OPERATING INSTRUCTIONS

716-P4

TYPE 716-P4 GUARD CIRCUIT

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GENERAL RADIO COMPANY
CAMBRIDGE 39, MASSACHUSETTS, USA

OPERATING AND MAINTENANCE
INSTRUCTIONS

TYPE 716-P4 GUARD CIRCUIT

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GENERAL RADIO COMPANY

275 MASSACHUSETTS AVENUE

CAMBRIDGE 39 MASSACHUSETTS

SALES ENGINEERING OFFICES

NEW YORK: Broad Avenue at Linden
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Figure 1. Type 716-P4 Guard Circuit.

SPECIFICATIONS

Capacitance Range:	Designed for use with M1 multiplier ranges of the Type 716-C Capacitance Bridge, i.e., 0-1050 μμf SUBST or 100-1150 μμf DIRECT.
Frequency Range:	Corresponds to that of Type 716-C Capacitance Bridge.
Guard Balance Capacitor:	Any value of capacitance between the guard point and the high measuring terminal up to 1000 μμf can be balanced out.
Mounting:	Available in two models: Type 716-P4M in walnut cabinet matching cabinet of Type 716-CM; Type 716-P4R for relay-rack mounting. Leads are arranged for placing the guard circuit directly behind (716-P4M) or above (716-P4R) the bridge.
Accessories Supplied:	One Type 874-Q2 Coaxial Adaptor and one Type 838-B Alligator Clip.
Dimensions:	Height 8-3/4 in., width 19 in., depth 9-5/8 in., over-all.
Weight:	Type 716-P4R, 17 lb. Type 716-P4M, 23 lb.

U.S. Patent No. 2,548,457.
GENERAL RADIO EXPERIMENTER reference: Vol XXVII No. 3, August 1952.

TYPE 716-P4 GUARD CIRCUIT

Section 1
INTRODUCTION

1.1 PURPOSE. The Type 716-P4 Guard Circuit (Figure 1) is designed primarily as an accessory to the Type 716-C Capacitance Bridge to permit three-terminal measurement of capacitance up to 1100 μμf. It is especially useful for two- and three-terminal measurements over wide temperature and humidity ranges where the unknown must be kept in a conditioning chamber. Since the guard circuit eliminates the effects of the leads from the bridge to the unknown, the accuracy of measurement is the same as if the unknown were placed directly at the bridge terminals.

1.2 DESCRIPTION.

1.2.1 GENERAL. The Guard Circuit is supplied in either a walnut cabinet (to match the cabinet of the Type 716-CM) or a relay-rack mounting.

1.2.2 CONTROLS. The following controls are on the panel of the Type 716-P4 Guard Circuit:

Name	Type	Function
COUPLING RESISTOR COARSE FINE	Continuous rotary control Continuous rotary control	Provide coupling balance.
GUARD RESISTOR	Continuous rotary controls (4)	Control adjustable resistors of guard arm.
SELECTOR	4-position selector switch	Connects guard point as required for various balances.
GUARD CAPACITOR	Rotary knob and dial	Provides capacitive guard balance.
SUBST CAPACITOR	Rotary knob and dial	Provides balancing capacitor for substitution measurements.
METHOD	2-position selector switch	Connects guard circuit for either direct or substitution measurement.
FREQUENCY	4-position selector switch	Connects proper resistive arms for measurement frequency.
UNKNOWN	2-position selector switch	Connects unknown capacitor for substitution measurements.

1.2.3 CONNECTIONS. The following connections are on the panel of the Type 716-P4 Guard Circuit:

Name	Type	Function
DETECTOR	Jack-top binding posts (2)	Connection to Type 1231-B Null Detector or equivalent.
UNKNOWN SUBST	Cable, Type 274 connector	Connection to Type 716-C UNKNOWN SUBST.
UNKNOWN DIRECT	Cable, Type 274 connector	Connection to Type 716-C UNKNOWN DIRECT.
716 DET	Cable, Type 274 connector	Connection to Type 716-C DETECTOR terminal.
UNKNOWN	Cable, Type 874 connector	Connection to specimen or component under measurement.

