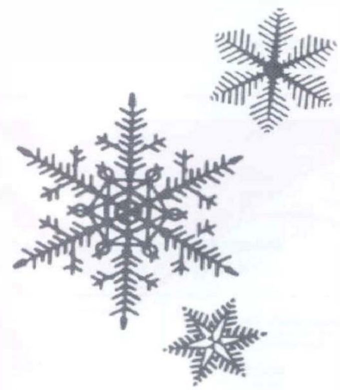
THE GENERAL RADIO
Experimenter

VOLUME 43
NUMBERS 11,12
NOVEMBER/DECEMBER 1969

THE
GENERAL RADIO
Experimenter

VOLUME 43 **NUMBERS 11,12** **NOVEMBER/DECEMBER 1969**

The *General Radio Experimenter* is mailed without charge to engineers, scientists, technicians, educators, and others interested in the instruments and techniques of electrical and electronics measurements. Address all correspondence to Editor, *General Radio Experimenter*, General Radio Co., West Concord, Mass. 01781.



In the lead article of this *Experimenter* we have taken issue with a view held by many people — that computers are intelligent. The article is presented with the hope that the aura that surrounds computers, in general, will be reduced and that computers will be accorded the respect due them, but only to the extent that it is deserved.

If, however, computers are more wily than we are prepared to admit, we hasten to draw attention to our cover. By assigning to a computer the slight human frailty of repeating itself, and also attributing to it a small sense of human kindness, we have made it serve our purpose. For, unlike our elfin operator, who forgot what season of the year it is, our computer has "remembered" and stirred itself to speak for all of us at General Radio.

To all our readers, wherever you are, we sincerely hope you will join with us in this special season, to count our blessings and to give thanks for all that is good. We wish you, one and all, "SEASONS GREETINGS."

C. E. White
Editor

Why Computers in Measurement Systems?

"Computers are smart?"* is a question raised quite often even by people who have knowledge of, access to, or control of computers. Of course computers aren't smart -- they are clever *tools* that reflect the intellect of the special group of people who have wedded themselves to these machines. For the past two decades, many in this special group have devoted themselves to the specific task of forging an alliance of computers, humans, and measurement instruments.

Just why should all this effort be expended in this direction? Well, first let's review some of the advantages and disadvantages of the simple combination of measuring instrument and operator. The operator's mind is able to grasp the significance of data derived from the instrument, to recognize patterns in the observed test data, and to react in the appropriate and positive manner. All this can be done, but not for any prolonged interval of time, and not very fast. Fatigue sets in, the operator's mind is less responsive to signals, and the operator's usefullness deteriorates rapidly. On the other hand, a computer is not susceptible to fatique (exclusive of electronic or mechanical deterioration). Properly programmed, the computer can perform all the above functions – faster!

But even with its ability to store *all* the knowledge derived by the operator from training and experience, the computer is merely an electromechanical *slave*, incapable of thinking, analyzing, and reacting to a problem for which we have not supplied instructions. Why then is it so important to utilize the services of the computer? Let's look at a few specific advantages of the combination of computer, operator, and measuring instrument:

- Instrument operation can be faster.
- More data can be derived in a given time interval.
- Comparisons of derived data with built-in reference standards, tolerances, or specifications are quicker by orders of magnitude.
- Provided bilateral interfacing has been built into the system, the operator maintains strict control of test operations.
- Systematic errors due to operator bias are eliminated.
- Test data can be displayed automatically in any of several forms – paper or magnetic tape, punched cards, line printers or teletypewriters, automatic graphic recorders or X-Y plotters, etc.

The advantages inherent in compatible interfacing between the units of the combination are more apparent as we trace the growth in complexity of measurements and realize the need to perform and interpret measurements more quickly.

Measurement Systems are COMPLEX!

Development of manual-measurement techniques has progressed from single-point measurements of simple parameters to swept measurements with automatic readout and

*According to Hughes Aircraft publication *Vector* (First Quarter 1969), "The credentials of any machine that believes 1 + 1 = 10 are suspect."

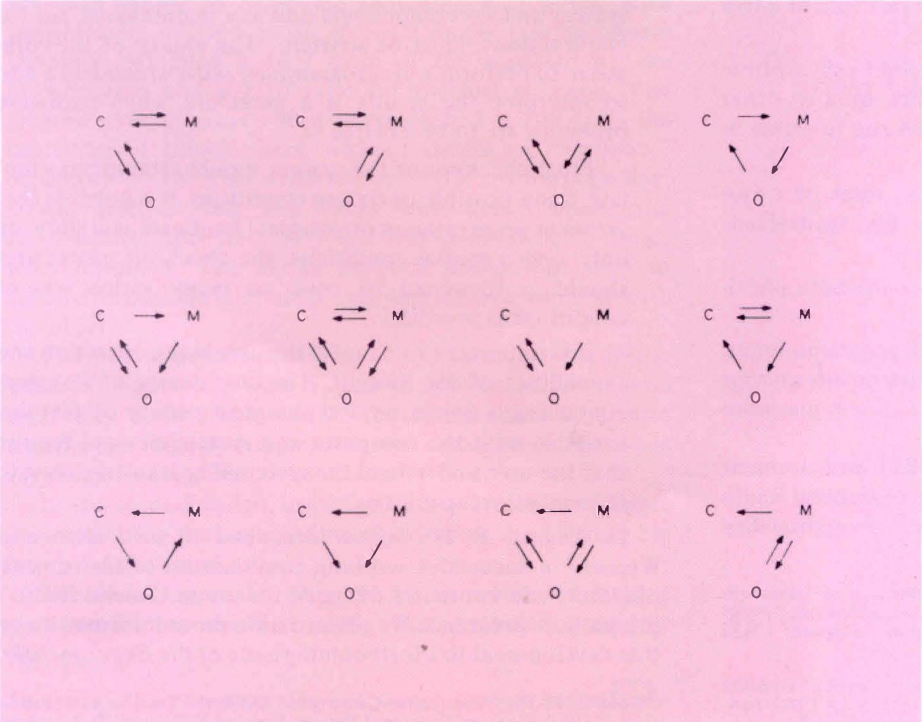


Figure 1. A few of many arrangements for instrument-computer-operator interfaces.

data displays followed by analysis of these data by comparison with recorded standard performance data. The complexity of the latter technique is sufficient to overtax the ability of an operator.

