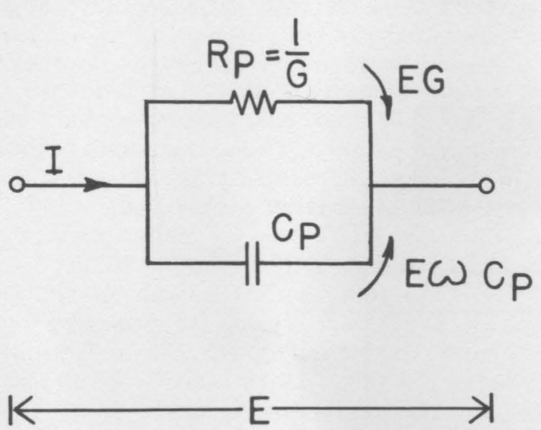
d. Following the procedures outlined in Section 4.2, make a balance. If the guard circuit is functioning, the measured value should agree with the value obtained by the two-terminal method.

Section 3

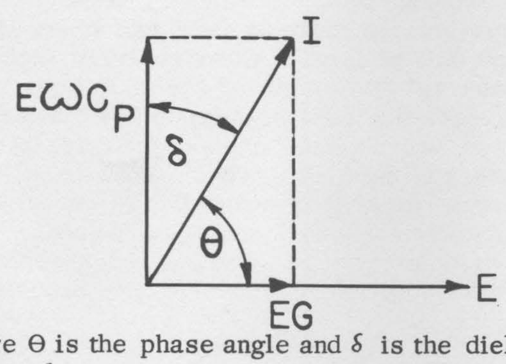
OPERATING PROCEDURE

3.1 CHARACTERISTICS OF CAPACITORS. Every capacitor is characterized by a loss parameter as well as the desired capacitance parameter. The loss parameter can be represented as either a parallel or a series resistance.

In parallel notation the equivalent circuit is:



where the resistance, R_p, represents the loss component and the capacitance, C_p, is the pure capacitive component. The vector diagram for the equivalent parallel circuit may be represented as:

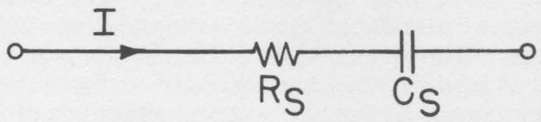


where Θ is the phase angle and δ is the dielectric loss angle.

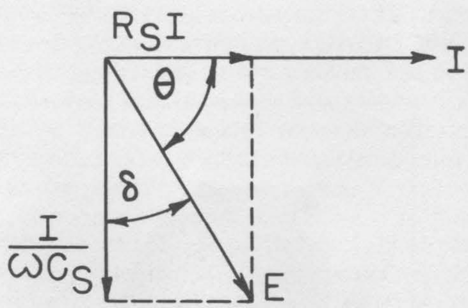
Then, the dissipation factor, D, defined as the cotangent of the dielectric phase angle is:

$$D = \cot \Theta = \tan \delta = \frac{G}{\omega C_p} = \frac{1}{\omega C_p R_p} \quad (1)$$

A capacitor may also be represented by series notation:



The vector diagram for the series equivalent is:



In the series equivalent case the dissipation factor now becomes:

$$D = \cot \Theta = \tan \delta = \frac{R_s}{\frac{1}{\omega C_s}} = \omega C_s R_s \quad (2)$$

The series equivalent and parallel equivalent values can be related to one another by the following equations:

$$C_p = \frac{C_s}{1 + D^2} = \frac{C_s}{1 + \tan^2 \delta} = C_s \cos^2 \delta \quad (3)$$

$$R_p = \frac{R_s (1 + D^2)}{D^2} = \frac{1 + D^2}{D \omega C_s} \quad (4)$$

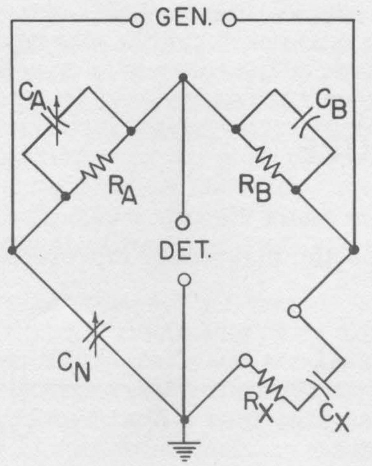


Figure 2. Simplified Circuit Diagram of Type 716-C Capacitance Bridge.

3.2 MEASUREMENTS OF DIELECTRIC MATERIALS. The dielectric constant and dissipation factor of insulating material is measured by placing the material to be tested between electrodes to form a capacitor. The capacitance and dissipation factor of the dielectric are then determined by normal bridge techniques. From this measured value, the dielectric constant of the material can readily be found. For a full mathematical treatment and discussion on the evaluation of dielectric constants and loss factors refer to the American Society for Testing Materials Specification D-150.

3.3 TYPE 716-C CAPACITANCE BRIDGE. The Type 716-C Capacitance Bridge is a modified Schering bridge, whose simplified schematic is shown in Figure 2.