1.2.4 ACCESSORIES. A Type 874-Q2 Adaptor and Type 838-B Alligator Clip are supplied with the Guard Circuit.

Section 2

PRINCIPLES OF OPERATION

2.1 THREE-TERMINAL CAPACITANCE NETWORK. It is often desired to measure the direct capacitance between two points, each of which has capacitance or complex impedance to a third point (see Figure 2). Such a configuration is sometimes produced deliberately, as, for example, when a "guard ring" (Figure 2) is introduced in an electrode system used for the measurement of dielectric materials, either liquid or solid. In other instances it arises inevitably, as, for instance, in a variable air capacitor in which both rotor and stator are insulated from the frame. Here there exists, besides the desired direct capacitance between plates, a capacitance between each plate structure and frame. Another common example is a two-wire shielded cable.

2.2 FIVE-TERMINAL BRIDGE NETWORK.

2.2.1 BALANCE CONDITIONS. With the addition of a fifth point[1] to a conventional four-arm bridge network it becomes possible to measure the direct impedance between two points of a three-terminal network. Such a network is shown in Figure 3, with impedances between the fifth point and each of the four corners of the bridge. It can be shown that the network is in balance if either of the following conditions are met:

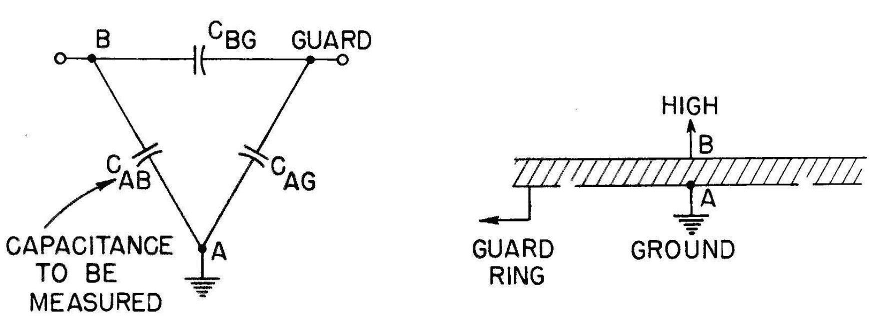

Figure 2. Three-terminal Capacitor and Guarded Sample.

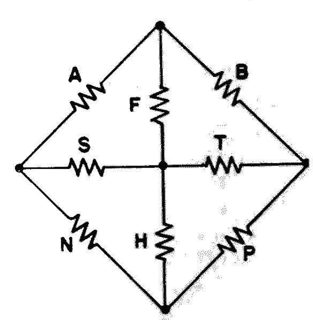

Figure 3. Five-terminal Bridge.

$$\frac{A}{N} = \frac{B}{P} = \frac{F}{H} \tag{1}$$

$$\frac{A}{B} = \frac{N}{P} = \frac{S}{T} \tag{2}$$

These conditions include the ordinary balance equation of the four-arm network A-B-N-P.

2.2.2 TERMINOLOGY. The terminology used in connection with a network such as that of Figure 3 is not clearly established. The word "guard" is often used to designate the third point in a three-electrode measuring system, the implication being that the third electrode "guards" the two measuring electrodes. However, the usage with respect to the measuring network itself is less consistent. The circuit arrangement used in the Type 716-P4 Guard Circuit is often called a "Wagner Ground". On the other hand, the circuit connected across the voltage source is often called a guard circuit and the circuit across the detector a coupling circuit. This terminology can cause trouble if the generator and detector are interchanged, as they may be, particularly in a low-voltage bridge.

The following terminology is adopted in connection with the Type 716-P4 Guard Circuit and is used in this manual.

a. The third terminal of a three-terminal network or electrode system is called the guard or guard point.
b. The fifth terminal of the measuring network is also called the guard or guard point.
c. The two arms connected across the similar arms of the bridge are called the guard circuit, regardless of the method of connecting generator and detector.
d. The two arms connected across the unlike arms of the bridge are called the coupling circuit.
e. The entire auxiliary circuit is named the Type 716-P4 Guard Circuit.