As measurement techniques have evolved there has been a metamorphosis in the systems and techniques of recording and applying measurement data. The simple inspection data sheet that displayed a measurement result vis-a-vis a reference standard, and alerted an operator to make a quality evaluation to accept or reject the inspected item, has now changed into the automatic visual presentation and analysis of data. In such a system, units tested are automatically accepted or rejected, adjusted from out-of-tolerance conditions to within tolerance (if feasible), or the computer may alter the test sequencing for further analysis or action. For specific applications, the interfaces can be unilateral or bilateral[1] and in any number of arrangements, some of which are shown in Figure 1.

At this point it would be wise to define two terms prevalent in the work of coupling computers, instruments, and operators. *Computer-assisted* refers to the general case of the combination of computer and instrument system in which the computer does not exercise control of the test agenda, reacts passively to record data for analysis, and alerts the operator to take certain actions. The term *computer-controlled* signifies both indirect and direct control by the computer over the measurement system and test process. The computer asserts authority over the measurement system by transmitting command pulses to programmed measuring equipment and control units. In each case, assist or control, the computer memory has stored within it all the instructions required to conduct the test program.

Programmable Instruments Don't Just Happen Along

Modern instrument designers must consider problems such as these if they wish to incorporate an instrument into a programmed measurement system:

> Programming circuitry or units must not be susceptible to shock, vibration, temperature, noise or any other environmental condition that could give rise to errors in program signals.
>
> Very short time commands, of the order of nanoseconds, could be delayed effectively by inadvertent introduction of long-line connections.
>
> Interfacing between units must be compatible physically, electrically, and mechanically.

Unless these problems and others are solved, programming an instrument does not necessarily make an instrument a better one. Many measuring instruments, *but not all*, are programmable.

Design of a practical computer-controlled measurement system was outlined by M. L. Fichtenbaum of General Radio recently during a GR measurement seminar.[2] He approached the problem in this manner:

Evaluate the measurement requirements in terms of what can and cannot be done. A system proposal may call for straightforward tasks; it may also demand measurements that are impractical.

Check whether there is available hardware to perform the measurement functions. Is it possible to modify existing instruments, or to make measurements from which the computer can calculate the required information? What would be the cost of developing any special-purpose equipment?

Decide with the user on final system specifications. It is likely that the system designer does not know all about the user's needs; it is also likely that the user does not know all the system designer's limitations and capabilities.

Choose a specific hardware configuration. With the final instrumentation defined, the interface necessary to tie the instruments to the computer can be designed. Typically, an interface will consist of enough standard modules to transfer all necessary data between computer and instruments, plus one or two "special" modules to perform functions specific to the system.

Consider the three main areas in software development. Each instrument in the system has associated with it program segments to control the instrument and to translate data between instrument and computer formats. In most cases, these "instrument module" programs can be developed for use with one instrument and used essentially unchanged in all systems that use the instrument. Each system will have a unique "main-line" program to perform the test functions required. These include the initial setup (of limits, ranges, etc), the sequence through test configurations, and presentation of data in the proper form.

Diagnostic programs, both for initial checkout of the system and its components and as a maintenance aid for malfunctions, must be written. The ability of the computer to perform a preprogrammed self-test sequence and to interpret the results is a great aid when hardware problems are to be isolated.

Final checkout of the system should attempt to simulate many possible operating conditions. It is possible that errors in programming or marginal hardware will show up only under special conditions; the checkout procedures should be designed to cover as many varied sets of conditions as possible.

It is important to educate the user in the operation and capabilities of the system. The complexity of a system containing a computer and the great variety of features available with the computer as a system element require that the user understand the system if he is to employ it to its maximum capabilities.

In August, P. H. Goebel described to an audience at Wescon[3] a successful working combination of instrument, operator, and computer designed for use in General Radio's production programs. We plan to have more information on this development in a forthcoming issue of the *Experimenter*.

[1] Beatty, R. W., "Short Discussion of Error Reduction in Network-Parameter Measurement Through Computerized Automation," *Progress in Radio Science – 1966-1969*, (Commission I Report) URSI XVIth General Assembly, Ottawa, August 1969.

[2] Fichtenbaum, M. L., "Computers in Instrument Systems," General Radio Automatic-Impedance-Measurement Seminar, May 1969 (unpublished).

[3] Goebel, P. H., "Computer-Controlled On-Line Testing and Inspection," *1969 Wescon Technical Papers, Session 8*, August 19-22, 1969.

Search for a Better Transformer

Far back, in the comparative antiquity of June 1926, General Radio was very much interested in the problems of transformer design.[1] During the years that followed we never relaxed our interest, nor our desire to tell our readers about what is considered good design.

Burke noted in 1926 the difficulty of designing ratio transformers for undistorted response over extreme ranges of frequency – 100 to 5000 Hz! Among other things, he demonstrated the importance of matching transformer impedances to the signal source and to the load. These elementary problems are still with us.

A recent problem was to design a ratio transformer for stable operation at 1 MHz and with low leakage impedance. Why? Well – we knew that a transformer could provide an excellent means of decade ranging for the new GR 1682 Automatic Capacitance Bridge.* Since there did not appear to be one available commercially, we continued our research into methods and means of devising such a unit.

During several sessions with GR engineer Dick Sette, the *Experimenter* editor was able to trace the progress made, from the first round-table discussions, through the preliminary design stages, to the final production models of the finished products. Note the use of the plural term – the final result was not one but two devices, each unique for its own function in the capacitance bridge.

The problems, as presented by Sette, were to supply a maximum stability to a wide range of measurements at 1 MHz and to achieve good accuracy at the UNKNOWN position 4 feet away. Thoughts of using computing amplifiers were considered and then dropped because of cost and state-of-the-art development.

It was considered necessary to use different transformers for each range, to overcome switching difficulties. With transformers of 10:1 ratio, it was a simple task to reverse windings, effecting a 10:1 ratio of the standard for the lowest range and a 1:10 ratio for the highest range. The greatest over-all range could be established at 100:1, by the cascading of transformers, without sacrificing "accuracy" capability of 1%. Past experiences of GR engineers Smiley, Hersh, Holtje, Hall, and Fulks were drawn upon, and constructive ideas for a very low leakage-impedance design were obtained. The design problem posed was: how to achieve maximum electrical coupling of one winding with the other.

The first approach considered was a toroidal core, bifilar wound (Figure 1), with a twisted 11-wire cable wound uniformly around the toroid. The result was a 10:1 ratio transformer, tightly-coupled but not satisfactory for use at very high frequencies.

