ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A GUARD CIRCUIT
FOR THE CAPACITANCE BRIDGE

● **TO INCREASE** the usefulness and flexibility of the very popular TYPE 716-C Capacitance Bridge, the TYPE 716-P4 Guard Circuit is now offered as an accessory. Although the vast majority of capacitance measurements, whether one is dealing with components or material testing, can be made with a two-terminal connection, there are a number of situations where a three-terminal measurement is required. One of the most common is encountered in the measurement of the dielectric properties of insulating materials. In many instances it is possible to make entirely satisfactory dielectric measurements on two-terminal specimens, but there exist conditions under which it becomes essential to use a guarded or three-terminal measurement in order to realize the best possible accuracy of measurement. While it is possible to compute with reasonable accuracy the fringing effects that occur in two-terminal measurements, it is frequently necessary to eliminate the surface effect from the measurement. For example, the measurement of dissipation factor of a two-terminal specimen under conditions of high humidity can sometimes run into serious difficulty because of leakage over the edge of the material being measured.

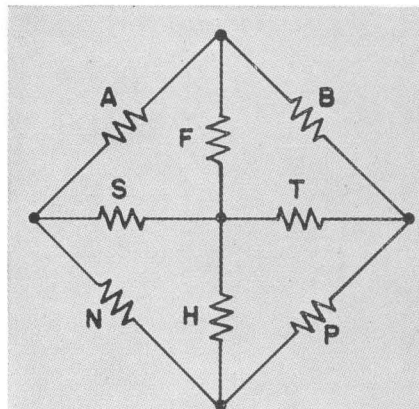The guard circuit, which provides the solution to the above problem,

Figure 1. General bridge network with guard circuit.

also provides the solution to an important related problem. When components and materials are to be measured over wide ranges of humidity and temperature, as is required by modern testing specifications, the measurement should be made with the specimen in some sort of conditioning chamber. The problem raised by the connection between the specimen and the bridge is a very serious one when accurate measurements are desired and when only two-terminal equipment is available. The guard circuit is provided with a double-shielded cable which can be used between the bridge and the specimen mounted in the conditioning chamber. The high lead is guarded, and the undesired capacitances are placed in the guard circuit where they are effectively eliminated from the measuring circuit proper. This technique permits the same accuracy of measurement to be obtained when the component is at some distance from the bridge as would be obtained if it were connected directly to the terminals.

BASIC PRINCIPLES

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 1, 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:

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

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

[1]"A Guard Circuit for Capacitance Bridge Measurements," R. F. Field, *General Radio Experimenter*, March, 1940.

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

TERMINOLOGY

The terminology to be used in connection with a network such as Figure 1 is not clearly established nor standardized. The word "guard" is used rather consistently in the literature to designate the third point in a three-electrode measuring system, the connotation being that the third terminal or electrode "guards" the two measuring electrodes or terminals. With respect to the measuring network itself, however, the usage is not so consistent. The circuit arrangement used in the TYPE 716-P4 Guard Circuit is frequently referred to in the literature as a "Wagner Ground." On the other hand, the circuit connected across the voltage source is often referred to as a guard circuit, and the circuit across the detector called a coupling circuit. This terminology can cause difficulty, however, if the generator and detector are interchanged, as they occasionally may be, particularly in a low-voltage bridge.

The following terminology is arbitrarily adopted in connection with the TYPE 716-P4 Guard Circuit:

(*a*) The third terminal of a three-terminal network or electrode system is referred to as the "guard" or "guard point."

(*b*) The fifth terminal of the measuring network is also called "guard" or "guard point."

(*c*) The two arms connected across the similar arms of the bridge are called the guard circuit, irrespective of the method of connecting generator and detector.
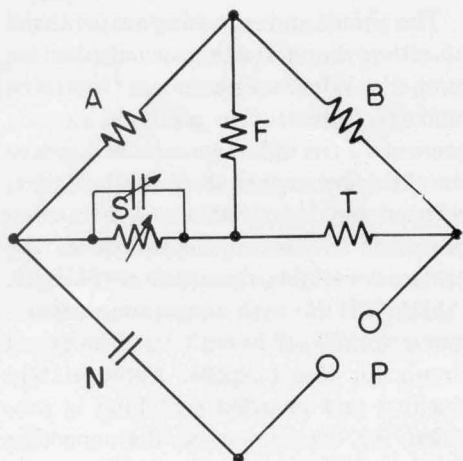
Figure 2. Basic schematic of bridge with guard circuit.

