THE GENERAL RADIO

EXPERIMENTER

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IN THIS ISSUE

Standards and Accuracy

THE GENERAL RADIO EXPERIMENTER

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COVER

Ivan G. Easton, Vice-President for Engineering, addresses a calibration seminar group on the subject of capacitance bridges.

STANDARDS AND ACCURACY

The recent calibration seminars[1] held at General Radio are a natural result of our long-standing interest in the field of impedance standards and measurements. In the course of these seminars we have had the opportunity to discuss problems of mutual interest with nearly one hundred engineers from commercial and military laboratories actively concerned with standardization. These discussions have suggested several areas where confusion and misunderstanding exist. Our viewpoint on some of these may be of particular interest to the larger audience of *Experimenter* readers.

TERMINOLOGY

Somewhat surprisingly, standardization for the language of standardization is lacking. Terms such as calibration accuracy and certification accuracy are used by different manufacturers with enough shades of difference in meaning to create confusion when specifications or calibration data are compared. Our usage of these and other terms is outlined below (with the full knowledge that inconsistencies in our own past publications and specifications may be found).

Absolute Value

By absolute value of an electrical unit is meant the value of the unit as derived from the fundamental units of mass, length, time, and the permeability of space. The determination of, the maintenance of, and the dissemination of the electrical units are the responsibility of the National Bureau of Standards (NBS).[2] The determination is always subject to some limitation and, therefore, the unit as maintained may differ slightly from the absolute value.

Standard resistors offer an excellent example of the relation between value as maintained by NBS and the absolute value of the same quantity. The fact that standard resistors are available which show a stability from year to year within 1 ppm or less does not necessarily mean that the absolute value of such resistors is known to the same accuracy. Publications by NBS and by the standardizing laboratories of the other countries indicate that the present certainty in the knowledge of the absolute value of the ohm is limited to something of the order of 10 or 15 ppm.[3] It is obvious, therefore, that considerable care must be taken in interpreting accuracy statements of ±0.001% which frequently appear in connection with standard resistors.

NBS Certification

It is important that the meaning of

Figure 1. A stable low-frequency inductance standard, the General Radio Type 1482 Standard Inductor.

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[1] Three such seminars have been held. See "Seminar on Standards, Calibrations, and Measurements," *General Radio Experimenter*, 34, 1, January, 1960.

[2] NBS Circular 531, "Extension and Dissemination of the Electrical and Magnetic Units by the National Bureau of Standards."

[3] Current work at NBS is expected to reduce this uncertainty.

the accuracy statement given on an NBS certification of inductance or capacitance be properly interpreted. The accuracy statement does *not* represent only the limit of absolute accuracy of the NBS measurement, but includes an assessment, based on experience, of the *probable stability* of the calibrated device. A *certificate* is therefore issued only for a product which has been available to NBS for a sufficient period of time to demonstrate a pattern of stability behavior. The accuracy figure assigned to calibrations after a history of performance is established is intended to be sufficiently conservative to give the user reasonable assurance that the standard will remain within the stated limits for, say, one year.[4]

When an item is submitted for which no performance history exists, a *report* is issued, rather than a *certificate*.

The NBS practice outlined above differs from some of the practices elsewhere. For example, in England the statement of accuracy attached to values of resistance, capacitance, and inductance normally refers only to the calibration as made, and no allowance is made for the stability of the device.

These differing practices have led to misunderstanding and improper conclusions drawn from a comparison of the certification accuracies offered by NBS and NPL. NBS certifications of inductors, for instance, are typically ±0.03%, those of NPL typically ±0.01%. In spite of these differences, values assigned by the two laboratories are in agreement within 0.01% as shown by informal comparisons.[5]

General Radio Certification

To clarify the terms used in General Radio calibration certificates, let us examine the numerical values associated with a typical standard (for instance, a Type 1409-Y Standard Capacitor): nominal value, adjustment accuracy, calibration or certified value, and calibration accuracy.

Nominal value and adjustment accuracy are engraved on the nameplate, i.e., 1.0 μf ±0.05%. The nominal value of 1.0 μf may be regarded as an abbreviation of the highly precise and absolute value that it would be desirable to have, perhaps 1.00000 μf. The adjustment accuracy represents the closeness to which we feel it is economically practical to adjust to the nominal value. This adjustment is made in terms of the known values of our reference standards, which are internally consistent and, we believe, compatible with NBS values to better than 0.01%. Allowance must be made for this uncertainty, for errors of observation, for minor differences in temperature, and for possible drift. These are all covered by the traditional General Radio practice of using as our laboratory acceptance figure for adjustment accuracy a value not more than ¾ the value engraved on the nameplate.