In the second design, use of cup cores in a toroid (Figure 2a) resulted in better coupling. Rewinding, as in Figure 2b, improved the coupling.

The third approach (Figure 3), in which we used a multi-conductor shielded cable that provided very low

*See page 6.

[1]Burke, C. T., "Amplifier Ins and Outs," *General Radio Experimenter*, June 1926.

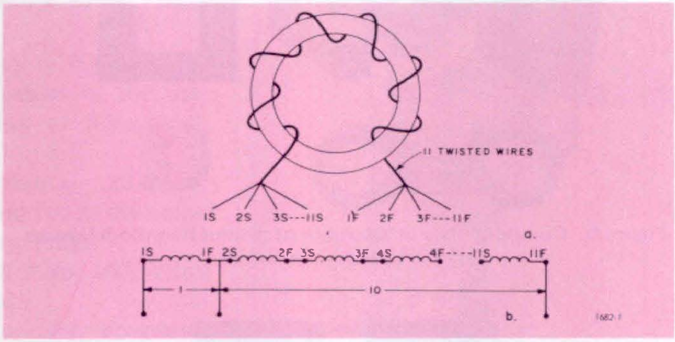


Figure 1. Simple design for 10:1 ratio transformer.

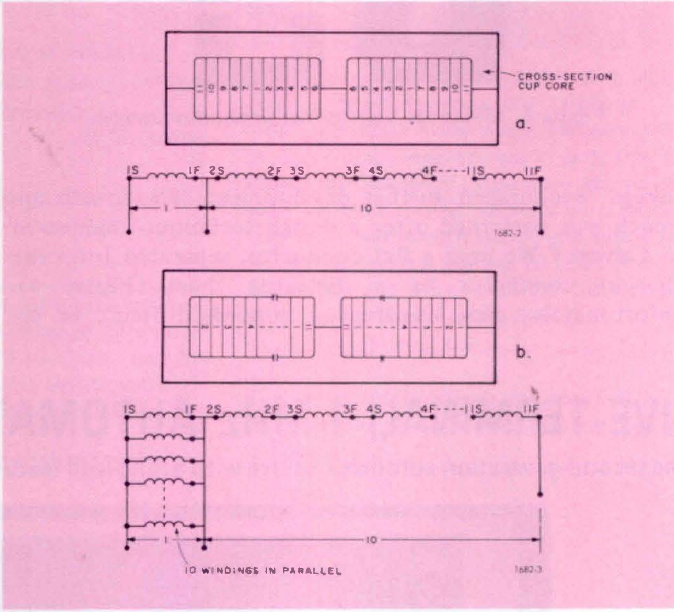


Figure 2. Use of cup cores for an improved design.

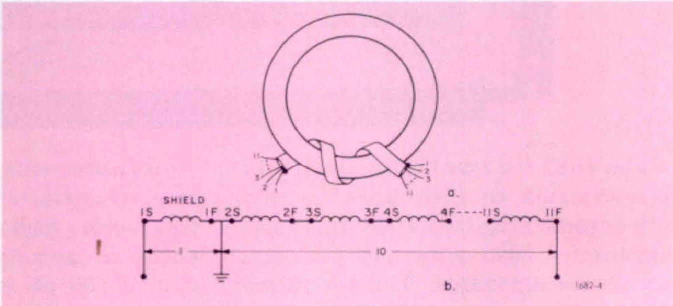


Figure 3. Multi-conductor shielded-cable winding.

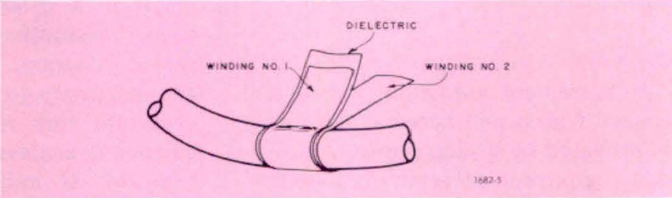


Figure 4. Flat-conductor transformer-winding design.

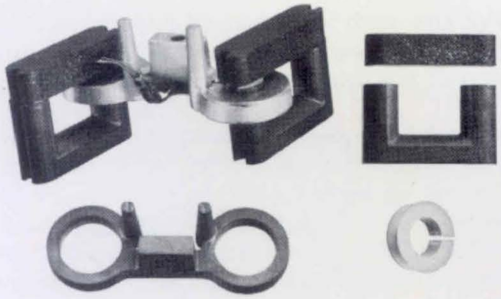


Figure 5. Components and assembly of production-model design of 10:1 ratio transformer.

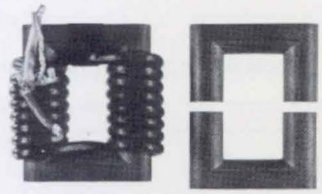


Figure 6. Mid-range transformer production model.

leakage, encouraged further development. The fourth approach was patterned after a design technique engineered by Calvert.[2] We used a flat conductor, separated from the adjacent conductor by a dielectric sheet (Figure 4). Unfortunately, this transformer proved difficult to assemble, and the coil had high capacitance loading. The latter problem was a serious detriment inasmuch as it increased the driving requirements excessively.

Finally, the decision was made to go to a machined-core design. A split, hollow, brass bobbin was made and used as a single turn. The bobbin was silver-plated to minimize skin effects at 1 MHz. To improvise leads for the single turn, the casting that held the bobbins was made with self-circuit leads (horns) that penetrated the mounting board for ease of connection. Ten turns were wound on the bobbin, which was sweated into place in the casting. Figure 5 illustrates the assembly. In order to switch the leads, to provide the desired ratio direction, reed relays were connected to the circuitry.

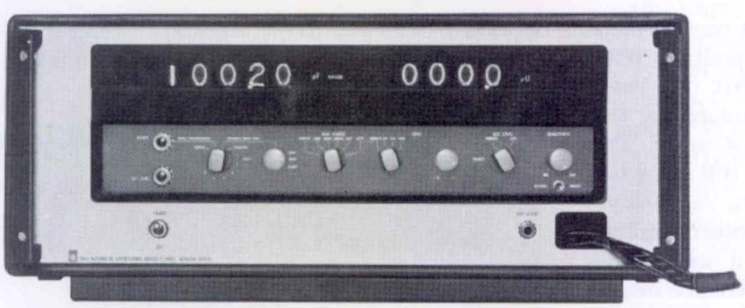
We still had the requirement for the mid-range 1:1 coupling transformer. A simple, balanced, 1:1 ratio transformer was constructed (Figure 6), consisting of a Triax cable wound around a core. The outer and inner shields were used as conductors; the inner conductor was ignored. This technique provided a transformer, simple to manufacture, with one conductor completely surrounded by the second, assuring maximum coupling.