2.2.3 METHOD OF BALANCE. There are several possible ways to adjust the elements of Figure 3 to satisfy equations (1) and (2). The method used in the Type 716-P4 Guard Circuit is to connect the guard point to the junction of the arms N-P, placing S-T in parallel with N-P. Successive balancing of the bridge alone and of the guard circuit and bridge in parallel will satisfy the conditions of equation (2). The coupling circuit can be balanced in a similar manner by successive adjustments of the bridge alone and with the coupling circuit (F-H) in parallel with B-P. In the Type 716-P4 Guard Circuit, appropriately shielded switching is provided for transferring the guard point to the various bridge corners as desired.

2.2.4 POTENTIAL CONSIDERATIONS. It is generally best to bring the guard electrode to the potential of the adjacent measuring electrode to obtain the correct answer for dielectric constant and dissipation factor in a three-electrode measurement. In the Type 716-P4 Guard Circuit, with the normal connection of generator and detector, the guard point is brought to ground potential. Consequently, the guarded electrode of a specimen should normally be connected to ground, as indicated by Figures 2 and 5.

2.3 CIRCUIT DESCRIPTION. (See Figures 4, 6, and 7.)

2.3.1 GUARD CIRCUIT. The guard circuit proper consists of a variable capacitor and a set of resistive arms (corresponding to S and T in the general network of Figure 3), one of which is a fixed resistor, the other variable, consisting of a pair of rheostats for coarse and fine adjustments. The variable capacitor and variable resistor together permit complete adjustment of the guard circuit.

2.3.2 COUPLING CIRCUIT. The coupling circuit consists simply of adjustable resistors connected between the guard point and the junction of the resistive arms of the bridge. This allows a partial coupling balance, balancing the capacitive component of the guard-to-ground terminal impedance. The availability of means for partial balance of the coupling circuit facilitates the balancing of the guard circuit.

2.3.3 SHIELDING. Components, switches, and leads of the guard circuit must be carefully shielded in order to realize the full accuracy of the Type 716-C Capacitance Bridge. In the Type 716-P4 Guard Circuit, all components that could contribute undesired capacitance to ground are mounted in an insulated shielded compartment connected to the guard point, thus placing the stray capacitances in the guard circuit, where they are harmless. Special double-shielded leads are used to connect the guard circuit to the bridge and to the unknown. The entire assembly is enclosed in a grounded metal cabinet, which serves to fix the internal guard-to-ground capacitance at a definite value and also to shield the guard system from 60-cycle pickup.

2.3.4 SUBSTITUTION CAPACITOR. When measurements are to be made by substitution methods (i. e., by connection of the unknown capacitor across the precision capacitor of the bridge), 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. The switching that connects and disconnects this capacitor is appropriately shielded and guarded. The only external connection required is that to the unknown itself.

Section 3
OPERATING PROCEDURE

3.1 INSTALLATION. The Type 716-P4 Guard Circuit is designed for mounting directly above (relay-rack mounting) or behind (cabinet mounting) the Type 716-C Capacitance Bridge. The ground shield is held in position by the panel screws, the lip of the ground shield being placed between the panel and the relay rack or cabinet.

3.2 CONNECTIONS. Connect cables of the Guard Circuit as follows:

a. Connect the UNKNOWN SUBST and UNKNOWN DIRECT cables to the terminals with corresponding markings on the panel of the Type 716-C Bridge. These are double-shielded cables, with the outer shield connected to ground and the inner shield to guard. The center leads connect the guard circuit across the like arms of the bridge.

b. Connect the 716 DET cable to the DETECTOR terminal of the bridge. This connects the fourth terminal of the bridge to the coupling circuit. The terminals on the Guard Circuit marked DETECTOR are placed in parallel with the bridge DETECTOR terminals, and should be connected to a Type 1231-B Null Detector or equivalent by means of one of the shielded cables supplied with the Type 716-C Bridge.

c. Connect the UNKNOWN cable to the specimen or component to be measured. The outer shield of this double-shielded cable is ground, with the clip terminal for connection to the ground side of the unknown. The shell of the Type 874 Coaxial Connector is connected to guard, with the center conductor used as the "high" lead to the unknown. (See Figure 4.)

d. The installation of a matching coaxial connector (Type 874-P) on specimen holders or conditioning chambers is recommended in order to obtain complete shielding of the "high" connection. If this is not practical, use the Type 874-Q2 Adaptor supplied. When this adaptor is used, the insulated binding post is high unknown, the other binding post is guard, and the ground connection is provided by the clip.

