the GENERAL® RADIO Experimenter

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TO

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GENERAL RADIO COMPANY

West Concord, Massachusetts

Telephone: (Concord) *EMerson 9-4400;* (Boston) *CLearwater 9-8900*

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: **6605 West North Avenue, Oak Park, Illinois**
Telephone — VIllage 8-9400

PHILADELPHIA: **1150 York Road, Abington, Pennsylvania**
Telephone — HAncock 4-7419

WASHINGTON: **8055 13th St., Silver Spring, Maryland**
Telephone — JUniper 5-1088

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Telephone — HOllywood 9-6201

SAN FRANCISCO: **1186 Los Altos Ave., Los Altos, Calif.**
Telephone — WHitecliff 8-8233

CANADA: **99 Floral Parkway, Toronto 15, Ontario**
Telephone — CHerry 6-2171

REPAIR SERVICES

EAST COAST: **General Radio Co., Service Dept., 22 Baker Avenue, West Concord, Mass.**
Telephone — Concord, EMerson 9-4400
Boston, CLearwater 9-8900

NEW YORK: **General Radio Co., Service Dept., Broad Ave. at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

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COVER

The Type 1429-A Fuel-Gage Tester (TTU–68/E) in operation at an Air National Guard Base.

A NEW GENERATOR OF RANDOM ELECTRICAL NOISE

Noise, to the electronics engineer, presents two contrasting aspects. In the one, it limits the realizable performance of electronic devices and communication channels; in the other, it presents him with a test signal, which has, for many measurements, properties that are more useful than those of a single-frequency signal.

Broad-band electrical noise is often called random noise, because it has a random, or Gaussian, distribution of amplitudes as a function of time. When used as a test signal, it also usually has a uniform spectrum level over its specified frequency range. The random-noise signal, embracing a wide range of frequencies and having a randomly varying instantaneous amplitude, closely approximates the signals normally encountered in many electronic circuits and particularly in busy communication systems.

The properties of random noise were discussed in a previous article,[1] which described the Type 1390-A Random-Noise Generator. This instrument has, during the past several years, been applied to an unusually wide variety of instrumentation problems. This wide use has led to a number of suggestions for improvement, many of which have been incorporated in a new model, the Type 1390-B, shown in Figure 1. The most important of these are:

(1) The noise output spectrum has been extended to lower frequencies than in the earlier instrument (see Figure 3).

(2) The new cabinet is small, convenient for bench use, and yet is readily adapted by means of panel extensions to relay-rack mounting.

(3) The power-supply hum in the output has been reduced to negligibility.

(4) A built-in output attenuator has been added.

(5) The necessary warm-up time delay is provided by an automatic thermal relay.

(6) The stray external noise field has been markedly reduced.

The instrument still supplies the high output level in three bands (5 c to 20 kc, 5 c to 500 kc, and 5 c to 5 Mc) that makes the earlier model so widely useful. In fact, it has been found possible to raise the specifications on maximum output of the lowest band to at least 3 volts

Figure 1. Panel view of the Type 1390-B Random-Noise Generator.

and the next band to 2 volts, while the highest band output remains at 1 volt.

APPLICATIONS

Before describing the new instrument in further detail, let us review briefly a number of its uses. These usually depend on one or more of the following characteristics of the output of the noise generator:

(1) The signal is similar to many that occur in practice.

(2) It follows a definite statistical pattern.

(3) It has a broad frequency spectrum.

The uses can be grouped in four main categories: electrical measurements; acoustical measurements; environmental tests with high-level acoustic noise; and tests with random vibration.

One of the main uses of the earlier model has been as a *signal source for measurements*, among them:

Frequency response of loudspeakers.[2, 3]

Intermodulation and cross-talk tests on multi-channel communications systems.[4, 5, 6]

Over-all calibration of systems.[7]

Simulation of impulse-noise characteristics of telephone-line noise.

Resonance tests.[8]

Tests on servo amplifiers.

Noise interference tests on radar.

Noise source for radar target simulator.

Dynamic range tests on electronic equipment.

Measurement of the rms and peak response characteristics of meters.[9]

Noise signal for electronic countermeasures equipment.

Evaluation of noise in transistors.

Setting levels on carrier equipment.

Study of simulated non-linear systems by correlation methods with an analog computer.

Use as an element of an electronic probability generator.[10]

There are many uses in *acoustic measurements* where the noise source drives a loudspeaker, among them:

Measurements of reverberation time.[11, 12]

Reverberant field calibration of microphones.

Reverberant testing of acoustical properties of materials.[3]

Measurements of sound attenuation in ducts.

Testing of silencers for aircraft and air conditioning systems.

Room acoustic tests.[3]

Frequency response measurements of rooms and microphones.[3]

Testing the sound transmission of walls, panels, and floors.[3]

Hearing tests.[13]

Masking measurements.[13]

In a third group of uses, the random-noise generator drives a loudspeaker to produce *high-level acoustic noise* for the fatigue testing of structures.[14, 15, 16, 17] A particular application is in the design of missiles. Without a design based on these tests, the missile can fail in flight as a result of the high level of random noise impinging on its surface.

In a new and important category of use, the TYPE 1390-B Random-Noise Generator supplies the signal for a power amplifier *to drive a vibration shaker*. The shaker is used for structural tests of components[18] and assemblies of rocket or jet-engine-driven structures and for microphonic tests of vacuum tubes. Jets and rockets generate vibration that is random in nature, and the logical approach is to test with a random vibration. The test methods have developed rapidly, and there is already a book devoted to the subject.[19] The procedures

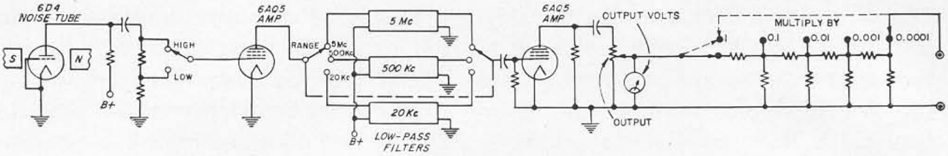


Figure 2. Elementary schematic of the generator.

and analysis of results are not simple, however, and there is some controversy regarding the method and its relation to testing with a swept sine-wave excitation.

In the classroom and laboratory, the noise generator has been used to demonstrate some of the properties of noise. Those who have been accustomed to sine-wave signals find it a new experience to try to handle noise signals. Since noise signals are now commonly encountered and measured, it is helpful to have a controlled source that can be used to familiarize one with the techniques of measurement.

DESCRIPTION OF THE GENERATOR

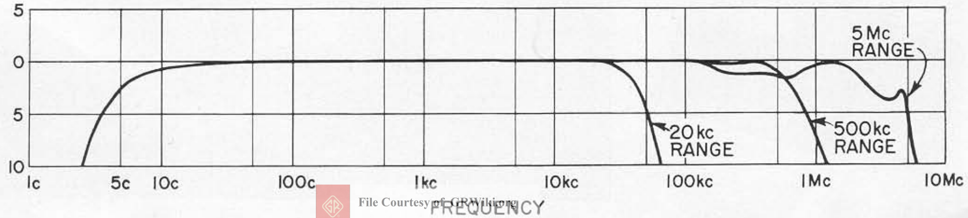
The original source of noise in this instrument is a gas-discharge tube with a transverse magnetic field applied.[20] This gas tube has a comparatively high noise output, which is amplified in a two-stage amplifier. Between these stages the noise spectrum is shaped to provide three output ranges to 20 kc, to 500 kc, and to 5 Mc. The high-frequency ends of these ranges are the same as in the earlier model, but the low-frequency performance has been improved.

Improved Low-Frequency Output

The output at low frequencies has been increased by changes in the time constants in the coupling circuits. The plot of the typical spectrum in Figure 3 shows that the output is down less than 3 db at 5 cycles per second, as contrasted with 10 db in the earlier model.

One of the problems encountered in producing this improvement came in devising a suitable technique for measuring the low-frequency output. This problem was happily solved by the use of the new Type 1554-A Sound and Vibration Analyzer.[2] The nature of this problem illustrates one of the characteristics of noise that is most apparent when measurements are made at low frequencies. Some years ago, when we tried to measure the low-frequency response of the earlier noise generator at frequencies down to 2½ cps on the Type 762-B Vibration Analyzer, we found the fluctuations of the pointer on the instrument were so large that we could not readily arrive at a suitable long-time average level. Calculations show that even for the wider band (5%) on that instrument it would be necessary to average over about a 6-minute period to have a 90% chance of being within ±1 db of the long-time average level.[21] For the third-octave band of the Type 1554-A Sound and Vibration Analyzer, the required time is reduced by a factor of 5.

Figure 3. Typical spectrum of the noise output.



The pointer still fluctuates considerably at these low frequencies, but the measurement becomes a reasonable one with the new analyzer. With a still wider bandwidth it is possible to obtain a quicker result, but then the resolution in terms of the range of frequencies measured becomes poorer. The one-third octave is an excellent compromise bandwidth.

What this problem illustrates is that the accuracy of measurement of level depends upon the bandwidth used and the time devoted to the measurement. Furthermore, the accuracy can be expressed only in terms of a probability figure. Although the concept is old and is not restricted to measurement of noise, the dependence is readily observed in low-frequency measurements of noise, but is usually not apparent in ordinary measurements with higher frequency sine-wave signals.

Attenuator and Reduced Leakage

To reduce and control the output voltage for low-level tests with the A-model it was necessary to use a separate attenuator. The output system on the new instrument consists of a continuous control, followed by a 4-step attenuator of 20 db per step. Metered levels from over 3 volts down to below 30 microvolts are conveniently obtained. When the attenuator is used, the output impedance remains essentially constant as the level is varied by the continuous output control.

This low-level output obtainable from the attenuator necessitated a reduction in the noise field radiated from the instrument at high frequencies. This reduction has been accomplished by additional filtering in the power-line leads in the instrument and by a change in the measuring circuit so that the meter is bypassed to ground.

New Cabinet

When an instrument is used on the bench, it is customary to have it horizontal. Often, however, a tilted position permits the meter to be read more conveniently. In the new cabinet shown in Figure 4 this tilted position is made possible by the extendible legs near the panel.

For relay-rack mounting, wings are supplied to extend the panel to relay-rack width as shown in Figure 5. Thus the user can have the convenience of a small bench instrument for experimental work and yet readily mount it in a rack if the instrument becomes part of a relatively permanent test rack.

ACKNOWLEDGMENT

The new cabinet was developed by H. C. Littlejohn and M. C. Holtje. The electrical circuit redesign was worked out by R. J. Ruplenas.

— A. P. G. Peterson

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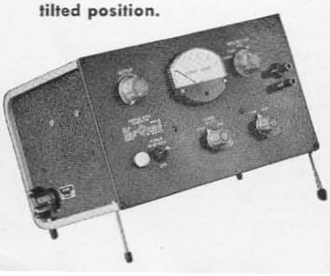

Figure 4. Extendible legs allow instrument to be used in a tilted position.

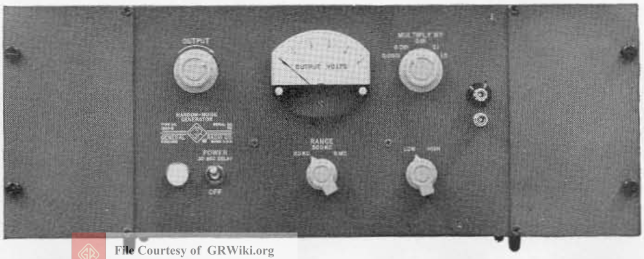

Figure 5. Panel extensions are furnished to adapt the instrument for relay-rack mounting.

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SPECIFICATIONS

Frequency Range: 20 kc: spectrum level is uniform from 20 cps to 20 kc within ±1 db. 500 kc: spectrum level is uniform from 20 cps to 500 kc within ±3 db. 5 Mc: spectrum level is uniform from 20 cps to 500 kc within ±3 db and from 500 kc to 5 Mc within about ±8 db. Noise energy is also present beyond these limits. The level is down about 3 db at 5 cps.

Output Voltage: Max. open-circuit output is at least 3 volts for 20-kc range, 2 volts for 500-kc range, and 1 volt for 5-Mc range.

Typical Spectrum Level (with one volt output): 20-kc band: 5 mv for 1-cps band. 500-kc band: 1.2 mv for 1-cps band. 5-Mc band: 0.6 mv for 1-cps band.

Output Impedance: Source impedance for max. output is approx. 900 ohms. Output is taken from a 2500-ohm potentiometer. Source impedance for attenuated output is 200 ohms. One output terminal is grounded.

Waveform: Noise source is a gas tube that has good normal or Gaussian distribution of amplitudes for narrow ranges of the frequency spectrum. Over wide ranges the distribution becomes less symmetrical because of dissymmetry introduced by the gas tube. Appreciable clipping occurs on the 500-kc and 5-Mc ranges.

Voltmeter: Rectifier-type average meter measures output. It is calibrated to read rms value of noise.

Attenuator: Multiplying factors of 1.0, 0.1, 0.01, 0.001, and 0.0001. Accurate to ±3% to 100 kc, within ±10% to 5 Mc.

Accessories Supplied: Power cord, spare fuses, extensions for relay-rack mounting.

Mounting: Metal cabinet.

Power Supply: 105 to 125 (or 210 to 250) volts, 50 to 60 cps.

Power Input: About 50 watts.

Tubes Supplied: 6D4(1), 6AQ5 (2), 3-4 (1), 115-NO3OT (1).

Dimensions: Width 12¾ in., height 7½ in., depth 9¾ in. Panel height for 19-inch relay-rack mounting is 7 inches.

Weight: 12 lb. bench mounting.

Type		*Code Word*	*Price*
1390-B	**Random Noise Generator**	BUGLE	**$295.00**

A NEW, SMALLER, LIGHTER AIRCRAFT FUEL-GAGE CALIBRATOR

Four years ago[1] the first TYPE MD-1 Field Variable Capacitance Tester was announced as being on the shelves available for sale. The ink was hardly dry on this announcement when, in consonance with the current passion for making everything smaller, we were urged to redesign it into a smaller package.

This development was undertaken after negotiation with potential users determined the nature of the minor changes, acceptable to them, that would result in the desired size reduction. As so often happens in a redesign aimed only at size and weight reduction, the cost of making the equipment actually increased somewhat.

In Figure 1 you may see side by side the old and the new testers, noting the difference in size and mechanical arrangements. Volume has been reduced 30%, weight 15%. The older instrument was called the General Radio TYPE P-579, while the new one is the TYPE 1429-A.

In essence the redesign was accomplished by the use of a smaller variable capacitor in the main simulating section and by more efficient use of space within both the instrument case and the transit case. The main or left-hand variable capacitor has a linear $\triangle$ C of 200 $\mu\mu$f. Its range is expanded to that of the 1100-$\mu\mu$f TYPE 722 Variable Capacitor it replaces by a switch that adds five steps of solder-sealed-silvered-mica capacitors of 200 $\mu\mu$f each, thus filling in between the steps of the 1000-$\mu\mu$f-per-step switch.

Opportunity was taken to make several changes in the transit case:

1. The cable stowage compartment, originally larger than it needed to be, was moved from the rear to one end of the transit case, occupying much less room.
2. Case was painted a bright yellow to make it more readily visible around an airport.
3. The change in the case proportions made it practical to move the handle up to the top, where it belongs, and this, in turn, makes possible the elimination of one set of rubber feet. A commercially available vinyl-

Figure 1. View of the old and new testers side by side to show the difference in size.

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[1] P. K. McElroy, "A Calibrator for Aircraft Fuel Gages," *General Radio Experimenter*, 30, 4, September, 1955.

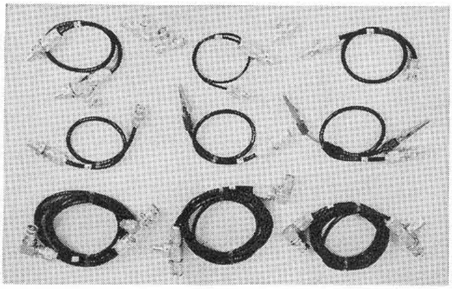


Figure 2. Connectors to fit many types of fuel gages are furnished with the tester.

coated handle makes carrying more comfortable and cuts several pounds off the weight.

Figure 2 shows the connecting cables and tee adaptors supplied with the Type 1429-A. These are exactly the same as those supplied with the older Type P-579. This is in conformity to an ARDC decision that it is impractical to try to keep up to date this group of adaptors supplied with the tester, because of the fast proliferation of requirements as new systems keep coming into use. Not only is the new miniature coax-connector series used with military aircraft a factor, but at least as much complication is caused by the fact that every lot of commercial planes is likely to have its own peculiar combination of manufacturer, individual and totalizing indicators, and hence special cable harness for attaching to the tester.

These other specific adaptors, either simple fittings or cables, or complicated cable harnesses, are available from the manufacturers of the fuel-gage systems actually used in each particular aircraft. Identification of the adapting equipment needed will be found in "-2 Technical Orders" for military aircraft or in the instruction manuals for commercial and civilian aircraft.

Qualification testing of the Type 1429-A to the same requirements as the Type P-579 (Type MD-1) has been completed at WADC and the military designation "TTU-68/E Tester, Fuel Quantity Gage, Variable Capacitance Field" assigned to the instrument. Because of the several superiorities above described of the new tester over the old one, the Type MD-1 will be superseded by the Type TTU-68/E.

Type 1429-A (TTU-68/E) Field Variable Capacitance Testers are currently available for commercial or military use and can be supplied with or without Government inspection at our plant. Detailed specifications follow.

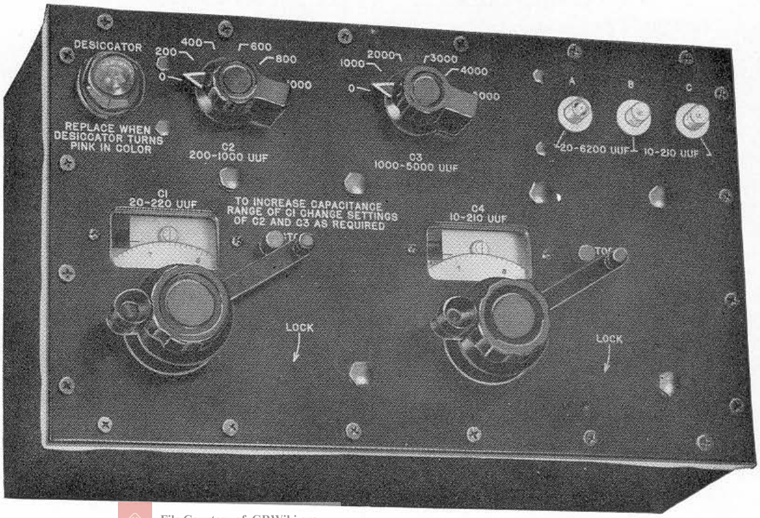


Figure 3. Panel view of the Fuel-Gage Tester.

SPECIFICATIONS

Capacitance Range: Main capacitor continuously variable linearly from 20 to 220 $\mu\mu$f, thence by switched steps of 200 $\mu\mu$f to 6220 $\mu\mu$f. Compensating capacitor continuously variable linearly from 10 to 210 $\mu\mu$f.

Accuracy: Capacitance of the main variable air capacitor is indicated by dial reading within $\pm0.5\%$ or ±0.75 $\mu\mu$f, whichever is greater. Corresponding figures for the compensating variable air capacitor are $\pm1.5\%$ or ±0.5 $\mu\mu$f, whichever is greater. Switched capacitors are accurate to $\pm0.5\%$.

Correction Chart: A correction chart laminated between plastic sheets for mechanical and climatic protection is supplied, giving corrections at multiples of 10 $\mu\mu$f for the variable capacitors and at each switch position for the stepped capacitors. When these corrections are applied, the capacitance is correct to plus or minus 0.1% or 0.15 $\mu\mu$f, whichever is greater.

Maximum Voltage: 500 volts peak.

Dielectric Supports: Plates of low-loss steatite support the stator assembly; glass-bonded-mica washers support the rotor.

Dielectric Losses: Almost negligible for the air capacitors, since solid insulation is largely outside the electric field. Not over 0.001 for the switched silvered-mica capacitors.

Temperature Coefficient of Capacitance: For small temperature changes, approximately $+0.002\%$ per degree Centigrade for air capacitors, $+0.0035\%$ for mica ones.

Backlash: Less than one-third division (out of 2,000), corresponding to 0.02% of full-scale value. If the desired setting is always approached in the direction of increasing scale reading, no error from this cause will result.

Terminals: Three special, keyed, coaxial connectors, the center one of which is connected to both rotors.

Mounting: All capacitors and a renewable desiccant cartridge are mounted on an aluminum panel and enclosed in a moisture-sealed aluminum cabinet. The latter is shock mounted in an aluminum transit case with handle. The case contains a compartment to hold nine connecting cables and three tee adaptors.

Dimensions: (Height) 10½, (width) 17½, (depth) 10½ inches, over-all.

Weight: 28¾ pounds.

Type		*Code Word*	*Price*
1429-A	**Fuel-Gage Tester**	GAGER	**$900.00**

CORRECTION (*December Issue*): The carrying case listed as supplied with the Type 1554-A Sound and Vibration Analyzer is available on special order only. It is not supplied as a standard accessory.

ACCURATE FUEL GAGES DEPEND UPON ACCURATE CAPACITANCE STANDARDS

The fuel-quantity gages used on modern airplanes are accurate electrical devices employing servo-balanced, 400-cycle capacitance bridges to give an automatic indication of the quantity of fuel in the tanks. These gages are adjusted, calibrated, and periodically tested in terms of three-terminal capacitance standards, which are assembled into a convenient package for use in the field. The testers, in turn, are checked against precise capacitance bridges, the final link in a carefully designed program that assures fuel-gage reliability by leaving nothing to chance.

Accurate capacitance standards, maintained by the manufacturers of testers and bridges, are at the heart of this program. General Radio Company, leader in supplying laboratory capacitance standards, has for many years furnished the standards upon which the program depends. Fuel-gage testers, Type MD-1 and later Type TTU-68/E (described above), have been supplied to both military and civilian activities.

Another of this company's products in the aviation field, the Type TTU-24/E Capacitance Bridge, which is used to check the calibration of the testers, has an interesting history.

Because General Radio engineers felt that for this purpose a better bridge was needed than those currently being procured, the company decided to develop one, not on contract, but with its own funds. This was done; the development was completed in about a year. The new bridge, although of a different design from that called for by Air Force specifications, meets the same requirements and, at the same time, is smaller, lighter, and more accurate. Its capacitance range is greater and it has a number of convenience features.

Evaluation tests by the Air Force resulted in the assignment of the military designation, TTU-24/E. This bridge was described in the February, 1958, issue of the *Experimenter*.

SEMINAR ON STANDARDS, CALIBRATIONS, AND MEASUREMENTS

Standards of inductance and capacitance were among the earliest products manufactured by the General Radio Company 45 years ago and have continued to be an important part of our business ever since that time. Of equal interest and importance to us have been the design and manufacture of the bridges, by whose means these standards can be put to practical use in impedance measurement.

The rapid growth of the electronics industry, particularly in defense contracts, has pointed up the necessity of uniform standards and uniformity of measurement procedures. The basic standards of the nation are the responsibility of the National Bureau of Standards. To them, all other standards are referred. General Radio calibrations, for instance, are all traceable to NBS calibrations.

Measurement procedures must be a matter of common agreement. Uniformity of procedure is necessary in order that the results of all laboratories

John Hersh of the General Radio Engineering Staff discusses inductance measurements at the seminar.

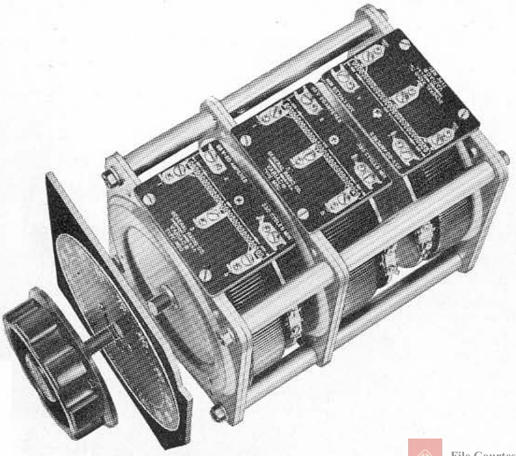
may agree; refinement of method assures maximum accuracy. The General Radio Company, as a leading supplier of both standards and bridges, is in an excellent position to implement the cooperation between agencies that will achieve these goals.

To this end we have recently completed a seminar on the low-frequency standardization of inductance and capacitance which was attended by twenty-three representatives from sixteen different U. S. and Canadian government calibration laboratories, including the National Bureau of Standards and the National Research Council (Canada). The three-and-one-half-day seminar included seven lectures on the design, construction, and use of standards of inductance and capacitance; five two-hour workshop sessions in measurement practice; two informal group dinners; and a session on criticism, evaluation, and future trends.

Both those who attended and those who conducted the seminar feel that the effort was a complete success and that a definite foundation has been laid for cooperation between laboratories and for uniformity of measurement methods. Certainly we at General Radio have derived from the seminar fully as much as those who attended. We hope that it will be possible to conduct other seminars in the future.

M-MODEL 400-CYCLE VARIAC® AUTOTRANSFORMERS

In the interest of improved delivery schedules and manufacturing economics, M-type (400 cycle) Variac assemblies are now basically the same as W-type (50-60 cycle) Variac assemblies. Except for their lower weight, reduced axial length, and militarized finish, the M-model Variacs exactly duplicate the W-model line. The principal difference will be noticed in M gangs, where the practice of assembling two coils back-to-back on a single base has been abandoned in favor of the practice, standard on W gangs, of having a separate base for each coil. This practice allows ganging of units with a minimum of modifications and special parts, with resultant lower costs and more rapid deliveries.



Users of M-type Variac® auto transformers, who may be "frozen" into the older designs, can still obtain the older design on a special order basis. We do seriously suggest, however, that, wherever possible, substitution of the new standard design will be to your advantage.

SEMINAR HELD FOR OVERSEAS REPRESENTATIVES

Since its founding in 1915, the General Radio Company has had an international market for its products. Our customers abroad have been well served by some twenty resident representatives and almost as many sub-agencies located all over the world. Many of these have been associated with us for over twenty-five years.

The growing complexity of electronic instruments, resulting in a need for person-to-person communication with our overseas representatives, led to the organization of a seminar for the exchange of information, questions, and ideas.

With the enthusiastic and competent help of GROENPOL, our representatives for the Netherlands, the first seminar was held in Amsterdam, November 2 to 7, 1959, with that organization acting as our hosts.

The seminar schedule included 10 hours of technical lectures, 21 hours of practical instruction at 7 simultaneously operating workshops, and 4 hours of general discussion. Some $25,000 worth of the latest General Radio instruments were used in the workshops. The GR team consisted of three engineers: R. W. Frank, P. J. Macalka, and W. R. Thurston, reinforced by D. B. Sinclair, Vice-President and Chief Engineer, who stopped there en route to a scientific meeting in Hungary.

The participants at the Seminar included members of the technical sales staffs of most of our European representatives and from India and Israel as

Front row, left to right, **Binetti, Belotti, Lara, Danziger, Motwane, Mrs. Nyman, Berlin, Myrseth;** ***second row,*** **Clementz, Nüsslein, Nyman, Frank, Smith;** ***third row,*** **Bhat, Love, Robert, Buys, Steur, Sablon, Van Gent;** ***on stairs at rear,*** **Steinkühler, Macalka, Watson, Rietbergen, Thurston, Teir, Lyons, Korte, Sinclair.**

well. The total attendance at the technical lectures was 26; the "workshops" were attended by 20 sales engineers.

Among those present were:

Belgium — **S. A. Multitechnic** Messrs. K. Sablon, P. Steur

England — **Claude Lyons Limited** Messrs. E. Lyons, N. Love, A. Smith, D. Watson

Finland — **K. L. Nyman** Mrs. E. Nyman, Messrs. K. Nyman, K. Teir

France — **ETS. Radiophon** Messrs. P. Fabricant, M. Berlin, J. Robert

Germany — **Dr. -Ing G. Nüsslein** Dr. -Ing G. Nüsslein

Holland—**Groenpol Industrial Sales Company** Messrs. W. L. Rietbergen, B. A. Geerlings, P. van Gent, A. Korte, A. Buys, H. Steinkühler

India — **Motwane Private Limited** Messrs. N. Motwane, V. Bhat

Israel — **Landseas Eastern Company** Mr. R. Danziger

Italy — **ING. S. & DR. Guido Belotti** Dr. G. Belotti, Mr. C. Binetti

Norway — **Maskin - Aktieselskapet Zeta** Mr. I. Myrseth

Spain — **AD. Auriema, Inc.** Mr. A. Lara Saenz

Sweden — **John C. Lagercrantz** Mr. U. Clementz

This seminar was so successful that consideration is being given to repeating it at regular intervals and at various locations, to permit convenient attendance by representatives from all areas.

SALES-ENGINEERING PERSONNEL CHANGES

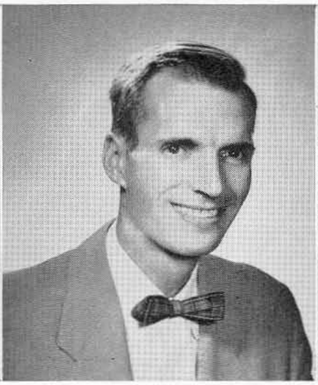
Myron T. Smith, Sales Manager of the General Radio Company, has been appointed its Director of Sales. William R. Saylor, manager of the Los Angeles district office, is appointed Sales Manager to succeed Mr. Smith.

Mr. Smith, after graduation from the Massachusetts Institute of Technology in 1931 with the degrees of SB and SM in Electrical Engineering, came with General Radio as a development engineer, changing later to sales engineering. After opening and managing the New York and the Los Angeles district offices, he was appointed Sales Engineering Manager in 1944 and Sales Manager in 1948.

Mr. Saylor, also a graduate of MIT with the degrees of SB and SM in Electrical Engineering in 1937, came to General Radio as a development engineer after three years with General Electric Company and three years as instructor in electrical engineering at MIT. His interests later shifted to sales and application engineering, and in 1954 he was appointed manager of General Radio's newly opened Washington office. He became manager of the Los Angeles district office in 1957.

Joseph E. Belcher succeeds Mr. Saylor as manager of the Los Angeles district office. An engineering student of Lowell Institute of the Massachusetts Institute of Technology, Mr. Belcher also studied business management at Northeastern University. He came to the General Radio Company in 1942 and from 1944 to 1946 was in the U. S. Navy.