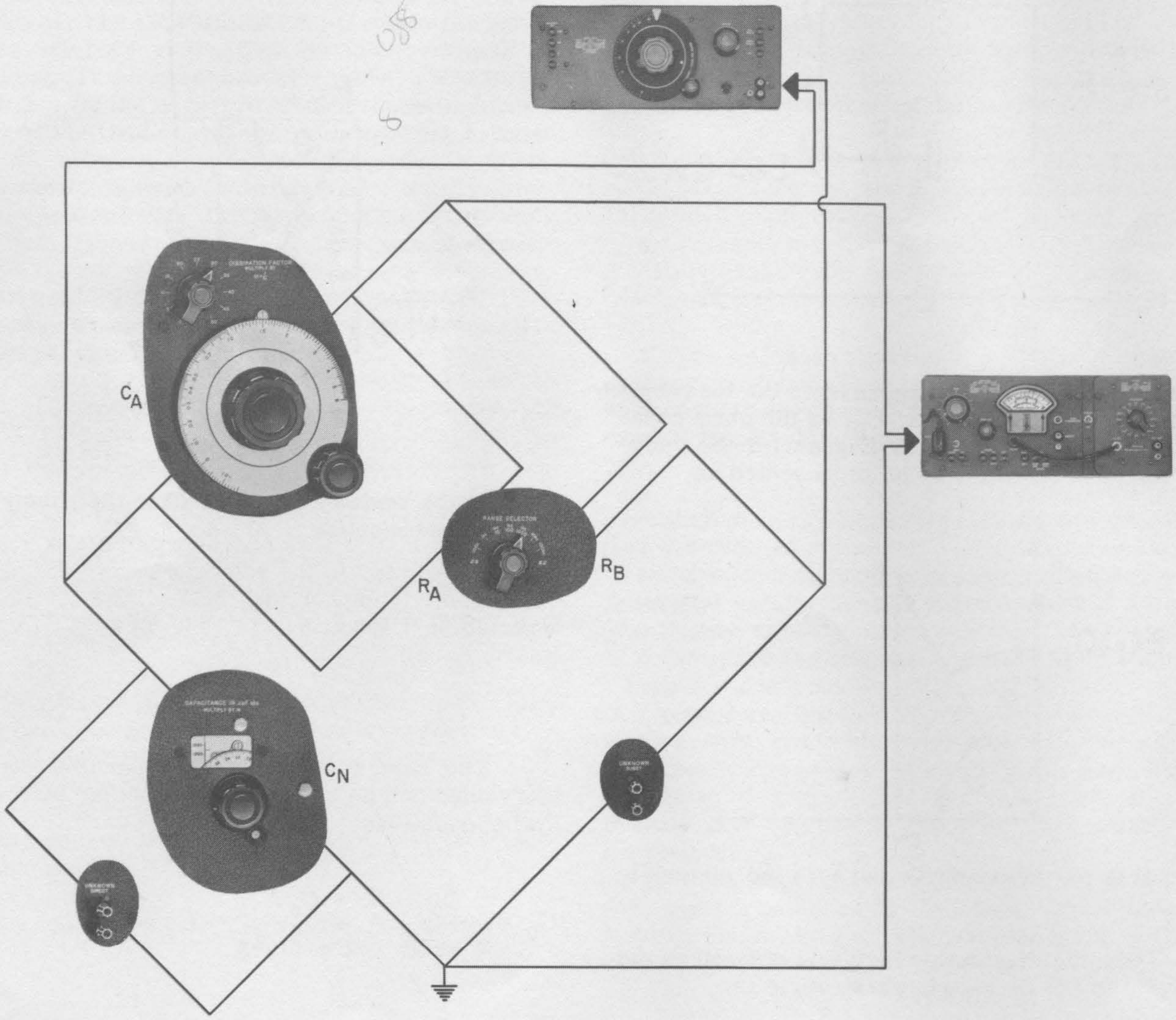


Figure 3.
Pictorial Representation of Bridge Controls and their Placement in the Simplified Circuit.

The capacitor C_N is a precision, worm-driven unit, adjusted to be direct-reading in capacitance. The direct reading range is 100 to 1150 μμf, given as the sum of the drum and dial reading.

The dissipation factor controls consist of a variable air capacitor and a decade capacitor, which are represented in the simplified diagram as C_A. These are calibrated to be direct reading in dissipation factor of the unknown at the frequency selected by the RANGE SELECTOR.

The RANGE SELECTOR controls the ratio arms R_A and R_B, which determine the multiplier ratio M. Equal ratio arms are provided for 100 cycles, 1 kc, 10 kc, and 100 kc. In addition, multiplying factors, M, of 10, 100, and 1000 are provided at 1 kc.

Figure 3 is a pictorial representation showing the bridge controls and their placement in the simplified circuit.

The equations of balance for the Schering bridge circuit are:

$$C_x = C_N \frac{R_A}{R_B} \tag{5}$$

$$D_x = R_A \omega C_A \tag{6}$$

where C_x is the series equivalent capacitance of the unknown, and D_x is the dissipation factor of the unknown.

3.4 TYPE 716-P4 GUARD CIRCUIT. It is frequently desirable to measure the direct capacitance between two points, each of which has capacitance or complex impedance to a third point, as suggested by Figure 4a. Such a configuration is sometimes produced deliberately, as, for example, when a "guard ring" (see Figure 4b) is introduced in an electrode system used for the measurement of dielectric materials, either liquid or solid. In other cases it arises inevitably, as, for instance, in a variable air capacitor in which both rotor and stator are insulated from the frame. In this instance, there exists, in addition to the desired direct capacitance between plates, a capacitance between each plate structure and frame. Another common example is a two-wire shielded cable.

The Type 716-P4 Guard Circuit provides a means of measuring the direct capacitance between two specified electrodes, eliminating from the measurement the capacitance from each of these electrodes to the third electrode, which is connected to the guard point. Figure 5 shows schematically the combination of guard circuit and bridge.

By proper adjustment of the resistance-capacitance combination S, the guard point can be brought to the same potential as the detector terminals of the bridge. When this condition is realized, the bridge reads correctly the capacitance and dissipation factor connected in the UNKNOWN arm.

Figure 7 is a pictorial representation of the controls of the guard circuit, superimposed on the schematic diagram.

The Type 716-P4 Guard Circuit also provides a means for making accurate measurements of a capacitor or a dielectric sample located at some distance from the measuring terminals of the bridge. Measurements of materials or components in a conditioning chamber or oven, while exposed to a specified temperature or humidity may thus be made.

When measurements are to be made by substitution methods it is necessary to connect a balancing capacitor in the adjacent arm of the bridge. A variable air capacitor (SUBST. CAPACITOR) with a maximum capacitance of 1150 μμf is built into the guard circuit for this purpose.