(*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.

CIRCUIT DESIGN CONSIDERATIONS

The usual design of guard circuit for capacitance bridges makes the guard arm impedances S and T approximately equal to the impedances A and B of the arms of the bridge. When this is done, the guard arms must be capable of being balanced to about the same degree of precision as the bridge arms themselves, and the precise balance must be made irrespective of the magnitude of the undesired impedances in the three-

terminal network being measured. A different design approach is used in the General Radio guard circuit in that the guard arms are of relatively high impedance compared to the ratio arms of the TYPE 716-C Capacitance Bridge. The basic philosophy is that of introducing no more admittance than is necessary to balance the admittance between the high terminal and guard. When this condition is met, the guard circuit balance is less critical.

In the TYPE 716-P4 Guard Circuit the capacitance balance provided consists of a 1000 $\mu\mu$f variable capacitor, with the only fixed capacitance being the zero capacitance of the variable unit plus the circuit wiring stray capacitance.

For the resistive balance, a fixed resistor is used in arm T and a variable resistor in arm S. These elements, shown schematically in Figure 2, make it possible to balance any combination of capacitance and loss introduced across arm T by the terminal impedance of the unknown.

DESCRIPTION

An elementary schematic diagram of the TYPE 716-P4 Guard Circuit is shown in Figure 3, as connected to a TYPE 716-C Capacitance Bridge, also shown in elementary form.

The guard circuit proper consists of a set of resistive arms (corresponding to S and T in the general network of
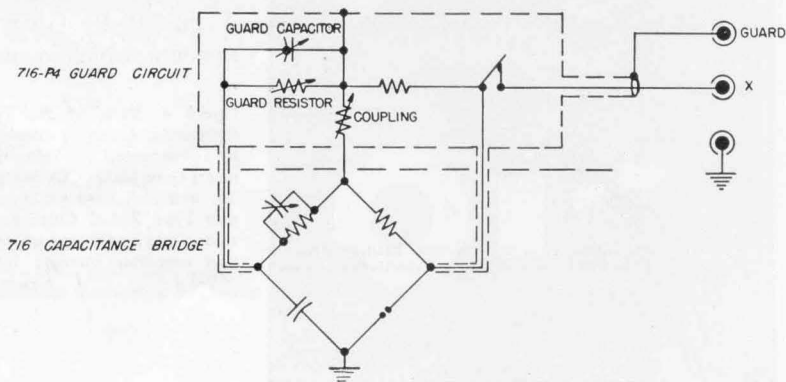

Figure 3. Elementary schematic circuit diagram of the Type 716-P4 Guard Circuit connected to the Type 716-C Capacitance Bridge.

Figure 1) one of which is a fixed resistor, the other variable, consisting of a pair of rheostats for coarse and fine adjustment. The variable capacitor and variable resistor together permit complete adjustment of the guard circuit.

The coupling circuit consists simply of an adjustable resistor 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.

The circuit and switching are arranged by either direct reading or substitution methods. When measurements are to be made by substitution methods, i.e., by connecting 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 1100 $\mu\mu$f is built into the guard circuit for this purpose. Appropriately shielded and guarded switching is provided for connecting or disconnecting this capacitor as required. Thus the only external connection required is that to the unknown itself, whether direct-reading or substitution methods are employed.

Four pairs of ratio arms are provided in the bridge, for direct-reading operation at 100 cycles, 1 kc, 10 kc, and 100 kc. Correspondingly, four sets of resistive guard arms are provided in the guard circuit, selected by a panel switch. Four adjustable resistors are provided, with the switching so arranged that they are used in pairs for each switch setting, one "coarse" and one "fine" adjustment.