William R. Saylor



Joseph E. Belcher

Myron T. Smith

After a few years in the calibration laboratory, he became Service Engineer in 1952 and in this capacity has become known to users of General Radio equipment all over the country. He has also actively supervised the operation of exhibits of GR instruments both at technical conventions and on the road. He transferred his activities to the Sales Engineering Department in 1959.

NEW SALES ENGINEERS

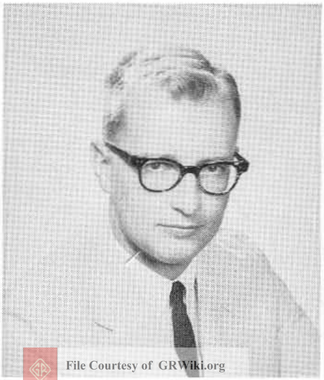
We have welcomed lately three new members to our sales engineering staff.

Howard O. Painter, who received his B.S. in Electrical Engineering from Worcester Polytechnic Institute in 1958, worked briefly as an engineer in the Hartford Electric Light Company, then spent two years with Uncle Sam's Signal Corps. After an extensive training program in various General Radio departments, he will settle into the Advertising Department, working on promotional material.

David S. Nixon, Jr., received his B.A. from the University of Connecticut, spent two years as a lieutenant in the Air Force, and received his S.B. and S.M. in Electrical Engineering at M.I.T. in 1959. His cooperative work at M.I.T. was with the Philco Corporation. After his training course, his first assignment

Howard O. Painter

David S. Nixon, Jr.



John R. Ross

will be in the Sales Engineering Department at the Home office.

John R. Ross, who has recently joined the Sales Engineering Staff of our Los Angeles office, holds a B.S. in Electronic Engineering from California State Polytechnic College. His later experience was at Bendix Aviation Corporation, working on radar design and development. He is at present working toward his M.S. degree at U.C.L.A.

His first assignment at General Radio is to assist in setting up the new service facility at our Los Angeles office. Later, he will devote full time to Sales Engineering.

1960 CONFERENCE ON STANDARDS AND ELECTRONIC MEASUREMENTS

The second national Conference on Standards and Electronic Measurements, co-sponsored by the National Bureau of Standards, The Institute of Radio Engineers' Professional Groups on Instrumentation and Microwave Theory and Techniques, and the American Institute of Electrical Engineers, will be held June 22–24, 1960, at the National Bureau of Standards Laboratories, Boulder, Colorado.

The 1960 Conference will provide a broad review of recent developments. Six sessions are planned on the following subjects:

(1) Current and Future Problems in Electronic Standards: Traceability of calibrations to National Standards, anticipated requirements, and overcoming adverse environments.

(2) Direct-Current and Low-Frequency Standards and Calibrations: Current, voltage, power, resistance, impedance, and attenuation.

(3) Methods of Measurement for Materials: Complex permittivity and permeability, tensor permeability, and tensor conductivity.

(4) Frequency and Time Standards: Molecular, atomic, and quartz standards; measurement and utilization.

(5) Microwave Standards and Calibrations: High and low power, phase shift, impedance, attenuation, and noise.

(6) High-Frequency Standards and Calibrations: Voltage, current, power, impedance, attenuation, phase shift, and field strength.

The General Chairman of the 1960 Conference is Ivan G. Easton, General Radio Company, West Concord, Massachusetts.

National Bureau of Standards personnel associated with the conference are W. D. George, Co-Chairman; George E. Schafer, Chairman of the Technical Program; and James Brockman, Chairman of Local Arrangements Committee. Further information can be obtained from Mr. Brockman at the National Bureau of Standards, Boulder, Colorado.

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THE GENERAL RADIO
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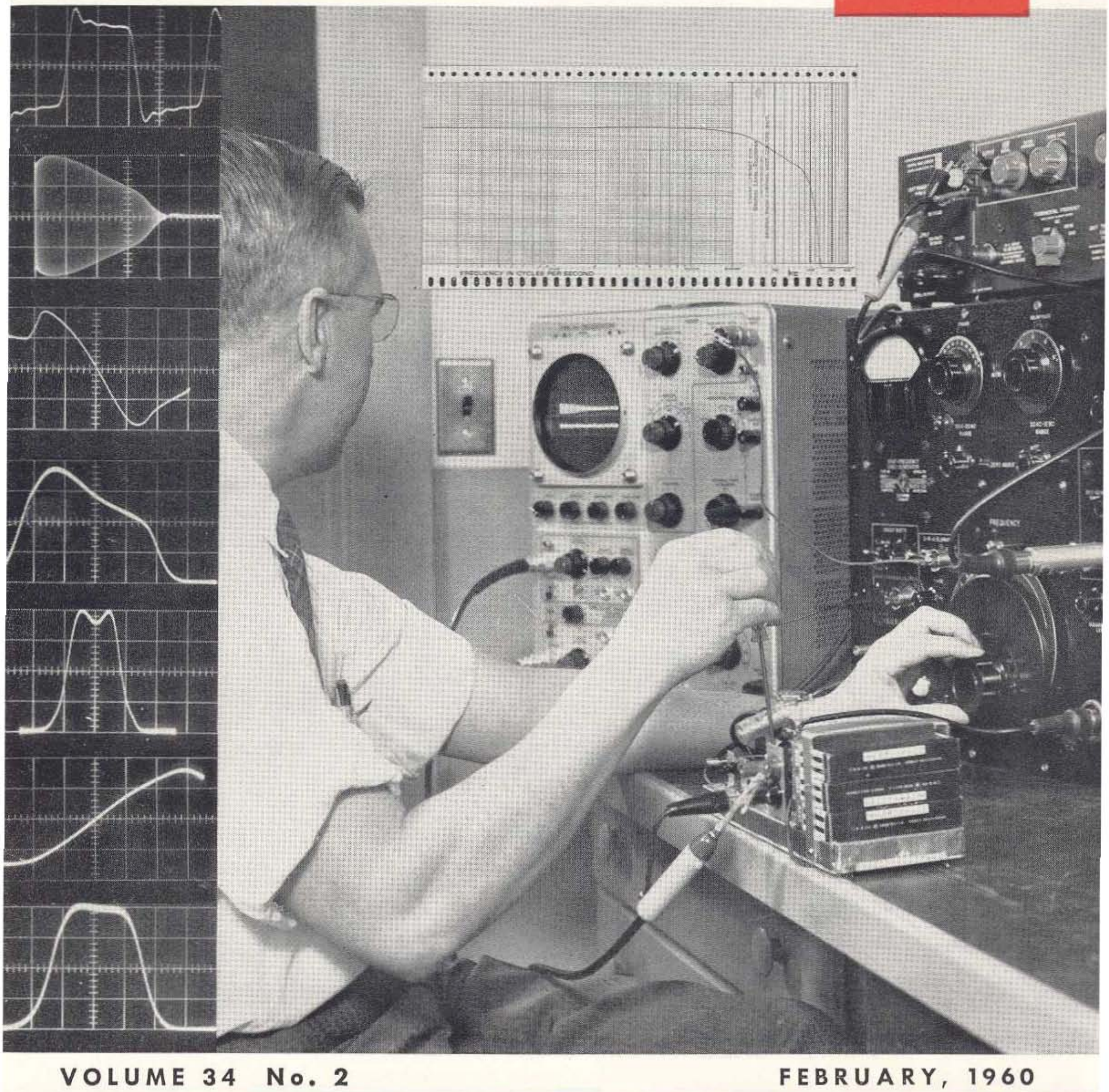

VOLUME 34 No. 2 FEBRUARY, 1960

IN THIS ISSUE

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New Coaxial Adaptors

THE GENERAL RADIO EXPERIMENTER

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The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. 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

West Concord, Massachusetts

Telephone: (Concord) *EMerson 9-4400;* (Boston) *CLearwater 9-8900*

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: **6605 West North Avenue, Oak Park, Illinois**
Telephone — VIllage 8-9400

PHILADELPHIA: **1150 York Road, Abington, Pennsylvania**
Telephone — HAncock 4-7419

WASHINGTON: **8055 13th St., Silver Spring, Maryland**
Telephone — JUniper 5-1088

LOS ANGELES: **1000 North Seward St., Los Angeles 38, Calif.**
Telephone — HOllywood 9-6201

SAN FRANCISCO: **1186 Los Altos Ave., Los Altos, Calif.**
Telephone — WHitecliff 8-8233

CANADA: **99 Floral Parkway, Toronto 15, Ontario**
Telephone — CHerry 6-2171

REPAIR SERVICES

EAST COAST: **General Radio Co., Service Dept., 22 Baker Avenue, West Concord, Mass.**
Telephone — Concord, EMerson 9-4400
Boston, CLearwater 9-8900

NEW YORK: **General Radio Co., Service Dept., Broad Ave. at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

MIDWEST: **General Radio Co., Service Dept., 6605 West North Ave., Oak Park, Illinois**
Telephone — VIllage 8-9400

WEST COAST: **Western Instrument Co., 826 North Victory Boulevard, Burbank, Calif.**
Telephone — VIctoria 9-3013

CANADA: **Bayly Engineering, Ltd., First St., Ajax, Ontario**
Telephone — Toronto EMpire 2-3741

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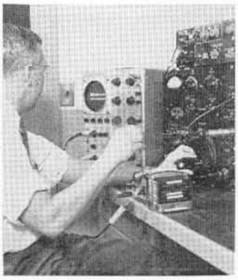


Adjusting the response of a transistor amplifier with the Beat-Frequency Video Generator and an oscilloscope. The Type 1213-D Time/Frequency Calibrator, shown above the generator, furnishes the timing markers. The oscillograms and charts at the left are examples of the many uses of this generator. See text for further details.

A BEAT-FREQUENCY GENERATOR FOR AUDIO, ULTRASONIC, AND VIDEO FREQUENCIES

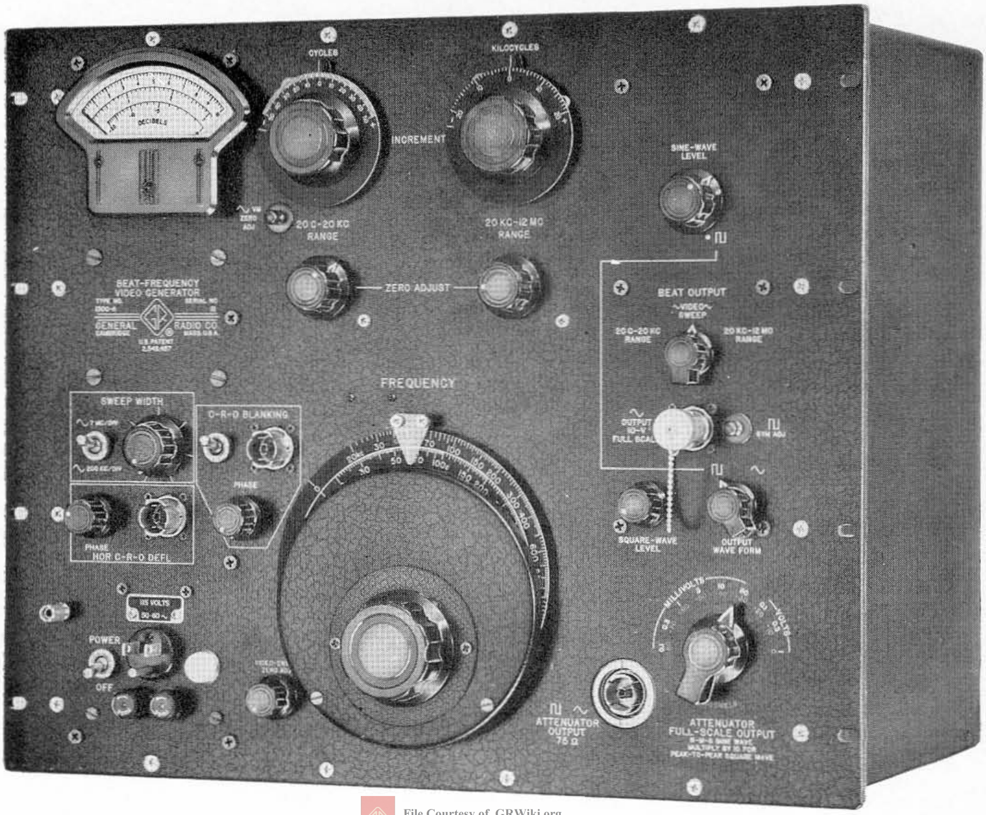
SINE-WAVE, SQUARE-WAVE, AND SWEPT OUTPUTS

For circuit measurements and testing at both audio and video frequencies, the new TYPE 1300-A Beat-Frequency Video Generator offers an unusual combination of features. To the ability to measure circuit response by four methods, it adds the recognized advantages of beat-frequency generation of the test signal. Prominent among these advantages are: (1) either the audio or the video range can be spanned by a single rotation of the frequency dial and (2) high resolution at any frequency can be provided by a separate control whose calibration is independent of the main dial setting.

This new generator covers frequencies from 20 cycles per second to 12 megacycles in two ranges and provides not only a sine-wave signal for point-to-point measurements but also a sweep signal for oscilloscope display and a square-wave signal for transient tests. Provision for automatic graphic recording adds still a fourth test method to this list.

A maximum of 10 volts, open circuit, is available at all frequencies. An accurate output attenuator is included to give output levels as low as 10 microvolts. For i-f circuit testing, additional outputs are available in the 30-48 megacycle range.

Figure 1. Panel view of the Beat-Frequency Video Generator.



OUTPUT SIGNALS

For Audio-Frequency Response Measurements: A sine-wave signal, adjustable in frequency from 20 c to 20 kc, provides a test signal for frequency response measurements on both active and passive audio networks, transducers, and acoustical devices. The dial calibration is logarithmic, and the dial can be driven by the TYPE 1521-A Graphic Level Recorder for plotting the response automatically on logarithmic charts. A frequency-increment (△f) dial, with a range of ±50 c, offers a means of studying the characteristic of narrow-band devices, either manually or with the TYPE 1750-A Sweep Drive.

For Transient Response Tests at Audio Frequencies: A square-wave signal, adjustable in frequency from 20 c to 20 kc, whose excellent waveform permits measurements on amplifiers with low-frequency cut-offs as low as 1 or 2 c.

For Frequency Response Measurements at Ultrasonic and Video Frequencies: A sine-wave signal adjustable from 20 kc to 12 Mc, useful in response measurements on ultrasonic amplifiers, transducers, and networks, and on video systems in television receivers. The △f dial, which has a span of ± 20 kc, is useful in the measurement of very-narrow-band circuits, where a knowledge of the fine structure of the frequency characteristic is important. For oscilloscope display, this dial can be driven by the TYPE 1750-A Sweep Drive.

For graphic records, the dial can be driven by a TYPE 908-R Dial Drive and the data plotted by an X-Y Recorder.

For Transient-Response Tests at Video Frequencies: A square-wave signal from 20 kc to 2 Mc for transient response tests on ultrasonic equipment and video amplifiers.

For Sweep Tests at Video Frequencies: A sine-wave signal swept at the power-line frequency over any bandwidth from 10 kc to 12 Mc. The sweep technique allows the response characteristic of the device under test to be presented on a cathode-ray tube and is thus very useful for rapid production tests and adjustments, as well as for laboratory measurements. Frequency markers at 100 kc and 1 Mc for this range can be provided by the TYPE 1213-D Time/Frequency Calibrator,[1] which is recommended for use with this generator.

Two Additional Uncalibrated and Unadjustable Outputs are Available at Jacks Accessible from the Rear of the Instrument: (1) A sine-wave signal, swept at the power-line frequency up to ±6 Mc, with center frequency adjustable from 36 to 42 Mc, which can be used to test television and other i-f amplifiers, and (2) a high-frequency signal adjustable from 30 to 42 Mc, and useful for general testing in this range.

CIRCUITS

Oscillators

Five internal oscillators are used to obtain the various frequency ranges, as shown in the block diagram of Figure 2.

The fixed oscillator frequencies are approximately 190 kc for the low range and 42 Mc for the high. Approximate frequencies for the variable oscillators are 170 to 190 kc and 30 to 42 Mc, respectively.

The same main tuning capacitor is common to both oscillators and has plates so shaped that the main frequency-dial calibration is logarithmic from 20 c to 20 kc. The dial calibration for the high-frequency range is approximately logarithmic up to about 5 Mc, approaching linearity above 5 Mc.

The frequency of each of the fixed oscillators is adjustable over a small frequency range by means of a small adjustable capacitor whose dial is calibrated in terms of the frequency increment, independent of main dial setting. This is possible only with the beat-frequency type of generator.

The fifth, or sweep, oscillator replaces the high-frequency fixed oscillator for the video-sweep range. The tuned circuit uses a small inductor wound on a ferrite toroidal core located between the pole pieces of an electromagnet and in the constant field of a permanent magnet. A power-line-frequency sine-wave current in the control winding of the electromagnet causes a variation of magnetic flux in the ferrite core, which, when combined with constant bias flux from the permanent magnet, results in a sinusoidally varying flux. The permeability, and therefore the inductance, of the ferrite core varies with this field and causes the frequency of the oscillator to vary with a very nearly sine-wave distribution over a range determined by the magnitude of the current. The frequency variation is adjustable from about 20 kc to over 12 Mc (±6). The center frequency can be adjusted from 36 to 42 Mc by a capacitor accessible from the rear and $\pm\frac{3}{4}$ Mc by a panel control. For a 42-Mc setting, the panel FREQUENCY dial indicates the approximate center frequency.

Both the frequency sweep and the horizontal 60-cycle or other power-line frequency deflection voltage are sinusoidal, resulting in an approximately linear CRO display.

Buffer Amplifiers

A cathode-follower amplifier between the mixer and each oscillator decreases coupling between the oscillators through the mixer to such an extent that zero beat on the audio range can be adjusted with an accuracy of $\frac{1}{2}$ cycle or less and on the video range within 1 kc or less.

Mixer

The oscillator signals are fed to the grids of the pentagrid mixer. To minimize the distortion of the output signal from the mixer, a common bias adjustment for grids No. 1 and No. 3 and a separate bias adjustment for grid No. 3 are provided. The common adjustment is used to set output level and the other is used as a nearly independent adjustment to minimize distortion.

Amplifier

The five-stage output amplifier makes use of high-transconductance tubes and negative feedback to supply up to 10 volts at the high-output terminal with low distortion and an output-vs.-fre-

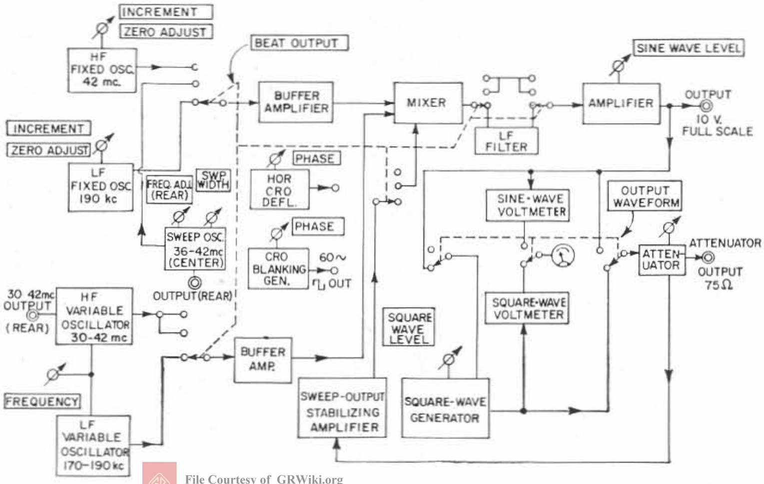


Figure 2. Block diagram of the generator.

quency characteristic that is flat within ±1db up to 12 Mc. When the video sweep range is being used, a portion of the output voltage is rectified, amplified, and fed back to one of the mixer grids in order to maintain the swept output-frequency characteristic flat within ± 1 db for output frequencies up to 12 Mc.

Square-Wave Generator

A Schmitt circuit driven by a sine-wave signal from the amplifier generates the square waves. The output is dc-coupled to the output attenuator in order to minimize ramp-off, and to keep the rise time as short as possible. The positive peaks of the square wave are at ground potential, and so the output contains a negative dc voltage component with a magnitude of one-half the peak-to-peak amplitude of the square-wave output. A separate level control has been provided for continuous adjustment of the output from the square-wave generator.

Output System

A level control, located at the amplifier input, permits the high-output sine-wave voltage to be varied continuously from 0 to 10 volts, open circuit, and the voltage at the 0-db attenuator output to be continuously varied from 0 to 1 volt, open circuit.

The square-wave output is available only at the attenuator output jack. The maximum output is over 10 volts, peak to peak, open circuit, or 2.5 volts, peak to peak, across a 75-ohm load and is continuously variable from zero to maximum by means of the square-wave-signal level control.

The same panel meter is used to indicate the sine-wave and square-wave output voltages and has two voltage scales and a db scale. It indicates the rms sine-wave voltage at the high-output jack and the voltage behind 75 ohms at the attenuator output jack. The square-wave output indication is the peak-to-peak voltage behind 75 ohms at the attenuator output jack.

For both sine-wave and square-wave output the attenuator range is from 0 db to —80 db in steps of 10 db. The attenuator, a recent development, has been designed for use at frequencies in the kilomegacycle region, and thus its frequency error over the frequency range of the video generator is essentially zero.

APPLICATIONS

The wide variety of output functions offered by the TYPE 1300-A Beat-Frequency Audio Generator suggests many applications both in the laboratory and on the production line. The range of these applications can be partially illustrated by a few examples.

Audio Frequencies

The use of this generator in determining the performance of audio-frequency networks is shown by Figures 3 through 5. Figure 3 is the amplitude-vs.-frequency characteristic of an amplifier over the audio range as recorded automatically on the TYPE 1521-A Graphic Level Recorder, coupled mechanically to the generator. The right-hand end of the chart shows the response on the video range, up to 200 kc.

The oscillograms of Figure 4 show the transient response of the same amplifier, excited by square waves from the Beat-Frequency Video Generator. The interpretation of such patterns is found in most modern textbooks and in previous articles.[2, 3, 4]

Figure 5 is the frequency characteristic of a narrow-band filter, taken point by point with the frequency increment dial.

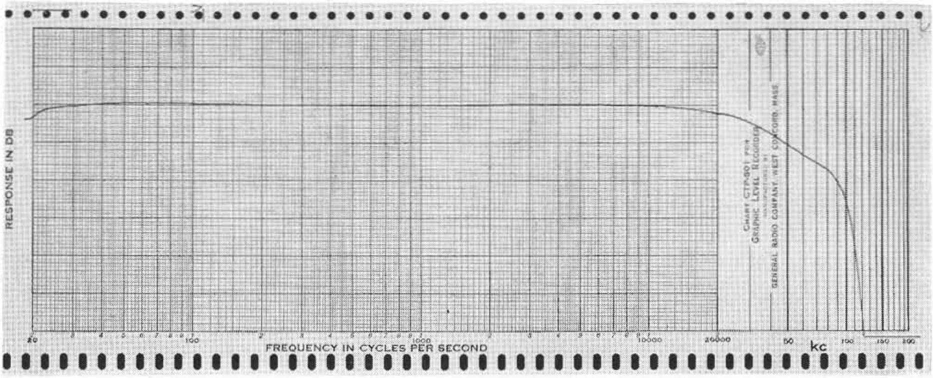
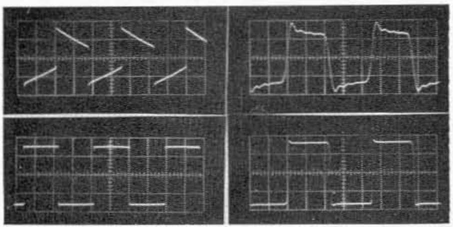
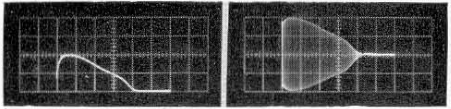


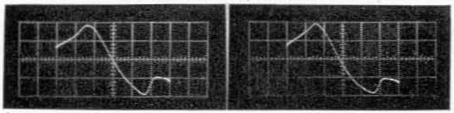
Figure 3. Frequency characteristics of an audio amplifier over the audio range. Generator dial was driven by the Type 1521-A Graphic Level Recorder to plot the curve automatically. Beyond the printed portion of the chart, at the right, is shown response at frequencies above audio range, still plotted automatically but with the video range of the generator.



▲ Figure 6. Square-wave response of television receiver video amplifier at (*left*) 60 cycles and (*right*) 400 kilocycles. Output waveform is shown at the top, input waveform at the bottom.

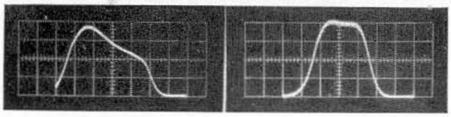


▲ Figure 7. Sweep patterns of video amplifier characteristic of a television receiver. Rectified output is shown at left, video output applied to picture tube at the right. Frequency increases left to right; scale is 1 Mc/cm.



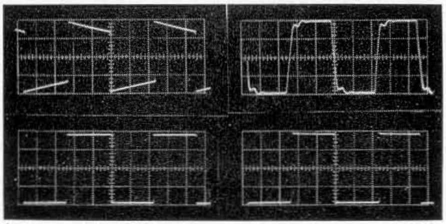
▲ Figure 8. Aural discriminator characteristics of television receiver, under slightly differing conditions of adjustment. Center frequency is 4.5 Mc; scale 50 kc/cm.

▼ Figure 9. I-F response of television receiver, as measured with direct output of sweep oscillator (available at rear of generator). Left-hand curve was taken before adjustment, right-hand curve after adjustment for best characteristic. Frequency at center line is 44.5 Mc.



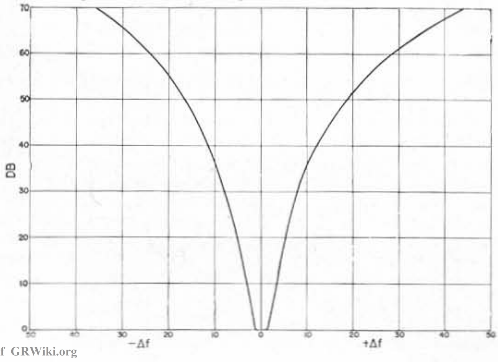
Video Frequencies

The use of the Beat-Frequency Video Generator at higher frequencies is well illustrated by the oscillograms, shown in Figures 6 through 9, which show the characteristics of a television receiver. Figure 6 shows the square-wave response of the video amplifier at 60 c and 400 kc. This type of transient testing at



▲ Figure 4. (*Left*) Transient response of same amplifier to 100-cycle square wave from the Beat-Frequency Audio Generator. (*Right*) Transient response to 10-kc square wave. Output level for both signals was 2.5 watts. Input square wave is shown at the bottom.

▼ Figure 5. Response of 50 kc crystal filter. Point-by-point measurement, with Δf dial on audio range, centered at 5 kc. Generator frequency was heterodyned with auxiliary oscillator to 50 kc.



video frequencies has been described previously in the literature.[5, 6] The characteristics of the same video amplifier, as determined by sweep methods, are shown in Figure 7.

Figure 8 shows sweep patterns for the sound discriminator of a television receiver.

With the direct output of the sweep generator, which is available at the rear of the generator, it is possible to measure the i-f response of television receivers. Figure 9 shows the i-f response of the previously mentioned television receiver, both before and after adjustments for the best characteristic.

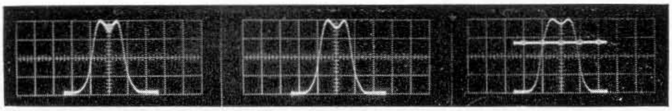
AM-FM Receiver

Measurements on an AM-FM tuner are shown in Figures 10-12. Figure 10 shows the i-f characteristic of the FM section; Figure 11 shows the FM discriminator characteristic of the same tuner both with and without the i-f amplifier included.

Figure 12 shows the characteristic of the AM section when the frequency is swept from either end and with both curves superposed. These curves show the distortion caused by a sweep rate that is too high for the circuit being tested. In this instance, the distortion is not great, and the circuit was adjusted so that approximate mirror image characteristics were obtained in the two directions of sweep.

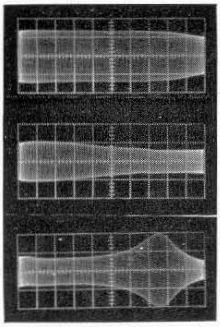
Other Sweep Tests

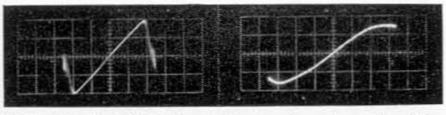
Figure 13 is the frequency response to a swept frequency of a transistor video-frequency amplifier under different conditions, as might be encountered



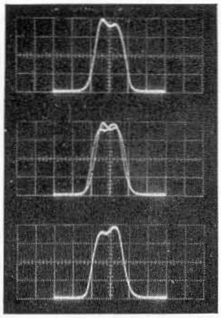
▲ Figure 10. FM i-f characteristic of an FM-AM tuner. Center frequency is 10.7 Mc; (*left*) with marker at 10.7 Mc; (*center*) same without marker; (*right*) with 100-kc markers from the Type 1213-D Time/Frequency Calibrator. Scale, 100 kc/cm.

Figure 13. (*Top*) Frequency response of a transistor amplifier; range, 0 to 10 Mc; scale, 1 Mc/cm. (*Center and bottom*) Response characteristics obtained during adjustment of the transistor amplifier. Center pattern shows response from 0 to 10 Mc; the lower pattern, with a center frequency of 11 Mc, shows a peak at approximately 13.5 Mc. ➤





▲ Fig. 11. (*Left*) FM discriminator characteristic of the tuner; signal through i-f amplifier; center frequency, 10.7 Mc, 100 kc/cm. (*Right*) Discriminator characteristic signal into first limiter, so that response is not limited by i-f characteristic. Scale, 0.5 Mc/cm.



◀ Figure 12. AM i-f characteristic of the tuner. Frequency at center line is 455 kc; scale, 10 kc/cm. (*Top*) Frequency swept from low to high frequency; (*bottom*) from high to low; (*center*) both traces superposed.

▼ Figure 15. Series and parallel resonance characteristics of (*left*) a 5-Mc quartz crystal and (*right*) a 7-Mc crystal, which shows a secondary resonance about 20 kc above fundamental series resonance. Scale is 4 kc/cm. Generator voltage was applied to crystal through a resistance. Oscillogram shows voltage across resistor. Δf dial of generator was swept with Type 1750-A Sweep Drive.