These development chores completed in a satisfactory fashion, manufacturing was able to move out on the final construction of the new GR 1682 Automatic Capacitance Bridge.

[2]US Patent No. 2,659,845 assigned to Wayne-Kerr Laboratories, Ltd.

FIVE-TERMINAL, 1-MHz AUTOMATIC CAPACITANCE BRIDGE

The second-generation automatic bridge with a long-lead feature



The 1682 is a *true* bridge, capable of measurements to high accuracy and with ensured long-term stability. It uses transformer ratio arms and precision admittance standards. The five-terminal-type connection for the unknown minimizes the inaccuracy effects of lead impedances.

Why Measure at 1 MHz?

Measurement guidelines for several classes of glass and ceramic capacitors are provided by military specifications, which require 1 MHz as the measurement frequency.

Measurements at 1 MHz are necessary to characterize low-value capacitors with high shunt conductance. Given a capacitance-conductance circuit of 100 pF and 10 kΩ, a measurement at 1 kHz would yield a large real-current component, which would result in a balance with considerable loss of resolution, as indicated by the vector diagram, Figure 1a. The real and imaginary currents at 1 MHz, however, are very nearly equal, and the balance is achieved with maximum resolution, as indicated by the vector diagram, Figure 1b.

In the integrated-circuit industry, capacitance versus junction-bias-voltage measurements are important sources of analytical data from which several characteristics of semiconductor junctions can be determined. Because present isolation techniques use reverse-biased junctions and thin-oxide films, shunt losses are unusually high for the small-value capacitors being measured. Therefore, measurements at 1 MHz provide maximum resolution and accuracy.

How We Did It

Operation at 1 MHz with long cables to the unknown called for a design to include a ratio-transformer, 5-terminal, ac Kelvin bridge and was, in effect, an extension of a lower-frequency version.[1] The result is the five-terminal configuration shown in Figure 2. To achieve minimum measurement errors due to shunt loading, low-leakage-

[1]Hill, J. J. and Miller, A. P., "An AC Double Bridge with Inductively Coupled Ratio Arms for Precision Platinum-Resistance Thermometry," *Proceedings of the Institute of Electrical Engineers,* February 1963.

impedance ratio transformers were developed.* Loading Z_A appears across the ratio transformer winding N_2, and loading Z_B is across the low input impedance of the bridge preamplifier.

It is extremely important to evaluate the accuracy of a bridge at the terminals of the capacitor being measured, not at the bridge terminals. If a three-terminal measurement were attempted at 1 MHz, the inductance of the go and return paths to the component would cause considerable error, restricting the measurement to the bridge terminals. For example, if a 1000-pF capacitor is measured at the end of two twisted coaxial leads, three feet long, the error in measurement will be approximately 4%.

To provide meaningful measurements of semiconductor-junction parameters, the test-signal level at the unknown is low, 500 mV to 5 mV over the three lowest ranges, and is constant during balance operations in any one range.

The balancing technique is simple, implemented entirely with integrated circuits. The automatic-ranging feature is designed to provide maximum resolution of measurements over the four bridge ranges.

*See page 5.

Outstanding Features

- Wide range – 00.001 to 1999.9 pF and 02.00 to 19.99 nF in four ranges.
- High basic accuracy – 0.1% at the end of four-foot cables to the unknown, due to use of 5-terminal connections.
- Rapid automatic balance – 20 measurements per second for ±10% components, on any one range.
- Built-in bias from 0 to 100 Vdc; external to 200 Vdc.
- All functions remotely programmable.
- Various data output and test fixture options.
- Accessory test fixtures available for use of rf capacitance standards* to check bridge performance.

– R. F. Sette

*Typical are GR 1406, 1407, and 1403 Capacitance Standards.

The GR 1682 was developed by the author. D. S. Nixon provided the design of the digital servo; W. A. Montague, D. W. Carey, and A. W. Winterhalter contributed significantly to the mechanical design, etched-circuit layout, and technical support.

R. F. Sette received his BSEE and MSEE degrees from Northeastern University in 1960 and 1962 respectively. He joined GR in 1964 after research work with the AF Cambridge Research Laboratory and service with the US Army at the electronics laboratory at Ft. Monmouth testing and evaluating IC circuits. He is a member of IEEE and Eta Kappa Nu and works with the GR Component and Network Testing Group.

Complete specifications for the GR 1682 are included as a tear sheet at the back of this issue.

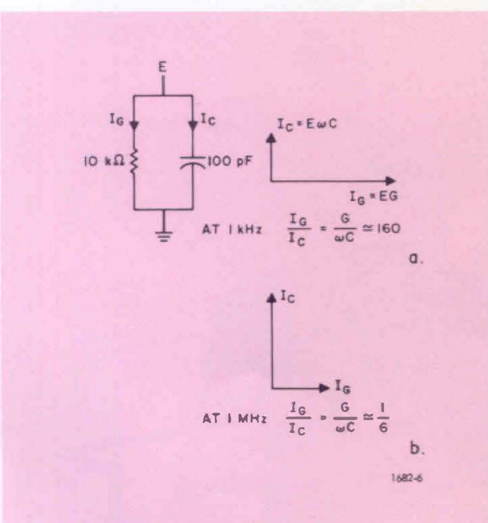


Figure 1. Current vector diagram.