Shielding

Although the circuits just described are exceedingly simple, it is necessary that components, switches, and leads of the guard circuit 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 which could contribute unde-
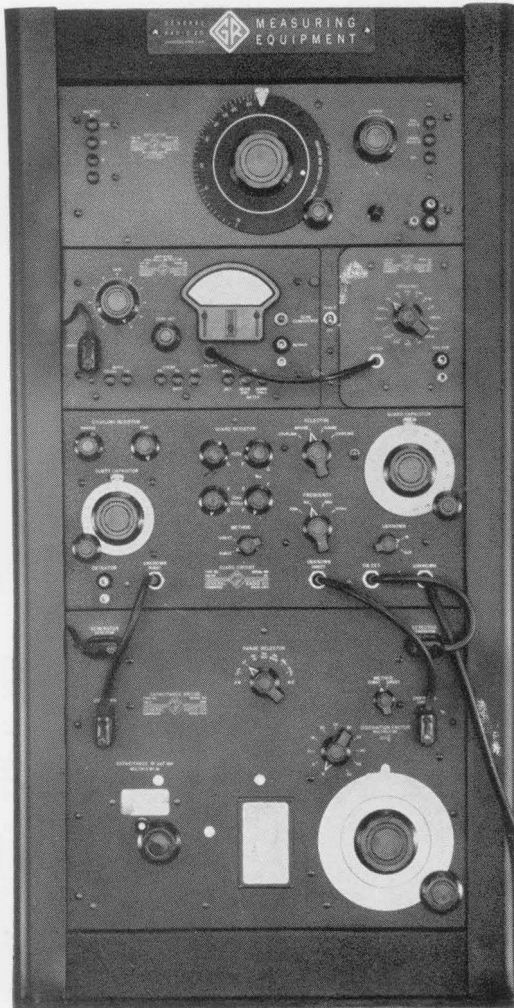
Figure 4. View of the Type 1610-A Capacitance Measuring Assembly consisting of guard circuit and bridge mounted in a relay-rack with associated equipment: Type 1302-A Oscillator, Type 1231-BRFA Amplifier and Null Detector, Type 716-P4R Guard Circuit, and Type 716-C Capacitance Bridge. Assembly includes relay rack and all necessary cables. Oscillator and amplifier operate from a 115-volt, 60 cycle power line.

sired capacitance to ground are mounted in an insulated shielded compartment, which is connected to the guard point, thus placing the stray capacitances into 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 system against 60-cycle pickup.

The circuit connections are so arranged, as shown in Figure 3, that two-terminal measurements can be made directly with the bridge. It is merely necessary to disconnect the two cables at the UNKNOWN DIRECT and UNKNOWN SUBST. terminals of the bridge. No other circuit rearrangement is necessary.

—IVAN G. EASTON

SPECIFICATIONS FOR THE 716-P4 GUARD CIRCUIT

Capacitance Range: Designed primarily for use with the x1 multiplier ranges of the TYPE 716-C Capacitance Bridge, i.e., a range of 0-1000 $\mu\mu f$.

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 $\mu\mu f$ 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 above the bridge.

Accessories Supplied: One TYPE 874-Q2 Coaxial Adaptor.*

Net Weight: TYPE 716-P4R, 17 lbs.; TYPE 716-P4M, 23 lbs.

Dimensions: 19 x 8¾ x 9⅝ inches.

*U. S. Patents 2,125,816 and 2,548,457.

Type		Code Word	Price
716-P4M	Guard Circuit (in Walnut Cabinet)...............	BOSOMGUARD	$315.00
716-P4R	Guard Circuit (for Relay-Rack Mounting).........	BONUSGUARD	295.00

TYPE 1610-A CAPACITANCE MEASURING ASSEMBLY

The new guard circuit described above, in conjunction with equipment regularly available, makes a well-integrated assembly for the measurement of capacitance and dissipation factor over a wide range of frequency.

For convenience in ordering, setup, and use, the bridge, guard-circuit, oscillator, and detector are assembled in a bench type cabinet rack, complete with all interconnections. The assembly is designated as TYPE 1610-A Capacitance Measuring Assembly.

With this equipment, two-terminal or three-terminal measurements of capacitance and dissipation factor can be made either by direct or substitution methods, over the frequency range from 60 cycles to 100 kc.

Type		Code Word	Price
1610-A	Capacitance Measuring Assembly...............	SEDAN	$1850.00