3.3 DIRECT-READING MEASUREMENTS (CAPACITANCE RANGE 100 TO 1150 μμf).

NOTE

All preliminary balances should be made with low amplifier gain to prevent overloading.

a. Set the RANGE SELECTOR switch on the Type 716-C Bridge to within a factor of ten of the operating frequency, f, and set the METHOD switch to DIRECT.

b. Set the Type 716-P4 FREQUENCY switch to the corresponding frequency and the METHOD switch to DIRECT.

c. Set the Type 716-P4 UNKNOWN switch to IN.

d. If the approximate value of the capacitance being measured is known, set the Type 716-C CAPACITANCE IN μμf control to this approximate value. Set the DISSIPATION FACTOR control to zero or to the approximate value, if known.

e. If the approximate value of the capacitance being measured is unknown, set the Type 716-P4 SELECTOR switch to the BRIDGE position, and adjust the Type 716-C CAPACITANCE IN μμf and DISSIPATION FACTOR controls for minimum bridge output. A precise null is not necessary at this time since subsequent readjustments will probably be required.

f. Set the SELECTOR switch to the COUPLING position and adjust the COUPLING RESISTOR control for minimum output.

g. Set the SELECTOR switch to the GUARD position and adjust the GUARD CAPACITOR and GUARD RESISTOR controls for minimum output. Be careful to adjust resistors corresponding to the FREQUENCY switch setting.

h. Increase the amplifier gain, and repeat the BRIDGE and GUARD balances as often as necessary to insure the desired precision. The COUPLING balance normally need not be readjusted, but experience will indicate whether readjustment is necessary or desirable.

i. When the bridge and guard are in proper balance, the CAPACITANCE IN μμf and DISSIPATION FACTOR dials of the Type 716-C Bridge read directly the corresponding values of the unknown capacitor, to the same accuracy as for a two-terminal measurement without guard circuit. (Refer to Type 716-C Operating Instructions for details.)

3.4 SUBSTITUTION MEASUREMENTS (CAPACITANCE RANGE 0 to 1050 μμf).

3.4.1 GENERAL. Two sets of balances are required for this type of measurement, one with the unknown connected and the other with it disconnected. The unknown capacitance is substituted directly for part