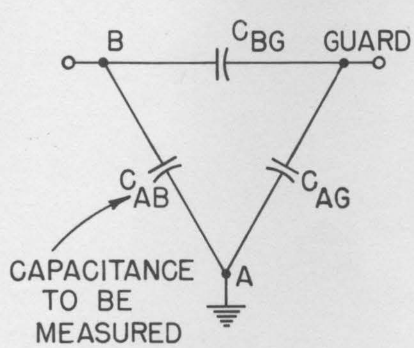


Figure 4a.

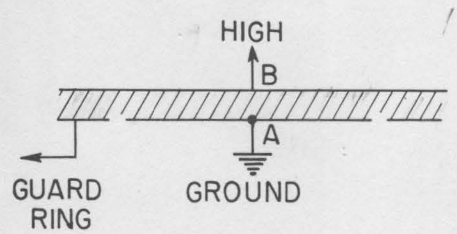


Figure 4b.

Configuration of a Three-Terminal Capacitor

3.5 TYPE 1690-A DIELECTRIC SAMPLE HOLDER. Although not an integral part of the Type 1610-A Measuring Assembly, the Type 1690-A Dielectric Sample Holder is often used in conjunction with it, for measuring the dielectric properties of solid materials.

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 to measure the capacitance and dissipation factor of the resulting capacitor. One of the simplest electrode systems is a pair of circular plates; the Type 1690-A Dielectric Sample Holder is basically such an arrangement (see Figure 6).

The micrometer-capacitor type of holder has been recognized as the most satisfactory method of holding specimens of solid dielectric material for measurement at radio frequencies. Holders of this type are recognized in ASTM Specification D-150 for use in the frequency range to about 100 Mc. In addition, the use of this type holder, properly calibrated, virtually eliminates the errors from fringing fields and stray capacitance. For this reason its use at lower frequencies is also recommended.

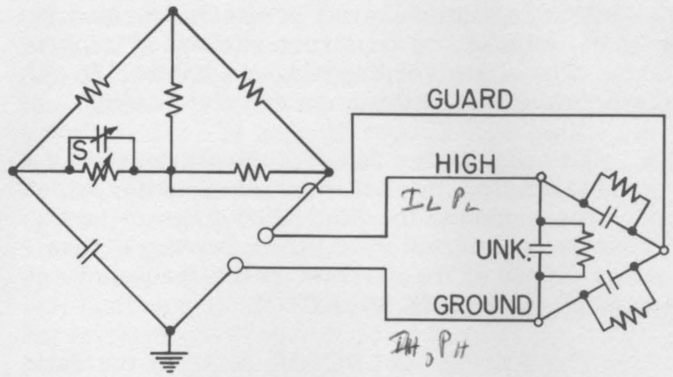


Figure 5. Simplified Diagram of the Type 716-P4 Guard Circuit.