The significance of any adjustment accuracy needs examination when that accuracy is comparable in magnitude to the tolerance of NBS certification. For example, the adjustment accuracy of the GR Type 1409 Capacitors is now ±0.05%. The National Bureau of Standards places a typical tolerance of ±0.03% on the certification of our reference standards. Theoretically, therefore, the actual value of a standard capacitor adjusted to ±0.05% could differ from the nominal value by (0.05 ±0.03)%.

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[4] For example, an NBS certificate for a standard resistor carries the following statement: "The accuracy shown is based upon this Bureau's record of the stability of the resistor, or, for resistors submitted for the first time, upon experience with resistors of the same type. It is expected that the resistance value will be reliable to the accuracy given for at least one year from the date of test."

[5] "Stability Records of Standards of Inductance and Capacitance," *General Radio Experimenter*, 34, 4, April, 1960.

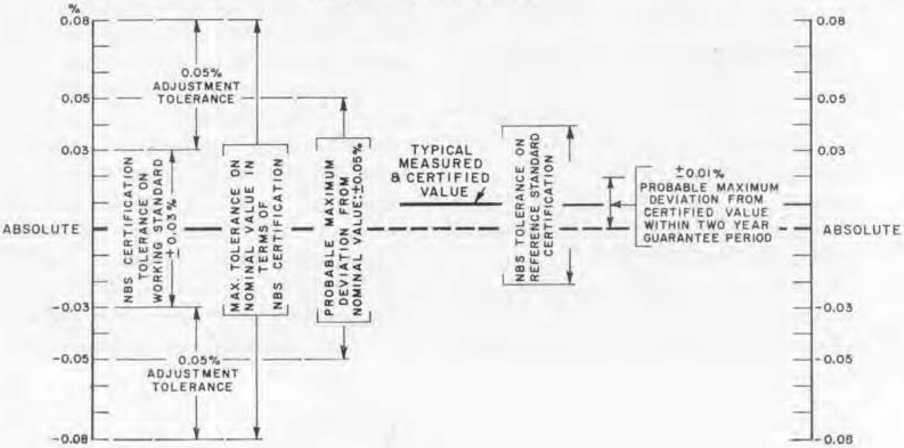
Figure 2. A 0.1-µf Type 1409 Standard Capacitor.

Obviously, in the extreme case, the difference would be 0.08%. Actually, we have good reason to believe that such an extreme deviation will never occur. Our experience with NBS certifications of many of our reference standards for many years in the standards maintenance program described later in this article indicates that the NBS unit of capacitance is constant to better than ±0.01%. (See preceding section on NBS Certification for the reason for the ±0.03% tolerance.) As noted above, the NBS units agree within ±0.01% with those of other national standards laboratories. When one of our capacitors is sent to NBS (or other laboratory) for calibration, the certified value will be within ±0.05% of nominal. For example, the 1.0-µf standard of our previous example would, at worst, be certified as, say, 1.00049 µf ±0.03%.

The measurement of the actual value of a standard can usually be made with greater accuracy than the adjustment to nominal value can be made. The *measured value, or calibrated value*, is, therefore, the value to be used for accurate measurements.

The measured data are frequently referred to as a "calibration" and the piece of paper carrying the information is often referred to as the "calibration certificate." Far more important than what the document is called is the significance, or *accuracy*, of the number appearing on it. The accuracy at the time of measurement depends upon two factors, (1) the precision of the comparison against the working standard used and (2) the absolute accuracy of that standard. The subsequent usefulness of the newly calibrated standard and its certification depends upon the stability, and a standard is truly useful only after its own stability history is known, although knowledge of representative stability of standards of the same type and manu-

Figure 3. Chart showing the relation between nominal and calibrated values for a General Radio standard of capacitance or inductance.



facture is, in the case of a new standard, reassuring.