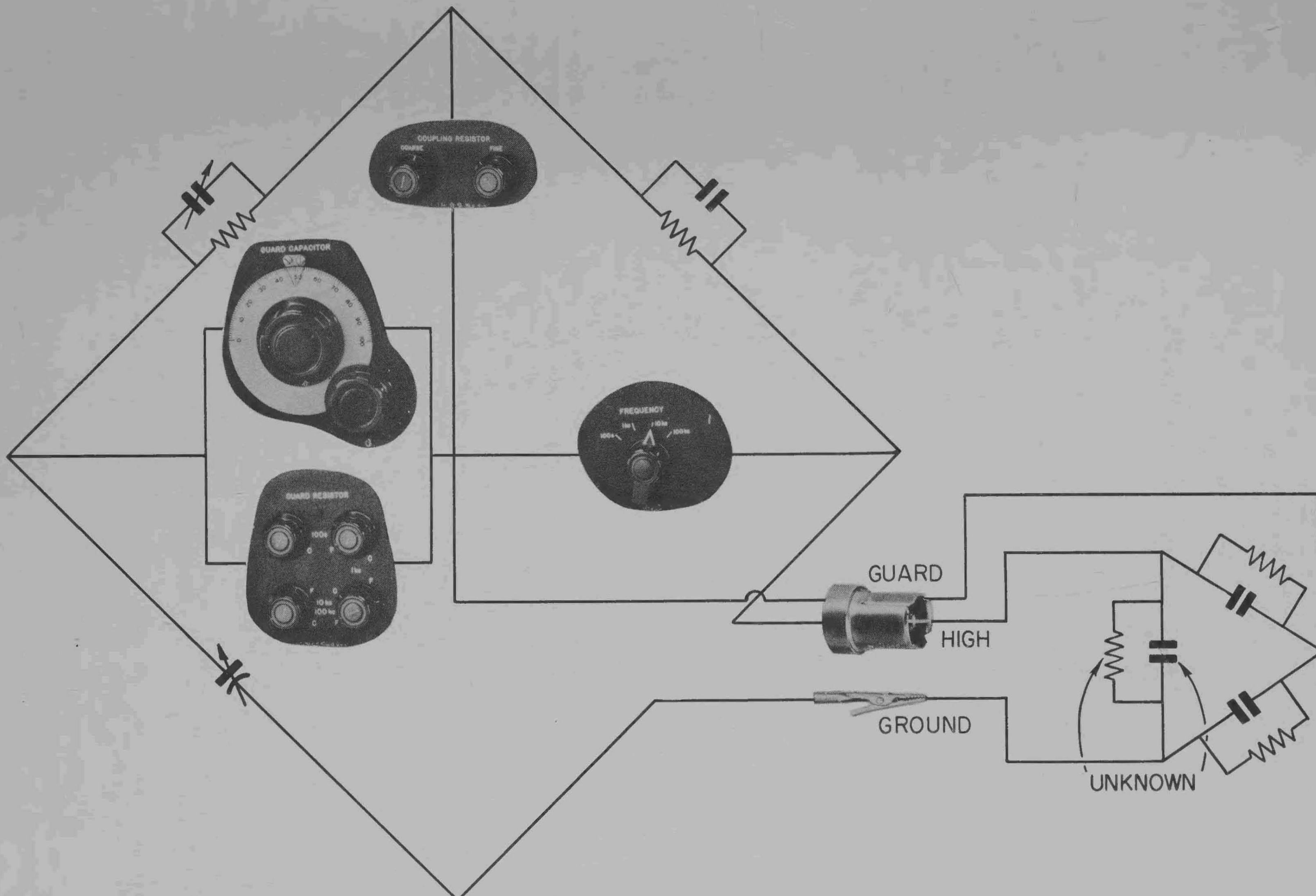

Figure 4. Pictorial Representation of Guard Circuit Controls and their Placement in Simplified Circuit, Including Bridge.

of the precision capacitor in the bridge. Thus the correction chart on the bridge panel may be used to attain a greater capacitance accuracy. If the bridge capacitor has a worm calibration, even greater accuracy may be realized.

The determination of the unknown dissipation factor is also more accurate since it does not depend on internal adjustments but on the change in reading of the DISSIPATION FACTOR controls. Accuracy will be greater if the ratio of the total capacitance in circuit to the capacitance of the unknown is small, especially if the unknown has a small loss. Also, to improve resolution, the ratio f/f_0 should be less than 1 (but preferably not less than 0.1).

Normally, therefore, it is best to make the first balance with the UNKNOWN switch at IN and the Type 716-C CAPACITANCE IN μμf control set at 100 μμf. If several like units are to be measured, it is more convenient to make a single first balance with the UNKNOWN switch OUT. In either instance the first capacitance balance should be made with the SUBST CAPACITOR control. The balance with the UNKNOWN switch IN should occur with the Type 716-C CAPACITANCE IN μμf control indication near 100.

3.4.2 PROCEDURE.

NOTE

All preliminary balances should be made with low amplifier gain to prevent overloading.

a. Set the bridge and guard METHOD switches to SUBST.

b. Set the FREQUENCY and RANGE SELECTOR switches to the desired value (refer to paragraph 3.3, steps a and b).

c. Set the UNKNOWN switch to IN (refer to paragraph 3.4.1). Set the SELECTOR switch to BRIDGE. Set the Type 716-C CAPACITANCE IN μμf control to 100 μμf. Adjust the Type 716-P4 SUBST CAPACITOR and the Type 716-C DISSIPATION FACTOR controls for minimum output.

d. Set the SELECTOR switch to COUPLING and adjust the COUPLING RESISTOR control for minimum output.

e. Set the SELECTOR switch to GUARD and adjust the GUARD CAPACITOR and GUARD RESISTOR controls for minimum output.

f. Increase the amplifier gain, and repeat the BRIDGE and GUARD balances as often as necessary to insure the desired precision.

g. Set the UNKNOWN switch at OUT and the SELECTOR switch at BRIDGE (refer to paragraph 3.4.1). Adjust the Type 716-C CAPACITANCE IN μμf and DISSIPATION FACTOR controls for minimum output. Do not move the SUBST CAPACITOR control during the second balance.

h. Set the SELECTOR switch to COUPLING and adjust the COUPLING RESISTOR control for minimum output.

i. Set the SELECTOR SWITCH to GUARD and adjust the GUARD CAPACITOR and GUARD RESISTOR controls for minimum output.

j. Increase the amplifier gain and repeat the BRIDGE and GUARD balances as often as necessary to insure the desired precision.