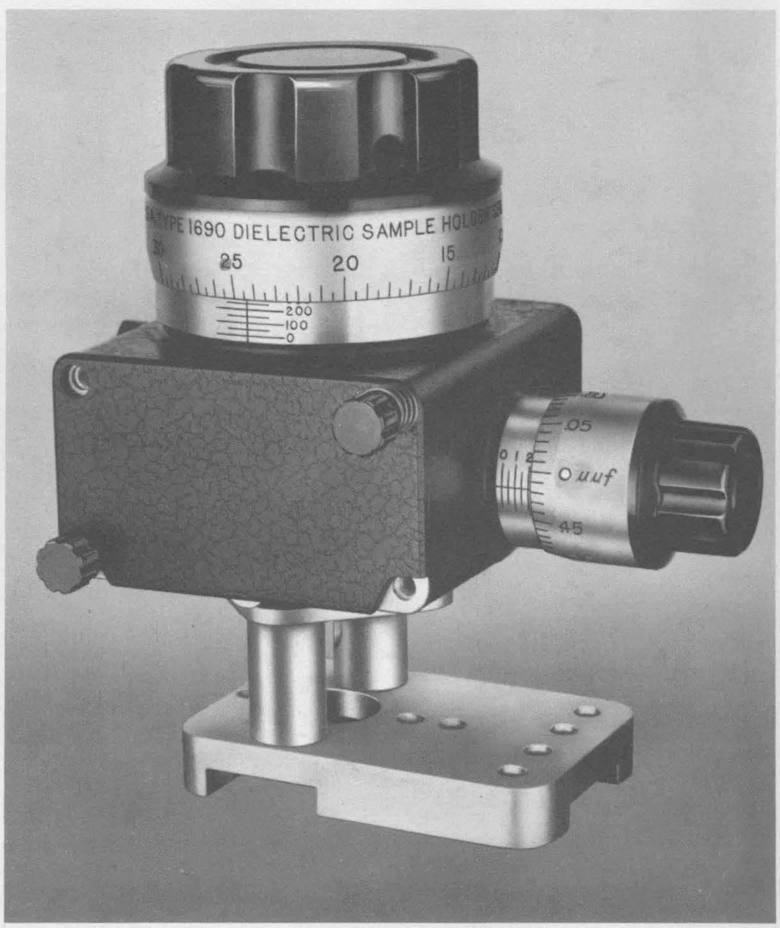


Figure 6.
Type 1690-A Dielectric Sample Holder with the Type 1690-P1 Adaptor

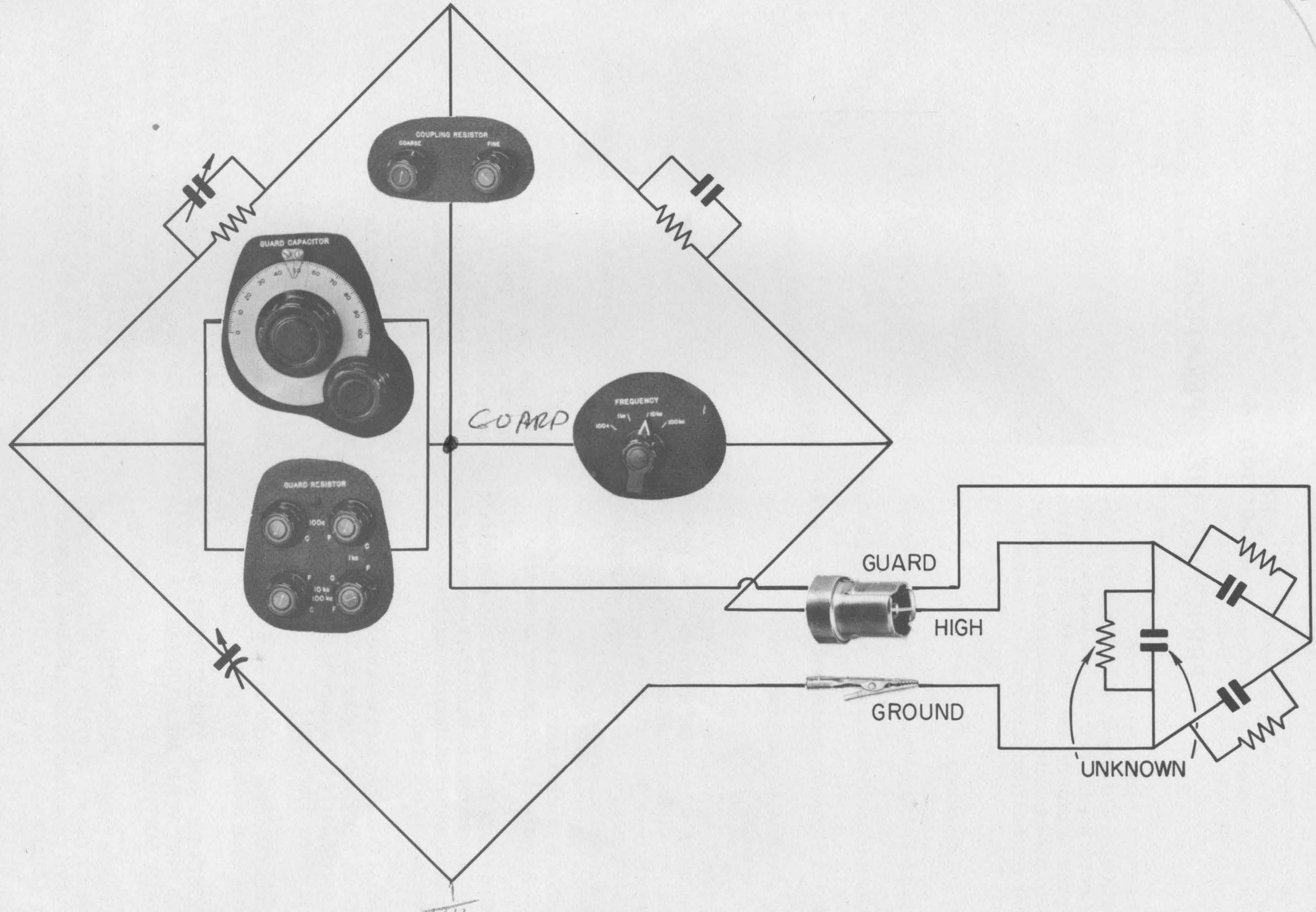


Figure 7.
Pictorial Representation of the Guard Circuit Controls and their Placement in the Simplified Circuit.

Section 4

PRINCIPLES OF OPERATION

4.1 GENERAL. The Capacitance Measuring Assembly can be used in four different ways for the measurement of capacitance. The choice depends on whether the capacitor to be measured is two terminal or three terminal, and on the accuracy requirement.

The four methods are:

A. Direct-Reading Measurement with the Guard Circuit.
B. Substitution Measurement with the Guard Circuit.
C. Direct-Reading Measurement less Guard Circuit.
D. Substitution Measurement less Guard Circuit.

Method A is used with three-terminal capacitors, guarded dielectric specimens, and when components or dielectric materials are measured at a distance from the bridge terminals, with a guarded cable used to eliminate lead capacitance from the measurement.

Method B is used under the same conditions as Method A, but will yield greater accuracy.

Method C is the most rapid and convenient method. It is used for two-terminal measurements of components and of dielectric samples when a guard electrode is not used.

Method D is used for the same measurements as Method C, but yields higher accuracy of measurement particularly for values of dissipation factor that are less than 0.001

In the following sections step-by-step procedures for each method are given.

4.2 PROCEDURE FOR THREE-TERMINAL OR GUARDED NETWORK MEASUREMENTS USING THE DIRECT METHOD.

Capacitance range: 100 to 1150 μμf
Frequency range: 30 cycles to 300 kc
Accuracy: capacitance, ±2 μμf when dissipation factor of unknown is less than 0.01; dissipation factor, ±0.0005 or ±2% of dial reading, whichever is the larger, for values of D below 0.1.

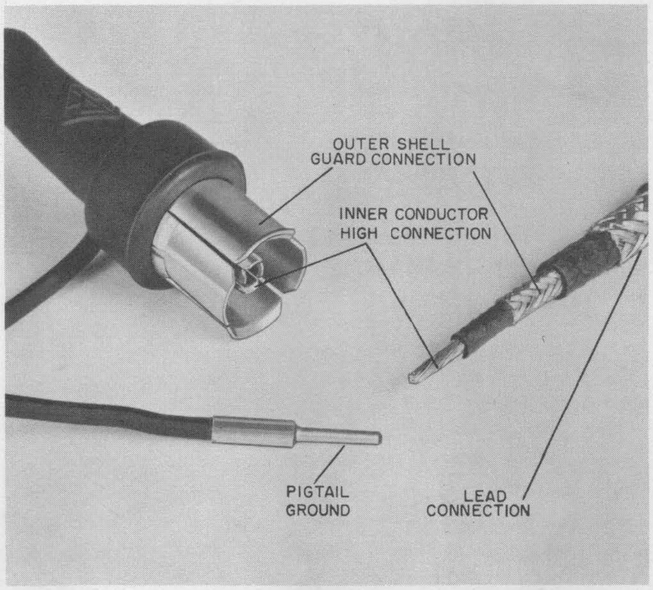


Figure 8.
Guarded Cable Connection.