We believe that it is much more useful to provide information on all the items contributing to uncertainty than to combine them into one over-all accuracy statement. Therefore, the certification of the TYPE 1409-Y Standard Capacitor reads, "This capacitance value was obtained by direct comparison, precise to better than ±0.01%, with a like standard certified by the National Bureau of Standards to an accuracy of ±0.03% in absolute capacitance." Temperature coefficient is also specified. Since the stability of this standard is stated as ±0.01% for a period of two years, the user looking at this certificate within a few months of its date has reasonable assurance that the value given is correct within about 0.01%. On the other hand, if all three factors were combined and the accuracy stated as ±0.05%, the user could only conclude that that number represented his limit of confidence in the given value.

USING A STANDARD

In summary, when a standard is to be used, the following items of information are desirable, in the order described:

(1) The *nominal value*.

(2) The *adjustment accuracy*.

(3) The *certificate* or *calibration* value.

(4) The *accuracy of calibration:*

  a. Precision of calibration.
  b. Accuracy of working standard against which calibration was made.
  c. Stability, as known or assured.

(5) Knowledge of environmental conditions and their possible effect.

Given such information, one is ready to use the standard for checking a piece of measuring equipment, or for calibrating another standard to be used for that purpose.

The extent to which one must be concerned with some of the finer points discussed above depends upon the accuracy requirement of the job to be done. If, for instance, a 1% or a ½% bridge is to be checked, and the available standard of desired *nominal* value has an *adjustment accuracy* of ±0.05%, it should not be necessary to worry about items (3), (4), and (5). If, on the other hand, a 0.25% device is to be checked, the 0.05% would consume a significant portion of the desired accuracy and the *calibrated value* of the standard should be used as a precaution. If the maximum possible accuracy is required, attention must be given to all the factors listed in order to assess the real accuracy that is obtained. Finally, attention must also be paid to the technique of measurement, in order to realize the maximum available accuracy of the standard.

TRACEABILITY

To those concerned with standardization, "traceability" has, in the past few years, become a matter of importance.

A program has been instituted by the Department of Defense to insure that the calibrations of standards used in quality-assurance programs are, in fact, properly referred to the national standards. The objective of this program is to insure agreement of dimensions, electrical component values, and performance among equipments produced by different manufacturers, at different times, and in different localities. Compatibility of interconnected elements of a system, or of components used in a given equipment, requires a common base of fundamental electrical and mechanical standards. By definition and by law, the common base is the standards as main-

Two-Year Warranty

We warrant that each new instrument sold by us is free from defects in material and workmanship and that properly used it will perform in full accordance with applicable specifications for a period of two years after original shipment. Any instrument or component that is found within the two-year period not to meet these standards after examination by our factory, district office, or authorized repair agency personnel will be repaired or, at our option, replaced without charge, except for tubes or batteries that have given normal service.

GENERAL RADIO COMPANY
WEST CONCORD, MASSACHUSETTS

This Instrument was Inspected and Calibrated by

Calibration standards as applicable are traceable to the National Bureau of Standards.

Figure 4. This 2-year warranty tag, which is supplied with all instruments, carries a statement of traceability.

tained by the National Bureau of Standards.

To meet the desired objective, certain military procurement programs now require, as part of quality-assurance procedures, that some demonstration be given by equipment manufacturers that the units used in their calibrations can be traced to those established by the National Bureau of Standards.

The execution of this excellent plan has created some difficulty because the nature of the required "demonstration" or "certification" is not clearly defined. The answer evolved by General Radio, in response to many requests to "certify," "warrant," or "demonstrate" traceability of our standards, is a seal stating traceability to NBS embossed on all General Radio calibration certificates. To cover instruments with which calibration certificates are not normally supplied, a statement has been added to the warranty certificate that is attached to each instrument shipped. This warranty tag with the traceability statement is shown in Figure 4. The seal and/or the warranty statement have been satisfactory to the vast majority of our customers, military as well as commercial. In a few instances, however, we have been requested to supply more detailed information. A common request in such cases is that we state the latest date of calibration of our standard by NBS.

There are a number of reasons why we do not consider this to be the proper approach for a manufacturer of standards and we have consistently avoided the supplying of such information. The most significant objection to this procedure is that it constitutes an oversimplification and does not recognize the true nature of a standards structure. To illustrate the complexity of the problem, the General Radio procedure for the maintenance of capacitance standards is described later in this article. Because the validity of any calibration depends upon so many factors — the standards, the methods of measurement, and, indeed, the integrity of the entire organization — we believe quality assurance cannot be obtained from any single detail such as the date of an NBS calibration. If there is any doubt about the validity of a calibration, the unit in question must be referred to a qualified independent standards laboratory or to NBS.