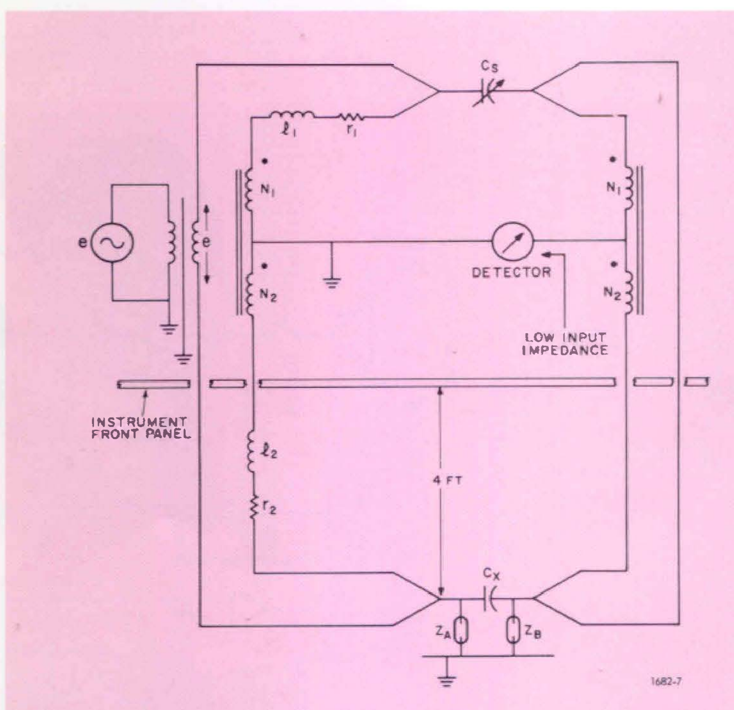


Figure 2. Simplified bridge circuit.

VERSATILE RESISTANCE BRIDGE

A self-contained resistance-measuring system with laboratory accuracy and production speed

The demand for reliability in present complex electronic equipment emphasizes the need for large-volume resistor testing. Measurements of resistors to parts-per-million accuracy formerly were made on a Kelvin or Wheatstone bridge that required manual balancing. Today the old high-accuracy measurement techniques are too slow.

The need for faster measurements was recognized at General Radio more than a decade ago. As a result, the 1652-A Resistance Limit Bridge[1] was developed for use at GR and later offered for general sale because of its versatility. No bridge balance was required. Percentage deviation of the unknown resistor from an adjustable internal standard was indicated but accuracy was limited to 0.2%.

Continued demand for an improved economical resistor-testing device that offered greater versatility, speed, accuracy, and more automatic features than the 1652 was the incentive to develop our latest resistance limit bridge.[2]

[1] Hague, W. M., Jr., "Versatile Resistance Limit Bridge Doubles as Laboratory Standard," *GR Experimenter,* January 1952.

[2] Szpila, R. T., "A Resistance Deviation Bridge Utilizing a Photo Chopper DC Amplifier," MIT Master's Thesis, Electrical Engineering, June 1966.

Some Features

Improved features of the GR 1662 Resistance Limit Bridge, which supersedes the GR 1652-A Bridge, include:

- Resistance range from 1Ω to 111 MΩ.
- Comparison precision to 100 parts per million.
- Five deviation ranges from 0.3% to 30% full scale.
- Internal-resistance-standard limit of error better than 0.02%.
- Operating rate up to 4 measurements per second.
- Four-terminal Kelvin connections.
- Linear analog output voltage to

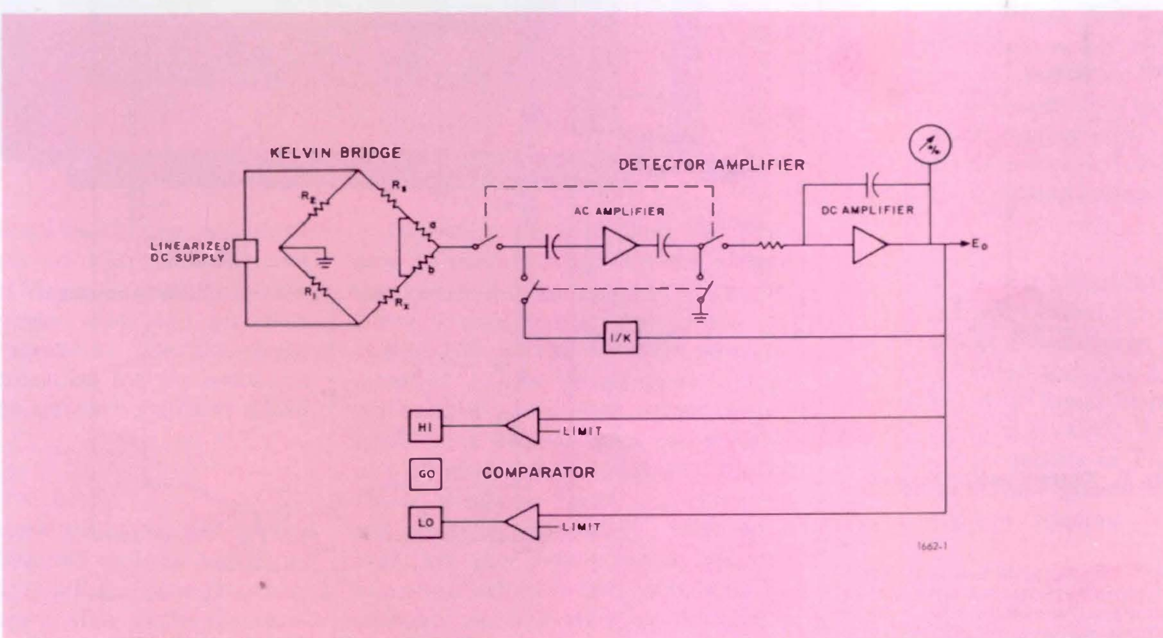


Figure 1. Block diagram of GR 1662 Bridge.

drive DVM's, limit comparators, dc recorders.

- HI-GO-LO limit indication by panel lights.
- Manually-preset or external-programmable limiting.
- Less than 12 mW dissipated in unknown (minimizes self-heating effect on low-power devices).

The block diagram of the GR 1662 bridge, Figure 1, shows the basic elements of the instrument: a dc generator, an active Kelvin bridge, a detector amplifier, and the HI, GO, LO limit circuitry.

The floating dc generator is guarded and shielded to reduce stray leakage paths to ground, thereby preserving bridge accuracy even at the range extremes. The Kelvin bridge consists of exceptionally stable and high-accuracy resistors adjusted to better than 0.01%. The bridge circuit is linearized by means of feedback to the dc source to measure the resistance deviation as a percent of the standard.

Inner Workings

When the ratio R_1/R_2 does not equal R_x/R_s, an unbalance-error signal results. Depending on the unbalance, this error voltage can be quite small. It must be amplified to a useful level so that it can be displayed on a deflection meter as the percent difference between the standard and the unknown resistor. A highly sensitive photo-chopper amplifier is used as the detector amplifier to provide high gain and to minimize drift and noise. The dc input is converted into ac by the photo-chopper. It is then amplified by a dc amplifier that is also used as a Miller integrator to provide an effective filter for the demodulated signal. The gain of the detector amplifier is stabilized by feedback around the over-all system. The deviation voltage is indicated on a zero-centered meter and by the analog-voltage output.

