THE General Radio EXPERIMENTER

VOLUME XXVII No. 3 AUGUST, 1952

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A GUARD CIRCUIT FOR THE CAPACITANCE BRIDGE

Also

IN THIS ISSUE

● **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,

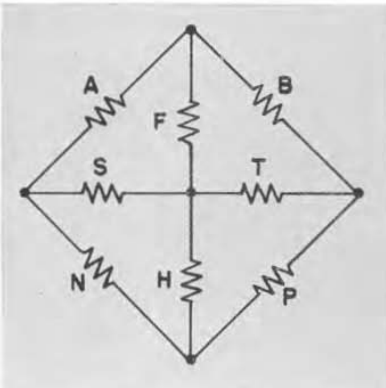


Figure 1. General bridge network with guard circuit.

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.

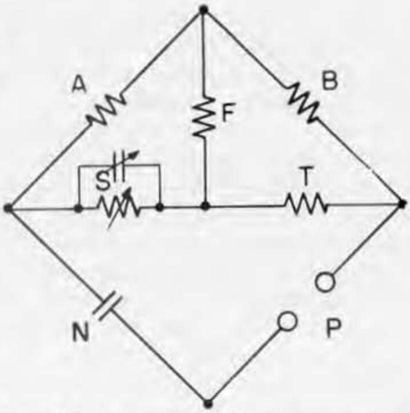


Figure 2. Basic schematic of bridge with guard circuit.

(*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

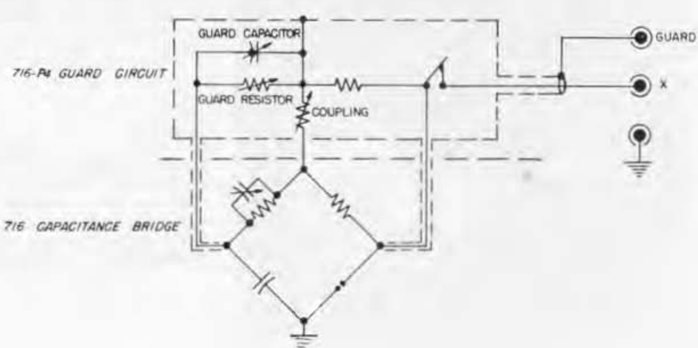


Figure 3. Elementary schematic circuit diagram of the Type 716-P4 Guard Circuit connected to the Type 716-C Capacitance Bridge.

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**

A GOOD CAUSE

The letter reproduced below merits the consideration of all electronic engineers and manufacturers. Few will deny that electronic equipment is tending to become increasingly complex — in design, in construction, in operation, and in maintenance.

At the recent Joint AIEE-IRE-RTMA Symposium on Progress in Quality Electronic Components, the statement was made that 60 per cent of all electronic equipment in operation by the fleet is not operating satisfactorily. When we consider that a destroyer uses

DEPARTMENT OF THE NAVY
BUREAU OF SHIPS
WASHINGTON 25, D. C.

IN REPLY REFER TO
S67(801)
EN8/A2-6
Ser 801/819-45
6 June 1952

Attention Technical Director for Research and Engineering

Gentlemen:

Subj: Electronics; project simplification

The increasing complexity and resultant increased maintenance and reduced reliability of electronics equipment is a matter of great concern to the Bureau of Ships. Every effort is being made by the Bureau of Ships to simplify the design of electronics equipment. To successfully accomplish our objective, the full cooperation of the engineering staffs of all Bureau of Ships contractors is needed.

The Bureau of Ships solicits and will welcome proposals from contractors which will result in the production of less complex and more easily maintained equipment. Such proposals for simplification of designs are desired any time during the performance of existing contracts and will be evaluated on a not-to-delay production basis. It is understood that under no circumstances shall changes be invoked in existing contracts unless authorized by formal change under the contracts.

In order to insure proper evaluation by the Bureau of proposals for simplification of design, it is requested that the proposal completely set forth any existing specification requirements which cannot be fully met. Such proposals should also recommend specification changes which will be necessary to accomplish the proposed simplification.

Proposals for simplification of designs on existing contracts should be forwarded to Bureau of Ships, Electronics Design and Development Division, Code 810, Washington 25, D. C.