3.4.3 COMPUTATIONS. The capacitance and dissipation factor of the unknown direct capacitance are computed from the two sets of bridge measurements in the same manner as for two-terminal measurements. (Refer to Type 716-C Operating Instructions for details.)

When the dissipation factor of the unknown is less than 0.1, the capacitance and dissipation factor can be calculated from the changes in readings of the CAPACITANCE IN μμf and DISSIPATION FACTOR dials, by means of the formulas:

$$C_x = C' - C = \Delta C \quad (3)$$

$$D = \frac{C'}{\Delta C}\frac{f}{f_0}(D - D') \quad (4)$$

where readings with the UNKNOWN switch at OUT are designated by primes, f is the operating frequency, and f_0 is the RANGE SELECTOR frequency. For greater C_x accuracy, chart or worm corrections may be added to C and C'.

With the IN-OUT switch in the OUT position, a capacitance not exceeding 0.2 μμf appears across the bridge arm. To measure the value of this capacitance and its associated dissipation factor, cap the UNKNOWN lead with a Type 874-WO Open-Circuit Termination and observe the change in capacitance and dissipation factor readings of the bridge with the switch changed from IN to OUT.

3.5 EXTERNAL SHIELDING.

3.5.1 GENERAL. As noted in paragraph 3.2c, the lead to the unknown capacitance is double-shielded, permitting measurements with the unknown at a distance from the bridge terminals. Since the GUARD and COUPLING BALANCES remove its impedance from the measurements, the UNKNOWN cable can be extended if necessary. If a double-shielded cable is not available, a Type 874-R20 Patch Cord plus a ground lead may be used. The exposed guard shield may introduce a small amount of power-frequency pickup, but this will not normally cause any trouble if a frequency-selective detector is used.

A grounded metal-braid sleeving can be drawn over the extension cable to serve as a ground shield.

By means of the Type 716-P4 Guard Circuit, capacitors or dielectric specimens can be measured in a conditioning chamber or oven while exposed to specified temperature or humidity, at the same accuracy as would be obtained directly at the bridge terminals.

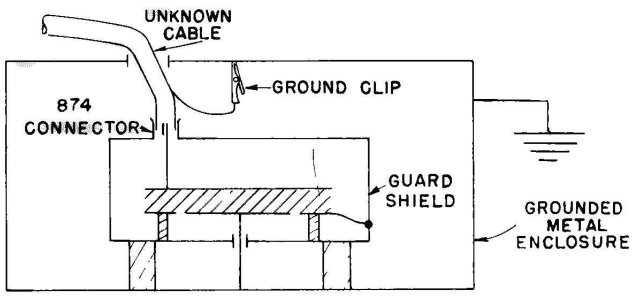

Figure 5.
Method of Connection of Guard and Ground Shields.

3.5.2 MEASUREMENT OF TWO-TERMINAL COMPONENTS. For measurements of two-terminal components, simple shielding against 60-cycle hum pickup may be required, and this is usually provided by the metallic case of the oven or chamber.

Connect the unknown between the high center conductor and the grounded clip terminal of the UNKNOWN cable. Make the measurement as described in paragraph 3.3 or 3.4.

3.6 GUARDED MEASUREMENTS. For guarded dielectric specimens, a guard shield should be provided around the specimen to eliminate from the measurement the capacitance to ground of the unguarded electrode. In most locations it will be necessary to enclose this guard shield against hum pickup. This grounded enclosure is usually provided by the oven or chamber when measurements under controlled temperature or humidity are made. Figure 5 indicates schematically the method of connection.

Section 4

SERVICE AND MAINTENANCE

4.1 GENERAL. Service problems should be referred to our Service Department, which will cooperate as much as possible by supplying information as well as by furnishing any replacement parts needed. When notifying our Service Department of any difficulties in operation or service, please specify the serial and type number of the instrument. Also report the trouble encountered and steps taken to eliminate the trouble.