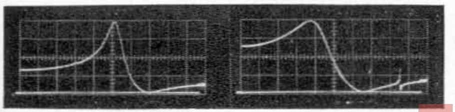
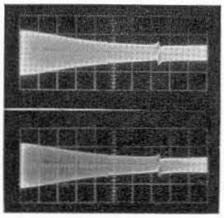


Figure 14. (*Bottom*) This pattern shows a sharp resonance and affords an excellent example of the value of sweep methods of measurement. With a point-by-point method, the resonance might easily escape detection. ➤



during adjustment of circuit capacitors.

Figure 14 shows the frequency response of a transistor amplifier with sharp resonances, which might easily go undetected in a point-by-point measurement.

Mechanical Sweep Drive

For oscilloscope display with a very slow sweep rate, the Type 1750-A Sweep Drive is recommended. Figure 15 shows the characteristics of a quartz crystal measured in this way.

For graphic recording, the Type 908-R Dial Drive provides a horizontal deflection voltage proportional to dial rotation angle and is suitable for use with an X-Y Recorder.

— C. A. Woodward, Jr.

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1 R. W. Frank and H. P. Stratemeyer, "A Time/Frequency Calibrator of Improved Stability," *General Radio Experimenter*, Vol. 33, No. 10, October, 1959.

2 L. B. Arguimbau, "Network Testing with Square Waves," *General Radio Experimenter*, Vol. XIV, No. 7, December, 1939.

3 L. B. Arguimbau, "Transient Response of a Broadcast System," *General Radio Experimenter*, Vol. XIV, No. 11, April, 1940.

4 Gilbert Swift, "Amplifier Testing by Means of Square Waves," *Communications*, Vol. 19, No. 2, February, 1939.

5 A. V. Bedford and G. L. Fredendable, "Transient Response of Multistage Video-Frequency Amplifiers," *Proc. IRE*, Vol. 25, No. 4, April, 1939.

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SPECIFICATIONS

OUTPUT: *Frequency Range*	*Signal*	*Open-Cir. Amplitude*	*Tolerance*	*Impedance*
20-20,000 c	Sine Wave	0-10 v	<±0.25 db	820Ω ±2%
20-20,000 c	Sine Wave	0-1 v	<±0.25 db 40 c-20 kc 0.75 db at 20 c	75Ω ±2% Attenuator
20-20,000 c	Square Wave	0-10 v p-to-p (0-2.5 v p-to-p across 75Ω)	<±0.25 db	75Ω ±2% Attenuator
20 kc-12 Mc	Sine Wave	0-10 v	±1 db	820Ω ±2%
20 kc-12 Mc	Sine Wave	0-1 v	±1 db	75Ω ±2% Attenuator
20 kc-2 Mc	Square Wave	0-10 v p-to-p (0-2.5 v p-to-p across 75Ω)	±0.5 db	75Ω ±2% (Attenuator)
20 kc-12 Mc Center Freq. 0-±6 Mc Sweep	Sine-Wave Sweep*	0-10 v	±1 db (up to 12 Mc)	820Ω ±2%
20 kc-12 Mc Center Freq. 0-±6 Mc Sweep	Sine-Wave Sweep*	0-1 v	±1 db (up to 12 Mc)	75Ω ±2% (Attenuator)
30-42 Mc	Sine Wave	Approx. 50 mv	±1 db**	Approx. 50Ω
36-42 Mc Center Freq. 0-±6 Mc Sweep	Sine-Wave Sweep*	Approx. 100 mv	±2 db**	50Ω or higher load recommended

*Sweep rate is at power-line frequency.

**Typical, not guaranteed.

Frequency Controls: The main control has a dial with two scales.

The inner scale covers the audio range and is calibrated from 20 to 20,000 cycles per second with a true logarithmic distribution. The total scale length is approximately ten inches. The effective angle of rotation is 240° or 80° per decade of frequency.

The outer scale covers the video range and is calibrated from 20 kilocycles per second to 12 megacycles per second. The scale is approximately logarithmic but approaches a linear distribution at the high-frequency end. The total scale length is approximately 12 inches.

The frequency-increment dial for the audio range is calibrated from −50 to +50 cycles per second, and the frequency-increment dial for the video range is calibrated from −20 to +20 kilocycles per second.

Frequency Calibration Accuracy:

Audio Range: The calibration of the main frequency dial can be relied upon within ±(1% + 1 cycle) after the oscillator has been correctly set to zero beat. The accuracy of calibration of the frequency-increment dial is ±1 cycle.

Video Range and Video-Sweep Range: The calibration of the main frequency dial can be relied upon within ±(1% + 1 kc) from 500 kc to 12 Mc and within ±(2% + 1 kc) below 500 kc after the oscillator has been correctly set to zero beat. The accuracy of calibration of the frequency-increment dial is ±0.5 kc. The frequency-increment dial is not effective on the VIDEO-SWEEP RANGE.

Zero-Beat Indicator: The output voltmeter is used to indicate zero beat.

Frequency Stability:

Audio Range: The drift from a cold start is less than 20 cycles in two hours.

Video Range: The drift from a cold start is less than 20 kilocycles in two hours.

Output Voltmeter: The panel meter has two voltage scales, 0 to 10 and 0 to 3, and a db scale, −20 db to 0 db, referred to full deflection on the 0 to 10 scale. Calibration accuracy is within ±3% of full-scale deflection for sine waves, ±5% for square waves. The voltage scales are calibrated to indicate the r-m-s value of sine-wave output voltage and the peak-to-peak value of square-wave output voltage. The sine-wave voltmeter is connected in series with a 10-μf capacitor to the 10-volt output jack.

Output Attenuator: The 75-ohm attenuator has eight steps of 10 db each, with an accuracy of ±1% of the nominal attenuation. Maximum output from the attenuator is one volt for sine-wave output, 10 volts peak-to-peak for square-wave output. Sine-wave, full-scale, open-circuit voltages are 0.1 mv, 0.3 mv, 1 mv, 3 mv, 10 mv, 30 mv, 0.1 v, 0.3 v, and 1 v. Square-wave, full-scale, open-circuit voltages are 1 mv, 3 mv, 10 mv, 30 mv, 100 mv, 300 mv, 1 v, 3 v, and 10 v.

Horizontal Deflection Voltage: 4 volts at 60 cycles (or power-line frequency) are provided for horizontal deflection of a cathode-ray oscilloscope. Since both this voltage and the frequency distribution of the sweep output vary sinusoidally, the oscilloscope pattern is approximately linear. A blanking voltage (50-volt, peak-to-peak, square wave) is also supplied.

Square-Wave Characteristics: At 60 cycles the tops are flat within 2% of the peak-to-peak amplitude, at 20 cycles within 5%. Rise time for frequencies from 300 kc to 2 Mc is less than 75 millimicroseconds. At 20 kc the rise time is approximately 150 millimicroseconds. Overshoot is about 10% of the peak-to-peak output voltage.

Harmonic Distortion: The total harmonic distortion of the sine-wave output is less than 1% of output on the 20 c-20 kc range and less than 4% of output on the VIDEO SWEEP and 20 kc-12 Mc ranges.

A-C Hum: Less than 0.1% of the output for voltmeter readings above 10% of full scale.

Terminals: Type 874 Coaxial Terminals are provided for all outputs.

Mounting: Aluminum, 19-inch, relay-rack panel; aluminum cabinet. For table mounting (Type 1300-AM), aluminum end frames are supplied to fit ends of cabinet; for relay-rack mounting (Type 1300-AR), brackets for holding cabinet in rack are supplied. Relay-rack mounting is so arranged that panel and chassis can be removed from cabinet, leaving cabinet in rack, or cabinet can be removed from rear of rack, leaving panel attached to rack.

Power Supply: 105 to 125 (or 210 to 250) volts, 50 to 60 cycles. Power input at 117 volts is approximately 175 watts, maximum. Instrument will operate normally, except for sweep output, at supply frequencies up to 400 cycles.

Power input receptacle will accept either 2-wire (Type CAP-35) or 3-wire (Type CAP-15) power cord. Two-wire cord is supplied.

Tube Complement:

1 — OB2
1 — 5651
1 — 6080
2 — 6197
4 — 6AB4
2 — 6AQ6
1 — 6AV6
1 — 6BA7
1 — 6BC4
1 — 6BK7-B
1 — 6BQ5
1 — 6J6
4 — 12AX7

Accessories Supplied: One Type CAP-35 Power Cord; two Type 874-R22 50-ohm Patch Cords; one Type 874-413 75-ohm Patch Cord; three Type 874-C58 Cable Connectors, one Type 874-Q2 Adaptor, and spare fuses.

Other Accessories Available: Type 1521-A Graphic Level Recorder for automatic recording at audio frequencies; Type 1750-A Sweep Drive for slow-speed sweeping; Type 908-R Dial Drive for X-Y plots; Type 1213-D Unit Time/Frequency Calibrator for timing markers.

Dimensions: 19 (width) x 15¾ (height) x 14⅜ inches (depth) over-all.

Net Weight: 64 pounds.

Type		*Code Word*	*Price*
1300-AM	**Beat-Frequency Video Generator (Bench Model)**	ANGEL	**$1950.00**
1300-AR	**Beat-Frequency Video Generator (Relay-Rack Model)**	ASPEN	**1950.00**

U. S. Patent No. 2,548,457.

NEW COAXIAL ADAPTORS

In line with our aim of providing low-VSWR connections between coaxial line circuits fitted with Type 874 Connectors and all other commonly used types of connectors, adaptors to three relatively new types of connectors, Type SC, Type TNC, and Type LT, have been added to the line of Type 874 Components. By means of these adaptors, the comprehensive General Radio line of high-frequency instruments and components can be applied to circuits fitted with these connectors with only a very small increase in VSWR.

The Type SC Connector is similar to a Type C but makes use of screw-type locking arrangement rather than a bayonet type. There are other minor differences, and connectors of the two series will not mate with one another. Adaptors from Type 874 Connectors to both male and female Type SC Connectors have been designed.

A similar modification of the Type BNC Connector has resulted in the Type TNC Connector. There are several versions of this connector, which differ slightly from one another. The new adaptors to Type 874 Connectors, the Type 874-QTNP and the Type 874-QTNJ, are designed for proper mating with the Sandia version of this connector.

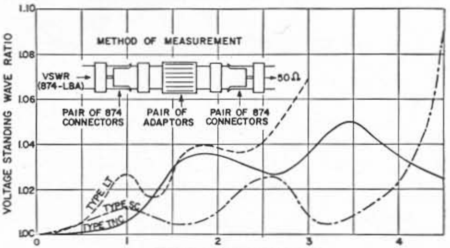


Figure 2. Standing-wave ratio of typical pairs of adaptors as a function of frequency.

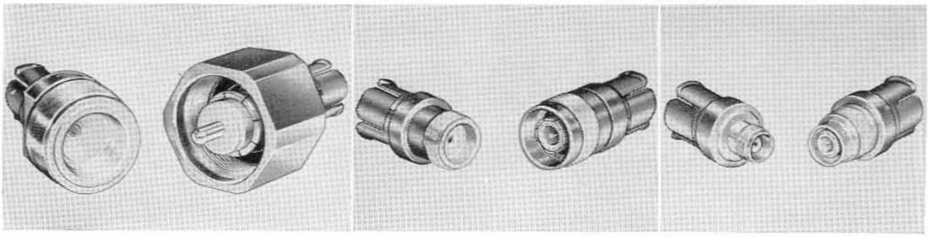
The Type LT Connector, intended for use with large-size Teflon cables, Types RG-117 and RG-118, has come into widespread use, and low-reflection connections can be made to it by use of the Type 874-QLTP and 874-QLTJ Adaptors.

The reflections introduced into a matched 50-ohm line at various frequencies by typical pairs of adaptors are shown in Figure 2. The VSWR of a single adaptor will, in general, be lower than indicated by the curve. Voltage and power ratings of these adaptors are listed in the table on page 12.

Type	*Contains Type 874 Connectors and*	*Fits*	*Code Word*	*Price*
874-QSCP	**Type SC Male**	SC Female	COAXCASHER	**$9.50**
874-QSCJ	**Type SC Female**	SC Male	COAXCOSTER	**9.50**
874-QTNP	**Type TNC Male**	TNC Female	COAXTUSKER	**8.00**
874-QTNJ	**Type TNC Female**	TNC Male	COAXTUNNER	**8.00**
874-QLTP	**Type LT Male**	LT Female	COAXLOBBER	**23.00**
874-QLTJ	**Type LT Female**	LT Male	COAXLAGGER	**23.00**

U. S. Patent No. 2,548,457.

Figure 1. Type 874-ALTJ, Type 874-QLTP, Type 874-QSCJ, Type 874-QSCP, Type 874-QTNJ, Type 874-QTNP.



FOR THE CONVENIENCE OF USERS OF TYPE 874 COAXIAL COMPONENTS, WE ARE LISTING BELOW THE VOLTAGE AND POWER RATINGS FOR ALL OF THESE ELEMENTS

Type	*Name*	*Peak Voltage Volts*	*Max. Allowable Average Power* at 1000 Mc (inversely proportional to square root of frequency)*
874-B **874-L 10, 20, 30** **874-EL** **874-T**	Basic Connector Air Lines Ell Tee	1500	150 w
874-C, C8, C9 **874-R20**	Cable Connectors Patch Cord	1000	150 w
874-C58 **874-R22**	Cable Connector Patch Cord	500	55 w
874-LA **874-LK**	Adjustable Line Adjustable Line	1500	100 w†
874-K	Coupling Capacitor	500	55 w
874-F Series	Filters	200	55 w
874-LBA	Slotted Line	1500	150 w‡
874-QBP, QBJ **QTNP, QTNJ** **QUP, QUJ**	Adaptor to BNC Adaptor to TNC Adaptor to UHF	500	55 w
874-QCP, QCJ **QNP, QNJ** **QSCP, QSCJ**	Adaptor to C Adaptor to N Adaptor to SC	1000	150 w
874-QHP, QHJ **QLP, QLJ** **QLTP, QLTJ** **QU3A, QV3A** **QU2A, QV2** **QU1**	Adaptor to HN Adaptor to LC Adaptor to LC Adaptors to Rigid Lines	1500	150 w

* For pulses, peak power rating is the average power rating divided by the duty cycle, within voltage limitations.
† For permanent installations, 30 w maximum at 1000 Mc.
‡ At high powers, the output of the crystal diode must be shunted to limit output voltage to 2 v.

NEW REPRESENTATIVE FOR DENMARK

We announce the appointment of the Danish firm of Semler & Matthiassen as exclusive General Radio representative for Denmark. Effective February 1, 1960, Semler & Matthiassen took over these responsibilities for Mogens Bang & Company and is now directly serving our customers in Denmark and Greenland with competent technical assistance and advice.

All inquiries, whether technical or commercial, concerning General Radio products, should be addressed to:

Semler & Matthiassen
Teglvaerksgade 22
Copenhagen, Denmark

General Radio Company

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THE GENERAL RADIO

EXPERIMENTER

VOLUME 34 No. 3 MARCH, 1960

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GENERAL RADIO COMPANY

West Concord, Massachusetts

Telephone: (Concord) *EMerson 9-4400;* (Boston) *CLearwater 9-8900*

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: **6605 West North Avenue, Oak Park, Illinois**
Telephone — VIllage 8-9400

PHILADELPHIA: **1150 York Road, Abington, Pennsylvania**
Telephone — HAncock 4-7419

WASHINGTON: **8055 13th St., Silver Spring, Maryland**
Telephone — JUniper 5-1088

LOS ANGELES: **1000 North Seward St., Los Angeles 38, Calif.**
Telephone — HOllywood 9-6201

SAN FRANCISCO: **1186 Los Altos Ave., Los Altos, Calif.**
Telephone — WHitecliff 8-8233

CANADA: **99 Floral Parkway, Toronto 15, Ontario**
Telephone — CHerry 6-2171

REPAIR SERVICES

EAST COAST: **General Radio Co., Service Dept., 22 Baker Avenue, West Concord, Mass.**
Telephone — Concord, EMerson 9-4400
Boston, CLearwater 9-8900

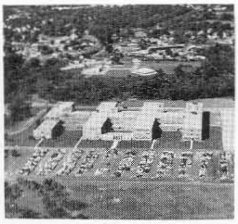
NEW YORK: **General Radio Co., Service Dept., Broad Ave. at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

MIDWEST: **General Radio Co., Service Dept., 6605 West North Ave., Oak Park, Illinois**
Telephone — VIllage 8-9400

WEST COAST: **Western Instrument Co., 826 North Victory Boulevard, Burbank, Calif.**
Telephone — VIctoria 9-3013

CANADA: **Bayly Engineering, Ltd., First St., Ajax, Ontario**
Telephone — Toronto EMpire 2-3741

COVER



Airplane view of the new General Radio Plant.

GENERAL RADIO AT CONCORD

General Radio, after 44 years in Cambridge, has now completed its move to a new home in Concord, Massachusetts. The fact of this westward migration is established in our signature on nameplates, letterheads, and labels. To GR's friends who would like to know something about the new plant, and how we came to be here, we offer the following brief account.

Since 1915, General Radio had stayed within a block or two of its birthplace in heavily industrialized Cambridge. We had expanded steadily, at a rate controlled to ensure a good environment for the production of quality instruments. By the end of World War II, GR's brick-and-mortar consisted of five buildings, with about 150,000 square feet of plant and office space. With these buildings and several off-street parking areas, the Company had run out of adjacent real estate for future growth and began to plan for relocation.

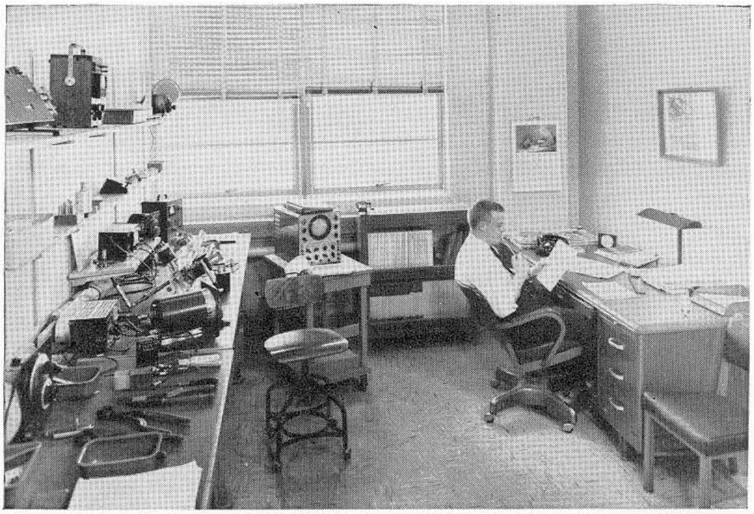
Why Concord? Choice of a plant site naturally involved many interlocking factors but, basically, General Radio chose to build in Concord because most of its employees lived in that direction (i.e., west of Boston), because Concord and its environs were desirable residential towns, and because there was available in Concord a clear, level, 84-acre tract, adjacent to a main highway and a rail junction. (Assumed here is the earlier, easier decision to remain near Boston, for its educational, cultural, business, and transportational advantages.)

The land was acquired in 1948. There on the banks of the Assabet, 20 air miles from the gilded dome of Boston's State House, our first Concord plant — a 72,000 square-foot T-shaped, three-story building — was completed in 1952.

For the next five years, the Concord plant was a separate manufacturing division — primarily for Variac® autotransformers. What is now known as "the move to Concord" began in early 1958, with the completion of the second T and the transfer of Engineering and some Production operations to Concord. An H-shaped building, completed in 1959, finished the building pattern symmetrically, and GR ended its stay in Cambridge. For the first time in seven years, the entire organization (with the exception of our district sales offices) was together, enjoying the easy communication, efficient material flow, and simplified administration provided by a modern, well-planned, integrated manufacturing plant.

General Radio's new home is a smart, three-story, brick complex of 293,000 square feet (about twice the size of our Cambridge plant). The building configuration is a series of H's (see cover photo), planned so that every office is an outside office. Around the building are a small fish pond (mostly black bass, with some perch and pickerel), a 600-car parking lot, and a well-groomed outfield (the word is apt; the grass mixture is the same as that used at Fenway Park). State Route 2, the Mohawk Trail from

View of a section of the spacious employees' cafeteria.



View of a typical engineer's office, which combines office desk and laboratory bench space for convenience and efficiency.

Boston to New York State, brushes the land, and the West Concord railroad station is nearby. (West Concord is our postal address, incidentally; politically, we are in the town of Concord.) The plant is a half-hour drive from Cambridge's Harvard Square and is about seven miles west of Greater Boston's famed circumferential highway, Route 128.

Although the plant was built in three stages, each part anticipated the next, so that departments were laid out to minimize movement of people and material. For instance, raw aluminum sheets are now received, cut to panel size, and stored in the same area of the first floor. Similarly, a panel is cleaned, painted, and engraved all in one area. Machine tool sections are arranged as logically: a metal cabinet is punched, drilled, formed, welded, and sanded all at one end of the department. Parts manufacture and processing operations (machine shop, painting, plating, etc.) feed, from their first- and third-floor corners, the centralized second-floor stockroom and Assembly Department. The machined

Instrument display area in the Sales Engineering Department.

part does not detour to a mechanical inspection department; this group is split up to function in the several critical areas where it is needed. Such logistic layout ensures the straight-line material flow that is the essence of any efficient manufacturing operation.

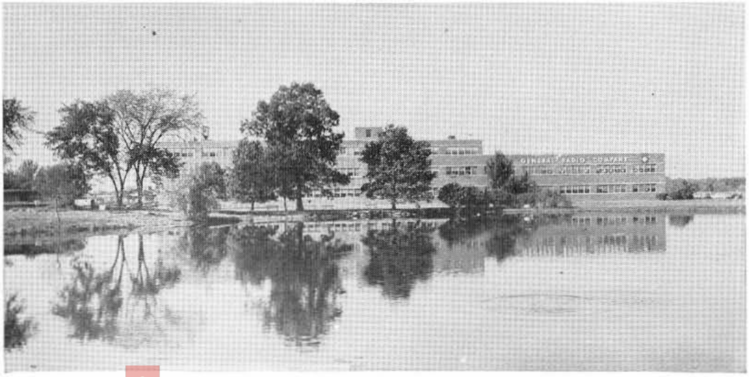
In the Engineering Department, the Company's one-engineer-per-office policy is maintained throughout. The typical office is a miniature library, laboratory, and sanctum for the development man. The offices of the Sales Engineering staff surround a demonstration area, where the GR product line is neatly displayed. Near the Sales Department is the Commercial Department, and the heavy paper traffic between these two groups is swift and direct.

The Concord plant is not just a new shuffle of an old deck. Plating, painting, and cleaning equipment is all new, and includes 48 stainless-steel tanks, new baking ovens and spray booths, and even a well-stocked, professionally manned chemical laboratory. Separate data-processing installations in the Commercial and Production offices get smarter day by day, as invoices, inventories, payrolls, and other statistics become holes in IBM cards. Add Autocall and voice-paging systems, Dial-a-Matic pneumatic-tube network, and a 3000-volume technical library, and you have a plant second to none in modern facilities.

But people, not devices, determine a company's future, and the new plant is, not accidentally, a very pleasant place to work. A precedent Concordian named Emerson once wrote that "Nothing great was ever achieved without enthusiasm." General Radio employees find it easier than ever to be enthusiastic. Everything from the vast private parking lot to the new 350-seat cafeteria is larger, cleaner, and more comfortable. The grounds are ideal for extracurricular activities (so far, archery sets, ice skates, golf clubs, fishing rods, horseshoes, and toy rockets have sprouted on campus). The town is a peaceful community, as proud of its present as it is of its past. And the countryside is pure New England, more handsome than pretty, and never letting you forget what season it is.

This is the "new plant," in detail necessarily sketchy, but, we hope, revealing enough to make you think of visiting us when you have a chance. There are bigger plants, and there are undoubtedly even a few newer ones. What makes General Radio so proud of its new home is neither its size nor newness; it is the conformance of structure and setting to an ideal. We think it *looks* like GR: solid, friendly, of lasting value. From it you can expect what we are historically committed to produce — the best instruments in electronics.

— F. T. Van Veen



General Radio's Walden.

THE CASE OF THE WELL DESIGNED INSTRUMENT

The word design means many things to many people. To us at General Radio it means the integration of functional, electrical, mechanical, manufacturing, and esthetic factors to produce a more useful product. To some degree, all these factors are interdependent, and appearance, in particular, becomes most effective when tied closely to function.

General Radio's new color scheme, use of proprietary meter cases, and complete instrument packaging philosophy are some of the results of an appearance-design and mechanical-design program in which human engineering is given its proper emphasis.

THE COLOR

The new color scheme uses a scale of grays. Black dials, charcoal-gray panels, medium-gray knobs and cases, and white legend and hardware combine eye convenience with eye appeal. The light gray of the control knobs stands out in contrast to the charcoal gray of the panel, as does the white aluminum exposed by the engraved panel legend.

Meters and dials on which the eye must usually concentrate are in black and white. To yield maximum contrast with minimum eyestrain in prolonged use, dials have black backgrounds with white legend. For dial behind windows, however, and for meter dials, reflections must be avoided, and so here the pattern is reversed — black lines on a white background.

Instrument cases are a medium gray, a shade carefully chosen to look cleaner longer. Too dark a gray shows dust easily, while too light a gray shows smudges.

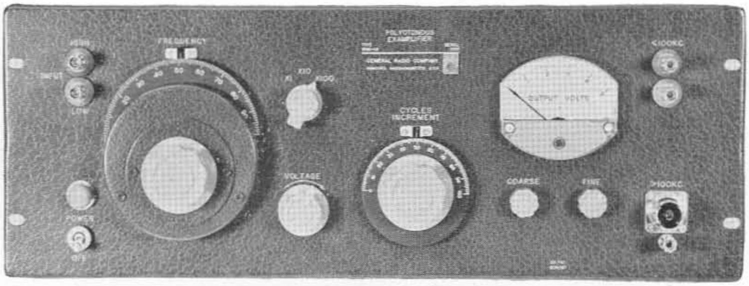
Natural-color anodized aluminum in the metal hardware harmonizes well with the cabinet gray and is as durable as it is decorative.

THE PACKAGE

Supporting and complementing this well designed façade is the instrument cabinet. General Radio instrument cases can be classified into five basic types, each designed to meet specific requirements of function and use. These are shown in the accompanying illustrations. A prominent feature of all these designs is the adaptability to rack mounting of the basically bench-mounted types and, conversely, the bench-type mounting provision in relay-rack instruments.

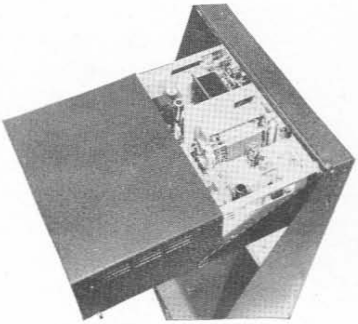
Relay-Rack

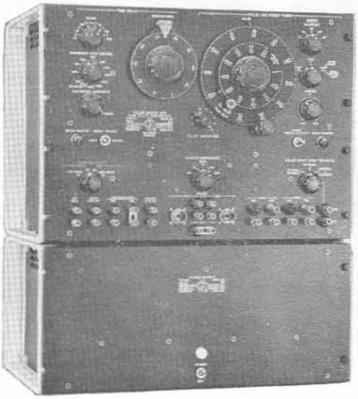
General Radio's relay-rack design is used for fairly large instruments. These instruments can be mounted in standard 19-inch relay racks, with front and rear accessibility to the interior of the instrument without complete removal from the rack. Although designed primarily for rack mounting, they can also be supplied with different hardware for use out of the relay rack, on a bench or stacked one above another in a quasi-relay-rack assembly.



The new-look panel, charcoal gray, with black dials, light-gray knobs. Proprietary meter design yields maximum scale length for panel space occupied.

Relay-rack instruments make possible cabinet removal from rear of rack, as shown at left, and stacking in tiers with bench-mount end frames, as shown at right.





Relay-rack instruments have heavy-gauge metal cabinets capable of supporting the weight of the instrument. These cabinets are mounted in the rack by means of two sheet-metal supports. With an instrument cabinet mounted in a relay rack, the instrument can be slid into it from the front just as a drawer is slid into place. The instrument is retained in its case by screws going through the panel into the rack. The instrument can be partially withdrawn and serviced from the front of the rack, or the case can be removed from the instrument at the rear of the rack, with the instrument left mounted in the rack.

For bench use, the relay-rack instrument can be equipped with end frames that hold the instrument into its cabinet as the rack does, and which serve as carrying handles and supporting feet at the same time. These end frames are designed to nest one above the other so that instruments can be stacked. Holes are provided for bolting the end frames together to make a permanent stack.

Rack-Bench

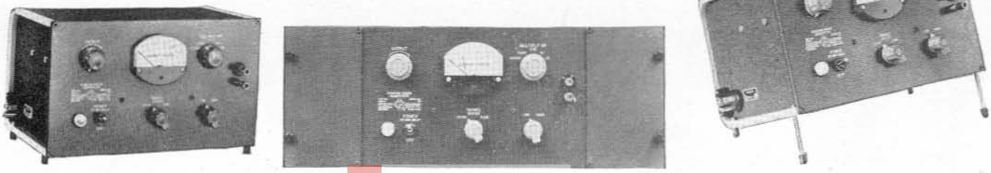
Small and medium-sized instruments, which are commonly used on the bench, are housed in a cabinet having carrying handles, rubber feet, a tilting feature, and readily removable dust cover. Panel extensions permit them to be used in a relay rack.

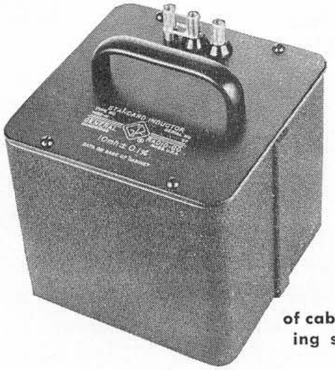
The rack-bench instruments can be lifted by handles on the side panels and can be tilted by the extension of the front feet. Quick-action clamping fasteners hold the dust cover in place and at the same time permit easy removal of the cover. The same screws that hold the instrument sides to the panel also attach the panel extenders installed for relay-rack mounting.

Laboratory-Bench

Laboratory instruments, such as impedance standards and decade boxes which are seldom, if ever, mounted in relay racks, are equipped with cases appropriate to their size and weight. Very small units have one-piece drawn-

The three aspects of the rack-bench cabinet: *left*, conventional rack-bench cabinet; *center*, with wings for relay-rack mount; tilted for convenient operation.