Sincerely yours,

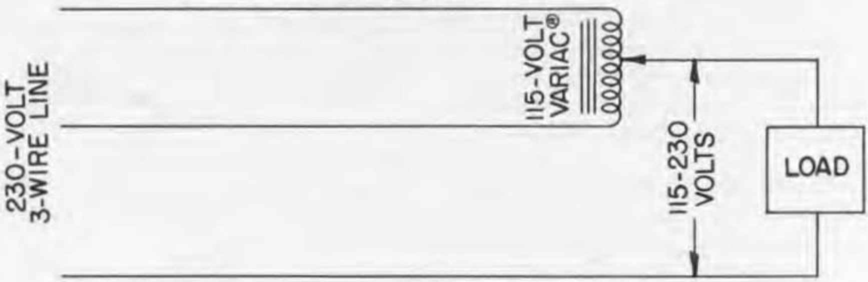
/s/ H. E. Bernstein
Acting Assistant Chief of Bureau
for Electronics

3200 vacuum tubes and that the process of navigation in a B-50 involves some 2500, such a statement no longer seems startling.

With these thousands of tubes in the operation of each fighting unit, the possibilities for failure are high and the maintenance requirements are severe.

Simplification of design is a prime necessity if the world is not to become bogged down in a morass of inoperative devices. Design simplification offers a challenge to the engineer that he must accept. The simplest way is often the most difficult, requiring considerable horse sense and, usually, a higher degree of creative endeavor than mere textbook engineering.

A USEFUL VARIAC CIRCUIT



The circuit shown in the accompanying illustration will be found useful where a limited range of control is needed on a 230-volt, 3-wire circuit.

The range of control is from 115 to 230 volts, and the effective rating of the 115-volt Variac is doubled. Since the common wire in a 3-wire system is usually grounded, the load should *not* be grounded when this connection is used.

NATIONAL ELECTRONICS CONFERENCE

Plan to visit the General Radio exhibit at the 1952 National Electronics Conference to be held in Chicago September 29 through October 1. In booths 62 and 63, General Radio will show an extensive line of UHF-VHF measuring equipment, the new General Radio Sound-Measuring System, and a number of impedance bridges for laboratory and production testing.

The UHF-VHF equipment on display will include instruments for the measurement of voltage, power, frequency, standing-wave ratio, admittance, impedance and receiver characteristics.

The sound-measuring equipment includes the sound-level meter, sound-survey meter, auxiliary microphones, octave-band and continuous-spectrum analyzers, and an acoustic calibrator.

Among the bridges exhibited will be a resistance-limit bridge, useful for both laboratory measurement and production testing, and an a-c comparison bridge for checking capacitors and inductors against a standard sample at 1000 and 5000 cycles.

MISCELLANY

ELECTED — Harold B. Richmond, Chairman of the Board, General Radio Company, to Life Membership of the Corporation of the Massachusetts Institute of Technology.

NATIONAL ELECTRONICS CONFERENCE, Chicago, Sept. 29 - Oct. 1. Visit Booths 62 and 63 to see displays of General Radio Equipment.

CONGRATULATIONS to Seyffer and Co., A.G., exclusive distributors of General Radio products in Switzerland, who this year are celebrating the 30th anniversary of the founding of their company. Our pleasant association with this firm and its officers began in 1939.

RECENT VISITORS FROM OVERSEAS—Jacques Bendayan, Chief, Telecommunication Laboratories, Cables de Lyon de le Compagnie Génerale de Electricité, Lyon, France. Mr. Bendayan was accompanied by Marius Berlin, of Radiophon, Paris, exclusive distributors of General Radio products in France and the French colonies.

—Professor Abdul Rahman Hamoui, of the Engineering School, Syrian University, Aleppo, Syria.

—Dr. A. Malodi, Director of Broadcasting, Republic of Indonesia, Djakarta, Indonesia.

—Stanley H. Lives, General Works Manager, A. C. Cossor, Ltd., London.

—Per-Olof Lundbom, Research Engineer, Research Institute of National Defense, Stockholm, Sweden.

—Masaru Ibuka, President, Tokyo Telecommunication Engineering Company, Ltd., Tokyo, Japan.

THE General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in communication-frequency measurement and control problems. When sending requests for subscriptions and address-change notices, please supply the following information: name, company address, type of business company is engaged in, and title or position of individual.

GENERAL RADIO COMPANY
275 MASSACHUSETTS AVENUE
CAMBRIDGE 39 MASSACHUSETTS
TELEPHONE: TRowbridge 6-4400

BRANCH ENGINEERING OFFICES

NEW YORK 6, NEW YORK
90 WEST STREET
TEL.—WOrth 2-5837

LOS ANGELES 38, CALIFORNIA
1000 NORTH SEWARD STREET
TEL.—HOllywood 9-6201

CHICAGO 5, ILLINOIS
920 SOUTH MICHIGAN AVENUE
TEL.—WAbash 2-3820

PRINTED IN U.S.A.