Connect assembly as outlined in Section 2.2. Connect the component under measurement to the unknown cable. The three connections on the unknown cable are: the "high" connection, which is the center conductor of the Type 874 Connector, the guard connection, which is the outer shell of the connector and the ground connection, which is the pigtail lead (see Figures 7 and 8). The capacitor under measurement is connected between "high" and "ground".

a. Flick the POWER switch on. This switch is located between the Type 1231-B Amplifier and Null Detector and the Type 1231-P5 Filter.
b. Oscillator Settings.
(1) Press the UNBAL 5000 Ω button on the Type 1302-A Oscillator.
(2) Set the oscillator to the desired frequency by means of the main dial and by pressing the appriate multiplier button.
(3) Advance the OUTPUT control slightly.
c. Amplifier and Null Detector Settings.
(1) Press the INPUT < 1 v and NULL DET buttons on the Type 1231-B Amplifier and Null Detector.
(2) Advance the GAIN control slightly.

d. Filter Settings.

(1) Plug the cable from the Type 1231-P5 Filter into the FILTER jack of the Type 1231-B.

(2) Set the pointer knob on the Type 1231-P5 Filter to the same frequency as supplied by the Type 1302-A Oscillator. If measurements are desired at frequencies other than those available, connect a suitable capacitor to the terminals provided on the Type 1231-P5 Filter. With proper selection of capacitors, the filter can be made to tune to any frequency from 20 cycles to 100 kc.

Initial Balance:

e. Set the following on the Type 716-P4 Guard Circuit:

(1) METHOD switch to DIRECT position.

(2) UNKNOWN switch to IN.

(3) FREQUENCY switch to the nearest value of frequency as produced by the Type 1302-A Oscillator.

(4) SELECTOR switch to BRIDGE position.

f. Set the following on the Type 716-C Capacitance Bridge:

(1) METHOD switch to DIRECT position.

(2) RANGE SELECTOR switch to the nearest value of frequency as produced by the Type 1302-A Oscillator. Note that the Guard Circuit is not intended to operate at the M10, M100 or M1000 positions. The bridge will operate at all frequencies from 30 cycles to 300 kilocycles with the accuracies stated, provided that the ratio of the frequency f applied to the bridge to the frequency f_o indicated by the RANGE SELECTOR switch lies between 0.1 and 3. No correction for f/f_o is necessary for capacitance between these limits. The correction for dissipation factor, however, is directly proportional to frequency (see equation engraved on Capacitance Bridge panel).

g. Adjust both CAPACITANCE IN μμf and DISSIPATION FACTOR controls alternately for a minimum meter reading on the Type 1231-B Amplifier and Null Detector. If necessary advance the GAIN and/or OUTPUT controls. Headphones connected to the OUTPUT terminals of the Type 1231-B Amplifier and Null Detector are helpful in making measurements in the vicinity of one kilocycle and improve the sensitivity of measurement by a factor of 20 to 50.

h. Make the following adjustments on the Type 716-P4 Guard Circuit:

(1) Set the SELECTOR switch to the GUARD position.

(2) Adjust the GUARD CAPACITOR for a minimum meter reading on the Type 1231-B Amplifier and Null Detector.

(3) Beneath the area marked GUARD RESISTOR there are four knob controls grouped together. Select the pair that function at the frequency set on the FREQUENCY switch. This is indicated on the panel by engraving between the knobs. The letters "C" and "F" indicate coarse and fine adjustments. Care should be taken in determining which "C" or "F" belongs to which frequency (see Figure 9). Should adjustment on the fine control be lacking, return the fine control to its center position and readjust the coarse control for minimum meter reading.

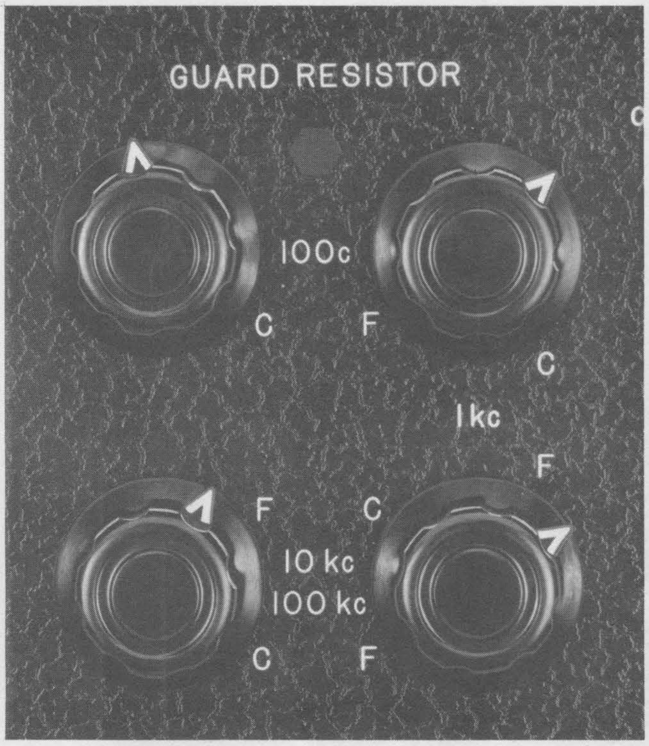


Figure 9. Panel Arrangement of Guard Resistor Controls. For example: at 100 kc the bottom left-hand control is the coarse adjustment and the bottom right-hand control is the fine adjustment.