Standard inductor shows laboratory-bench type of cabinet with locking strip at side.

metal boxes, whereas larger units are housed in heavy-gauge aluminum enclosures. These enclosures are fabricated from sawed or extruded plates and held together by locking strips. Rugged construction, electrical shielding, and pleasing appearance are combined in these cases.

Unit Instruments

For the Unit-line instruments, where economy and small size are the controlling factors, a very simple case is used. The panel is bent into a U, as is the dust cover, and the two interlock firmly to comprise the entire enclosure. With this design, too, relay-rack mounting is possible and adaptor panels are available.

Flip Tilt

Instruments of a basically portable nature use the General Radio Flip-Tilt case, which boasts the following features:

It is its own complete enclosure for transport without an extra carrying case.

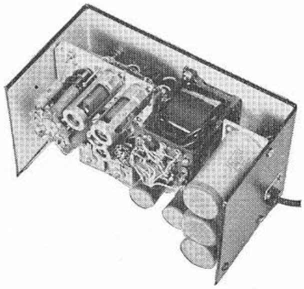
It can be readily set up for use at any desired viewing angle.

The protective cover is attached by a convenient carrying handle.

An accessory storage space is provided.

It can be simply adapted to relay-rack use.

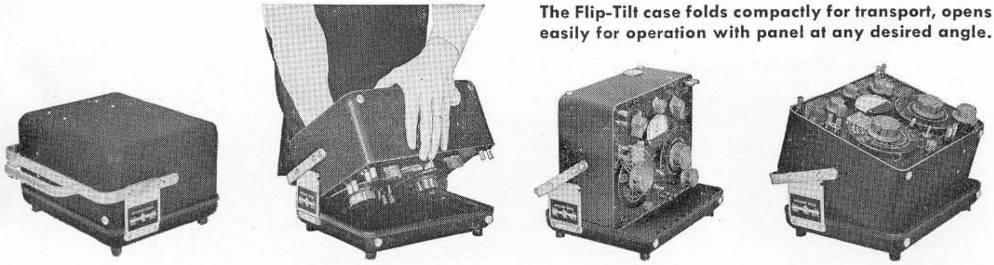
A one-piece drawn-aluminum instrument case and control-panel cover results in a lightweight yet sturdy enclosure. The control-panel cover serves as storage space for accessories, and functions as a base when the instrument is in operation. A rubber gasket around the edge of the control-panel cover seals the closed case. When the instrument is in use, this gasket provides the friction to keep the instrument at whatever tilt angle is selected. The mechanical linkage uniting the instrument case and control panel is extended in the form of a carrying handle, which also serves as the lever for lifting the instrument while it is being flipped.



Unit-type construction uses U-shaped chassis, as shown here; mating U-shaped piece provides dust cover and complete enclosure.

The Flip-Tilt type instrument is easily mounted in a rack, since the cabinet reinforcing frame at the edge of the panel serves as a natural stop against a relay-rack panel cut out to fit the instrument case.

— H. C. Littlejohn



The Flip-Tilt case folds compactly for transport, opens easily for operation with panel at any desired angle.

GENERAL RADIO DISTRICT OFFICES

While the General Radio home office sales organization plays the usual important part in the over-all business operations of the Company, it is largely through our engineers in branch offices that we meet our customers. By means of our own factory-trained people we are best able to provide the high-quality service expected of a producer of precise measuring instruments.

District offices with service and repair sections as well as sales-engineering and order-handling groups are situated in the larger centers of electronic activity: New York, Chicago, Los Angeles, and Boston. Other offices, but without service and repair organizations, are located near Philadelphia, Washington, D. C., San Francisco, and Toronto, Canada.* Each of these offices is staffed by two to four sales engineers, and clerical and secretarial personnel.

District Office Functions

The district office serves the customer by:

- Bringing to his attention General Radio instruments and developments.
- Making certain that his General Radio equipment is operating well and is being used in the most effective manner.
- Furnishing information and advice about measurement techniques.
- Providing liaison between the customer and the engineering or production specialist at our plant.
- Furnishing price and delivery quotations, processing orders, clarifying incomplete orders, making special arrangements for the customer's convenience, and keeping track of scheduled dates and shipments so as to be able to furnish progress reports when requested.
- Stocking many products for over-the-counter sales, thus providing prompt attention to the needs of local customers.
- Maintaining a collection of demonstration instruments that can be seen at the district office and can be borrowed for trial.
- Feeding back information to the home office concerning instrument acceptance, future instrument requirements, and industry trends that may aid the Company in its planning of new products.

Up-to-date service facilities at New York District Office are also typical of those at Chicago and Los Angeles. These installations are fully equipped for the repair and recalibration of General Radio products. Every instrument handled is completely recalibrated regardless of other work requested and receives a warranty of one year from the date of its servicing.

District-office engineers hear R. A. Soderman, of the Development Engineering Department, describe characteristics of a new instrument at a typical Workshop Session.

---

*Repair service is provided in Toronto by Bayly Engineering Limited, First Street, Ajax, Ontario, Canada.

By means of the telephone, or through personal visits, the district-office engineer is in close touch with those in his area. Such short-distance work has the advantage of informality and convenience. Those in need of assistance can, and do, call frequently for information — technical or otherwise. In fact, many have developed the habit of first telephoning the district office when they have a measurement problem, because they have learned that the district office's specialized knowledge will often provide an answer. When, as with unusual applications, a complete answer cannot be given over the telephone, the district office will arrange a trial of the equipment at the customer's plant.

District offices are inherently able to give personal attention to individual requirements. For instance, customer orders can be serviced faster if they come to the nearest district office rather than traveling farther to the home office. No time is lost — shipment priority of orders is determined by their *date of arrival at the district office*, and not the date (usually the following day) the order arrives at the main office from the district office.

The General Radio Sales Engineer

The General Radio district office engineer has a substantial stake in his Company and is an important member of the professional and management group who administer its operations. He is typically one of the Company's stockholders (almost all General Radio voting capital stock is owned by about 100 professional and managerial employees). Thus the GR man's interests are long-term. He is on straight salary; he loses no commission if the sale of some particular equipment is not made. He will recommend only equipment that is suited to the need at hand, even if it is a competitor's product. He knows that only through quality business and engineering service will he produce the lasting customer satisfaction upon which the future of his Company depends.

General Radio sales engineers are engineering graduates (many have advanced degrees). These men are thoroughly familiar with the design, manufacture, and use of the products they sell. Because the extensiveness of the GR product line involves them in work in practically all areas of the frequency spectrum and in diverse industries, they *must* be well trained technically. Each district-office engineer has spent considerable time in the Development Engineering Department. In addition to valuable engineering experience acquired there, he gains a familiarity with engineering methods which stands him in good stead if later he has occasion to refer back to an engineering specialist for information. In short, he learns where to go for the answer and what it means when he gets it.

At least once a year, General Radio district-office engineers return to the plant to acquaint themselves with new instruments and measurement methods. They learn these techniques by *working* at them at lengthy workshop sessions alongside the design engineer who developed the products or ideas.

These men are active participants in professional-society activities. The typical district-office engineer is a member of a number of different committees, some purely technical and others primarily concerned with local or national activities of the IRE, AIEE, and other organizations.

Recalibration, Repair, and Service

The service groups, located in im-

TORONTO OFFICE


A. KINGSNORTH
Manager


R. J. PROVAN
Engineer

SAN FRANCISCO OFFICE

Los Altos
California


J. G. HUSSEY
Manager


D. M. VOGELAAR
Engineer

NEW ENGLAND OFFICE

West Concord, Mass.


R. B. RICHMOND
Manager


C. W. ALSEN
Engineer


D. S. NIXON
Engineer


R. J. PETERSON
Engineer

PHILADELPHIA OFFICE

Abington,
Pa.


K. ADAMS
Manager


J. E. SNOOK
Engineer

WASHINGTON OFFICE

Silver
Spring, Md.


C. W. HARRISON
Manager


F. J. FINNIGAN
Engineer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Engineer

CHICAGO OFFICE

Oak Park, Illinois


W. M. IHDE
Manager


R. P. DELZELL
Engineer


L. C. FRICKE
Engineer


L. W. GORTON
Engineer


J. A. DUNN
Service Mgr.

LOS ANGELES OFFICE


J. E. BELCHER
Manager


A. O. ABEL
Engineer


F. J. THOMA
Engineer


J. R. ROSS
Engineer


A. J. GUAY
Service Mgr.

NEW YORK OFFICE

Ridgefield, N. J.


G. G. ROSS
Manager


L. J. CHAMBERLAIN
Engineer


P. B. BISHOP
Engineer


E. F. SUTHERLAND
Engineer


D. W. BROWN
Service Mgr.

portant areas of electronic activity, are staffed by factory-trained service engineers and expert technicians. These service organizations in the field are available for repair, recalibration, and standardization of General Radio equipment of all types. For those customers able to make their own repairs, a good stock of parts is available as well.

The availability of local service facilities not only cuts transportation costs but minimizes time for service as well. Furthermore, where circumstances require it, a service engineer can visit the customer at his plant. This service is as near as the telephone. For those outside district office territories, prompt service can be obtained from the Service Department at Concord, Massachusetts.

—C. J. Lahanas

AT THE IRE SHOW

General Radio will be in Booths 3201-3208, directly opposite the escalator on the third floor.

We shall show a complete laboratory for the low-frequency standardization of inductance and capacitance, plus bridges and other equipment for impedance measurements from dc to 5000 megacycles. Accurate laboratory standards of inductance and capacitance will be displayed, as well as precise bridges for their intercomparison and for their use in the calibration of other elements. Other bridges will be set up for impedance measurements on components and circuit elements for the measurement of dielectric properties of insulating materials and for VSWR, impedance, and transfer-function measurements at ultrahigh frequencies. A feature of the Transfer-Function Bridge display will be the measurement of tunnel diode characteristics at several hundred megacycles.

All these bridges will be in operating condition, and engineers will be in attendance. General Radio is one of the leading manufacturers of this type of equipment and will show a truly impressive array of instruments.

Also on display and in operation will be the Type 1554-A Sound and Vibration Analyzer, the Type 1390-B Random-Noise Generator, and the Type 1300-A Beat-Frequency Video Generator, all of which have been described in recent issues of the *Experimenter*, and pulse and time-delay generators.

Another display will illustrate the new design features of General Radio instruments, which are described in this issue of the *Experimenter*.

A conference area will also be provided in the booth, for the convenience of customers who wish to discuss their measurement and instrumentation problems with GR engineers, free from the distraction of normal exhibit-booth traffic.

We look forward to seeing you.

Look for this booth, 3201-3208, just in front of the escalator on the third floor.

General Radio Company

THE GENERAL RADIO

EXPERIMENTER

VOLUME 34 No. 4 APRIL, 1960

IN THIS ISSUE

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- Stability of Standards

THE GENERAL RADIO EXPERIMENTER

Published Monthly by the General Radio Company
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The General Radio EXPERIMENTER is mailed without charge each month to engineers, scientists, technicians, and others interested in electronic techniques in measurement. 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.

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West Concord, Massachusetts

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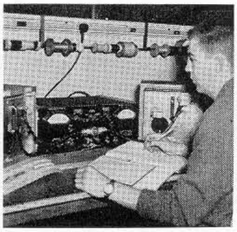
CANADA: **Bayly Engineering, Ltd., First St., Ajax, Ontario**
Telephone — Toronto EMpire 2-3741

COVER



VITRAMON,® Inc., uses the Impedance Comparator for comprehensive measurements on statistical samples from each production lot of capacitors.

IMPEDANCE COMPARATOR ADAPTABLE TO MANY KINDS OF MEASUREMENTS AND TESTS

"Double-duty" instruments that provide laboratory accuracy in production-line testing, as well as production-test speed in laboratory measurements, are universally welcomed. The General Radio Type 1605-A Impedance Comparator has proved to be just this type of instrument and it has, time and again, proved its versatility and adaptability in a variety of applications throughout the electronics industry.

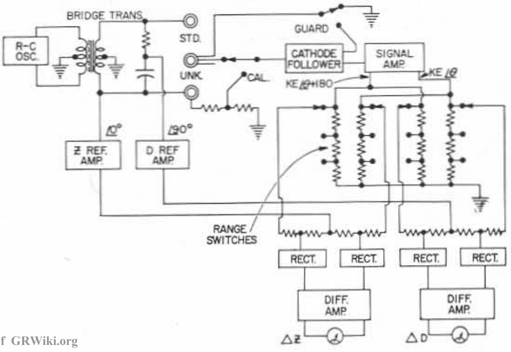
The Impedance Comparator indicates directly the impedance difference between a standard and an unknown and eliminates the tediousness of manual bridge balancing. Many of the limit-bridge predecessors of the Impedance Comparator operated at a fixed low frequency, which limited their sphere of application. The G-R Impedance Comparator not only has a built-in oscillator providing 100-c, 1-kc, 10-kc, and 100-kc operation but, in addition, incorporates features which allow a much greater degree of precision and considerably more versatility than do previously available instruments.

Basically, this instrument[1] is a self-contained impedance measuring system comprising a signal source, a bridge, and a detecting circuit (Figure 1). The bridge circuit consists of the standard and unknown external impedances, which are to be compared, and two highly precise transformer-type unity ratio arms. The voltages across these ratio arms are equal within one part in a million. Hence the accuracy of the impedance measurement depends primarily upon the accuracy of the external standard used. Detector sensitivity permits impedance-difference measurements to a precision of 0.01% and phase-angle difference measurements to 0.0001 radian. The meters, which indicate impedance difference and phase-angle difference, can be read at a glance.[2]

Laboratory Accuracy, Production Speed From One Instrument

The many applications of the G-R Impedance Comparator in industry well illustrate the instrument's versatility. A typical use is that at Vitramon,® Inc., of Bridgeport, Connecticut, manufacturers of porcelain-dielectric capacitors. Vitramon uses the Comparator to determine the temperature coefficients of their capacitors. The temperature of a sample capacitor is varied from —55°C. to 200°C. while bridge readings are taken periodically at a number of temperatures. From these data, a plot of percent deviation of capacitance versus temperature is obtained, the slope of which is the temperature coefficient. The inherent ability of the Impedance Comparator to make measurements without manual balancing or readjustment and the built-in guard circuit, which eliminates the effect of lead capacitance, enable Vitramon to obtain the desired laboratory accuracy at a speed heretofore unattainable by conventional test methods.

Figure 1. Block diagram of the Type 1605-A Impedance Comparator.



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[1] Holtje, M. C., and Hall, H. P., "A High Precision Impedance Comparator," *General Radio Experimenter*, Vol. 30, No. 11, 1956.

[2] See page 6 for a panel view of the Comparator.

Figure 2. Semi-Automatic Tester at Bendix Radio Division, Bendix Aviation Corporation.

On the production line where speed is essential, the Impedance Comparator has become a Vitramon workhorse. Used in conjunction with a standard capacitor, the bridge permits 100% checks of capacitor production lots, as opposed to the spot testing, without increase in labor costs. This go-no-go type of test is made with an accuracy of the order of 0.1% for both capacitance and phase angle.

Semi-Automatic Sorting

When engineers of Bendix Radio Division of Bendix Aviation Corporation, Baltimore, Maryland, needed a "brain" for their Semi-Automatic Tester (Figure 2), they chose a Type 1605-A Impedance Comparator. The Semi-Automatic Tester, which can check all components on a printed-circuit subassembly and thus verify adequacy, is manufactured under subcontract for IBM and the United States Air Force.

Here is how Bendix put the Comparator to work: the Impedance Comparator panel meters were disconnected. The metering voltages, proportional to impedance-magnitude difference (in percent) and phase-angle difference (in radians), are amplified by the tester and compared to allowable tolerances. Printed-circuit components which produce voltages in excess of pre-set tolerances are automatically rejected. Built-in relays permit automatic switching of Comparator impedance ranges by a remote punched-card programmer. With automatic programming, testing rate is one measurement per second!

Here are a few reasons why Bendix uses the Impedance Comparator: it indicates *both* impedance magnitude and phase angle without knob twiddling; it provides d-c voltages proportional to percentage deviation from a standard; it has excellent guard circuitry which permits the long cable runs usually necessary in automatic equipment; and it combines a wide impedance range with high measurement accuracy.

Environmental Testing

An interesting application evolved from Inland Testing Laboratories' need to make environmental reliability tests on a large number of capacitors. The automated instrumentation system (Figure 3), built at their Morton Grove, Illinois, plant to accomplish this measurement, incorporates the Type 1605-A Impedance Comparator. The system measures and records, in sequence, insulation resistance, capacitance, and phase angle of many thousands of capacitors of several types, each operating at a different voltage level and temperature. These capacitors are housed in two large compartmentalized environmental test chambers. The instrumentation system is remote with respect to the components in the chamber.

The Type 1605-A Impedance Comparator, which is the heart of this intricate test apparatus, serves as the measuring device for capacitance and loss measurements. Comparator meter-

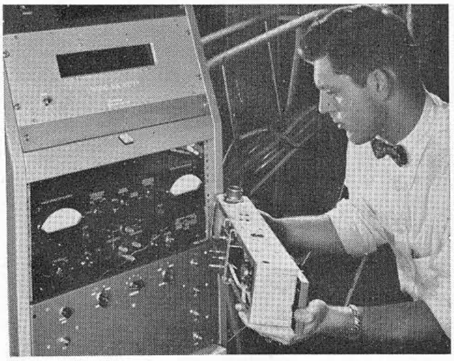


Figure 3. Inland Testing Laboratories use the Impedance Comparator in an automated instrumentation system for environmental reliability tests on capacitors.

ing voltages are fed into a digital voltmeter and are converted to digital form for punched-card recordings. The data so recorded will provide detailed statistical information concerning reliability and life cycles of capacitors operating under various voltage and environmental conditions.

A Research Tool

Measurement of small dielectric changes of gases requires a precision that taxes the resources of even the most sensitive impedance-measuring device. Professor R. H. Cole[3] of Brown University asked the General Radio Company to modify a TYPE 1605-A Impedance Comparator so that it would have an impedance-difference sensitivity several times that of the catalog model. He wished to make measurements of small dielectric constant changes of gases and of dilute solutions. Although these measurements are usually made by heterodyne resonant circuit or resonant-cavity methods, the Impedance Comparator won out because of its advantages of simplicity of operation, its freedom from lead capacitance and other stray effects, and its ability to operate at frequencies below 100 kc.

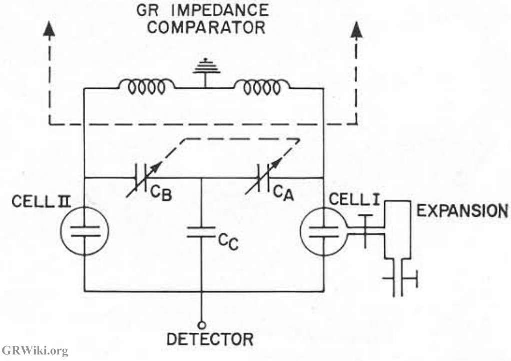
The phase-sensitive detector circuits are stable and quiet enough to permit further modification of the instrument, so that, with an external detector, the usable sensitivity is one part per million!

In order to accomplish these measurements, Professor Cole constructed the circuit shown in Figure 4. The comparison method used for gases consists of two identical cells which are 80-pf three-terminal parallel-plate capacitors. Differences in capacitance, when cell I is filled with the gas of interest, and cell II with a reference gas or vacuum, are balanced by the capacitance wye network $C_AC_BC_C$. The variable capacitors C_A and C_B are ganged in opposition, so that rotation gives a linear shift of reference capacitor C_C from the electrical midpoint. Values of C_C are chosen to give 0.5-, 5-, and 50-pf full-scale deflection. Data obtained for such gases as nitrogen, argon, and carbon dioxide are consistent to ten parts per million or better.

These are but a few of the many applications in which the Impedance Comparator has demonstrated its usefulness. It is truly a universal instrument; one which meets both the laboratory criterion of accuracy and the production criterion of speed.

— HOWARD PAINTER

Figure 4. Circuit used for measurement of small changes in dielectric constant.



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[3] Cole, R. H., "Methods for Dielectric Measurement of Fluids," National Academy of Sciences — National Research Council Conference on Electrical Insulation, 1958 Annual Report.

THE TYPE 1605-AS2 IMPEDANCE COMPARATOR

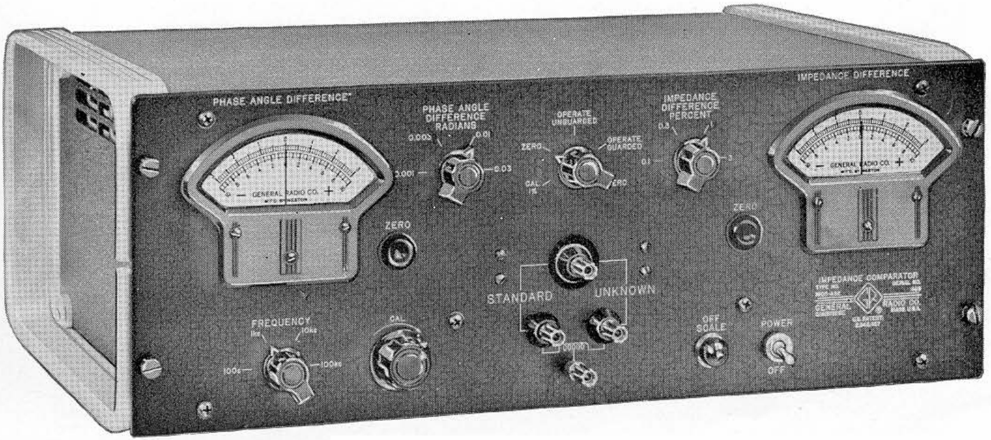
In the preceding article, mention was made of a modification of the Impedance Comparator to give a higher degree of resolution than the standard model. While the full-scale standard ranges of 10%, 3%, 1%, and 0.3%, with corresponding ranges for phase angle, are adequate for most uses, there are always applications where increased sensitivity is desirable.

In our own laboratory, for instance, it soon became apparent that, while a sensitivity of 0.003 full scale for dissipation factor is useful, an increase in sensitivity by a factor of 3 to 0.001 would vastly enhance the usefulness of the instrument. For example, with a sensitivity of 0.003 full scale, the dissipation factor of good capacitors made of low-loss materials such as mica, teflon, or polystyrene, although detectable, represents extremely small-scale deflections. With 0.001 full-scale reading on the other hand, sufficient deflection is obtained so that the instrument can be used for the sorting of high-quality silvered mica films. Selection for capacitance value and rejection for high dissipation factor can both be accomplished rapidly. A number of such instruments of increased full-scale sensitivity have been supplied and are now being manufactured in limited production quantities.

Since any well-designed instrument represents a compromise between numerous economic and technical factors, it is rarely possible to increase performance in one respect without sacrificing in some other characteristic. In the Impedance Comparator the increased sensitivity is obtained by an increase in the low-resistance limit of measurement and by elimination of the 10% deviation ranges. Neither compromise is necessary on a technical basis, but is arrived at rather on an economic basis. The impedance limitation comes about from the fact that the increased sensitivity is most readily obtained by a change in the turns ratio of the bridge transformer. Since the available power from the internal oscillator is not changed, the increase in the measurable impedance naturally follows. Similarly, the elimination of one range to make room for the new range is dictated by the mechanical considerations of switch design, available space, and panel layout.

— I. G. Easton

Panel view of the Type 1605-AS2 Impedance Comparator.



SPECIFICATIONS

Impedance Ranges: Resistance or impedance magnitude: 20 Ω to 20 MΩ. Capacitance: 40 μμf to 80 μf; to 0.1 μμf with reduced sensitivity. Inductance: 200 μh to 10,000 h.

Internal Oscillator Frequencies: 100 c, 1 kc, 10 kc, 100 kc; all ±3%.

Meter Ranges: Impedance Magnitude Difference: ±0.1%, ±0.3%, ±1%, ±3% full scale. (Can be adjusted for maximum of 50%.) Phase Angle Difference: ±0.001, ±0.003, ±0.01, ±0.03 radian full scale (equal to dissipation factor on lowest ranges).

Accuracy of Difference Readings: 3% of full scale; i.e., for the ±0.3% impedance-difference scale, accuracy is 0.009% of the impedance magnitude being measured.

Voltage Across Standard and Unknown: Approx. 1 volt.

Accessories Supplied: TYPE CAP-35 Power Cord, telephone plug, external-meter plug, adaptor plate assembly (fits panel terminals) and spare fuses.

Tube Complement: 1-5651, 1-5751, 3-12AX7, 4-6AL5, 5-12AT7, 3-6U8, 1-6AS7G, 1-3A10, 1-VE65A-1

Power Supply: 105 to 125 (or 210 to 250) volts, 50 to 60 cycles; about 100 watts input at 115 volts. Instrument will operate satisfactorily on power-supply frequencies up to 400 cycles, provided that the supply voltage is at least 115 volts.

Power input receptacle will accept either 2-wire (TYPE CAP-35) or 3-wire (TYPE CAP-15) power cord. Two-wire cord is supplied.

Mounting: Relay-rack panel with cabinet; TYPE 1605-AR has fittings to permit either instrument or cabinet to be removed from rack without disturbing the other; TYPE 1605-AM has end supports for table or bench use.

Dimensions: Panel, 19 x 8¾ inches; depth behind panel, 12 inches.

Net Weight: 29½ pounds.

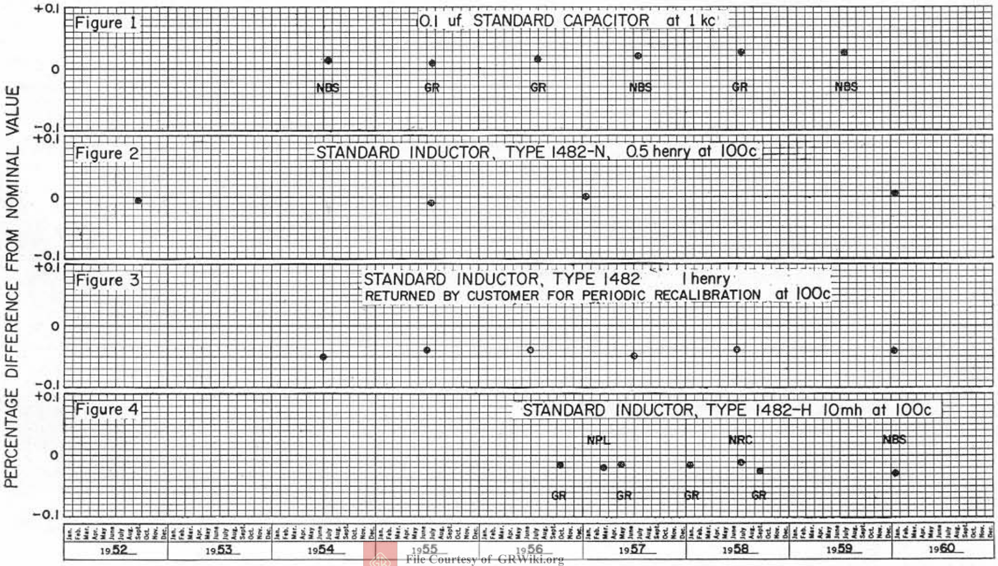
Type		*Price*
1605-ARS2	**Impedance Comparator (relay-rack mounting)**	**$925.00**
1605-AMS2	**Impedance Comparator (bench mounting)**	**925.00**

U. S. Patent No. 2,548,457.

STABILITY RECORDS OF STANDARDS OF INDUCTANCE AND CAPACITANCE

The data shown in the accompanying plots will be of considerable interest to all who use General Radio standards of inductance and capacitance.

Figure 1 shows a six-year record of measurements on a capacitor of the 1409-type, having a nominal capacitance of 0.1 μf. In this period, three measure-



ments of the capacitor were made by the National Bureau of Standards, and three were made in the General Radio Laboratories in terms of NBS-calibrated standards. The total spread of 0.0075% for all measurements in this six-year period is indicative of the stability of the capacitor.

Figure 2 is a record of NBS measurements over a nine-year period of one of General Radio's 0.5-henry reference standards of inductance. The total spread is ±0.0075%.

Figure 3 is the record of General Radio's measurements of a 1-henry standard inductor TYPE 1482-P, returned to us each year for recalibration. The total spread over a six-year period is ±0.005%.

Figure 4, a record of measurements on a 10-mh TYPE 1482-H Standard Inductor, is of particular interest because it includes measurements made by national laboratories in three countries, the National Physical Laboratory in England, the National Research Council in Canada, and the National Bureau of Standards in the United States. Three measurements by General Radio are also included. The total spread in these measurements is ±0.01%, a remarkable agreement when we consider that the measurements include any drift which might occur over a 4 to 5-year period, plus a round trip across the Atlantic, another to Canada, and a third to Washington.

All measurements in these plots have been corrected to a temperature of 20.5°C.

LOS ANGELES OFFICE

— *CORRECTION* —

The editor offers his apologies to Mr. Kenneth Castle, sales engineer at our Los Angeles office, whose name and photo were omitted from the list in the March issue of the EXPERIMENTER. Mr. Castle, whose photo is shown herewith, is very much a part of our Los Angeles staff.

MINIMUM BILLING AND INSPECTION CHARGE

We find it necessary to put into effect as of May 2, 1960, a minimum billing amount of $10.00 applicable to all orders except those for repair parts or for cash sales.

Should Government or other Source Inspection be required, there is a surcharge of 1% with a minimum of $2.50 per shipment.

General Radio Company

PRINTED IN U.S.A.

THE GENERAL RADIO
EXPERIMENTER

VOLUME 34 No. 5

MAY, 1960

IN THIS ISSUE

VSWR Measurements

Tools for Type 874 Coaxial Connectors

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COVER

Richard L. Brereton, of Canada Wire and Cable Co., Ltd., Leaside, Ontario, well-known authority on cable testing, is shown operating his convenient, rack-mounted assembly of General Radio equipment for the measurement of attenuation and other characteristics of high-frequency cable.

RAPID VSWR MEASUREMENTS WITH THE ADMITTANCE METER

Although the TYPE 1602-B UHF Admittance Meter is widely used for high-frequency impedance and admittance measurements, its possibilities for the rapid measurement of standing-wave ratio are not so well recognized. With this instrument, VSWR can be calculated from the values of conductance and susceptance which are measured directly, but the measurement can be greatly simplified when VSWR alone is required, without phase information. Two approximately direct-reading methods have been developed, one of which requires a mechanical movement of one of the controls on the instrument while the other uses only the meter reading on the detector as an indication of the VSWR. The former method is exact for all values of VSWR, while the latter method is approximate and is limited to a VSWR range up to approximately 1.2. Both methods require a detector capable of giving an accurate measure of the relative output level, as, for instance, one of the Type DNT Detectors.