In addition to the percent-deviation meter readout, a HI-GO-LO indication is also available. The output voltage is fed to a set of analog comparators where it is compared to some preset voltage level to determine if the resistance measured by the bridge is higher, lower, or within the selected tolerance.

Typical Applications

A practical application illustrating the instrument's versatility is resistor sorting at production speed. The meter readout indicates the percentage deviation of the resistor under test from an adjustable internal or external standard. For manual sorting, resistors can be conveniently connected to the bridge by use of the 4-terminal-connected GR 1662-P1 Test Fixture. Completely automatic and faster sorting capability is possible when the bridge is paired with the GR 1782 Analog Limit Comparator[3] and with external handling and sorting equipment.

The GR 1662 is also suitable for use as a laboratory instrument to measure precision resistors to within 200 parts per million. Such precision can be achieved by nulling techniques, as in a conventional Kelvin bridge.

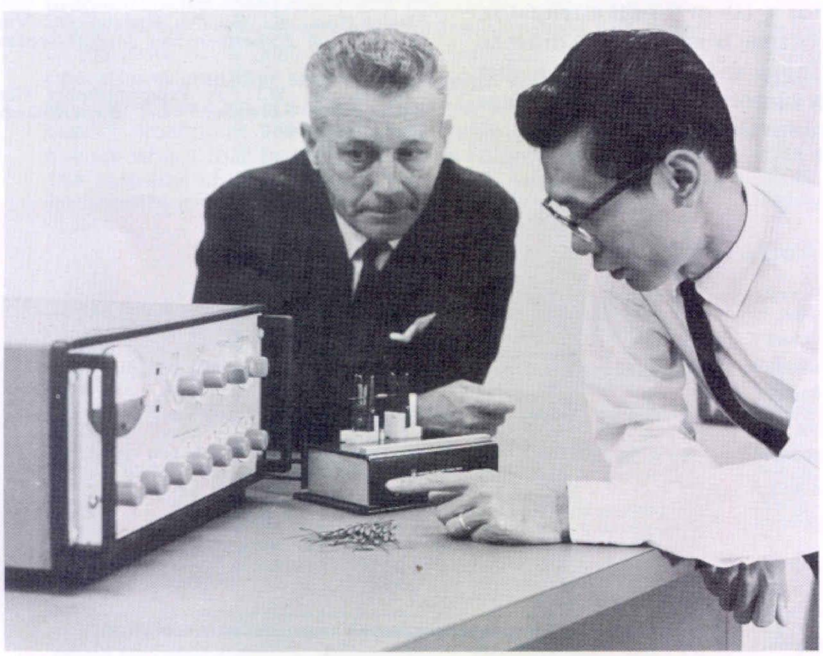
Other interesting applications are matching of resistors, temperature-coefficient measurement of resistors, and trimming of thin-film resistors by controlling production processes with the relay-equipped GR 1782 Analog Limit Comparator that provides four tolerance-limit settings. —R. K. Leong

[3] Leong, R. K., "Impedance Comparison Sprints Ahead," *GR Experimenter*, May/June 1969.

A brief biography of engineer R. K. Leong appeared in the May/June 1969 issue of the *GR Experimenter.*

The GR 1662 was developed by the author, with contributions by R. G. Fulks and R. T. Szpila during the early phases of the development work.

Complete specifications for the GR 1662 are included as a tear sheet at the back of this issue.



Engineer Bob Leong demonstrates GR 1662 bridge to Editor White.

WIDEBAND 20-dB/RANGE AC MILLIVOLTMETER

The ac millivoltmeter is a fundamental tool in electronic measurements. Although many instruments of similar capability are already in existance, the new millivoltmeter from GR makes a unique contribution to ac measurements.

Basically, the GR 1808 is an average-reading voltmeter calibrated to indicate the rms-value of sine waves. But what sets this voltmeter apart from others is its 10-Hz to 10-MHz bandwidth coupled with a 20-dB dynamic range per range. This wide dynamic range makes possible a single voltage scale that, in turn, avoids confusion in reading the meter. The single scale is not only convenient for many amplifier response measurements but is also necessary in some automatic testing or calibration set-ups.

Applications

Because the millivoltmeter is a general-purpose, laboratory- and production-type voltmeter it is difficult to describe a particular application as a "typical" application. Here are some illustrations of interesting applications:

- Most operational amplifiers have the open-loop frequency-response curve shown in Figure 1. Quite often it is desired to know the frequency, f_2, where the second breakpoint occurs in order to maximize the design stability of the amplifier.

  The GR 1808, with its 10-MHz bandwidth, is well suited for this type of measurement.

- The wide dynamic range and wide bandwidth of the GR 1808 encourage its use for attenuator calibration or testing. For a 10- or 20-dB attenuator, no range change is necessary in order to read the input and output. For higher value attenuators, minimum of range changing is involved.

- Frequently, we wish to make ac measurements with higher resolution than the specified accuracy of the available instruments. For example, in tests of the stability of an amplifier with temperature, the absolute value of a measurement is not so important as the change in the measurement as a function of temperature.

  The dc output from the 1808 may be coupled into a GR 1807 DC Microvoltmeter/Nanoammeter[1] to form such a high resolution system. The GR 1807 has an interpolation feature that will enable the user to read the dc output with 0.1% resolution. The system shown in Figure 2 will increase resolution of ac voltages approximately ten times compared with the GR 1808 meter reading. It is also important to note that the dc-voltage output of the GR 1808 can be used to drive a GR 1522 Recorder[2] for a permanent recording of data. The output of the GR 1807 can be connected to the recorder if high resolution recording is desired.

- An important application for the millivoltmeter is voltage measurement from accelerometers, strain gauges, microphones or other similar transducers. In general, such transducers can be reduced to an equivalent-voltage source in series with a capacitance (Figure 3). The voltage source is usually less than 100 millivolts and the capacitor C may be a

(cont. on page 11)

[1] Balekdjian, K. G., "A Unique DC Voltmeter," *GR Experimenter,* August-September, 1968.

[2] Basch, M. W., "A Programmable High-Speed DC Recorder," *GR Experimenter,* May/June 1969.