(4) Turn the SELECTOR switch to either COUPLING position.

(5) Adjust the COUPLING RESISTOR for a minimum in meter reading. Here again, coarse and fine adjustments are provided.

(6) Return the SELECTOR switch to the BRIDGE position.

Final Balance:

i. Repeat the procedure from section 4.2g on until readjustments of the CAPACITANCE in μμf and DISSIPATION FACTOR settings are unnecessary. To obtain additional sensitivity for bridge balance, advance the OUTPUT control of the Type 1302-A Oscillator and/or the GAIN control of the Type 1231-B Amplifier and Null Detector. Use of.

the INPUT 0.03 v setting of the Type 1231-B will also increase the sensitivity.

j. The value of series capacitance in μμf is then read directly and the value of dissipation factor is found from the equation:

$$D_x = 0.01 \frac{f}{f_o} D \qquad (7)$$

where:

D = sum of the readings of the DISSIPATION FACTOR switch and dial setting.

f = frequency setting of oscillator.

f_o = frequency setting of the bridge RANGE SELECTOR.

Additional equations in terms of parallel and series equivalent values will be found on page 3 of the Type 716-C instruction book.

4.3 PROCEDURE FOR THREE-TERMINAL OR GUARDED-NETWORK MEASUREMENTS USING THE SUBSTITUTION METHOD.

Capacitance range: 0.1 to 1050 μμf
Frequency range: 30 cycles to 300 kc
Accuracy: capacitance, ±0.2% or ±2 μμf, whichever is the larger; dissipation factor, ±0.00005 or ±2% of the change in dissipation factor observed, when the change is less than 0.06. Using correction chart, measurements can be made to ±0.1% or ±0.8 μμf, whichever is the larger. For capacitances less than 25 μμf the error will decrease linearly to ±0.1 μμf. With a worm correction calibration (supplied at extra charge) substitution measurements can be made to an accuracy of ±0.1% or ±0.2 μμf, whichever is the larger.

Follow the preliminary procedure outlined in steps 4.2a through 4.2d of the Procedure for Direct Method Measurements.

a. Set the following on the Type 716-P4 Guard Circuit:

METHOD switch to SUBST,
UNKNOWN switch to IN,
FREQUENCY switch to nearest frequency as produced by the Type 1302-A Oscillator, and
SELECTOR switch to BRIDGE.

b. Set the following on the Type 716-C Capacitance Bridge:

METHOD switch to SUBST,
CAPACITANCE IN μμf to a convenient low value, such as 100 μμf,
RANGE SELECTOR switch to nearest frequency as produced by the Type 1302-A Oscillator. Note that the Guard Circuit is not intended to operate with the bridge RANGE SELECTOR at M10, M100, or M1000.

c. Adjust the SUBST CAPACITOR in the Guard Circuit alternately with the DISSIPATION FACTOR switch and dial controls on the bridge to obtain a minimum meter reading.

d. Follow the procedure outlined in step 4.2h in the Procedure for Direct Method Measurements.

e. Repeat the above steps 4.3c and 4.3d until further readjustments become unnecessary.

f. Record the settings of the CAPACITANCE IN μμf and DISSIPATION FACTOR controls. Note that dissipation factor is the sum of the switch setting plus the dial reading.

g. Set the following switches in the Guard Circuit:

UNKNOWN switch to OUT, and
SELECTOR switch to BRIDGE.
DO NOT DISTURB SUBST CAPACITOR SETTING.

h. Repeat steps 4.2g, 4.2h, and 4.2i in the Procedure for Direct Method Measurements.

i. When the unknown capacitor has a dissipation factor less than 0.1, its capacitance and dissipation factor can be calculated from the changes in readings of the CAPACITANCE and DISSIPATION FACTOR dials.

$$C_x = \Delta C \qquad \Delta C = C' - C$$

$$D_x = \frac{C'}{\Delta C}(\Delta D) \qquad \Delta D = (D - D')\frac{f}{f_o} \qquad (8)$$

where readings with unknown disconnected (UNKNOWN switch in OUT position) are designated by primes and Δ signifies "change in". C and D are bridge readings with the unknown connected (UNKNOWN switch in IN position), f is the frequency setting of the oscillator, and f_o is the frequency setting of the bridge RANGE SELECTOR switch.

These equations will be accurate when the calculated dissipation factor is found to be less than 0.1, and approximately correct for values greater than 0.1.

When the calculated dissipation factor is found to be greater than 0.1, the equations on page 5 of the Type 716-C Capacitance Bridge instruction book will give accurate results. These equations will give results in terms of parallel or series equivalent values.

4.4 GUARDED MEASUREMENTS OF TWO-TERMINAL NETWORKS. Use of the guard circuit in two-terminal measurements is advantageous when it is desired to eliminate the capacitance of leads connecting the unknown to the bridge. Such a condition occurs when the component under test is a considerable distance away from the bridge. If guarded cable, such as "triaxial" cable (see Figure 8) is used in connecting the component under test to the bridge, the lead capacitance can be balanced out. The component under measurement is connected to the high and ground terminals of the bridge, and the cable shield is connected to the guard terminal of the bridge. The cable shield then effectively becomes the guard point of a three-terminal network. This double-shielded cable (Type ESMW-16) can be purchased from the General Radio Company.

The procedure for measurement is the same as the methods for three-terminal guarded measurements.

4.5 TWO-TERMINAL DIRECT MEASUREMENTS WITHOUT GUARD CIRCUIT.

Capacitance range: 100 μμf to 1 μf at 1 kc, 100 μμf to 1150 μμf at 100 cycles, 10 kc and 100 kc.
Frequency range: 30 cycles to 300 kc.

Prepare the assembly for measurement as outlined in paragraph 2.3. Connect the component under test to the UNKNOWN DIRECT terminals on the bridge panel. Follow steps 4.2a to 4.2d, 4.2b, 4.2g, and 4.2j in the procedure for three-terminal direct measurements using the guard circuit.