The Admittance Meter

In normal use the TYPE 1602-B Admittance Meter measures admittance or impedance in the frequency range between 40 and 1500 Mc with a nominal accuracy of ±3%. It is direct reading in conductance and susceptance (or resistance and reactance). Figure 1 shows the scales and controls, Figure 2 the rear; Figure 3 is a schematic. Admittance measurements are made by a null method in which voltages derived from the currents in the standard conductance arm and the standard susceptance arm are balanced against a voltage derived from the current in the unknown arm.

The coupling of each of the loops shown in Figure 3 can be varied by rotation of the loop. One of the coaxial lines is terminated in a conductance standard, which is a pure resistance equal to the characteristic impedance of the line; one in a susceptance standard, which is a short-circuited length of coaxial line; and one in the unknown circuit. The outputs of the three loops are com-

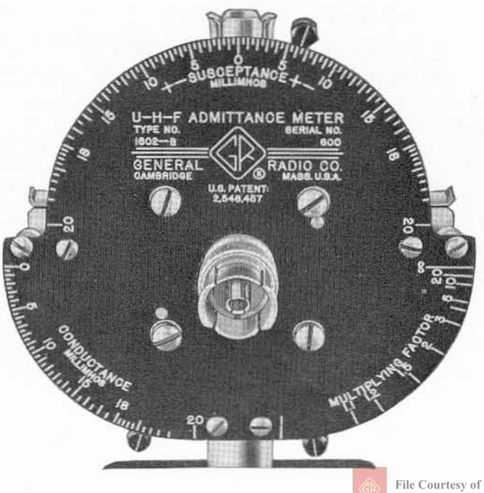


Figure 1. Close-up view of the scales and controls of the Admittance Meter.

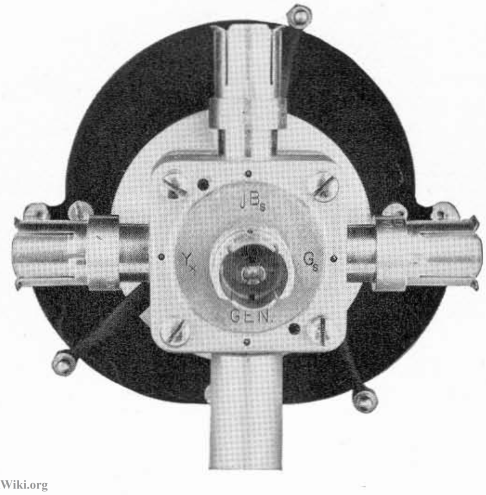


Figure 2. Rear view, showing identification of the coaxial lines.

bined in parallel and, when the loops are properly oriented, the net output is zero. The device therefore balances in the same manner as a bridge.

At balance the voltage induced in each of the three loops is proportional to the mutual inductance between each line and loop and to the current flowing in the corresponding line. Since all three lines are fed from a common source, the input voltage is the same for each line, and the current flowing in each line is proportional to the input admittance.

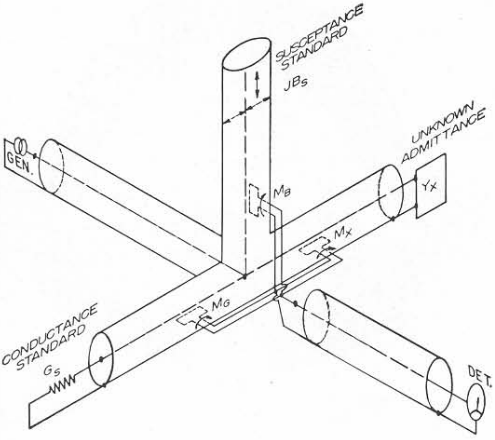
The loops associated with the unknown admittance and the standard conductance can each be rotated through an angle of 90°, but the loop associated with the standard susceptance is arranged to be rotatable through an angle of 180°, thus allowing the measurement of positive as well as negative values of unknown susceptance with a single susceptance standard.

The conductance scale is inherently independent of frequency. The susceptance standard is always adjusted to produce the same magnitude of susceptance at each frequency.

Admittance and Impedance Measurements

The three loops are adjustable by the arms shown in Figure 2 and carry indicators as shown in Figure 1. Thus the admittance parameters, G and B, can be read directly from the scales. The scale for the loop in the unknown line indicates the multiplying factor. If a quarter-wave line is inserted between the instrument and the unknown, the admittance is inverted. The millimho scale readings are then proportional to impedance and, when multiplied by 2.5, they indicate the series resistance and reactance in ohms.

Figure 3. Schematic diagram of the Admittance Meter, showing the functional arrangement of lines and loops.



VSWR Measurements by the Voltage-Ratio Method

For VSWR measurements, one simple method is based on a measurement of the ratio of the output voltages obtained at two settings of an indicator arm. This method is particularly attractive for measurements of the VSWR of antenna systems and components in which the VSWR is not greater than about 10 to 1.

In this method the 50-ohm termination is inserted in place of the susceptance standard in the B_s line; the G_s line remains open-circuited; the unknown is connected to the Y_x line. The conductance indicator is set to zero, and the multiplying factor indicator is set to 1. The ratio of the output voltage, V_1, obtained when the susceptance indicator is set to —20, to the output, V_2, obtained when the susceptance is set to +20 is equal to the magnitude of the reflection coefficient, Γ, and the VSWR can be determined as follows:

$$|\Gamma| = \left|\frac{V_1}{V_2}\right|$$

$$\text{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|} = \frac{1+\left|\frac{V_1}{V_2}\right|}{1-\left|\frac{V_1}{V_2}\right|}$$

TABLE 1

V_1/V_2 db	Γ	VSWR	V_1/V_2 db	Γ	VSWR
1	.8913	17.41	17	.1413	1.33
1.2	.8710	14.50	18	.1259	1.29
1.4	.8511	12.43	19	.1122	1.24
1.6	.8318	10.90	20	.1000	1.22
1.8	.8128	9.66	21	.0891	1.194
2	.7943	8.73	22	.0794	1.170
2.2	.7762	7.94	23	.0708	1.153
2.4	.7586	7.29	24	.0631	1.136
2.6	.7413	6.73	25	.0562	1.120
2.8	.7244	6.26	26	.0501	1.105
3	.7079	5.85	27	.0447	1.093
3.5	.6683	5.03	28	.0398	1.083
4	.6310	4.42	29	.0355	1.074
4.5	.5957	3.95	30	.0316	1.066
5	.5623	3.57	31	.0282	1.058
5.5	.5309	3.26	32	.0251	1.051
6	.5012	3.01	33	.0224	1.046
6.5	.4732	2.80	34	.0200	1.041
7	.4467	2.62	35	.0178	1.036
7.5	.4217	2.46	36	.0158	1.032
8	.3981	2.32	37	.0141	1.029
8.5	.3758	2.20	38	.0126	1.027
9	.3548	2.10	39	.0112	1.023
9.5	.3350	2.01	40	.0100	1.020
10	.3162	1.92	42	.0079	1.016
11	.2818	1.79	44	.0063	1.013
12	.2512	1.67	46	.0051	1.010
13	.2239	1.58	48	.0040	1.008
14	.1995	1.50	50	.0032	1.006
15	.1778	1.43	55	.0018	1.004
16	.1585	1.37	60	.0010	1.002

If the VSWR is less than 1.2, the following approximation is valid:

$$\text{VSWR} = 1 + 2\,|\,\Gamma\,| = 1 + 2\left|\frac{V_1}{V_2}\right|$$

The calculations can be eliminated through the use of Table 1, which indicates the value of Γ and VSWR for various values of $\frac{V_1}{V_2}$ expressed in decibels.

The voltage induced in the susceptance loop is proportional to the current flowing in the terminated line and is, therefore, $-KY_o$ when the indicator is set at —20 and $+KY_o$ when the indicator is set at +20. The voltage induced in the multiplying factor loop when the indicator is set at unity is KY_x. Therefore, the total voltage, V_1, at the detector when the susceptance indicator is set at —20 is

$$V_1 = KY_x - KY_o$$

and when the susceptance indicator is set at +20,

$$V_2 = KY_x + KY_o$$

or

$$\frac{V_1}{V_2} = \frac{Y_x - Y_o}{Y_x + Y_o} = \Gamma$$

and therefore in terms of the magnitudes alone,

$$|\,\Gamma\,| = \left|\frac{V_1}{V_2}\right|$$

For this measurement a detector with a wide linear range (at least 50 db) and a calibrated attenuator, such as one of the Type DNT Detectors, is required. With the Type DNT Detectors, the value of $\frac{V_1}{V_2}$ is obtained as the difference between two decibel readings.

For maximum accuracy the VSWR of the 50-ohm termination unit should be as close to unity as possible. If the termination is perfect, the resulting VSWR error is less than about 0.01 up to 500 Mc and 0.02 up to 1000 Mc for low VSWR magnitudes. The performance can be checked by substitution of another low-VSWR, 50-ohm termination for the unknown.

Rapid VSWR Measurements by a Direct Method

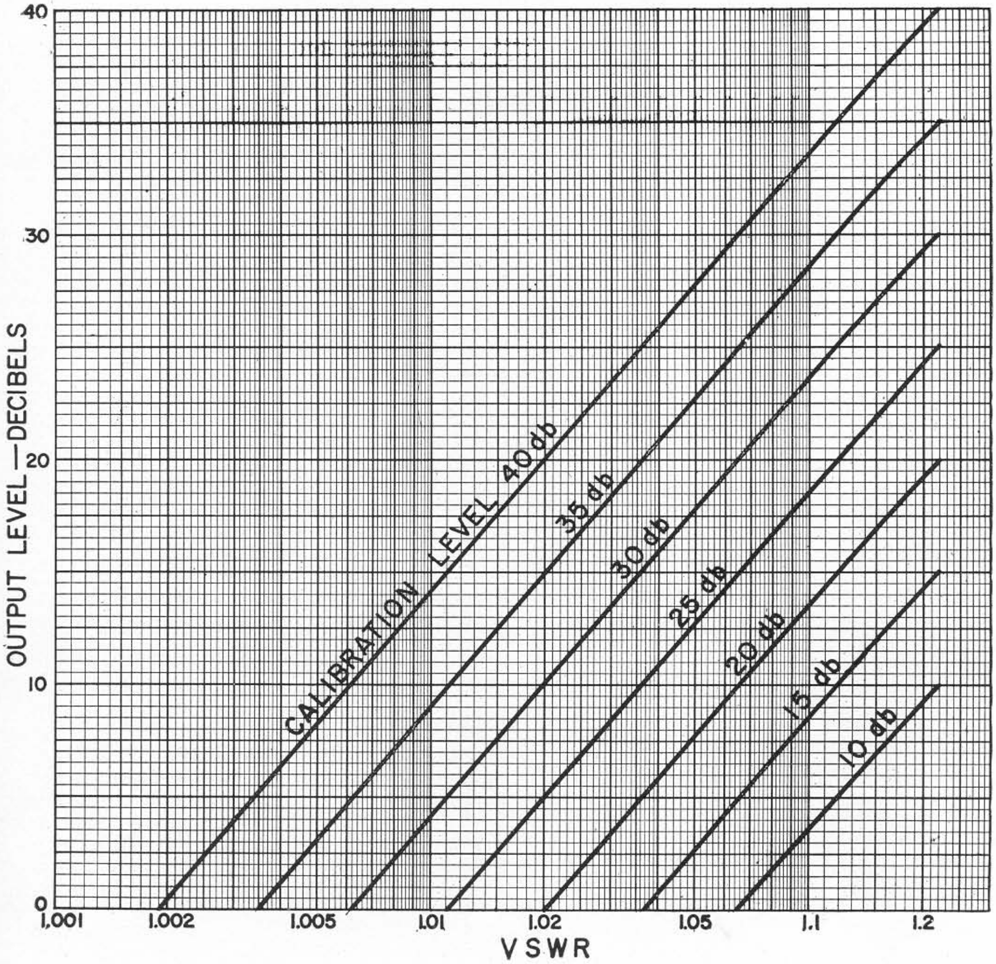
For VSWR measurements on a large number of components at a single frequency, or on a single component whose maximum VSWR must be measured over the whole range of some adjustment, as, for example, an adjustable-length line, an even more rapid method than that previously described can be used. This method is valid as long as the VSWR is less than about 1.2 and is particularly useful for the determination of small standing-wave ratios. Its high resolution permits the measurement of VSWR's as low as 1.002.

For this measurement the Admittance Meter is set up as for admittance measurements, with one of the Type DNT Detectors, with the standard conductance in the *G* arm, and with the standard susceptance stub set for the operating frequency in the *B* arm. A low-VSWR, 50-ohm termination is plugged into the unknown arm, and the meter is balanced for a null with the multiplier set exactly at 1.2.

The multiplier arm is then set at 1.0. This unbalance is equivalent to that produced by a VSWR of 1.22 in the unknown. The generator output is then adjusted to produce a detector reading equal to one of the calibration levels on the chart in Figure 4 (avc off). The multiplier is then returned to its 1.2 reading, and adjusted to produce a null balance. The unknown is then plugged into the unknown arm in place of the 50-ohm termination and the meter reading noted. The corresponding VSWR is then read from the chart of Figure 4.

Since no adjustments are required after the instrument has been calibrated, VSWR measurements can be made on a large number of elements very rapidly merely by plugging them into the instrument and observing the meter indi-

Figure 4. Chart for determining VSWR from detector output readings.



cation. Continuous measurements can also be made of the VSWR of components as they are adjusted.

The accuracy of the method at very low values of VSWR is primarily determined by the VSWR of the 50-ohm termination unit used to set up the instrument. The residual VSWR can be as large as twice the VSWR of this termination. The accuracy of the method also decreases at large values of VSWR, reaching ±0.006 at a VSWR of 1.1 and ±0.03 at a VSWR of 1.22.

— R. A. Soderman

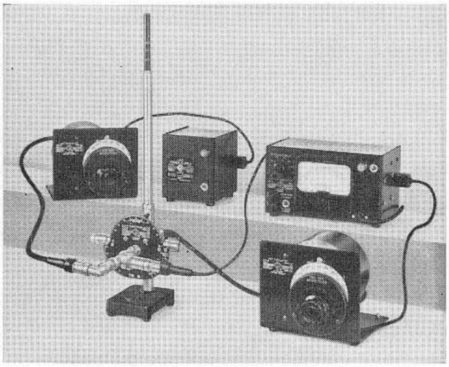


Figure 5. The Admittance Meter as set up for admittance or VSWR measurements, with a Type 1209-B Unit Oscillator and a Type DNT-3 Detector.

ASSEMBLY TOOLS FOR TYPE 874 COAXIAL CONNECTORS

To facilitate the assembly of our Type 874 Coaxial Connectors on cables or rigid line, we are making available a set of tools, illustrated in Figure 1. The Type 874-TOK Assembly Tool Kit consists of an outer-connector wrench, an inner-connector wrench, and a coupling-nut wrench, as shown in Figure 1. The inner-connector wrenches are used for holding and installing both the insulating bead and the inner connectors. They also prevent possible damage to the keyway in the bead during installation which can result in misalignment of the inner and outer connectors. The outer-connector wrench and the coupling-nut wrench are used to install the outer connector and to tighten the coupling nut properly without marring the surface. These three wrenches, which are sold as a

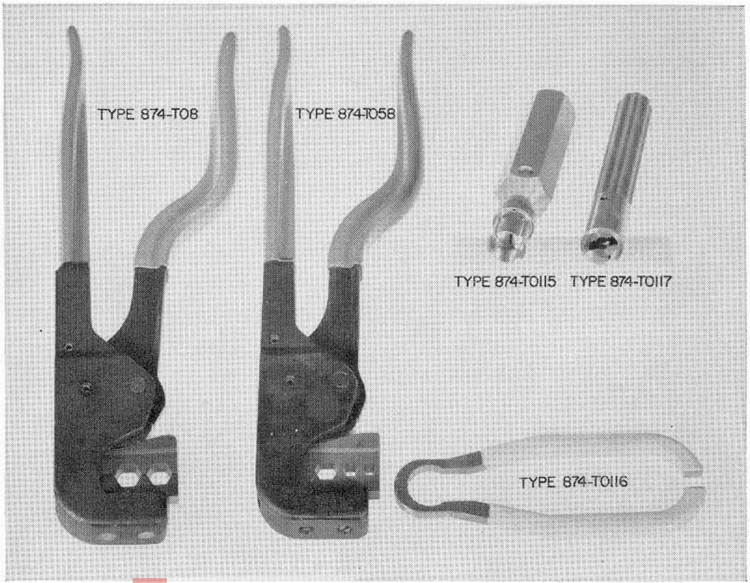


Figure 1. View of the assembly tools for assembly of Type 874 Coaxial Connectors. The three tools at the right, Types 874-TO115, 116, and 117, comprise the Type 874-TOK Tool Kit. The crimping tools are shown at the left.

unit, facilitate the installation of connectors on both rigid line and cable.

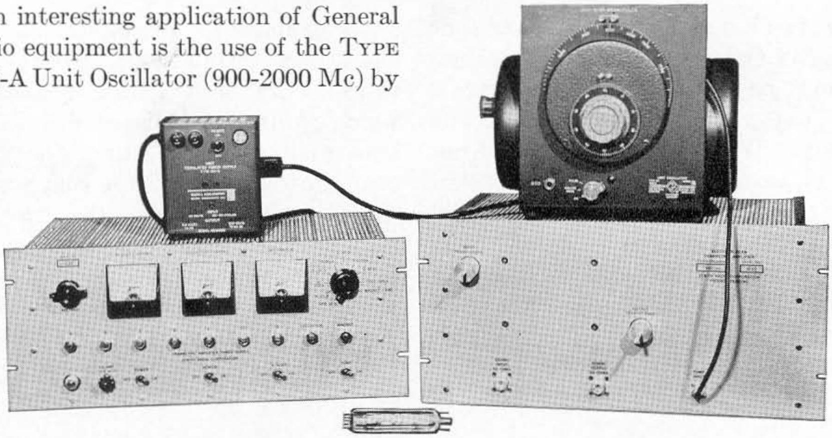
In the installation of shielded cable on cable connectors and panel connectors, a ferrule is crimped in place to secure the braid of the cable shield firmly to the shell of the connector. When large numbers of connectors are to be installed, or where the neatest possible crimp is wanted, the use of the TYPE 874-TO58 or the 874-TO8 Crimping Tools is recommended. These tools use hexagonal dies to produce a hexagonally shaped crimp. The appropriate tools for each 874-type cable or panel connector are indicated below.

Connector Type	*Crimping Tool Type*
874-C58, -P58, -PB58 874-C62, -P62, -PB62 874-C, -P, -PB	874-TO58
874-C8, -P8, -PB8 874-C9, -P9, -PB9	874-TO8

Type		*Code Word*	*Price*
874-TOK	**Tool Kit**	COAXKITTEN	**$20.00**
874-TO58	**Crimping Tool**	COAXCRIMPO	**75.00**
874-TO8	**Crimping Tool**	COAXCRIMBA	**85.00**

UNIT OSCILLATOR USED AS PUMP IN PARAMETRIC AMPLIFIER

An interesting application of General Radio equipment is the use of the TYPE 1218-A Unit Oscillator (900-2000 Mc) by the Zenith Radio Corporation to supply energy at the "pump" frequency in a parametric amplifier.



Shown in the photo is the Zenith Electron Beam Parametric Amplifier and associated power supply, together with a General Radio Unit Oscillator and regulated power supply.

Zenith is currently delivering Parametric Amplifiers in the frequency range of 350 to 1000 Mc (and soon 1300 Mc) and has selected General Radio Oscillators as standard equipment to "pump" the Parametric Amplifier.

Noise figures of the order of 1 db are observed over a wide band. Unconditional stability and high gain are characteristic of electron tube parametric devices.

General Radio Company

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IN THIS ISSUE

Standards and Accuracy

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CONTENTS

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GENERAL RADIO COMPANY

West Concord, Massachusetts

Telephone: (Concord) *EMerson 9-4400;* (Boston) *CLearwater 9-8900*

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: **6605 West North Avenue, Oak Park, Illinois**
Telephone — VIllage 8-9400

PHILADELPHIA: **1150 York Road, Abington, Pennsylvania**
Telephone — HAncock 4-7419

WASHINGTON: **8055 13th St., Silver Spring, Maryland**
Telephone — JUniper 5-1088

LOS ANGELES: **1000 North Seward St., Los Angeles 38, Calif.**
Telephone — HOllywood 9-6201

SAN FRANCISCO: **1186 Los Altos Ave., Los Altos, Calif.**
Telephone — WHitecliff 8-8233

CANADA: **99 Floral Parkway, Toronto 15, Ontario**
Telephone — CHerry 6-2171

REPAIR SERVICES

EAST COAST: **General Radio Co., Service Dept., 22 Baker Avenue, West Concord, Mass.**
Telephone — Concord, EMerson 9-4400
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NEW YORK: **General Radio Co., Service Dept., Broad Ave. at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
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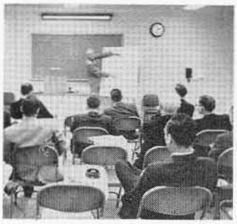


Ivan G. Easton, Vice-President for Engineering, addresses a calibration seminar group on the subject of capacitance bridges.

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

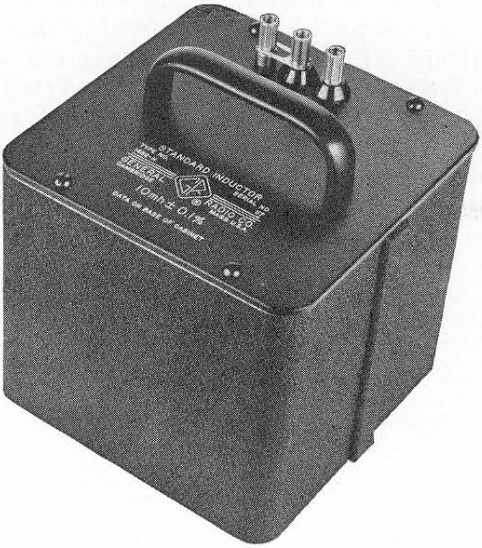
By absolute value of an electrical unit is meant the value of the unit as derived from the fundamental units of mass, length, time, and the permeability of space. The determination of, the maintenance of, and the dissemination of the electrical units are the responsibility of the National Bureau of Standards (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)%.

---

[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.

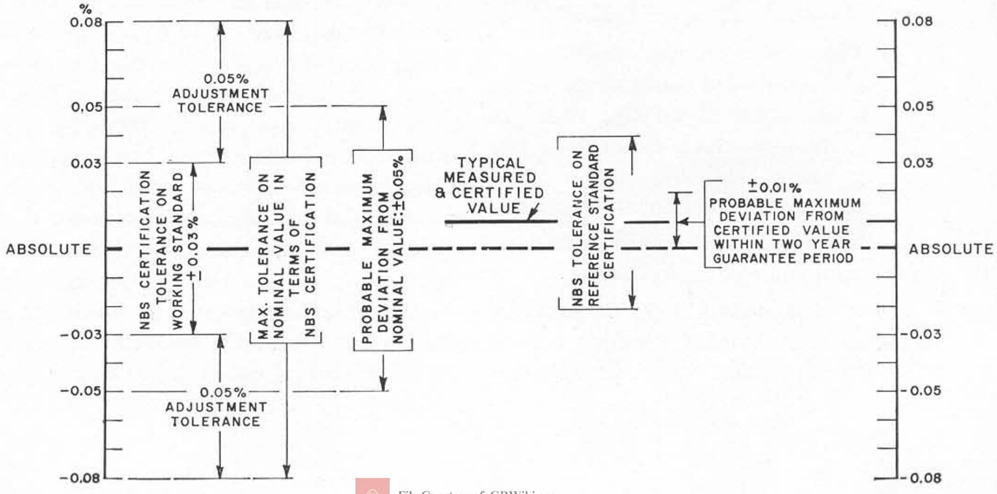
Figure 2. A 0.1-µf Type 1409 Standard Capacitor.

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 $1.0 \mu f$ with 1-2-5 values in each decade is sent to NBS periodically. Before ship-

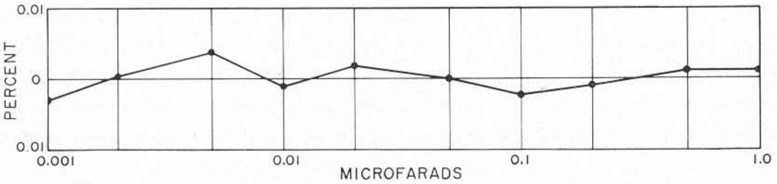


Figure 5. Plot showing consistency between General Radio-derived values and NBS calibration of General Radio reference standards after adjustment for over-all level.

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.

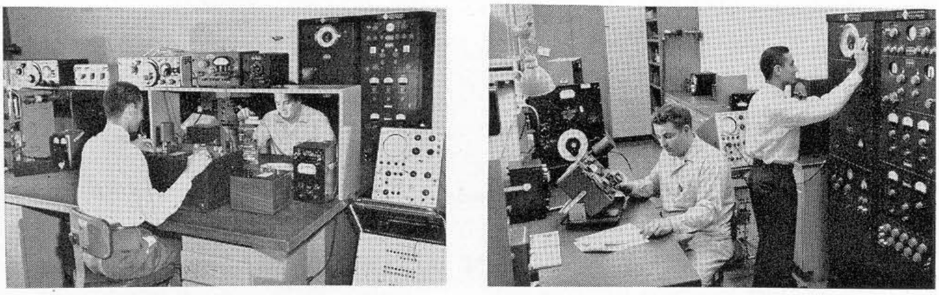
Subjects to be covered include pulsed stroboscopic lighting, optical high-speed cameras, Kerr cells, Faraday shutters, image converters, etc. Specialists in high-speed photography have been invited to cover their subjects at the seminar, and there will be practical laboratory demonstrations of many types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

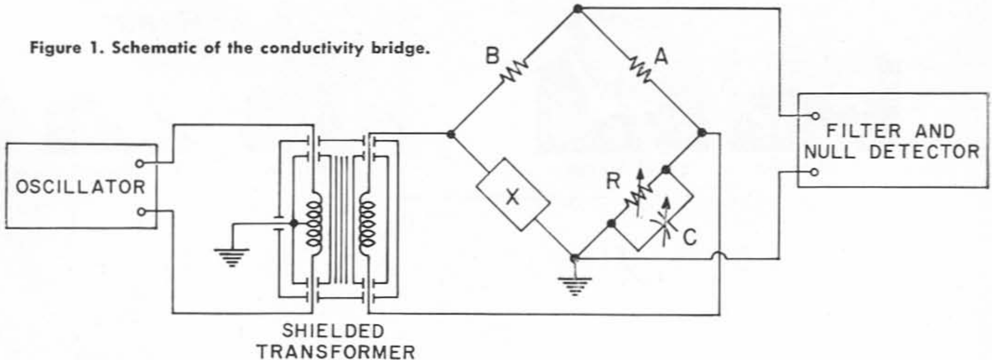


Figure 1. Schematic of the conductivity bridge.

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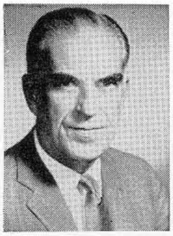
[1] Gary Felsenfeld and Sylvia Huang, "The Interaction of Polynucleotides with Cations," *Biochimica and Biophysica Acta*, Vol. 34 (1959), pp. 234-242.

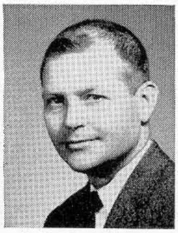
OUR 45th ANNIVERSARY


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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EXPERIMENTER

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IN THIS ISSUE

Tunnel-Diode Measurements

THE GENERAL RADIO EXPERIMENTER

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GENERAL RADIO COMPANY

West Concord, Massachusetts

Telephone: (Concord) *EMerson 9-4400;* (Boston) *CLearwater 9-8900*

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: **6605 West North Avenue, Oak Park, Illinois**
Telephone — VIllage 8-9400

PHILADELPHIA: **1150 York Road, Abington, Pennsylvania**
Telephone — HAncock 4-7419

WASHINGTON: **8055 13th St., Silver Spring, Maryland**
Telephone — JUniper 5-1088

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Telephone — HOllywood 9-6201

SAN FRANCISCO: **1186 Los Altos Ave., Los Altos, Calif.**
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Telephone — N. Y., WOrth 4-2722
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COVER

In Raytheon's Semiconductor Advanced Development Laboratory, William F. Moloney, Engineering Assistant Technical, measures tunnel-diode parameters with the General Radio Transfer-Function and Immittance Bridge. Inset shows details of coaxial mount.

MEASUREMENTS OF THE EQUIVALENT-CIRCUIT PARAMETERS OF TUNNEL DIODES

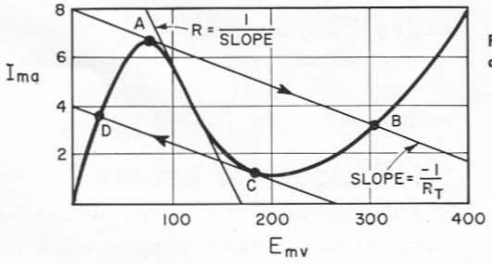
The measurement of equivalent-circuit parameters is of particular importance in the development of semiconductor devices, in the control of their uniformity in manufacture, and in their application in practical circuits. Tunnel diodes present unusual measurement problems, both because of their unstable behavior in the measuring circuit under certain bias conditions and because some of the characteristics to be measured are not directly accessible for measurement at the diode terminals. These problems, together with suggestions for their solution, will be discussed in this article.

Measurements are most conveniently made in the vhf-uhf ranges. Not only do the high-frequency characteristics give the best index of performance for practically all applications, but also the measuring instruments and circuits available at these frequencies offer the advantages of complete shielding and freedom from residual impedances that are characteristic of low-impedance coaxial systems.