Before returning an instrument or part for repair, please write to our Service Department, requesting a Returned Material Tag, which includes shipping instructions. Use of this tag will insure proper handling and identification. A purchase order covering repair of material returned should also be forwarded to avoid unnecessary delay.

[1] "A Guard Circuit for Capacitance Bridge Measurements," R. F. Field, GENERAL RADIO EXPERIMENTER, March, 1940.
"A Guard Circuit for the Capacitance Bridge," I. G. Easton, GENERAL RADIO EXPERIMENTER, August, 1952.

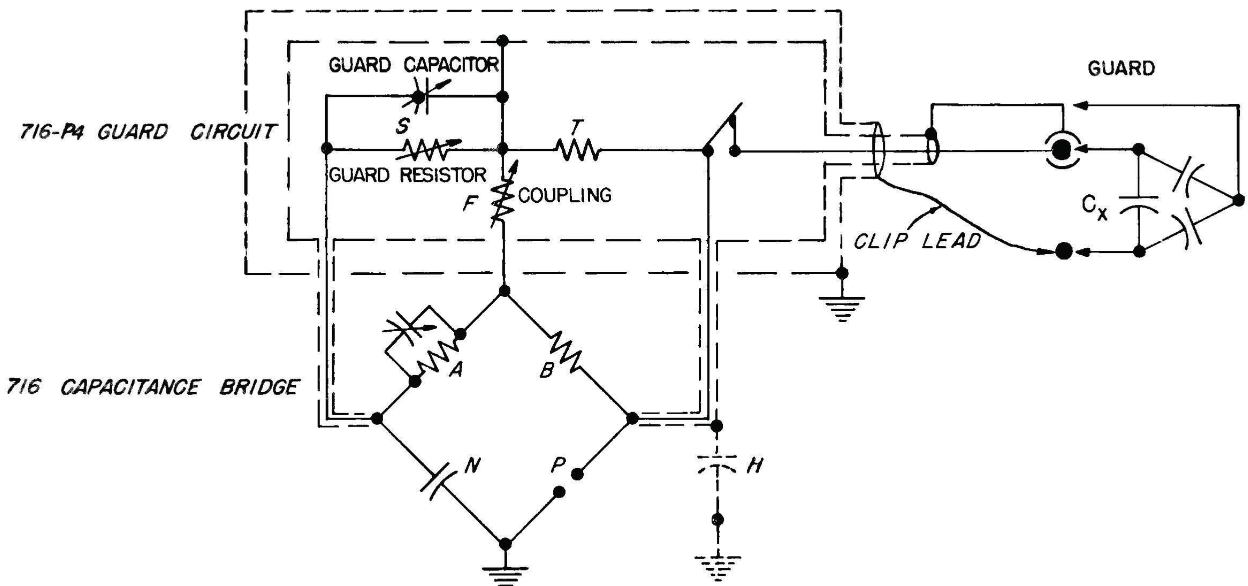

Figure 6. Elementary Schematic Diagram of 716-P4 Connected to 716-C.

Section 5

PARTS LIST

	REF DES				GR NO. (NOTE A)
RESISTORS (NOTE B)	R1	1M	±20%		POSC-7
	R2	10k	±10%		POSC-7
	R3	10M	±20%		POSC-7
	R4	1M	±20%		POSC-7
	R5	100k	±10%		POSC-7
	R6	10k	±10%		POSC-7
	R7	8.2M	±10%	1/2w	REC-20BF
	R8	820k	±10%	1/2w	REC-20BF
	R9	82k	±10%	1/2w	REC-20BF
	R10	8.2k	±10%	1/2w	REC-20BF

	REF DES		GR NO. (NOTE A)
CAPACITORS (NOTE C)	C1	20-1100	848-407
	C2	2.6-10.7	COA-25L
	C3	150, ±5%, 500dcwv	COM-20B
	C4	20-1100	848-408
	C5	2, ±0.5μμf	CC20CG020D
	C6	62, ±10%, 500dcwv	COM-20B
	S1	SWITCH	SWRW-64
	S2	SWITCH	SWRW-41
	S3	SWITCH	SWRW-88
	S4	SWITCH	SWRW-89

NOTES:

(A) GR Part No. designations as follows:

COA - Capacitor, air
COM - Capacitor, mica
POSC - Potentiometer, composition
REC - Resistor, composition

(B) M = Megohm k = kilohm

(C) All capacitances are in micromicrofarads.