MAINTENANCE OF CAPACITANCE STANDARDS AT GENERAL RADIO

In order to assure accurate and reliable calibrations, the General Radio Company follows a well-ordered program of inductance and capacitance standardizations. The capacitance standardization program is typical. A series of fixed capacitors ranging from .001 to 1.0μf with 1-2-5 values in each decade is sent to NBS periodically. Before ship-

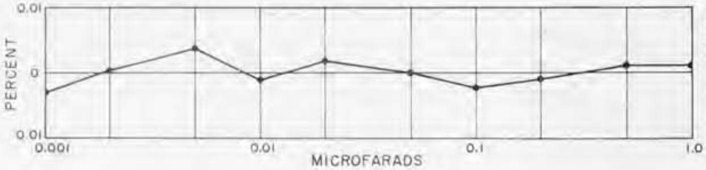


Figure 5. Plot showing consistency between General Radio-derived values and NBS calibration of General Radio reference standards after adjustment for over-all level.

ment these capacitors are compared, item by item, with similar units which are held in our laboratory under controlled conditions as reference standards. Immediately after return from Washington this comparison is made again. These measurements serve to guard against possible shifts in value that may occur from abuse in shipment, from possible mix-up of certificates, transposition of figures in data, etc. Any change in value that is observed between the two sets of measurements can reasonably be assumed to be a shift in the standard that was shipped, rather than in the reference standard which remained comfortable and undisturbed at home.

The steps described give reasonable assurance that the calibration values have been transferred successfully from NBS but one additional very important series of measurements is made which serves as a cross-check on the internal consistency of our measurement procedures and makes possible the assignment of values based on the *average* of the entire series of NBS calibrations. An intercomparison of the entire set from 0.001 to 1.0 μf is made by a "bootstrap" technique as follows: A value is assigned to a 0.001 μf unit and a second unit of like nominal value is measured in terms of the first; the two .001 units in parallel are then used to measure, in turn, the two .002 capacitors; the two .002's plus one of the .001's are paralleled to measure the two .005 standards; the two .005 capacitors in parallel are used to measure the unit values in the next decade. The process is repeated for each decade in the set. Additional sets of working standards, used in the capacitor manufacturing department and in the calibrating laboratory, are included in the above intercomparison.

The data are then plotted as deviations from nominal *vs.* capacitance magnitude and the plot connecting the measured points is adjusted upward or downward to reduce to a minimum the average difference between the derived values and the NBS values. Figure 5 shows the resulting final values. The difference between the two sets of points will then be zero if the following conditions have been met:

(1) The intercomparison was made with no error.

(2) The capacitors add properly when connected in parallel.

(3) The temperature of the capacitors was the same during intercomparison as during NBS calibration (or proper allowance was made for any variation).

(4) No changes in value have occurred.

(5) All the NBS values are perfect.

Typically, the two sets of values agree to better than 0.005% after the level of our data has been adjusted to agree most nearly with the average level of the NBS data. The procedures described establish our capacitance standards in the range 1000 pf to 1 μf. Capacitance values below 1000 pf are derived from the 1000-pf value. Techniques for subdividing from the larger capacitance value, using precision adjustable capacitors, have been developed which are internally consistent to a few hundredths of 1%. As a check on these procedures, low-valued standards are occasionally sent to NBS, and we have constructed an absolute standard at 0.5 pf which checks with the derived value within about .01%. Such agreement is reasonable evidence that the assumptions are sufficiently well satisfied, and that the precision and consistency of our measurements are adequate to transfer NBS values to the product shipped from our laboratories with no appreciable degradation of accuracy.

— Ivan G. Easton

VACATION CLOSING

During the weeks of July 25 and August 1, our Manufacturing Departments will be closed for vacation.

There will be business as usual in the Sales Engineering and Commercial Departments. Inquiries, including requests for technical and commercial information, will receive our usual prompt attention. Our Service Department requests that, because of absences in the manufacturing and repair groups, shipments of equipment to be repaired at our plant be scheduled to reach us after the vacation period.

SEMINAR ON HIGH-SPEED PHOTOGRAPHY TECHNIQUES AT M.I.T.

The scientific and engineering uses of high-speed photographic measurement techniques will be the subject of a one-week seminar at the Massachusetts Institute of Technology, starting Monday, August 15. The meetings will center at the Stroboscopic Light Laboratory where the theory and application of numerous methods will be discussed and studied.