TUNNEL-DIODE CHARACTERISTICS

The current-voltage relation for the tunnel diode is shown in Figure 1, and Figure 2 is an equivalent circuit. As is evident from Figure 1, the diode ac resistance, *R*, is a function of bias and can be either positive or negative. The capacitance, *C*, Figure 2, is also a function of bias, but changes more gradually. The small-signal ac characteristics of the diode are described in terms of the equivalent-circuit parameters, *L*, *C*, *R*, and R_s and of certain characteristic frequencies that are functions of these values, and which are usually defined in terms of operation in the region of minimum negative resistance. These frequencies are the self-resonant frequency, where the immittance of the diode is purely real, and the resistive cut-off frequency, where the immittance of the diode is purely imaginary, representing the upper frequency limit for diode negative resistance. A third characteristic frequency sometimes referred to is the oscillation frequency, which, by definition, is theoretically the frequency at which the diode will oscillate if short-circuited. In practice, the amplitude of this oscillation will be great enough to swing over the nonlinear region of the diode resistance and capacitance characteristics, so that the frequency of oscillation may not correspond to the true small-signal oscillation frequency.

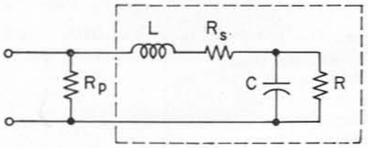
Figure 1. Current-voltage characteristic of a tunnel diode.



STABILITY CONSIDERATIONS

In the measurement of these quantities as well as in practical application of

Figure 2. Equivalent circuit of a tunnel diode (inside dotted rectangle), with shunting resistor, R_p, which stabilizes operation in a measuring circuit.



the diode, a number of precautions are necessary, owing to the negative-resistance, nonlinear, and multivalued-current characteristics of tunnel diodes. A shunt resistance, R_p, is generally required for stable operation. A specific choice of total circuit resistance is necessary for stability. Several modes of operation that depend upon this choice are shown graphically in Figure 3 as a function of the impedance, R_T, which is the sum of the diode resistance, R_s, and the equivalent source resistance, R_p'. The equivalent source resistance is, for ac, the shunt resistance, R_p, in parallel with the signal-source resistance. For dc, R_p' is R_p in parallel with the dc source resistance. If the dc circuit resistance of R_T is greater than the negative-resistance magnitude, R, operation will be unstable in the negative-resistance region. In Figure 1, R_T is large compared with the negative resistance, and, as the bias voltage is increased, the operating point of the diode will switch from A to B. If the bias voltage is then decreased, the operating point will switch back from C to D. If R_T is less than the negative resistance, no switching will occur. If the ac resistance of R_T is less than $\frac{L}{RC}$, the circuit will oscillate.

In the TYPE 1607-A Transfer-Function and Immittance Bridge, for example, the effective dc source resistance is the dc-bias-supply internal resistance, in series with the bias-filter resistance of 4 ohms. The ac source impedance at high frequencies is approximately 50 ohms at the operating frequency. At other frequencies the impedance may differ from 50 ohms, but will usually cause no difficulty if the shunt resistor is 50 ohms or less.

The stable region defined by $\frac{L}{RC} < R_T < R$ will vanish if the inductance L is greater than R^2C. With most currently available tunnel diodes, the package-and-holder inductance is small enough to permit stable operation. Since low-impedance diodes are necessarily designed with low parasitic inductances, the total circuit inductance between the diode and the equivalent source resistance R_p' must be exceedingly small. This is possible only in carefully designed mounts.

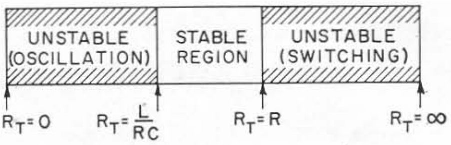


Figure 3. Modes of operation for the tunnel diode as a function of the total circuit resistance, R_T.

In the preceding analysis the source impedance is assumed to be purely resistive. In most practical applications this condition will not be exactly met, and the actual operating characteristics will differ somewhat from those outlined above. In actual measurements, in the negative resistance region, the best results have been obtained when the resistance of the shunt resistor itself is slightly lower than the minimum negative resistance of the diode.

As a further precaution, because the diode characteristic is nonlinear, the amplitude of the signal incident on the diode must be small. For the diode shown in Figure 1, a value of a few millivolts, rms, is a reasonable upper limit for small-signal measurements. Further, if a superheterodyne null detector is employed in the bridge measurements, local-oscillator leakage into the tunnel-diode circuit must not exceed a few millivolts.

DIODE TEST MOUNTS

The test mount for the diode must be designed to minimize stray inductance

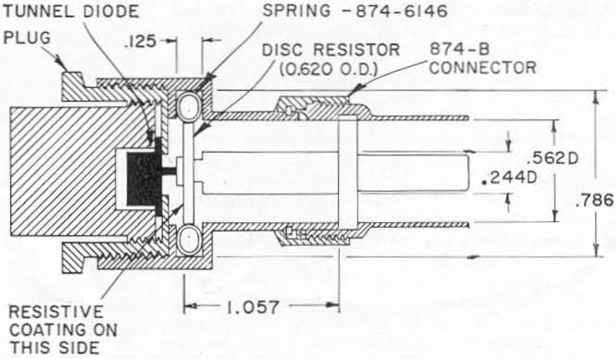


Figure 4. Suggested coaxial mount for connecting a tunnel diode into the measuring circuit.

The mount shown here is designed for the early Esaki diode manufactured by Sony, which has a single lead. A different arrangement is described in the article by Adler and Wonson (page 9) and is designed to accept the Raytheon CK40 type, which is in a microwave diode package. Diodes with two leads present a more difficult problem since the mount must be designed to accept the ground lead. For measurement purposes, the lead can be removed, but this is hardly a practical procedure for developmental and production testing.

and capacitance, particularly if the diode resistance, R, is low. Measurement accuracy is improved if the shunting resistor is located as close to the diode as possible, as shown in a suggested coaxial mount in Figure 4. This resistor should be lower than the negative resistance of the diode under test, be essentially noninductive, and have a negligible shunt capacitance. In coaxial systems film-type disk resistors are suitable. The electrical length of the coaxial mount shown in Figure 4 is equal to that of the General Radio TYPE 874-WN3 Short-Circuit Termination.

If a measurement of the diode capacitance and inductance outside the negative resistance region is desired, the shunting resistor is not necessary to obtain stable operation and can be omitted.

CHARACTERISTIC EQUATIONS

The diode admittance and impedance in terms of the circuit elements of the equivalent circuit, Figure 2, are

Admittance

$$G_e = -\frac{1}{R}\,\frac{1-\dfrac{R_s}{R}\left[1+(\omega CR)^2\right]}{\left(1-\omega^2LC-\dfrac{R_s}{R}\right)^2+\left(\dfrac{\omega L}{R}\right)^2\left(\dfrac{1-R\,R_s\,C}{L}\right)^2} \qquad (1$$

$$B_e = \omega C\,\frac{1-\dfrac{L}{CR^2}-\omega^2LC}{\left(1-\omega^2LC-\dfrac{R_s}{R}\right)^2+\left(\dfrac{\omega L}{R}\right)^2\left(1-\dfrac{R\,R_s\,C}{L}\right)^2} \qquad (2$$

Impedance

$$R_e = R_s - \frac{R}{1+(\omega CR)^2} \qquad (3$$

$$X_e = \omega\left[L - \frac{R^2C}{1+(\omega CR)^2}\right] \qquad (4$$

In these equations R is assumed to be negative, and no additional negative sign should be used.

CHARACTERISTIC FREQUENCIES

Self-resonant frequency

$$f_o = \frac{1}{2\pi\sqrt{LC}}\sqrt{1-\frac{L}{R^2C}} \qquad (5$$

Resistive cut-off frequency

$$f_{G_o} = \frac{1}{2\pi RC}\sqrt{\frac{R}{R_s}-1} \qquad (6$$

Oscillation frequency (low-level)

$$f_{osc} = \frac{1}{2\pi\sqrt{LC}}\sqrt{1-\frac{R_s}{R}} \qquad (7$$

Typical diode immittance-frequency characteristics are shown in Figures 5 and 6, for $R^2 < \frac{L}{C}$ except as shown.

Simplification of these expressions is required, in general, to relate the unknown quantity to be measured to the actual measured value. Measurement frequency and operating bias, forward and reverse, must be so chosen as to permit this simplification. The choice of measuring conditions is further restricted by measuring-instrument resolution. With some diodes, in particular some galium-arsenide types, the simplifications lead to only approximate values for the unknown quantities, regardless of operating conditions and measuring-instrument accuracy.

MEASUREMENT OF TUNNEL DIODE EQUIVALENT CIRCUIT ELEMENT VALUES AND FREQUENCIES

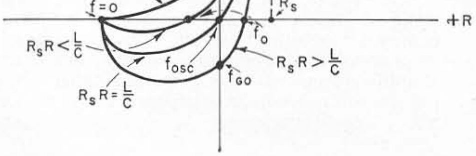
As indicated above, lead inductance between the diode and shunting resistance or between the diode and measuring terminals should be minimized to achieve stable operation in the negative-resistance bias region and to attain reasonable accuracy at any bias. Measurements are made at 25 Mc and above, and a coaxial mount, of the type shown in Figure 4, is necessary. The recommended measuring instrument is the TYPE 1607-A Transfer-Function and Immittance Bridge for frequencies up to 1500 Mc. Above 1500 Mc the TYPE 874-LBA Slotted Line can be used with appropriate provision for bias and in a reversed connection, that is, with the generator connected to the probe and the detector connected to the normal sending end of the line.

APPROXIMATE DIODE CIRCUIT VALUES NOT KNOWN

When the approximate negative-resistance value is not known, a dc measurement of the voltage-current characteristic will indicate the proper bias voltage and approximate negative-resistance value required to make a suitable shunting-resistance choice. When the other circuit constants are not known, the diode admittance or impedance is measured over a range of frequencies necessary to obtain a rough plot corresponding to Figures 5 and 6. From this plot the approximate self-resonant and resistive-cutoff frequencies can be obtained, as well as the upper boundary of the frequency range in which the measured conductance of resistance is essentially constant with frequency.

The desired characteristic frequencies and equivalent circuit constants can be determined from either admittance or impedance measurements. Admittance is the more convenient measurement, since the shunt admittance can be directly subtracted from the measured result to yield the diode admittance directly. When the diode impedance is low, however, better accuracy with the TYPE 1607-A Transfer Function and Immittance Bridge is achieved by an impedance measurement.

Figure 5. Plot of impedance characteristics as measured to obtain the approximate values for the self-resonant and resistive cut-off frequencies.



Measurement of Resistive Cut-Off Frequency, f_{G_o}

At the resistive cut-off frequency, the diode conductance is zero. With the shunting resistor installed, the frequency is sought at which the measured admittance is identically equal to the admittance of the shunt resistor. This frequency is best obtained by measurement, first of the shunt resistor alone and then of the diode plus the shunt resistor, at several frequencies in the expected range. A graph is made of these two measured values as a function of frequency to smooth the data and to reduce the number of measurements required. The frequency at which the two measured values are equal is the resistive cut-off frequency.

Measurement of Self-Resonant Frequency, f_o

At the self-resonant frequency, the diode susceptance or reactance is zero. Since the conductance at this frequency is high, measurement accuracy will be improved if impedance rather than admittance is measured. With the shunting resistor installed, the frequency is sought at which the diode reactance is zero. The diode impedance is measured over the region of the expected self-resonant frequency. A graph of reactance as a function of frequency is then made to smooth the data and to reduce the number of measurements required.

Measurement of Inductance, *L*

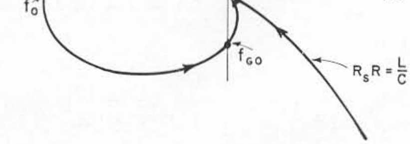
Back-Bias Method

With the diode biased in the reverse direction and in the ohmic region, the diode capacitance is essentially short-circuited, and inductance can be determined from an admittance measurement at some convenient frequency. From the diode reactance expression (equation 4), the following equivalent inductance expression is obtained:

$$L' = L\left[1 - \frac{1}{\omega^2 LC + \dfrac{L}{CR^2}}\right] \qquad (8$$

$$= L\left[1 - \frac{1}{\left(\dfrac{\omega}{\omega_r}\right)^2 + \dfrac{L}{CR^2}}\right] \cong L \qquad (9$$

Figure 6. Plot of admittance characteristics for determination of self-resonant and resistive cut-off frequencies.



where

L' = the inductance value measured

$$\omega_r = \frac{1}{\sqrt{LC}}$$

The diode capacitance, C, is, in this case, slightly lower than it is in the negative-resistance region.

Since the second term in the exact expression includes the unknown, L, it must be small, or the error in this approximation will be large. When $\frac{L}{CR^2}$ is sufficiently large (and this assumes that $\frac{L}{C}$ is known approximately), the measurement frequency choice is not critical. In order to reduce this term to 10% or less, then, at low frequencies (where $\left(\frac{\omega}{\omega_r}\right)^2 < \frac{L}{CR^2}\Big)$,

$$R \text{ must be less than } 0.3\frac{L}{C}$$

This requirement is met in most diodes, where typical values are $\frac{L}{C} = 100$, $R = 1$. A nominal low frequency choice would be about one fourth the self-resonant frequency, f_o. The shunt resistor is not required in this measurement.

Dummy-Diode Method

Since the diode inductance is principally in the connecting lead to the semiconductor element, an equivalent package can be made with the element replaced by a short-circuit. The inductance of this package can be measured without the above restrictions on frequency.

Capacitance Measurement

The diode capacitance can be directly measured at a frequency adequately below the self-resonant frequency. This capacitance can usually be measured in the negative resistance region, although instrument errors and errors from diode inductance and resistance can be serious. The frequency and diode ac resistance limitations are as follows:

From the diode susceptance expression (equation 2),

$$C' = C\,\frac{1-\frac{L}{CR^2}-\omega^2 LC}{\left(1-\omega^2 LC-\frac{R_s}{R}\right)^2+\left(\frac{\omega L}{R}\right)^2\left(1-\frac{R\,R_s\,C}{L}\right)^2} \qquad (10$$

Where C' = apparent capacitance as measured.

The right-hand term therefore should be made to be near unity for maximum accuracy. The first step to achieve this is to lower the measurement frequency. If the capacitance is to be measured to within 10%, then

$$f_m << \frac{1}{8\pi\sqrt{LC}} \text{ assuming that } R^2 > \frac{10L}{C}$$

If the measurement frequency is well below this limit (it should not be so low that the capacitance susceptance is comparable to instrument resolution), the measured capacitance reduces to

$$C' = C\left[1-\frac{L}{CR^2}\right]$$

When $R >> R_s$

It is assumed that the diode circuit parameters are approximately known to permit the frequency choice.

The error term is therefore $\frac{L}{CR^2}$, which is independent of frequency.

If reasonably accurate measurements are desired in the negative-resistance region, this error term must be appropriately small. There is no means of controlling the error except by a bias shift away from the region where the negative resistance is the smallest or by a reduction in L. In fact, for some diodes it may be necessary to operate nearer the peak and valley regions to obtain sufficient accuracy, as shown in Figure 7. In this figure, representing the low-frequency case, the effect of R^2 approaching $\frac{L}{C}$ is shown. The extreme case where $R^2 \leq \frac{L}{C}$ is not usually encountered in practical diodes, since this corresponds to the oscillation region overlapping the switching region operation.

For a diode with $C = 40$pf, $L = 2$mμh, $R = 30$ ohms, $R_s = 1$ ohm, a suitable frequency is between 30Mc and 70Mc, and the measurement in the negative-resistance region will not yield greater than a 10% error. Sometimes the condition $|R^2_{min}| > 10\frac{L}{C}$ is not met. In this case, operation at or near the peak and valley points, where the diode ac resistance is large, usually yields reasonably accurate results.

In addition to the errors mentioned above, the measuring instrument can introduce a further error in the negative-resistance region. In most instruments, when the resistance component of the network under test changes greatly, a small error in the reactive component will be produced. When the measured reactive component is small, the percentage error can be large.

Negative Resistance or Conductance Measurement

For this measurement the same conditions and approximately the same frequency-choice considerations apply as for capacitance measurement. The resistance expression (3) reduces to

$$R' = R - R_s$$

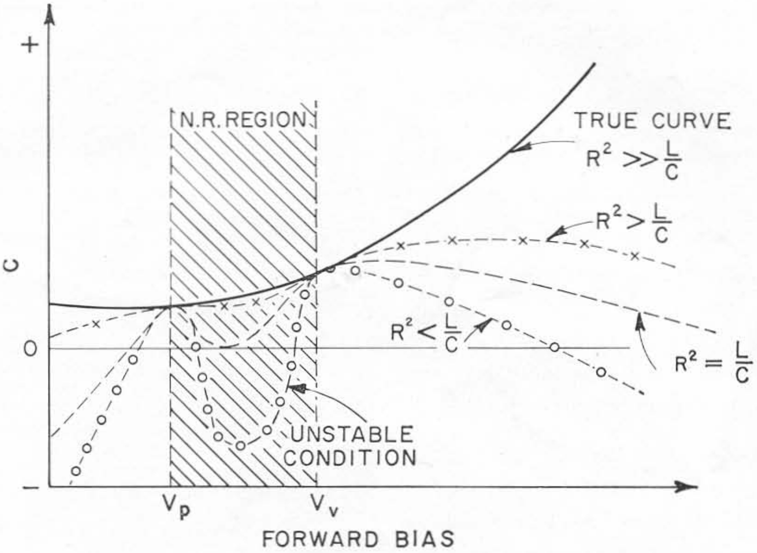


Figure 7. Plot showing how the magnitude of R^2 as compared with that of $\frac{L}{C}$ affects the measured values of capacitance.

where

R' = measured value

Usually R_s is sufficiently smaller than R that: $R' \cong R$, or $G' \cong G$

Series Resistance Measurement, R_s

Either of two procedures may be used. The first, the resistive cut-off frequency method, is reasonably accurate if the negative resistance and capacitance values are known accurately. The second, the back-bias method, yields an upper limit to this value and is accurate in most cases, since the actual series resistance and the diode back resistance, in series, are measured.

Resistive Cut-Off Method

The resistive cut-off frequency is measured as described in a preceding section. The capacitance, C, and the negative resistance, R, are measured as described above.

R_s is calculated from the expression:

$$R_s = \frac{R}{(R\omega_{G_0}C)^2 + 1}$$

where R, ω_{G_0}, and C are measured values.

Back-Bias Method

In the back-bias measurement, the diode impedance expression reduces to

$$Z_e = (R_s + R) + j\omega L$$

At a sufficiently large value of back bias, the barrier resistance, R, becomes very small, and

$$R_s \cong R_e$$

where R_e is the measured value. The shunt resistor is not required for this measurement.

Impedance vs. Admittance Measurements

In the measurement of the diode element values, greater accuracy is obtained if impedance and not admittance is measured when the impedance is much less than 50 ohms. The subtraction of the shunt impedance from the measured impedance to obtain the diode admittance is more complex in this case:

$$Y_e = \frac{1}{Z_m} - \frac{1}{Z_p}$$

where Z_m = measured impedance, diode plus shunt.

Z_p = measured shunt impedance.

Specific procedures for measuring tunnel diodes will be described in the Operating Instructions for the Type 1607-A Transfer-Function and Immittance Bridge.

— John Zorzy

The following article, published through the cooperation of the Raytheon Company, discusses a practical example of tunnel-diode measurements, made on that company's CK40 series developmental diodes.

THE USE OF THE GENERAL RADIO IMMITTANCE BRIDGE IN TUNNEL-DIODE MEASUREMENTS

by

E. Adler and R. C. Wonson*

The General Radio Transfer-Function and Immittance Bridge, Type 1607-A, arranged with the immittance indicator in place, is highly suitable for making measurements of tunnel-diode parameters. The plane where the actual measurements are made may be easily adjusted and determined, bias can easily be applied to the diode and spurious oscillations damped out, and no difficulty stands in the way of making measurements, either over a range of bias voltages in order to obtain detailed information on the behavior of the diodes, or at a very limited number of bias points so as to permit the rapid relative classification of a group of diodes. These remarks are made on the basis of considerable experience gained in the use of the bridge, further details of which are set out below.

The discussion that follows is limited to the measurement of the diode capacitance and negative conductance. The series inductance, being constant for a given package design, need be measured only once, possibly by use of a dummy diode. The series resistance may most easily be measured at conditions of very

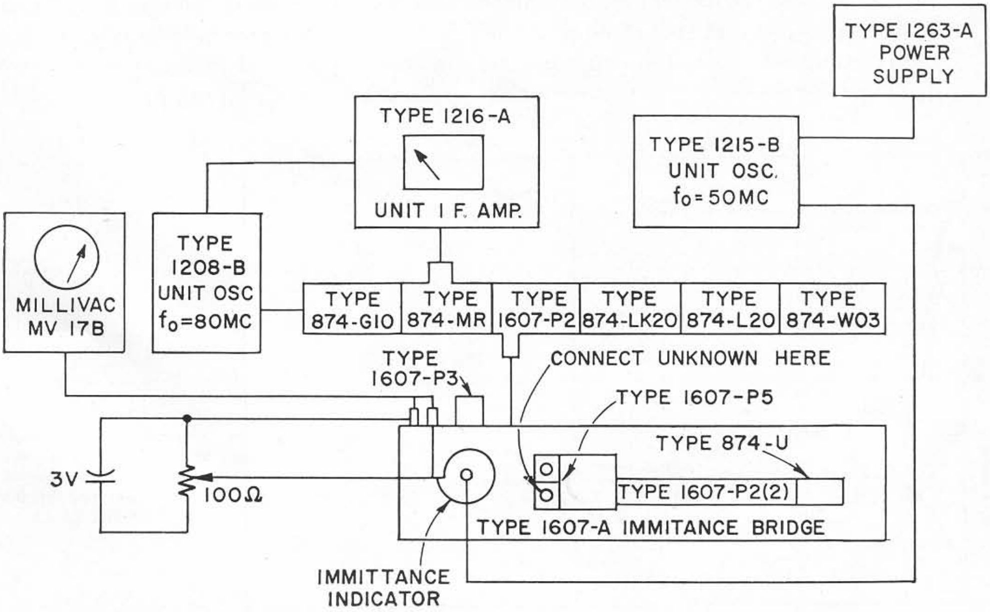
---

*Raytheon Co., Semiconductor Div., Newton, Mass.

Figure 1. Block diagram of the measuring equipment. Items not identified by name are:

Type 874-G10 Fixed Attenuator (10 db)
Type 874-MR Mixer Rectifier
Type 874-LK20 Line Stretcher
Type 874-L20 20-cm Air Line
Type 874-WO3 Open-Circuit Termination
Type 1607-P2 Tee Assembly
Type 1607-P3 Air Capacitor
Type 1607-P5 Range Extension Unit

The last three items are supplied as a part of the bridge.



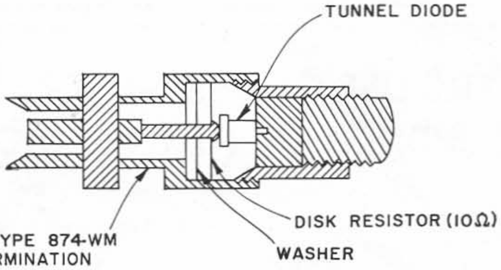


Figure 2. Coaxial mount used to connect the diode to the bridge. See also cover photo.

large applied reverse bias, in which case methods employing techniques other than those associated with the bridge presently considered are preferable, except where a high-frequency measurement is specifically desired.

The conditions of measurement were similar to those outlined in the preceding article; a shunt resistor was used, to assure that the unknown element presented a positive conductance to the bridge; the mount was designed to locate the measurement point in the plane of the diode junction; and the signal level was kept low, one millivolt or less.

A block diagram of the bridge and ancillary equipment used for the tests described is shown in Figure 1. It was found necessary to construct a coaxial mount* to hold the diodes and the stabilizing resistor, so that the whole could be easily plugged into the appropriate bridge terminal. A modified General Radio Type 874-WM 50-ohm Termination was found to be easily adapted for this purpose (see Figure 2). The final unit consists of the 874-WM shell, a 10-ohm disk resistor, and fittings to hold the diode in place. A disk resistor is used, not only for convenience but also, and more importantly, to keep the series inductance in the diode-plus-parallel-resistor circuit low and thus very effectively to satisfy the diode stability criterion; in addition, this arrangement keeps the circuit to be measured as nearly as possible in one plane.

The successive steps in the measurement procedure are as follows:

1) The initial setting up of the bridge consists of setting the output line to one half wavelength and "trapping out" the local oscillator signal as prescribed in the instruction manual in order to prevent parasitic signals from reaching the diode.

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*After a design by S. Cohen of Raytheon Co. (Research Div.).

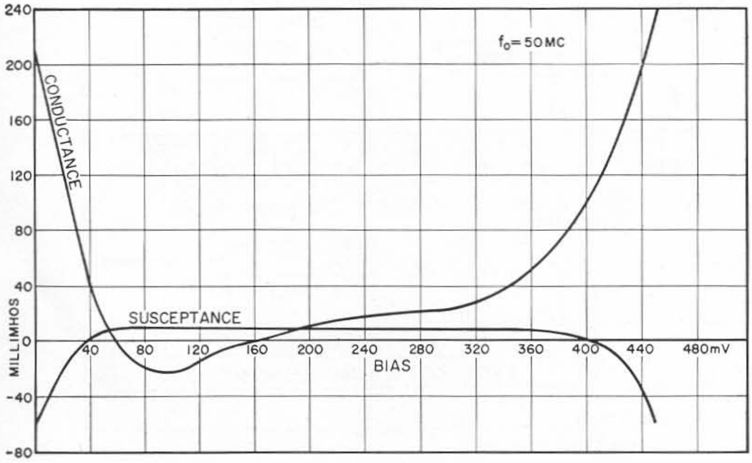

Figure 3. Admittance characteristics of Raytheon CK40 series diodes as a function of bias, measured at 50 Mc.

The correct setting of the output line may be performed with an 874-WN3 Short Circuit in place of the diode holder if desired, since this provides substantially the same reference plane as the latter. Alternatively a special (short circuited) diode may be placed in the holder; this choice is better in principle, since any lead inductance effects should be automatically compensated.

2) The admittance of the diode mount must be measured with the resistor, but no diode, in place. This value can then be subtracted from the readings taken with the diode in place, to obtain the true diode values.

3) A bias calibration is required. The components in the decoupling circuits which isolate the coaxial bridge lines from the external bias supply include series chokes having relatively large resistances. The complexity of the relation between the voltage applied to the bias terminals on the bridge and the actual bias applied at the diode will depend on the division of current between the diode and the stabilizing resistor, and thus it is simplest to take a direct calibration, connecting a coaxial tee between the diode mount and the bridge socket for this purpose. The tee should be removed when the diode admittance measurements are made.

4) The actual diode admittance measurement is made, the results being adjusted in accordance with (2) above.

Figure 3 shows typical results obtained from measurements, using the above techniques, made on a number of Raytheon CK40 series developmental tunnel diodes. These curves possess the shapes to be expected on the basis of theoretical predictions and agree closely with results obtained by alternative methods. It is intended to include a more detailed discussion of this subject in another article, but it might be mentioned that the change of diode susceptance from capacitive to inductive values at the extremes of the bias range is erroneous, being caused by the inductance and the decrease in diode resistance so that R^2 is not large compared with $\frac{L}{C}$. The effect of series inductance can be carried to the limit, i.e., to the extent where resonance with the diode capacitance takes place, by measurement at a higher frequency. Figure 4 shows curves obtained at a frequency of 500 Mc.

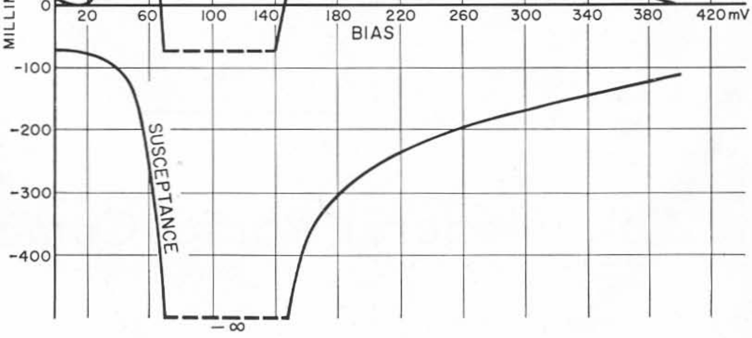

Figure 4. Admittance characteristics as measured at 500 Mc.

It should be pointed out that, under some circumstances, there are advantages in measurement at lower frequencies, and it is possible to operate the bridge at frequencies below the manufacturer's prescribed limit provided care is taken in connection with such difficulties as these:

a) self-resonance of the bias-circuit filters can occur, so that measurements must be confined to frequencies on either side of this resonance.

b) the three coupling circuits from the generator to the bridge elements become progressively less efficient as frequencies are lowered, but this problem can be overcome by the use of a detector having sufficiently high sensitivity.

c) the half-wavelength line connected in the "unknown" arm of the bridge can become very long and it may be necessary to use high-grade air line to keep losses to a minimum.

The modified microwave-diode-package form of the Raytheon tunnel diode, giving the advantage of very low series inductance, is well suited for connection to the Immittance Bridge. Diodes encapsulated in different packages, e.g. standard JETEC cases or designs intended for strip-line applications, can also be measured provided suitable jigs and fixtures are designed.

WESCON 1960

GENERAL RADIO COMPANY

BOOTHS 957-958

Measurements on semiconductors will be a feature of the General Radio exhibit at Wescon 1960. Operating exhibits will demonstrate the measurement of tunnel-diode parameters with the TYPE 1607-A Transfer-Function and Immittance Bridge and the rapid measurement of small capacitances in transistors and diodes with the TYPE 1605-A Impedance Comparator.

Other instruments in operating displays include:

TYPE 1300-A Beat-Frequency Video Generator

TYPE 1390-B Random-Noise Generator

TYPE 1554-A Sound and Vibration Analyzer

TYPE 1521-A Graphic Level Recorder

TYPE 1570-A Automatic Voltage Regulator

TYPE 1650-A Impedance Bridge

Variac® Autotransformers with *Duratrak* contact surface will also be displayed.