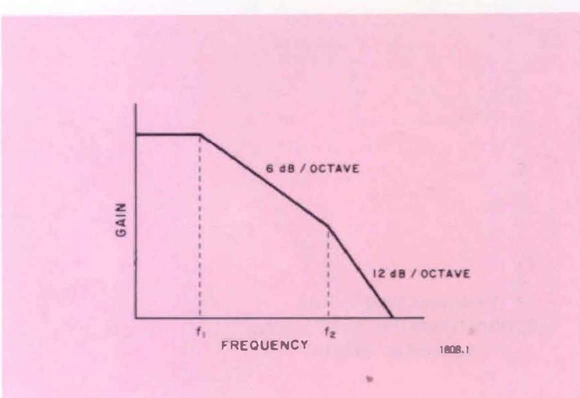


Figure 1. Typical open-loop frequency-response curve.

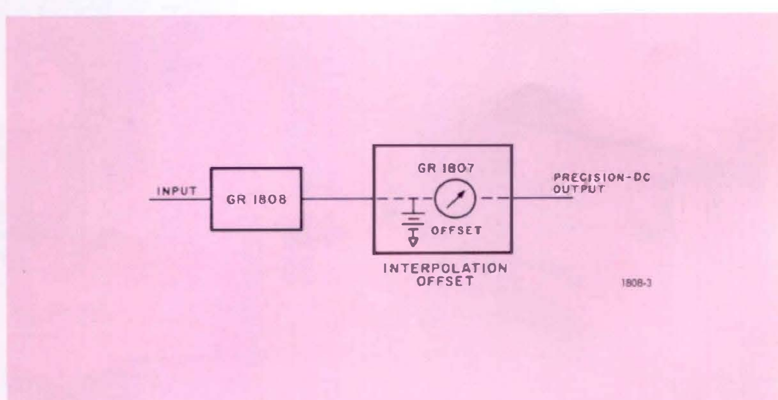


Figure 2. System for increased measurement resolution.

few hundred to a few thousand picofarads.

To measure the output of such a device with reasonable accuracy (1% - 5%), it is essential to have a voltmeter with very low input capacitance. The GR 1808 millivoltmeter with a Tektronix P6008 probe and GR 1808-P1 Probe Adaptor becomes an ideal combination for such measurements. The input capacitance of the probe will be approximately 7.5 pF and the sensitivity of the resulting combination will be 15 mV for full-scale deflection.

Theory of Operation

Figure 4 shows the block diagram of the GR 1808. The input buffer uses a field-effect transistor in order to achieve the high input impedance of the instrument. Both attenuator No. 1 and attenuator No. 2 are resistive type with capacitive frequency compensation. Attenuator No. 1 is used on the 150-V and 15-V ranges, and all switching is done by means of reed relays. This keeps high level ac signals from the sensitive detector circuits.

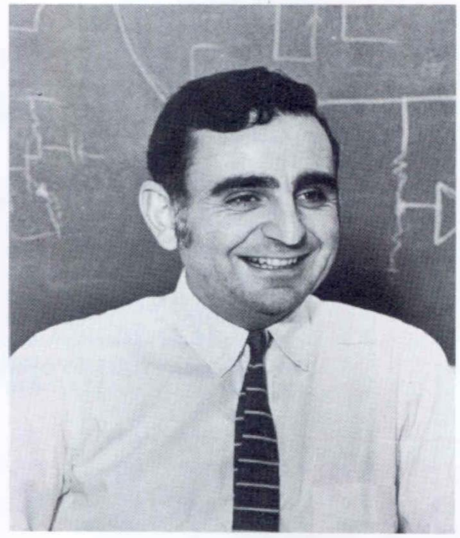
In order to achieve maximum stability, the gain of the 20-dB amplifier is never changed. Instead, attenuator No. 2 provides the proper signal levels for all ranges.

The heart of GR's new voltmeter is the ac-to-dc converter shown in Figure 5. Diodes CR1 and CR2 form a full-wave rectifier circuit. The dc-output voltage (read by the meter) is proportional to the difference between the rectified voltages V_1 and V_2. An important feature of this type of converter is the fact that nonlinear effects due to the diodes are eliminated from accuracy considerations, because the diodes are inside the feedback loop of amplifier A. The unbalance-leakage currents of these diodes are small enough to justify neglecting their effect since only the unbalance leakage current enters the accuracy considerations.

The key to the wideband and wide dynamic range of this converter is amplifier A. It has high open-loop voltage gain even at 10 MHz, to provide sharp rise and fall times at its output. Since most diodes will require 0.3 to 0.5 volt to draw at least 0.1-mA current, sharp rise/fall times are especially necessary at low level and high frequencies if errors are to be avoided.

The GR 1808 AC Millivoltmeter is not just another ac voltmeter; it is a distinct contribution to this basic branch of electronic measurements.

—K. G. Balekdjian



K. G. Balekdjian is a member of the GR Component and Network Testing Group. He received his SB and SM Degrees from Massachusetts Institute of Technology in 1955 and 1957 respectively and joined GR as a development engineer in 1964. George is a member of IEEE, Tau Beta Pi, Eta Kappa Nu, and Sigma Xi.

Complete specifications for the GR 1808 are included as a tear sheet at the back of this issue.

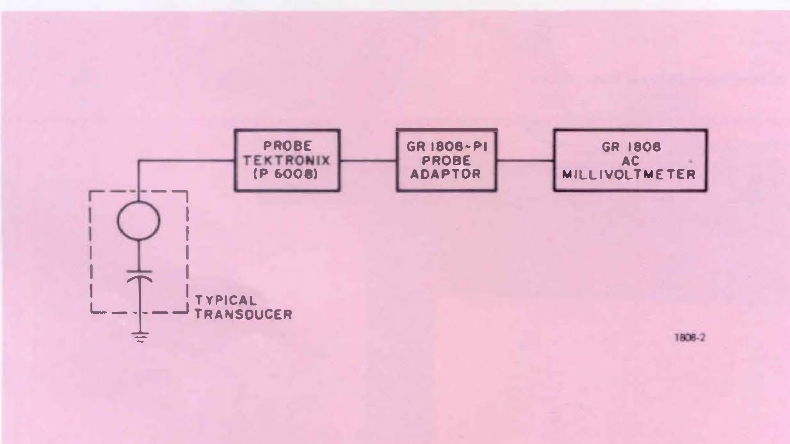


Figure 3. Suggested measurement system for transducer response.