It is planned that mornings will be devoted to theory and demonstrations while the afternoons to laboratory practice and experience.

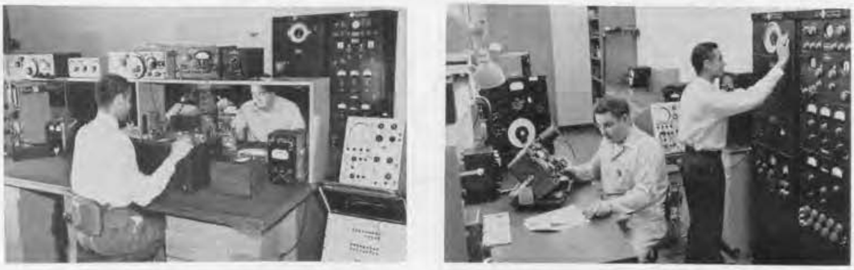
Subjects to be covered include pulsed stroboscopic lighting, optical high-speed cameras, Kerr cells, Faraday shutters, image converters, etc. Specialists in high-speed photography have been invited to cover their subjects at the seminar, and there will be practical laboratory demonstrations of many types of high-speed photography equipment.

The high-speed motion-picture and still cameras give space-time resolution for complicated mechanical motions. One can think of the high-speed camera for the mechanical engineer as being analogous to the cathode-ray oscillograph for the electrical. One of the objects of the seminar is to give those who attend a real working knowledge of the various devices.

The program is under the direction of Professor Harold E. Edgerton of the Department of Electrical Engineering at M.I.T.

For further information inquire from the Office of the Summer Session, Room 7-103, M.I.T., Cambridge, Massachusetts.

EXPANSION OF LOS ANGELES OFFICE INCLUDES SERVICE DEPARTMENT



Two views of the service laboratory at General Radio's Los Angeles Office.

General Radio's friends west of the Rocky Mountains will be interested to learn of our expanded operations at Los Angeles. Our office in that city now has complete service facilities for the repair and recalibration of General Radio instruments, along with a large stock of replacement parts. Alfred J. Guay, a factory-trained service engineer formerly in charge of our Chicago service department, is now at Los Angeles, supervising a team of expert service technicians. Customers in the western states should find the Los Angeles office the most convenient agency for repair of our instruments; instruments sent to Los Angeles for repair will normally be delivered back to the customer in less than two weeks. This extension of our district-office service operations terminates a long and pleasant association with the Western Instrument Company, for many years our West Coast service representatives.

The Los Angeles office ("LAO" to us) also includes a Commercial Department, under the direction of Robert W. Holland, ready to assist customers in all matters relating to orders. Many catalog items are carried in stock at Los Angeles for immediate shipment. And, like all General Radio district offices, "LAO" has a factory-trained Sales Engineering Staff available for counsel on your measurement problems. The office, at 1000 North Seward Street (Telephone HOllywood 9-6201), is managed by Joseph E. Belcher.

NATIONAL CONVENTION ON MILITARY ELECTRONICS

SHERATON PARK HOTEL, WASHINGTON, D.C. — JUNE 27 - 29, 1960

You are cordially invited to visit the General Radio exhibit in Booths 49 and 50 at this convention. Instruments on display will include pulse generators, sound-measuring instruments, impedance bridges, beat-frequency video generator, random-noise generator, admittance meter, and transfer-function bridge. All displays will be "live," so that you can operate the instruments and put them through their paces.

A CONDUCTIVITY BRIDGE ASSEMBLED FROM STANDARD PARTS

The ac impedance bridge is often used for measurements in scientific fields far removed from electricity and electronics. Investigations in chemistry, physiology, medicine, and biophysics, for instance, frequently require measurements of conductivity, capacitance, resistance, or dissipation factor, and the requirements of the problem are sometimes best met by a bridge that is often simpler in configuration and more flexible in range than standard catalog types. Such a bridge can be assembled from standard impedance decades and other suitable elements.

The bridge shown in Figure 1 was constructed in the Department of Biophysics at the University of Pittsburgh for the measurement, at 1 kc, of changes in the conductivity of aqueous solutions.[1] In conductometric titration, the rate of change of conductivity is a measure of the extent of interaction of the reagent with the material in the solution. Since only the change in conductivity was wanted, rather than the absolute value, an elaborate conductivity bridge was unnecessary. The degree of accuracy desired was about 1%.