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IN THIS ISSUE

NEW STROBOTAC®

THE GENERAL RADIO

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CONTENTS

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GENERAL RADIO COMPANY

West Concord, Massachusetts

Telephone: (Concord) *EMerson 9-4400;* (Boston) *CLearwater 9-8900*

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: **6605 West North Avenue, Oak Park, Illinois**
Telephone — VIllage 8-9400

PHILADELPHIA: **1150 York Road, Abington, Pennsylvania**
Telephone — HAncock 4-7419

WASHINGTON: **8055 13th St., Silver Spring, Maryland**
Telephone — JUniper 5-1088

LOS ANGELES: **1000 North Seward St., Los Angeles 38, Calif.**
Telephone — HOllywood 9-6201

SAN FRANCISCO: **1186 Los Altos Ave., Los Altos, Calif.**
Telephone — WHitecliff 8-8233

CANADA: **99 Floral Parkway, Toronto 15, Ontario**
Telephone — CHerry 6-2171

REPAIR SERVICES

EAST COAST: **General Radio Co., Service Dept., 22 Baker Avenue, West Concord, Mass.**
Telephone — Concord, EMerson 9-4400
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NEW YORK: **General Radio Co., Service Dept., Broad Ave. at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

MIDWEST: **General Radio Co., Service Dept., 6605 West North Ave., Oak Park, Illinois**
Telephone — VIllage 8-9400

WEST COAST: **General Radio Co., Service Dept., 1000 North Seward Street, Los Angeles 38, Calif**
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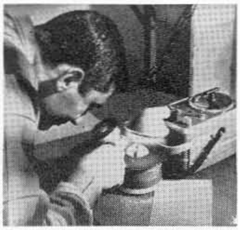

At Acoustic Research, Inc., of Cambridge, Massachusetts, the Strobotac casts new light on the performance of loudspeaker radiators.

NEW EYES FOR MODERN INDUSTRY

The Type 1531-A Strobotac®

WHAT IS THE STROBOTAC®?

The Strobotac® is a stroboscope, an instrument now familiar to nearly all mechanical and electrical engineers. It supplies intermittent illumination in the form of short, brilliant flashes of light, repeating at a controllable and known rate.

The word *stroboscope* comes directly from the Greek *strobos*, a whirling, and *scopos*, watcher. With the stroboscope, we can watch things that whirl (as well as things that vibrate and reciprocate), and from that watching we can derive a great deal of useful information about the thing that whirls.

By intermittent, periodic illumination of the whirling object, at a rate nearly equal to its rate of rotation, the object is seen in apparent slow motion, disclosing all the fine detail of its actual motion. When the rate of viewing is equal to the rate of rotation of the object, the object appears stationary, and, if the rate of illumination is known, the stroboscope becomes a tachometer. Hence the name *Strobotac®*, from *stroboscopic tachometer*.

The new Type 1531-A Strobotac represents the most important advance in commercial stroboscope design since 1935, when General Radio first introduced the now familiar Strobotac® stroboscopic tachometer. The new instrument offers a combination of performance characteristics not hitherto available in any commercial stroboscope, and it opens up many new fields of application for stroboscopic techniques.

A radically new Strobotron lamp, developed by Edgerton, Germeshausen & Grier, Inc., in cooperation with General Radio Company, provides three very important improvements in performance characteristics:

1. A white light flash, rather than red, produces higher contrast in the viewed image and makes objects appear in their natural colors. Also, the very much higher resolving power of the human eye for white light as compared to red light permits finer detail to be seen with less strain.

2. Higher light intensity, over 70 times as bright, allows effective use under normal room-lighting conditions and also allows objects deep inside a machine to be adequately illuminated.

3. Shorter flash duration, by a factor of 10 to 20 — 0.8 μsec at high flashing rates — allows a corresponding increase in the upper limit of speed of the viewed object.

Supporting this improved performance are many other major improvements in electrical performance and mechanical design, which contribute greatly to the utility, adaptability, and ease of handling of the new Strobotac.

4. Higher frequency range — from 110 rpm to 25,000 rpm in three ranges — permits direct measurement of 400-cycle devices.

5. Light beam is adjustable 180 degrees vertically and 360 degrees horizontally, so that the light beam can be aimed for best illumination of the object being viewed while the panel is positioned for convenient control manipulation and anti-parallax dial readings.

Figure 1. View of the Strobotac with case in totally open position. The convenient, large rpm dial is easily gripped by the hand for precise flash-rate setting.

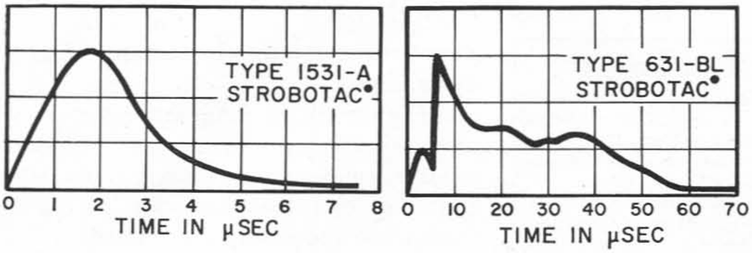

Figure 2. These plots show the marked improvement in flash duration in the new instrument. Both plots are for high-intensity, low-flash-rate conditions. Vertical scales are not comparable. Peak light intensity is about 70 times as great for the new instrument.

6. Flip-tilt case, which provides an adjustable stand for bench use and a permanently attached cover, which totally encloses the instrument for storage or transit.

7. Simplified controls—direct-reading rpm dial requires no multiplying factors, and only the range scale in use is visible.

8. Sensitive input circuit is easily triggered by an external mechanical contact or by electrical signals — only 6 volts, peak to peak, required.

9. Substantially smaller in size and lighter in weight, the new instrument can be held in one hand.

10. Neon calibrating lamp is located on panel, so that calibration can be easily checked at many speed settings.

New Strobotron Lamp

The new lamp produces a white light flash by an electrical discharge through xenon gas. Figure 2 shows a comparison of the light output pulses obtained from the new and old Strobotacs. Not only is the duration of the pulse much less for the new model, but the long tail characteristic of the neon Strobotron tube is not present in the new xenon tube, which results in much sharper definition of fast moving objects. Measured between the points at which the light intensity is one-third of peak light value, the light-pulse width of the Type 1531-A Strobotac is approximately 0.8 μsec, 1.2 μsec, and 3 μsec, on the low, medium, and high intensity positions, respectively.* On the other hand, the old Type 631-BL Strobotac has 11-μsec and 40-μsec pulse widths on the low- and high-intensity positions, respectively. The physical length of the arc is ⅜ inch, so that a narrow beam angle, with high illumina-

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*Measured at 10 per cent of peak intensity, the durations are 1, 3, and 6 μsec.

Figure 3. Two views of the new Strobotac, showing (*left*) flip-tilt case closed for carrying and (*right*) open with panel locked in tilted position for convenient use.

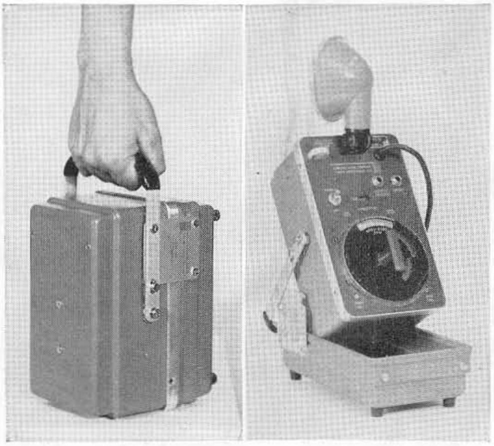
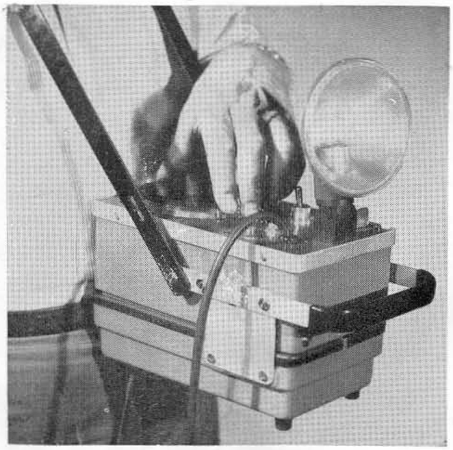


Figure 4. This adjustable neck strap supplied with the Strobotac frees the operator's hands for other functions.



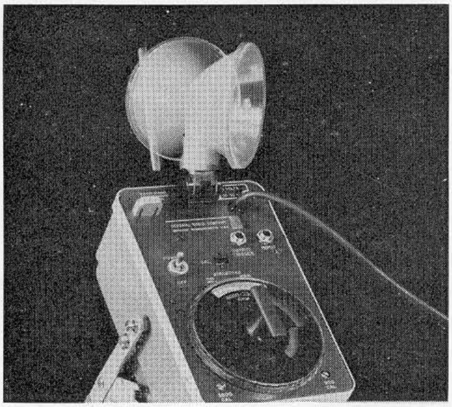


Figure 5. This multiple-exposure photograph illustrates the 360-degree reflector rotation. Hinged lamp assembly permits additional positioning in vertical plane.

tion of distant objects, can be achieved with a small diameter reflector. The life of the Strobotron is also improved, and the average user should be able to obtain between 500 and 1000 hours of operation before the lamp need be replaced.

Mechanical Features

The Type 1531-A Strobotac is housed in the flip-tilt case* now used for many new General Radio portable instruments. The permanently attached cover of this case can be locked in either the totally closed or the totally open positions, thus providing protection in storage or transit without being in the way when the instrument is in use. The tilting feature is very convenient when the instrument is to be used on a bench top. A neck strap is provided for supporting the instrument, so that the operator's hands can be free, if desired. (See Figures 3 and 4.)

The lamp arm is hinged to provide 180 degrees of travel, and the reflector rotates 360 degrees around a second, perpendicular axis to provide free aiming of the light beam. The multiple-exposure photograph (Figure 5) shows the reflector in three positions. The reflector is securely held to the lamp arm by means of a spring-loaded detent button, which allows the reflector to be removed easily for replacement of the Strobotron tube. A small amount of dispersion is built into the surface of the reflector, so that a nearly uniform light pattern is produced over the 10 degree width of the light beam.

All controls are located on a single panel, as shown in Figure 6. The range-selection switch and rpm control dial are concentric for ease of operation. Three rpm ranges provide flashing rates from 100 rpm to 25,000 rpm. The range in use is illuminated, while all others are covered by a mask attached to the range-selection knob to prevent confusion in reading the dial.

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*Patent pending.

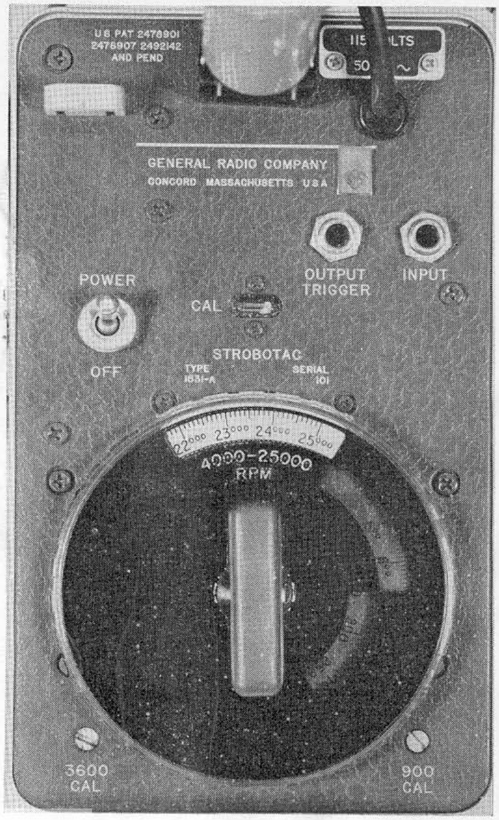

Figure 6. View of the panel, showing scale, mask, dial, and other conveniently arranged controls.

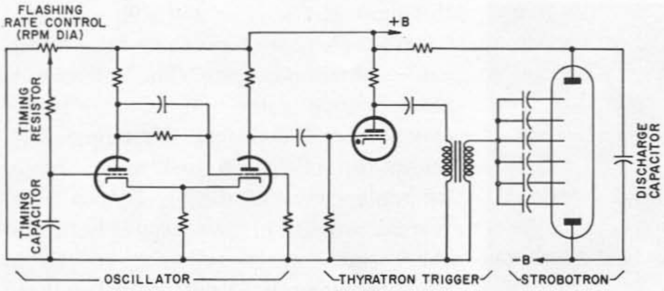

Figure 7. Elementary schematic of the circuit used in the Type 1531-A Strobotac.

A power switch is provided separate from the range-selector switch, and a six-foot power cord is permanently attached to the instrument. The cord can be conveniently stored when wrapped around the reflector housing and range knob (see Figure 6).

For maintenance or servicing, the instrument can be easily removed from the case. One etched board is hinged, so that all parts are readily accessible.

Oscillator Circuit

The internal oscillator used in the new Strobotac is a free-running, amplitude-sensitive, bistable circuit that is a modification of the familiar Schmitt circuit. The frequency at which this circuit operates is determined by a resistor-capacitor combination connected to the input and a variable dc voltage. When the dc voltage is changed, the charging rate of the capacitor and the time between output pulses change. The flashing-rate control (rpm dial) is a potentiometer, by means of which the dc voltage can be varied to produce a flashing-rate range of 6.25:1. The rpm scale is essentially linear with dial rotation. A 6-to-1 change in frequency is obtained between ranges by a corresponding change in the timing capacitor. Trimming resistors, set at the factory, are used to correct for small variations in capacitor values so the three ranges track properly.

External Trigger

When the range switch is set in any of the external-input positions, the oscillator circuit is converted into a conventional amplitude-sensitive Schmitt circuit. In these positions the flashing-rate control (rpm dial) adjusts the bias on the input grid and hence the sensitivity of the circuit.

It is possible to trigger the Strobotac from electrical input signals as well as from a mechanical contactor. An input signal of at least six volts, peak to peak, is necessary. When the input electrical signal is near the minimum required amplitude, satisfactory triggering is obtained by careful adjustment of the bias (rpm dial). If the input signal amplitude is large, satisfactory triggering will result over a wide range of rpm dial settings. With large-amplitude signals, a change of dial setting will vary the point on the positive-going edge of the signal that causes the Strobotron tube to fire. With a sine-wave input signal it is possible to vary the firing point over a range of approximately 120 degrees. This phase adjustment is not possible, obviously, with steep-wave-front signals.

Although the upper limit of the internal oscillator is 25,000 rpm, or approximately 420 cps, external triggering is usually possible at frequencies as high as 45,000 rpm (750 cps). The upper frequency limit depends on the characteristics of the individual Strobotron tube and will appear either as erratic operation of the tube or the formation of a low-intensity, continuous arc, called "hold-over."

For triggering by a mechanical contactor, part of a dc voltage divider is shorted by the contactor to generate the signal into the Schmitt circuit. Since a positive-going signal is necessary to produce the correct polarity trigger to operate the Strobotron, the light flash occurs on the *opening* of the mechanical contact, rather than on the closing. Because the time between opening and closing of the mechanical switch is usually sufficient for the Strobotron circuit to recover, care should be taken to eliminate contact bounce, which will produce unwanted extra flashes.

Calibration

Calibration is accomplished with a neon bulb rather than the vibrating reed used in the previous model. One element of the neon bulb is excited from the power-line voltage and the other element from the voltage across the Strobotron. As the flashing rate of the Strobotron approaches either the fundamental or a harmonic of the power-line frequency, the neon light intensity will vary at a rate equal to the difference frequency. Two front-panel adjustments are available for calibrating the rpm dial at 3600 rpm and 900 rpm*. Calibrations can also be made at other dial settings, between about 600 and 7200 rpm, which are integral or fractional multiples of the power-line frequency. When the best possible accuracy of speed measurement is desired, a calibration point can often be found near the speed setting used. Calibration is made difficult below 600 rpm by flicker and above 7200 by the low amplitude of the light-intensity variation.

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*3000 and 750 rpm when the power-line frequency is 50 cycles, 24,000 and 6000 rpm when it is 400 cycles.

SPECIFICATIONS

Flashing-Rate Range: 110 to 25,000 flashes per minute in three direct-reading ranges, 110 to 690, 670 to 4170, and 4000 to 25,000. Speeds up to 250,000 rpm can be measured.

Accuracy: One per cent of dial reading after calibration on middle range.

Calibration: Two screw-driver adjustments are provided on the panel for calibration against power-line frequency.

Flash Duration: Approximately 0.8, 1.2, and 3 μsec for high-, medium-, and low-speed ranges, respectively, measured at ⅓ peak intensity.

Peak Light Intensity: 0.21, 1.2, and 4.2 million-beamcandlepower minimum on high-, medium-, and low-speed ranges, respectively; 7 million-beamcandlepower for single-flash.

Reflector Beam Angle: 10 degrees at half-intensity points.

Output Trigger: 600 to 800 volts negative pulse available at a panel jack.

External Triggering: Strobotac can be triggered with a mechanical contactor or 6-volt peak-to-peak signal. (2-volt rms sine-wave signal down to 5 cps.)

Power Supply: 105-125 (or 210-250) volts, 50-60 cycles or 400 cycles.

Maximum Power Input: 35 watts.

Tube Complement: 4-1N1695, 2-NE2H, 1-5965, 1-5727, 1-1531-P1 Strobotron.

Accessories Supplied: Adjustable neck strap, plug to fit input and output jacks, 3-wire to 2-wire power-cord adaptor, spare fuses.

Mounting: Aluminum case with attached cover and carrying handle, gray-wrinkle finish.

Dimensions: 10⅝ x 6⅝ x 6⅛ inches, over-all, including handle.

Weight: 7⅛ pounds.

Type		*Code Word*	*Price*
1531-A	**Strobotac®**	BELAY	**$260.00**
1531-P1	**Replacement Strobotron**	DRUID	**15.00**

U. S. Patent Numbers: 2,478,901; 2,478,907, and 2,492,142.
Patent Pending.
Licensed under designs, patents, and patent applications of Edgerton, Germeshausen & Grier, Inc.

THE STROBOTAC AT WORK

The original Strobotac of 25 years ago changed the stroboscope from a laboratory toy to a reliable, inexpensive, industrial instrument, which has become an important factor in the design, operation, and maintenance of mechanical and electromechanical equipment. The new TYPE 1531-A Strobotac, with its greatly improved light intensity and flash duration of a few microseconds, provides industry with a tool of increased effectiveness for the study of not only conventional machines but also of today's high-speed and miniaturized mechanisms. Studies can be conducted now in normal room lighting, and the greatly improved clarity produced by the "sharp" flash makes possible the study of fine details that hitherto could not be seen. Where the part to be studied is inaccessible, the Strobotac's strong beam of light can usually be made to reach it. This feature, coupled with the versatility provided by the pivoting lamp, permits the instrument to be located conveniently and operated by one man, while the same man observes the results without the aid of an assistant. Extensive field testing, carried out over the past year, has proved the complete acceptability of the new design and has brought to light many interesting new applications, a few of which are discussed below.

The new Strobotac operates satisfactorily from 400 cycle power lines as well as from 50-60 cycle lines, which is a great convenience in aircraft applications.

Figure 8. The Strobotac produces enough light to "stop" the motion of the fan through the eight layers of glass in the door of this altitude chamber. Some reflection is produced by the glass layers, but its effect is minimized by aiming the Strobotac flash into the chamber at an angle rather than head on. The new instrument's increased speed range now makes it possible to measure directly the speeds of fans operating at 400 cycles (24,000 rpm), which are commonly used in aircraft.

Low-Power Devices

Speeds of fractional-horsepower motors cannot be measured by ordinary tachometers, because the load of a conventional tachometer alters operating conditions. The Strobotac, because it requires no mechanical or electrical connection to the motor, is the ideal tachometer for this use. Its usable accuracy of one per cent is better than that of most ordinary tachometers.

Measurements are made to determine: normal operating speed, speed variation due to line-voltage changes, speeds at various conditions of overload and underload, torque-speed characteristics, and critical speeds at which vibration occurs. By slow-motion observations, brush action can be studied, and chattering caused by commutator eccentricity as well as vibration of frame and parts can often be detected.

Measurement of torque with the Strobotac is a widely used technique. When the motor and load shafts are connected by an elastic coupling, and the rotational motion is stopped by the stroboscope, the position of a pointer on the spring coupling will change as the driven shaft is loaded. With the addition of a calibrated scale, the system becomes a torque meter.

Air-Moving Devices

In the stroboscopic study of the operation of fans [illegible] blowers, vibration can be located, and air currents around the blades can be observed through [illegible] use of chemical "smokes" introduced into [illegible] air stream. This technique has led to a considerable improvement in fan design.

At Rotro[illegible] Manufacturing Company, the Strobotac serves as the principal test instrument for speed measurements and the analysis of structural weaknesses of air-moving devices of all types. Blade resonances of developmental units are detected visually while the units are subjected to vibration on shake tables. Tests in altitude and pressure chambers are made to determine performance of fans that are to operate at high altitudes or are to push heavier-than-air gases. Other laboratory work includes dynamometer measurements and air-delivery tests in which it is important to measure speed accurately under pressure.

Figure 9. The bright Strobotac beam penetrates both an oil bath and the tube envelope to illuminate a rotating-anode X-ray tube at Machlett Laboratories.

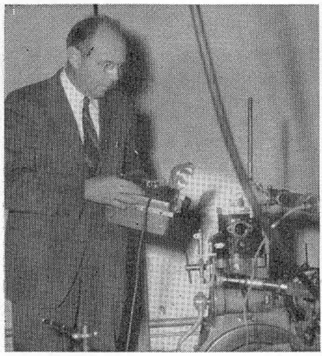

Figure 10. Dr. H. E. Edgerton watches the action of valve springs in an internal-combustion engine at the M.I.T. Automotive Laboratory.

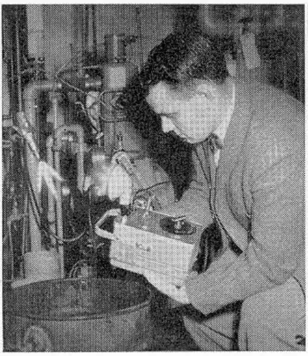

Figure 11. Watching fuel-injection sprays with the Strobotac. For a close-up of the spray, see page 10. The high-velocity droplets in the atomized spray can be studied in detail.

Figure 12. At General Electric's Small Aircraft Engine Department, engineers use the Strobotac to examine the vibratory modes in aircraft gas turbine blades. The short-duration white light gives excellent resolution. Mode shapes are clearly defined at various excitation frequencies produced by an electromagnetic driver.

Electronic and Electromechanical Equipment

With the Strobotac one can study tape-recorder mechanisms, relays, servos, and transducers of all types. Speaker voice-coil clearance, spider flexing, and cone performance are all susceptible to stroboscopic observation.

Acoustic Research, Inc., of Cambridge, Massachusetts, has used the new Strobotac to advantage in the study of a new hemispherical radiator for their AR-3 Loudspeaker System. In this technique, finely shredded rayon flock is applied on a radial line of glue along the radiator surface. The Strobotac is flashed at a rate differing slightly from an integral submultiple of the frequency of the driver, whereupon nodal points and the degree of vibration of the diaphragm can be determined by examination of the movement of the free ends of the flock under a magnifying glass (see cover photograph). Radiator break-up and other irregularities are readily revealed in this manner.

With the aid of this technique, uniform dispersion and a more uniform frequency response have been achieved for a new mid-range, hemispherical radiator. Whereas direct measurements were possible at radiator excitation frequencies to 1 kc with the older Strobotac, work can now be performed to 5 kc with the new model. The flocking technique extends this to 20 kc.

An unusual application was discovered in the development of a new X-ray tube of the rotating-anode type at Machlett Laboratories. In this new tube the anode rotates at 9000-10,000 rpm, which causes the target area to change continuously. This technique permits fine focusing of the X-rays without anode burn-out from excessive emission. Where other stroboscopes either do not have a repetition range that is high enough for this work or a light flash that is bright enough to penetrate the double window in the tank, the oil bath used for cooling, and the tube envelope, the Type 1531-A Strobotac has been found quite suitable (see Figure 9).

Large Machines and Engines

Uses in the automotive and large-machinery industries include studies of spring surge, valve operation, determination of the effect of flywheel mass on speed variation, studies of piston-ring action, and vibration studies to determine where shock mounts should be applied. For the study of reciprocating parts in an internal-combustion engine, the Strobotac is usually triggered by a contactor on the crankshaft. For the study of the action of pistons and other enclosed parts, a window is often cut in the side of an experimental engine.

The development and production testing of fuel-spray nozzles for diesels is greatly facilitated by the new Strobotac. The bright, short-duration flash makes possible detailed study of the action of rapidly moving parts and the formation of fuel-injection spray patterns. The Strobotac "freezes" the motion of the high-velocity droplets in the atomized spray, permitting the study of both droplet size and range. Figure 11 shows spray patterns under study at the M.I.T. Automotive Laboratories.

Vibration Studies

Vibratory motion and its effects can be readily studied with the aid of the very short light pulse from the Strobotac. Displacements in vibrating parts can be measured accurately with the aid of a microscope and cross hairs. This technique has been used by automotive and aircraft-power engineers in measuring crankshaft whip, vibrations, and turbine blade displacement.

Another important use is the detection of resonances in devices subjected to the cyclic forces produced by shake tables. Relays, fans, motors, and electronic equipment and systems — large and small — are subjected to the "dithering" action of shake tables while strobo-

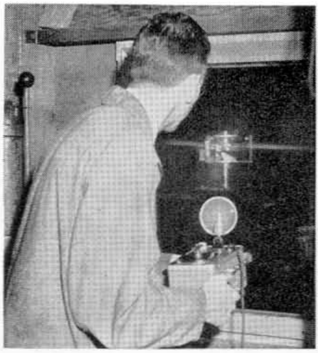

Figure 13. A model helicopter rotor in a wind tunnel is watched with the Strobotac. Blade lag and flapping are clearly observed in slow motion, just as they occur under various flight conditions. In addition to providing a good visual representation of the conditions encountered in flight, such studies serve as a visual check on vibration data provided by strain-gages mounted on the rotor head.

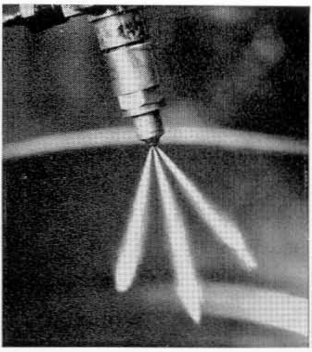

Figure 14. Strobotac single-flash photo of the fuel-injection spray of Figure 11. The bright, easily triggered flash makes it easy to take permanent records of observed phenomena.

Figure 15. The Strobotac and associated equipment for eye-movement studies by Dr. J. Y. Lettvin. Note the electrodes taped to the subject's face.

scopic light is used to detect damaging, self-created, vibratory conditions.

Printing

In the printing industry, the Strobotac can be used for all types of color registration. A manufacturer of gift-wrap paper has increased the production speed of a four-color rotogravure press to 450-500 ft./min. — twice that practical without the aid of stroboscopic light. One operator and his assistant are able to run this rotogravure press while they periodically check registration with the aid of the Strobotac. Stroboscopic observations not only show which of the four colors is off register, but also indicate the degree of correction required at the appropriate color stand. The result — more efficient utilization of production facilities.

Industrial Maintenance

In the operation of gears, cams, drills, saws, and cutting tools, the Strobotac will show misadjustments, misalignment, wear, sources of noise and vibration, etc., so that they can be corrected before failure of the machines occurs. Governor action, belt slip, lubrication, clearances, and the action of springs can be checked and measured.

Photography

It is possible to use the new Strobotac for photographing objects in motion, by either single-flash or multiple-flash techniques*. The diesel-spray pattern of Figure 14 was photographed with the camera shutter speed set to a value equal to the period between flashes, so that only one flash occurred during the exposure time. The ability to trigger the Strobotac from an external electrical signal greatly simplifies the techniques required to synchronize the flash of the Strobotac for single-flash photography. The output of a photocell or microphone, amplified if necessary, can be used.

Medical Applications

The new Strobotac has many applications in the medical, psychological, and physiological fields. The object of one such experiment conducted under supervision of Dr. J. Y. Lettvin of M.I.T. was to determine whether or not there was vision during eye movement. The subject's eye was connected by four circular silver electrodes to an oscilloscope, whose amplified output triggered a Strobotac each time an eye movement occurred. Thus, with the subject in a dark room, there was illumination only during periods of eye movement.

The white-light feature of the new Strobotac makes it an extremely effective aid for exploring other areas of vision such as color perception.

The instrument is also sutiable for use with tachistoscopes in psychological work. In conjunction with an external gated oscillator, the Strobotac can provide bursts of light pulses up to any burst duration (even continuous), with pulse rate during the burst well above flicker-fusion frequency.

Other medical uses include photic stimulation during electroencephalographic recording of brain waves and the inducing of epileptic-like seizures.

Neurologists have used stroboscopic equipment for a number of years in the study of seizures and temporary blackouts caused by a sensitivity to rhythmically interrupted light. This same type of flicker, caused by a revolving propeller interrupting the sun's rays at a critical rate, has long been suspected as the cause of mysterious pilot blackouts.

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*A table of guide numbers for various film types is available upon request.

Other Uses

Among other applications are the dynamic balancing of rotors, study of slip between friction-driven members, determination of the speed at which jaws of centrifugal clutches begin to open, the timing of moving-picture projectors, and the calibration of watt-hour meters.

A complete list of the potential uses of the new Type 1531-A Strobotac would take many pages. This instrument is useful wherever there are machines and moving mechanisms, and this includes just about every industrial plant.

— M. J. Fitzmorris
C. J. Lahanas
W. R. Thurston

TYPE 1532-C STROBOLUME

The Strobolume is still available and can be used with the new Strobotac®. While for most applications the very bright light emitted by the Type 1531-A Strobotac is more than adequate, the Strobolume will be found useful where large areas are to be illuminated or the particular requirements of the application dictate a very intense light.

The Strobolume, at maximum light intensity, can operate continuously at flashing rates up to 60 per minute and, for short periods of time, up to 1200. At greatly reduced light intensity, it will operate up to 3000 per minute continuously. The peak light is 10 million-beamcandlepower at 60 flashes per minute; its flash duration is 10 μsec at high intensity and 30 μsec at low intensity.

The electrical specifications are identical with those for the previous model, 1532-B. To connect the Type 1531-A Strobotac® to the Strobolume, the Type 1532-P3 Trigger-Cable and the Type 1532-P4 Adaptor are needed.

Type		*Code Word*	*Price*
1532-C	**Strobolume**	TITLE	**$315.00**
1532-P3	**Trigger-Cable**	TALLY	**15.00**
1532-P4	**Adaptor**	TIGER	**5.00**

INTERKAMA 1960

The International Congress and Exhibition for Instrumentation Control and Automation — INTERKAMA — will be held at the Düsseldorf Exhibition Grounds from October 19-26, 1960.