TYPE 716-P4 GUARD CIRCUIT

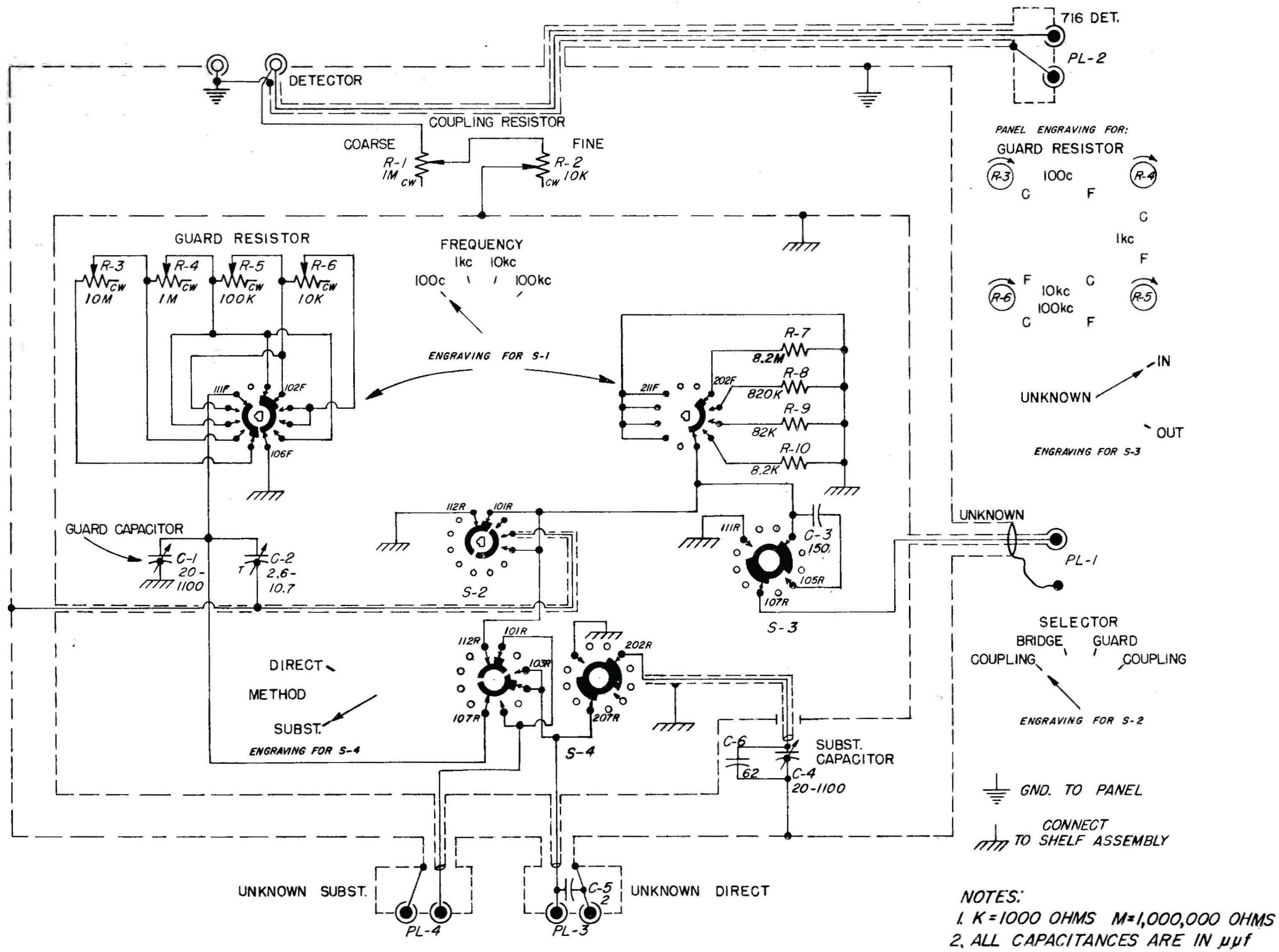

Figure 7. Schematic Diagram of Type 716-P4.