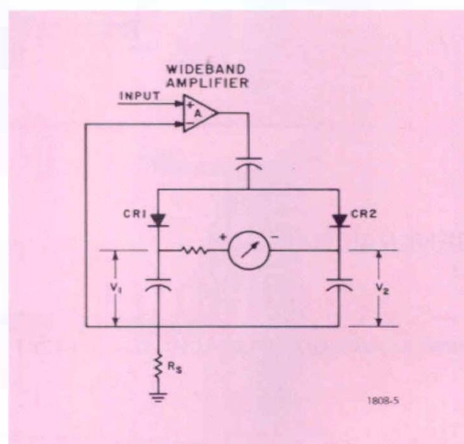


Figure 5. Schematic of ac-to-dc converter.

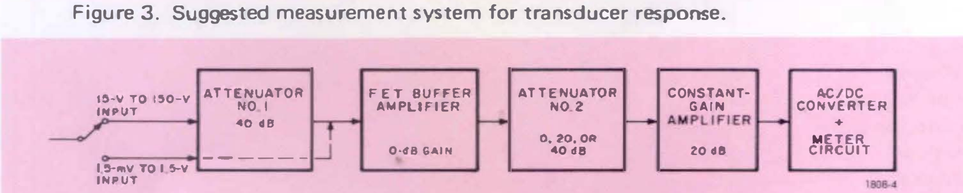


Figure 4. Block diagram of GR 1808 Millivoltmeter.

GENERAL RADIO

WEST CONCORD, MASSACHUSETTS 01781
617 369-4400

SALES AND SERVICE

ALBUQUERQUE	505 265-1097	DENVER	303 447-9225	*NEW YORK	(NY) 212 964-2722
					(NJ) 201 943-3140
ATLANTA	404 633-6183	DETROIT	313 261-1750	PHILADELPHIA	215 646-8030
BOSTON	617 646-0550	GREENSBORO	919 288-4316	ROCHESTER	315 454-9323
BRIDGEPORT	203 377-0165	GROTON	203 445-8445	SAN DIEGO	714 540-9830
BURBANK	213 899-2644	HARTFORD	203 658-2496	*SAN FRANCISCO	415 948-8233
*CHICAGO	312 992-0800	HOUSTON	713 464-5112	SEATTLE	206 747-9190
CLEVELAND	216 886-0150	HUNTSVILLE	800 241-5122	SYRACUSE	315 454-9323
COCOA BEACH	800 241-5122	INDIANAPOLIS	317 636-3907	*WASHINGTON, BALTIMORE	301 881-5333
*DALLAS	214 637-2240	*LOS ANGELES	714 540-9830		
DAYTON	513 434-6979				

INTERNATIONAL DIVISION

WEST CONCORD, MASSACHUSETTS 01781, USA

ARGENTINE and PARAGUAY
Coasin S. A.
Buenos Aires

AUSTRALIA
Warburton Frankl Industries Pty. Ltd
Sydney, Melbourne,
Brisbane, Adelaide

BRAZIL
Ambriex S. A.
Rio de Janeiro GB
Sao Paulo, S. P.

CANADA –
*General Radio Canada Limited
Toronto,
Montreal, Ottawa

CHILE
Coasin Chile Ltda
Santiago

COLOMBIA
Manuel Trujillo Venegas e Hijo, Ltda.
Bogota 2, D. E.

DEMOCRATIC REPUBLIC OF THE CONGO
Rudolph-Desco Co., Inc.
New York

HONG KONG and MACAU
Gilman & Co., Ltd
Hong Kong, B.C.C.

INDIA
Motwane Private Limited
Bombay, Calcutta, Lucknow,
Kanpur, New Delhi,
Bangalore, Madras

JAPAN
Midoriya Electric Co., Ltd.
Tokyo

KOREA
M-C International
San Francisco,
Seoul

MALAYSIA
Vanguard Company
Kuala Lampur

MEXICO
Electronica Fredin S A
Mexico, 10 D. F.

NEW ZEALAND
W. & K. McLean Limited
Auckland

PAKISTAN
Pakland Corporation
Karachi

PERU
Importaciones y Representaciones Electronicas S. A.
Lima

PHILIPPINES
T. J. Wolff & Company
Makati, Rizal

REPUBLIC OF SOUTH AFRICA
G. H. Langler & Co., Ltd.
Johannesburg

SINGAPORE
Vanguard Company
Singapore

TAIWAN
Heighten Trading Co., Ltd
Taipei

THAILAND
G. Simon Radio Company Ltd.
Bangkok

TURKEY
Mevag Engineering, Trading and Industrial Corporation
Istanbul

URUGUAY
Coasin Uruguaya S. A
Montevideo

VENEZUELA
Coasin C. A.
Caracas

*GENERAL RADIO COMPANY (OVERSEAS)

Helenastrasse 3, CH-8034, Zürich 34, Switzerland

AUSTRIA
Dipl. Ing. Peter Marchetti
Wien

BELGIUM
Groenpol-Belgique S. A.
Bruxelles

DENMARK
SEMCO Semler & Co
København Ø

EIRE
General Radio Company (Overseas)
General Radio Company (U.K.) Limited

FINLAND
Into O/Y
Helsinki

FRANCE
General Radio France
Paris, Lyon

GERMANY
General Radio GmbH
München, Hamburg

GREECE
Marios Dalleggio
Athens

ISRAEL
Eastronics Ltd
Tel Aviv

ITALY
General Radio Italia S.p.A.
Milano

NETHERLANDS
Groenpol Groep Verkoop
Amsterdam

NORWAY
Gustav A. Ring A/S
Oslo

PORTUGAL and SPAIN
General Radio Company (Overseas)

SWEDEN
Firma Johan Lagercrantz KB
Solna

SWITZERLAND
Seyffer & Co. AG
Zürich

UNITED KINGDOM
*General Radio Company (U.K.) Limited
Bourne End, Buckinghamshire

YUGOSLAVIA
Sanford de Brun
Wien, Österreich

*Repair services are available at these offices.

GENERAL RADIO
Experimenter
WEST CONCORD, MASSACHUSETTS 01781

Do we have your correct name and address—name, company or organization, department, street or P.O. box, city, state, and zip code? If not, please clip the address label on this issue and return it to us with corrections or, if you prefer, write us; a postcard will do.

PRINTED IN U.S.A.