In the circuit shown, the unknown, *X*, is a temperature-controlled conductivity cell, whose resistance, when filled with solution, is about 30 kilohms. The cell capacitance (1000 to 2000 pf) is balanced by the variable capacitor in the adjacent arm, so that the parallel resistance of the cell is indicated directly by setting of the decade resistor, *R*. The resistors *A* and *B* plug into jack-top binding posts, so that their ratio can be easily changed. For measurements at 1000 cycles, only a minimum of shielding was found to be necessary.

The detector, *D*, is a TYPE 1212-A Unit Null Detector with a TYPE 1951-A Filter.

The generator, *G*, is a TYPE 1214-A Unit Oscillator, fed to the bridge through a TYPE 578 Bridge Transformer.

A = TYPE 505, 50 kΩ, Fixed Resistor

B = TYPE 505, 5 kΩ, Fixed Resistor

R = TYPE 1432-M Decade Resistor 111, 110 ohms, in steps of 1 ohm.

C = TYPE 980 Decade Capacitors and TYPE 1420 Variable Air Capacitor, as required.

(We are indebted to Professor Gary Felsenfeld for permission to publish the above description of his bridge.)

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[1] Gary Felsenfeld and Sylvia Huang, "The Interaction of Polynucleotides with Cations," *Biochimica and Biophysica Acta*, Vol. 34 (1959), pp. 234-242.

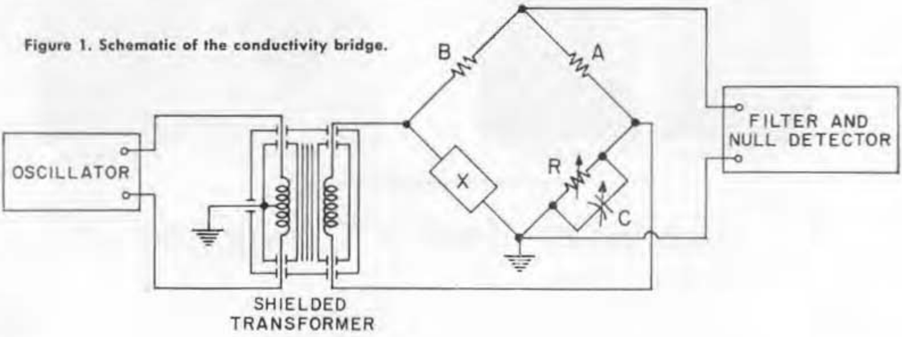

Figure 1. Schematic of the conductivity bridge.

OUR 45th ANNIVERSARY


A. E. Thiessen


C. C. Carey


D. B. Sinclair


L. H. Pexton


J. D. Quackenbos

June 14, in addition to being Flag Day, is the anniversary of the founding of General Radio Company back in 1915. Firmly established in our new Concord plant and surrounded by the accessories of modern business, we may not *look* 45, but we hope our long experience shows in the mature and sophisticated design of our products. A lot of electrons have gone down the wire since the early days, but General Radio's corporate identity has remained unchanged. Through prosperity, wars, and depressions, our business has consistently been the manufacture of electronic measuring instruments.

General Radio is an employee-owned corporation of Massachusetts. One hundred eleven key employees own about two-thirds of our common stock, and the General Radio Profit Sharing Trust, in which all employees have an interest, owns the remaining one-third. There are no outstanding preferred stocks or bond issues. Massachusetts Institute of Technology, by gift from one of the Company's founders, is our only outside stockholder and owns a few percent of the outstanding common.

Our 46th annual stockholders' meeting was held recently. At that meeting and at the directors' meeting which followed, the following principal officers were named:

* Arthur E. Thiessen, Chairman of the Board
* Charles C. Carey, President
* Donald B. Sinclair, Executive Vice-President and Technical Director
Ivan G. Easton, Vice-President for Engineering
Harold M. Wilson, Vice-President for Manufacturing
Lawrence H. Pexton, Treasurer
John D. Quackenbos, Secretary, Clerk
Charles E. Hills, Jr., Assistant Treasurer and Assistant Secretary
Edwin D. Hurlbut, Controller

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*Directors.


I. G. Easton


H. M. Wilson


C. E. Hills, Jr.


E. D. Hurlbut

General Radio Company

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