4.6 TWO-TERMINAL SUBSTITUTION MEASUREMENT WITHOUT GUARD CIRCUIT.

Capacitance range: 0.1 μμf to 1050 μμf with internal standard; to 1 μf with external standards. For measurements above 1050 μμf, refer to the Type 716-C Capacitance Bridge Instruction Book.
Frequency range: 30 cycles to 300 kc.

Prepare the assembly for measurement as outlined in paragraph 2.3. Follow steps 4.2a to 4.2d in the procedure for three-terminal direct measurements using the guard circuit.

a. Set the following on the Type 716-C Capacitance Bridge:

(1) METHOD SWITCH to SUBST.

(2) RANGE SELECTOR switch to the frequency position nearest to that used, and to a capacitance position for M equal to 1.

(3) Connect a balancing capacitor to the UNKNOWN DIRECT terminals. This balancing capacitor must be at least 100 μμf larger than the unknown capacitor and may be either fixed or variable.

(4) Connect the low terminal of the unknown capacitor to the UNKNOWN SUBST terminal marked G. Leave the lead from the remaining UNKNOWN SUBST terminal disconnected at the high terminal of the unknown capacitor and separated from it by about 1/4 inch. Make these leads of stiff, small-diameter wire.

(5) Balance the bridge for capacitance and dissipation factor as described in step 4.2g in the procedure for three-terminal direct measurements with the guard circuit. Record these values.

(6) Connect the high lead to the high terminal of the unknown capacitor and rebalance the bridge. The new reading for capacitance will be less than, and the new reading for dissipation factor will be greater than, the initial readings.

(7) Refer to step 4.3i in the procedure for three-terminal substitution measurements with guard circuit for calculation of capacitance and dissipation factor.

Section 5

PRECAUTIONS AND SPECIAL CONSIDERATIONS

5.1 GENERAL. In this section are included discussions of several aspects of the use and operation of this equipment. These are intended for the chemist, the biologist, the physicist, and others who are not familiar with the precision measurements of capacitance and related parameters.

5.2 GROUNDING. It is important, particularly when measurements are made at or near 60 cycles, that the equipment be solidly connected to a good ground. If this precaution is not observed, hum voltages may be induced in the system, which will obscure the balance point or introduce actual error in the measurement. With proper grounding, it should be possible for the operator to touch the cabinet, the instrument panels, or the bridge controls, without significant effect on the bridge balance.

Also, in a properly grounded and otherwise properly functioning system it should be possible to reverse the power plug without altering the balance point. A change in reading with power reversal may also be the result of electrostatic pickup (paragraph 5.3) or magnetic induction (paragraph 5.4).

It is essential, of course, that the cables interconnecting the various instruments of the assembly be properly connected. All these cables are shielded and correct orientation of the shielded plugs is necessary to ground the shields. The ground side of these plugs is identified by a "G" cast in the metal case.

5.3 ELECTROSTATIC SHIELDING. In any laboratory or industrial location, 60-cycle electrostatic fields of considerable magnitude may exist. When a high-impedance (to ground) circuit is exposed to such fields, a 60-cycle voltage will be induced in that circuit. The magnitude of the induced voltage depends on the capacitance between the exposed circuit element and the source of interference. This capacitance in turn depends on the physical size of the exposed portion of the circuit. For this reason, 60-cycle pickup trouble is often encountered in the measurement of large capacitors, or in the measurement of dielectric materials when a large unshielded electrode is used.

The measuring equipment and its interconnecting leads are, of course, carefully shielded. Care must be taken that the unknown capacitor and its connecting leads are sufficiently shielded against interference.

When the measuring frequency is other than 60 cycles, the discrimination available in the Type 1231-P5 Filter greatly reduces the interference. Pick-up should be kept to a reasonable minimum, even in these cases, since the presence of the undesired voltage can in some instances alter the characteristics of the capacitor being measured. In the event of severe pickup, overloading of the first stages of the detector may occur.

5.4 MAGNETIC INTERFERENCE. In some locations, strong magnetic fields may be a source of trouble. The input transformer of the bridge is magnetically shielded, but it is impractical to shield the entire equipment against magnetic fields. The circuits are actually relatively immune against magnetic pickup but when very precise measurements are being made, fluctuating fields, such as may result from the operation of nearby switch gears, transformers, and motors, may cause trouble. Line-voltage regulators of the saturable-core type are sometimes offenders, as are Variac® Autotransformers if in close proximity to the bridge.

5.5 LINE-VOLTAGE FLUCTUATIONS. Although the oscillator and detector are both provided with electronically regulated power supplies, severe line-voltage transients may cause fluctuation of the meter near balance. If such trouble occurs, an effort should be made to provide a power line to which no heavy, intermittent loads are connected. Welding equipment, for instance, is likely to be a source of trouble.

5.6 SENSITIVITY CONSIDERATIONS. The overall sensitivity of balance, or resolution, of the measuring system depends upon three factors: the voltage impressed by the signal source upon the bridge, an intrinsic bridge sensitivity factor, and the sensitivity of the detector system employed to detect the bridge unbalance voltage. The voltage on the bridge in turn depends upon the available open-circuit voltage, the output impedance of the oscillator, and the input impedance of the bridge. The bridge sensitivity factor can be computed from the constants of the bridge circuit. For the Type 716-C Capacitance Bridge the expression is:

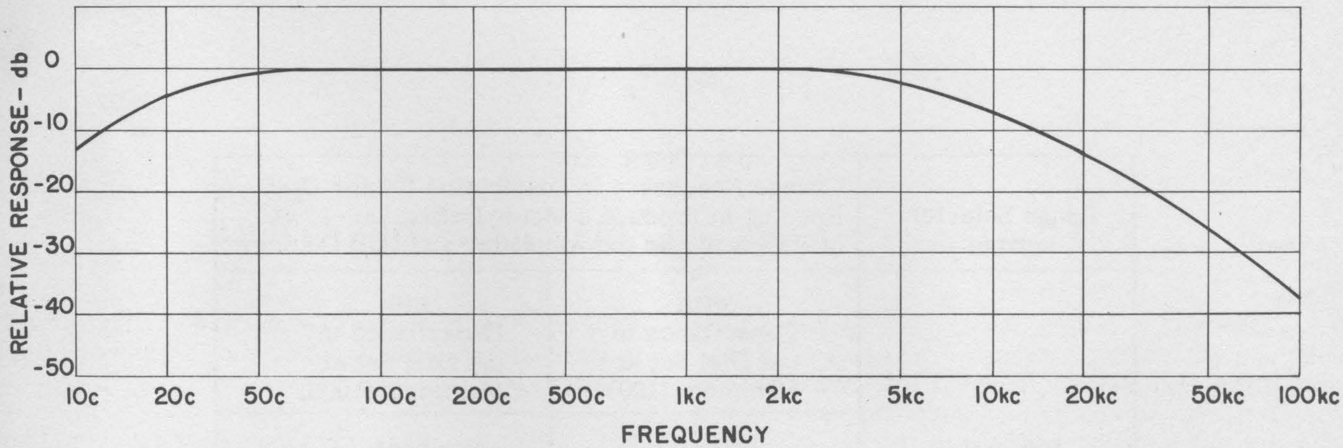


Figure 10.
Frequency Response of the Type 1231-B Amplifier and Null Detector.

$$S = \frac{E\ out}{E\ in} = \frac{M d}{(1 + M)^2} \qquad (9)$$

where M is the multiplier and d is the fractional unbalance, in capacitance or dissipation factor.

The output voltage E_{out} resulting from an unbalance as given by this expression is the open-circuit voltage of the bridge network. The actual voltage appearing at the detector input terminals depends on the impedance connected across the detector terminals of the bridge, and on the output impedance of the bridge circuit.

The maximum voltage impressed on the bridge by the Type 1302-A Oscillator varies from 26 volts to 21 volts, depending upon frequency and the RANGE SELECTOR setting.

The sensitivity factor S as given by eq (14) is 1/4, 1/12, 1/100, 1/1000 for multiplier settings of 1, 10, 100, and 1000, respectively. Note that this factor is independent of f_o.

The output voltage appearing across the DETECTOR terminals of the bridge is less than the open-circuit voltage calculated from equation (14) owing to the shunting effect of the internal capacitance to ground from the detector junction and the capacitance of the cable connecting to the null detector. This total capacitance is approximately 700 μμf. The reduction in available voltage resulting from this shunt capacitance is significant only for the M = 1 multiplier positions. The output impedance of the bridge is essentially the parallel combination of the unknown and standard capacitance. Thus, in the extreme case of M = 1, and with a measured capacitance of 100 μμf, the output capacitance is 200 μμf and the available output voltage is about 1/5th of that calculated from equation (14).

The 1-megohm input impedance of the Type 1231-B Amplifier and Null Detector is sufficiently high so that no loss in voltage occurs except at very low frequencies. An alternate input impedance of 10 megohms is provided to improve the sensitivity at low frequencies (60 cycles).

The relative sensitivity of the Type 1231-B Amplifier and Null Detector as a function of frequency is shown in Figure 10. The Type 1231-P5 Filter decreases the sensitivity at low frequencies and increases it at the higher frequencies, as shown in Figure 11.

The net over-all sensitivity of the Type 1610-A Capacitance Measuring Assembly is shown in Figure 12, expressed in terms of the minimum value of dissipation factor that can readily be detected.

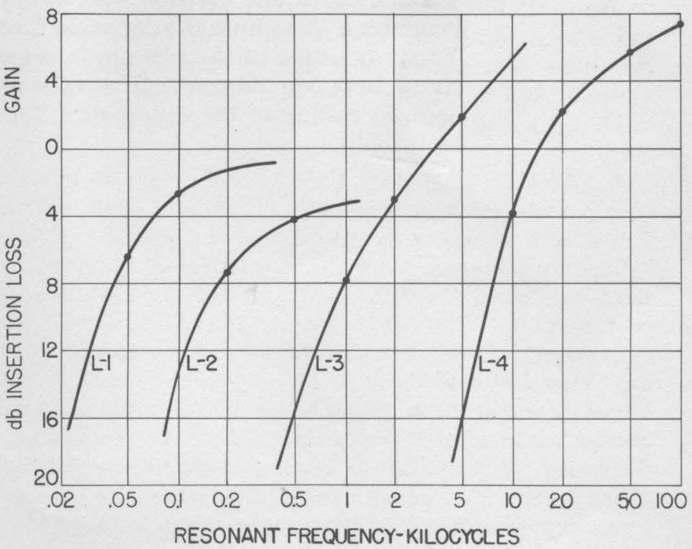


Figure 11.
Plot Sensitivity of the Type 1231-P5 Filter.

Range Selector Setting	Change Necessary in Dissipation Factor Dial Reading to Produce a Meter Deflection of 1% of Full Scale on the Amplifier and Null Detector.	
	with Capacitance in μμf Dial Set at Minimum (100)	with Capacitance in μμf Dial Set at Maximum (1000)
100 cycles x1	0.0015	0.0002
1 kc x1	0.0012	0.0003
1 kc x10	0.0009	0.0003
1 kc x100	0.004	0.0036
1 kc x1000	0.034	0.036
10 kc x1	0.0006	0.0004
100 kc x1	0.0085	0.0026

Figure 12.

Tabulation of the Change Necessary in Dissipation Factor Dial Reading to Produce a Minimum Discernable Change in Meter Reading (1% of full scale). The magnitude of the change in dissipation factor gives the relative sensitivity between ranges. The values in the above table are in terms of the actual reading of the dissipation factor dial. For absolute values multiply by 0.01.