The General Radio Company will exhibit its latest instruments in Booth 2008, which is located in Building B. Our representative in Germany, Dr. -Ing. Günter Nüsslein, will be in attendance together with General Radio representatives from other European countries. Engineers from General Radio factory at West Concord, Massachusetts, U.S.A., who will attend are Dr. Donald B. Sinclair, Executive Vice President and Technical Director; Robert A. Soderman, Administrative Engineer, and Peter J. Macalka, Engineer.

We look forward to welcoming our many overseas friends at this exhibition.

NATIONAL ELECTRONICS CONFERENCE

Hotel Sherman, October 9-11, 1960

At the 1960 NEC General Radio products will be exhibited in Booths 205, 206, and 207, the same location that we have had in past years. New items on display include:

Type 1531-A Strobotac.®

TYPE 1557-A Vibration Calibrator, for the calibration of vibration pickups.

TYPE 1142-A Frequency Meter, a wide-range electronic frequency meter and linear low-noise discriminator.

Other timely and interesting displays:

The TYPE 1300-A Beat-Frequency Video Generator in a setup showing sweep tests on a transistor amplifier.

The TYPE 1607-A Transfer-Function and Immittance Bridge in the measurement of equivalent-circuit parameters of tunnel diodes.

The TYPE 1605-A Impedance Comparator set up for the rapid measurement of collector-to-base capacitance of transistors.

ELECTRONIC INSTRUMENT MANUFACTURERS' EXHIBIT

The mobile instrument displays operated by our field engineers are becoming increasingly popular with our customers. These exhibits, often held in customers' plants, sometimes in hotels, have been outstandingly successful because they bring to small groups of interested engineers the opportunity to see and to operate our newest instruments.

In October we plan to conduct our exhibit with five other quality electronics manufacturers, whose products complement, and are scientifically related to, our own. In this way we feel that we can perform a greater service to our customers and at the same time continue what has proved to be the best way to bring them up to date on the operational capabilities of our new instruments.

We shall be exhibiting with:

FXR, Incorporated, of Woodside, New York, manufacturers of precision microwave equipment that extends in frequency up to 220,000 Mc.

Lambda Electronics Corporation, of College Point, Long Island, the only power supply manufacturer whose complete line carries a 5-year guarantee.

Panoramic Radio Products Company, Incorporated, of Mount Vernon, N. Y., pioneers of spectrum analyzers and other automatic measurement instruments.

Sensitive Research Instrument Corporation, of New Rochelle, New York, specialists in laboratory standard meters and other calibration devices.

Tektronix, Incorporated, of Portland, Oregon, leading manufacturer of cathode-ray oscilloscopes and accessory equipment.

We plan to exhibit in five locations around the metropolitan New York and Philadelphia areas. We will exhibit from one to nine P.M. at:

Sagamore Room, Roosevelt Field Shopping Center, Long Island, Oct. 5 and 6

Treadway Inn, Norwalk, Connecticut, October 11

Nelson House, Poughkeepsie, New York, October 13

The Meadowbrook, Cedar Grove, New Jersey, October 17

Cherry Hill Inn, Moorestown, New Jersey, October 19 and 20

Each company will have factory engineers on hand to describe the instruments and to answer all your technical questions. We cordially invite you to attend.

General Radio Company

PRINTED IN U.S.A.

THE GENERAL RADIO

EXPERIMENTER

VOLUME 34 No. 10

OCTOBER, 1960

IN THIS ISSUE

Connection Errors in Inductance Measurement

New Inductors and Capacitors

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CONTENTS

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GENERAL RADIO COMPANY

West Concord, Massachusetts

Telephone: (Concord) *EMerson 9-4400;* (Boston) *CLearwater 9-8900*

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: **6605 West North Avenue, Oak Park, Illinois**
Telephone — VIllage 8-9400

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COVER

Measuring the collector-to-base capacitance of transistors with the Type 1605-A Impedance Comparator.

CONNECTION ERRORS IN INDUCTANCE MEASUREMENT

As the pursuit of increased accuracy in electrical measurements moves downward into the fractions of microhenrys and of picofarads, the contributions to the measured quantity made by the connections between measured component and measuring instrument become increasingly important. When a capacitor or inductor is used or measured, it is connected to and becomes a part of a complete circuit. The impedance between its terminals therefore depends not only upon its self-impedance, but also upon the mutual impedances between the capacitor or inductor and the rest of the circuit. These mutual inductances and capacitances are usually sufficiently small to impose no appreciable limit on the accuracy of measurement as long as the self-inductance or capacitance is larger than, say, 100 μh or 100 pf. For smaller inductors or capacitors, some care must be taken both in the construction of standards and in the techniques of measurement to insure that the mutual impedances can either be neglected or can be included in the calibrated value without limiting the desired accuracy. A calibration of 100 microhenrys to an accuracy of 0.1% or to ±0.1 microhenry is not of much significance if the connections produce uncertainties of 0.1 microhenry.

The problems introduced into the measurement of small capacitance by mutual capacitances between capacitor terminals and connections have been discussed in an earlier article.[1] It was the purpose of that article to point out that uncertainties of the order of tenths of a picofarad can be introduced by casual connections; that one can reduce the uncertainties by an order of magnitude or more by making the geometry of the connections sufficiently definite, as, for example, by specifying the terminals to be used as the connection; and that still smaller uncertainties can be achieved by the use of the three-terminal capacitors and measuring techniques that exclude the mutual capacitances.

It is the purpose of this article to discuss the analogous problems introduced into the measurement of small inductance by mutual inductances between the inductor and the connections. In such measurements, the uncertainties with ordinary connections and techniques may be as large as tenths of a microhenry. Much smaller uncertainties can again be achieved by methods analogous to those used for capacitors. Most attention will here be given to the reduction of the mutual inductances themselves and to the reduction of their uncertainties by care in the construction and use of the inductors and connections. Although mutuals can be excluded by magnetic shielding and four-terminal measurements, the added cost and complexity of the shielding and special bridges is not yet justified by the need for higher accuracy in measurements of small inductance. This discussion will therefore be limited to methods of reducing errors when the usual two-terminal inductors and bridges are used.

An example of a two-terminal inductor connected to a bridge is shown in Figure 1. To suggest the origin of these components and to simplify the discussion, only a few of the possible inductances of

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[1] John F. Hersh, "A Close Look at Connection Errors in Capacitance Measurements," *General Radio Experimenter*, 33, 7, July, 1959.

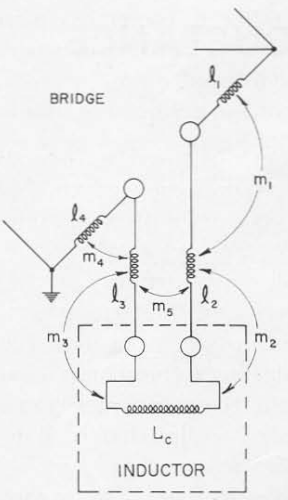

Figure 1. The circuit of an inductor connected to a bridge showing self and mutual inductances which are measured.

wires, l, and the mutuals, m, are shown here, and these are indicated as lumped parameters, although they are actually distributed over the entire circuit. The inductance value obtained by a direct bridge measurement of the components shown would be the sum of the self-inductance, L_c, of the inductor and all the connection inductances, l, and the mutuals, m. This measured value is subject to the uncertainties which can be introduced by accidental changes in the length or orientation of the connecting wires. It is possible to reduce the uncertainties to any desired level if we specify with sufficient precision the geometry of the connections and their environment. A direct measurement, is, however, seldom used when high accuracy is required.

It is usually more convenient to eliminate many of the connection errors by using a substitution rather than a direct measurement. If one measurement is made with the inductor connected as in Figure 1 and then a second measurement is made with the same connections but with the inductor replaced by a shorting link, the difference between the two measured values is independent of the self and mutual inductances, l_1, l_2, l_3, l_4, m_1, m_4, m_5, which appear in both measurements. The difference is still a measure not only of the inductance L_c but of the mutuals, m_2, and m_3, and of the inductance of the shorting link, l_s, and its corresponding mutuals. Although the substitution measurement can remove major portions of the connection impedances and the uncertainties produced by them, the small remaining mutuals must still be considered when small increments, say less than 0.01 microhenry, are significant.

The mutuals m_2 and m_3 represent the magnetic coupling between the inductor and the connecting wires, if it is assumed that the other portions of the bridge circuit are sufficiently remote to have negligible coupling. Their magnitudes change with the form and orientation of inductor and leads, and, hence, they are a source of uncertainty unless the configuration is precisely specified. The need for such precise specification of measurement conditions can be avoided if the coupling is reduced to a negligible value or if the coupling is made invariant with changes in the connecting wires. The coupling can be kept at a minimum by the use of twisted leads for the connecting wires and of toroidal rather than solenoidal coils in the inductor. The coupling can be made independent of connections if that portion of the connecting wires which is closest to the inductor terminals, and which thus contributes most to the coupling between the wires and the inductor or shorting link, is constructed as an integral and unvarying part of the inductor.

The smallest connection errors should, therefore, be obtained from an inductor constructed, as shown in Figure 2, to have both low and constant mutuals.

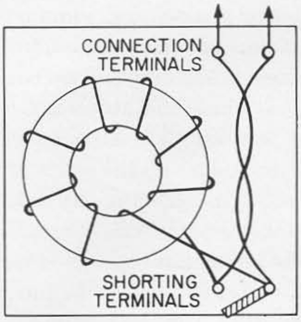

Figure 2. Inductor with separate terminals for connection and for shorting.

This inductor has two sets of terminals. The terminals at the top in Figure 2 are used to connect the inductor into the circuit in which it is measured or used. The terminals on the top are connected to the bottom ones by internal, twisted leads and also to the toroidal coil. The two measurements of the substitution method are made with the bottom right terminals first open and then shorted. The measured difference in inductance should be to a high degree independent of the connections to the inductor as long as they remain constant during the two measurements. Since the connections are made at separate terminals in this inductor, they are not easily disturbed by the application or removal of the shorting link.

The shorting link can, however, introduce error into the inductance measurement in another way. When the shorting link is connected across the inductor, the circuit connected across the bottom terminals of the inductor is that shown in Figure 3. As long as the resistance of the link, R_s, is not zero, there is an equivalent inductance, L', between these terminals, which is

$$L' = L_c \frac{R_s^{\,2}}{(R_s + R_c)^2 + \omega^2 L_c^{\,2}}$$

This inductance, like that of the link, appears only in the measurement with the inductor shorted and hence is part of the measured difference in inductance. The requirement for accuracy is, therefore, not that this inductance be zero, but that it be reproducible.

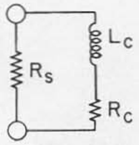

Figure 3. Circuit of shorted inductor.

Since the inductance L' depends upon R_s, any change of the contact resistance of the shorting link with time or with the method of application results in a change in the measured inductance. The relation between the change in the resistance, $\triangle R_s$, and the change in inductance $\triangle L'$ is

$$\triangle L' = 2L_c \triangle R_s \left\{ \frac{R_s}{(R_c + R_s)^2 + \omega^2 L_c^2} - (R_c + R_s) \left[\frac{R_s}{(R_c + R_s)^2 + \omega^2 L_c^2} \right]^2 \right\}$$

As an example of the magnitude of $\triangle L$, consider a standard inductor with $L_c = 10$ μh and $R_c = .02$ ohm and a shorting link with $R_s = .001$ ohm and a variation $\triangle R_s = 0.0001$ ohm at a frequency of 100 cycles, where $\omega^2 L_c^{\,2}$ can be neglected. The uncertainty is $\triangle L' = .004$ microhenry in an inductance of 10 microhenrys. The variations assumed for $\triangle R_s$ are those of a shorting link in good condition, so the uncertainties could be expected to exceed this figure in practice. The shorting link in parallel with the coil can, therefore, limit the accuracy of the measurement of low inductance at low frequencies.

This uncertainty can be eliminated very easily by use of a switch, or the shorting link as a switch, which connects to the terminals *either* the inductance coil *or* the short alone instead of connecting the coil alone or the coil shunted

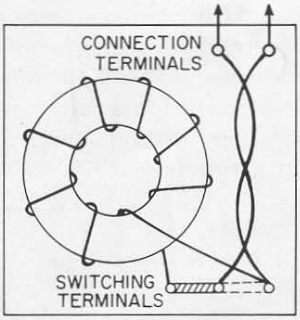

Figure 4. Inductor with shorting link arranged to disconnect coil when short is connected.

by the shorting link. An inductor with such switching is shown in Figure 4. With the shorting link in the position shown, the coil is connected to the connection terminals at the top; with the link moved to the dotted position to connect the right lower pair of terminals, the connection terminals are shorted and the coil is disconnected.

When an inductor having the construction shown in Figure 4 is calibrated in terms of the change in inductance when the shorting link is switched from one position to the other, the calibration accuracy can be very high and the inductance very low before connection errors impose a limit. Since the important section of connecting wires adjacent to the terminals where the change is made are an integral and constant part of the inductor, the form and position of the external connecting wires have negligible effect, provided only that they do not change while the difference is being measured. Since the switching link and its two positions are also an invariant part of the inductor, the self and mutual inductances of the link are both small and definite parts of the calibration. Since the link is not connected in parallel with the inductance coil, the contact resistances of the link have no effect upon the inductance. And, since the inductance coil is toroidal and the connections within the inductor are oriented to minimize the open loops, there is no coupling to external fields or conductors which can vary the inductance. The inductance so calibrated should be sufficiently definite to make the uncertainties less than 0.001 microhenry and to justify a calibration accuracy of 0.1% for inductance as low as 1 microhenry.

To conclude this discussion of connection errors without acknowledgment of the source of much of this information would be a large terminal error. From conversations and correspondence with members of the Resistance and Reactance Section of the National Bureau of Standards in Washington have come knowledge of some of the sources of error in inductance measurements as well as suggestions for their reduction.

— JOHN F. HERSH

NEW STANDARD INDUCTORS

MORE TERMINALS, LESS INDUCTANCE

The General Radio Company recently extended the range of its standard capacitors downward by several decades to 0.01 pf by the introduction of the new TYPE 1403 Standard Air Capacitors.[1] A parallel, but more modest, step is now being taken to extend the range of our standard inductors downward by the addition of a 50-microhenry unit. In anticipation of future demands for higher accuracy and smaller inductance, the design of this inductor and its two immediate predecessors, the 100-μh and

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[1] "New Three-Terminal Capacitors." *General Radio Experimenter*, 33, 8 & 9, August-September, 1959.

200-μh sizes, incorporates the additional terminals and new method of calibration discussed in the preceding article.

The New Inductor

A Type 1482 Inductor of 50 microhenrys has for some time been available on special order. The new Type 1482-A differs from the earlier models both in having the new six-terminal connections (see below) and in having lower resistance. The coils are now wound with 100/32 Litz wire to have a dc resistance of 0.043 ohms as compared to the 0.200-ohm resistance of previous inductors. An increase in wire size has also been made wherever possible in other inductors, and the low-frequency Q is now more nearly constant throughout the line of inductors.

As in all these inductors, the coil is a uniformly wound toroid on a ceramic core for high stability and low external field. The 50-microhenry coil and the coils up through 500 microhenrys have duplex windings, *i.e.*, their toroids are wound in two equal halves, and the halves are connected in parallel rather than in series, as shown in Figure 1. The duplex winding has two advantages for small inductance coils. For a given inductance, the number of turns is greater with the duplex winding, and the ease and accuracy of adjustment to nominal value are thereby increased. The parallel windings still confine almost all the magnetic field to the torus and, in addition, they can further reduce the small field produced by the equivalent single turn of the conventional toroidal winding. With the leads positioned as shown in Figure 1, the current does not make a complete circle around the circumference of the torus but travels across a diameter on one lead wire and returns in two parallel paths through the two halves of the winding. There are thus two D-shaped loops so phased as to produce very small external field which can contribute to the measurement uncertainties.

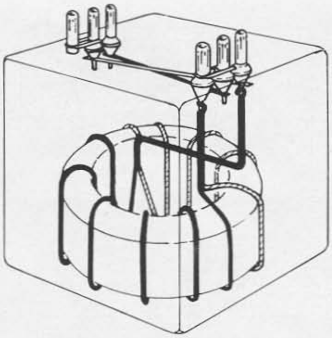


Figure 1. Diagram of duplex winding used for low-inductance standards.

Terminals and Wiring

Arrangement of terminals and wiring for the 50-, 100-, and 200-microhenry inductors is shown in Figure 2. In Figure 3 is shown for comparison the connections formerly used for all of the Type 1482 Inductors and still used for inductors of 500 microhenrys and higher. The obvious and significant difference is the addition of three more binding posts at the bottom of the new panel. Two of the new terminals (marked L_o) are connected by internal leads to the two insulated terminals at the top of the panel. The inductance coil is connected to the two outer bottom terminals. When the attached shorting link is connected between the left pair of bottom terminals (marked L), the coil is connected to the top terminals; when the link is moved to the right pair of bottom terminals, the coil is disconnected and the link short-circuits the leads to the top terminals. On both panels the upper left terminal is connected to the inductor case, and the inductor is usually used and calibrated with the adjacent terminal (*LOW*) con-

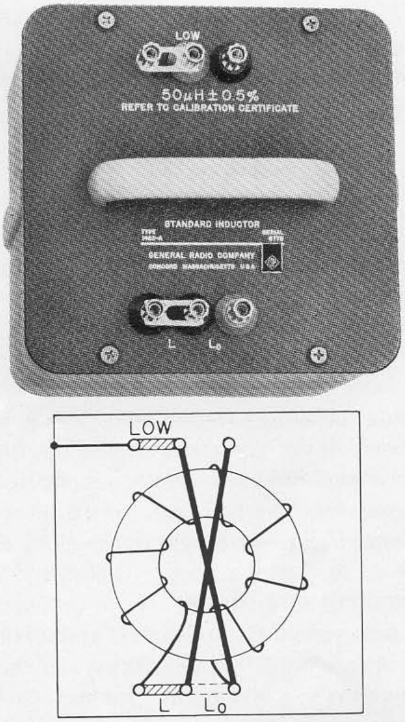


Figure 2. New six-terminal panel and connections.

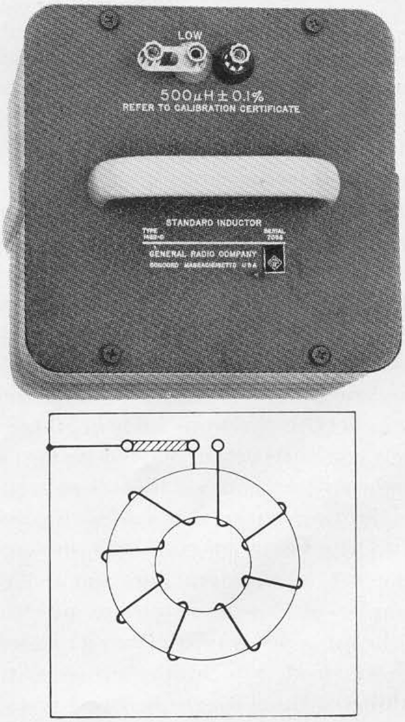
nected by the attached link to this terminal and to the case.

Calibration

In the initial calibration, usually at the National Bureau of Standards, inductors are calibrated by the substitution method in which two measurements are made: one with the inductor connected to the bridge and the other with the same connecting wires but with the inductor replaced by a short-circuiting bar or link. For an inductor with the three-terminal panel of Figure 3, the first measurement is made with the bridge connected to the pair of insulated terminals, and a short is then either applied to these terminals or the connecting wires are moved to the left pair of terminals which are connected by the link. For an inductor with the new, six-terminal panel of Figure 2, the bridge is still connected to the upper right pair of terminals (connection terminals). The measurement of the inductor is made with the link on the lower terminals in the left or *L* position to connect the coil. The short is then applied by moving the link to the right or L_o position on the lower terminals (reference terminals).

The advantages of the new panel and connections are that the mutual inductances between the internal leads, coil, and shorting link are independent of connections and environment because they are an invariant part of the inductor and that the connecting wires are not subject to disturbance when the short is applied at terminals separated from the connections. The connection errors and methods of reducing them have been discussed in detail in the preceding

Figure 3. Three-terminal panel and connections.



article. Since the errors are seldom larger than tenths of a microhenry, the advantages of the six-terminal panel in reducing these errors are appreciable only when the inductance is small. The upper limit of inductance with which the new terminal arrangement is used has been chosen somewhat arbitrarily to be 200 microhenrys, in part because this is also the dividing line between the hand-wound and the machine-wound coils in the TYPE 1482 Inductors.

Calibration by Direct Comparison

The major difference between a calibration with the short circuit at the connection terminals and one with the short at the reference terminals is the inductance of the internal leads between the two sets of terminals. This inductance (the difference between the two calibrations) is about 0.11 microhenry. Its value is important, not only in unintentional misuse of the short, but in a calibration by direct comparison of one of the six-terminal inductors with a three-terminal one of the same nominal value. In many calibrations outside of the National Bureau of Standards, a direct-comparison method is used. The unknown is simply compared to an inductor of almost equal value which has an NBS calibration and the measured difference used to obtain the value of the unknown. The measurement with the short circuit is implicit in this new calibration, however, because the Bureau used a short in their original calibration, and the new calibration is valid only with the short applied at the position used in the original calibration. If, therefore, a new 50-microhenry, TYPE 1482-A Inductor, is calibrated by direct comparison with an older one with an NBS or GR calibration, the calibrated value so obtained is that with the short at the connection terminals. The inductance obtained by a short at the reference terminals will be about 0.11 microhenry less. When accuracy to 0.01 microhenry is important, the lead inductance should be measured by moving the short from connection to reference terminals.

When a calibrated six-terminal inductor is available, the calibration of other inductors can still be influenced by the inductance of the internal leads. If the two inductors are compared in the usual manner by a difference measurement using the same external leads, the measured difference includes not only the difference between the two inductance changes at the reference terminals but also the difference between the two internal lead inductances. Calibration by this method is subject to error unless the differences in internal lead inductance are negligible or are measured. In these new TYPE 1482 Inductors, experience with a small initial sample indicates that in production the lead inductance of 0.11 microhenry may be held constant to better than 0.01 microhenry so that the error in direct comparison of similar inductors should be less than 0.02%.

When lead inductance is not sufficiently constant, its effect can be eliminated by another method of comparison. The two six-terminal inductors can be connected in series to the bridge. A first measurement is made with the short of one inductor in the L position while that of the other is in the L_o position on the reference terminals. A second measurement is then made with both links moved to the opposite position. The measured difference is the difference between the two inductance changes at the reference terminals and is independent of the internal lead inductances because they appear in both measurements and cancel in the difference.

— JOHN F. HERSH

MORE NEW INDUCTORS: FIXED AND DECADE

Type 1481 Inductors

Inductors in the TYPE 1481 series are high-Q units, toroidally wound on molybdenum-permalloy dust cores. Although not as accurately calibrated as the TYPE 1482 Standard Inductors, they have many uses in audio-frequency measurements, both as auxiliary standards and in circuit development.

Four new units have been added recently to this group as listed in the table below. Characteristics are similar to those of other TYPE 1481 Inductors, listed in our current catalog, except that TYPES 1481-AA, -BB, and -CC are wound on lower-permeability cores with corresponding changes in the frequency for Q_{max}, etc.

Dimensions: Case, (height) 3⅝ x (width) 3⅛ x (depth) 1⅝ inches (92 x 80 x 41 mm); over-all height, including terminals, 4⅝ inches (117 mm).

Net Weight: 14 ounces (0.4 kg).

Type	*Nominal Inductance*	*Accuracy of Adjustment**	*Rms Current for 0.1% increase in L*	*Resonant Frequency*	*Approx. dc Res.*	*Code Word*	*Price*
1481-AA	100 µh	±2 %	120 ma	3000 kc	0.020	INDUCTOMAP	**$37.50**
1481-BB	200 µh	±2	76 ma	2100	0.044	INDUCTOMUG	**37.50**
1481-CC	500 µh	±1	54 ma	1330	0.112	INDUCTOMEN	**37.50**
1481-N	10 h	±0.25	0.24** ma	10	416	INDUCTONAG	**50.00**

*Calibration is at zero frequency and initial permeability.

**For 0.25% increase in L.

Type 940-DD Decade-Inductor Unit

Inductors of the 1481 type, the 100-, 200-, and 500- µh sizes are used in the TYPE 940-DD Decade Inductor to provide decade steps of 100 µh, and a total of 1 mh for the decade. Four inductors are used in a 1-2-2-5 series, combinations are connected by the switch to yield successive unit values in the decade sequence.

Accuracy: 2%.

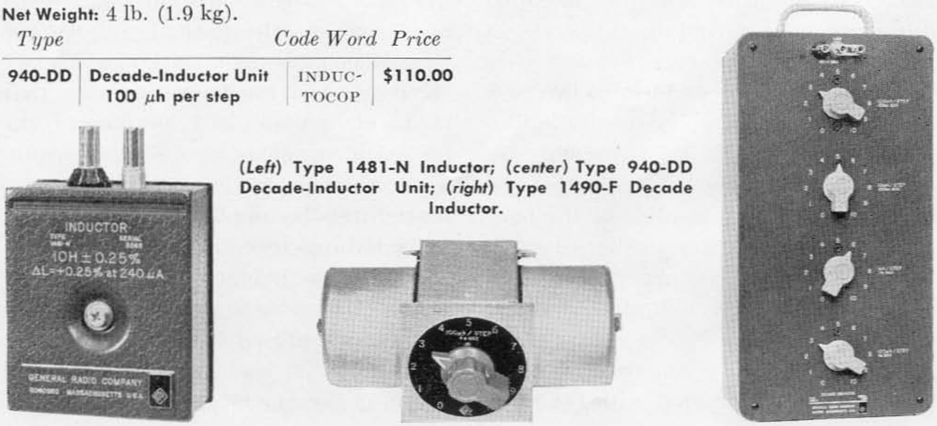
Net Weight: 4 lb. (1.9 kg).

Type		*Code Word*	*Price*
940-DD	**Decade-Inductor Unit 100 µh per step**	INDUCTOCOP	**$110.00**

Type 1490-F Decade Inductor

This four dial decade-inductance box incorporates the new TYPE 940-DD Decade-Inductor Unit together with one each of the TYPE 940-E, -F, and -G units, which have decade steps of 1 mh, 10 mh, and 0.1 h respectively. Total inductance is 1.111 henrys, adjustable in steps of 100 µh above the initial inductance.

Type		*Code Word*	*Price*
1490-F	**Decade Inductor 1.111 h**	FOCUS	**$450.00**



(*Left*) Type 1481-N Inductor; (*center*) Type 940-DD Decade-Inductor Unit; (*right*) Type 1490-F Decade Inductor.

MORE AND BETTER CAPACITORS

Improved Adjustment Accuracy for the Type 1409 Standard

As we constantly improve the stability of our electrical standards, it becomes equally desirable to improve the closeness of their adjustment to nominal values. Two factors influence the selection of this adjustment accuracy: first, the expected stability and, second, the complexity of the adjustment in terms of time and cost.

Recently published eight-year records for our Type 1409 Standard Capacitors,[1] which were introduced for sale only three years ago, indicate that stability can be disregarded as a limiting factor.

The skills acquired from two years' experience in assembling these capacitors impelled the men who build them to suggest that, without appreciable increase in cost, the adjustment could be made to a better nominal accuracy than the then current 0.1%, and, accordingly, a new tolerance of 0.05% was established. During a transition period, the nameplate continued to read 0.1%, and additional labels were affixed to the base, bearing the legend, "Adjustment Accuracy 0.05%." New nameplates now in use bear the 0.05% figure. A certificate, as before, accompanies the capacitor, giving the measured value[2] under stated environmental conditions.

(*Left*) Type 1409-T Standard Capacitor; (*right*) Type 980-J Decade-Capacitor Unit.

Type 980-J Added, 100 pf per step

For most of the life of the Type 980 Decade-Capacitor Units and their predecessors, the Type 380's, only three capacitance ranges were available, regardless of the dielectric used, and which had, respectively, 0.1, 0.01, and 0.001 μf per step. In our current Catalog P we now list a decade-capacitor unit having 100 pf per step, the Type 980-D. The favorable response accorded this decade unit, which has polystyrene dielectric, has resulted in the introduction of the Type 980-J Decade Capacitor, having silvered-mica dielectric and nominal capacitance increments of 100 pf per step. The capacitance increments from zero position are within $\pm(\frac{1}{2}\% + 2\text{ pf})$ of the indicated value for any setting for two-terminal connection and within $+0, -(2\% + 8\text{pf})$ for three-terminal connection. The differences between these adjustment-accuracy figures and those for the companion Type 980-F, -G, and -H are caused by the switch capacitance (which varies from position to position) and by the wider percentage adjustment tolerance of the low-valued capacitors. Similarly, the dissipation factor figure of <0.0006 is simply determined by the dissipation factor of the 100-pf capacitor.

New Three-Decade Capacitor, Type 1419-M, Replaces Type 219-M

The Type 219-M Decade Capacitor, our "economy" decade capacitance box, has been replaced by a new and improved model, the Type 1419-M. Mechanical changes bring the construction

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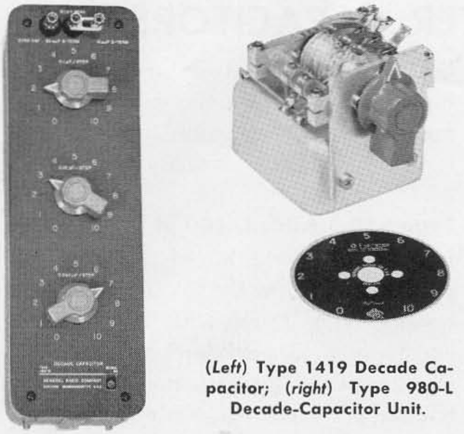
[1] "Stability Records of Standards of Inductance and Capacitance," *General Radio Experimenter*, 34, 4, April, 1960.

[2] I. G. Easton, "Standards and Accuracy," *General Radio Experimenter* 34, 6, June, 1960.



(*Left*) Type 1419 Decade Capacitor; (*right*) Type 980-L Decade-Capacitor Unit.

and appearance into line with the other Type 1419 units, which have previously replaced equivalent Type 219 models.

The individual mica-dielectric capacitors used in the 0.01-μf-per-step and 0.001-μf-per-step decades remain unchanged. The Type 980-L paper-dielectric decade, 0.1 μf per step, uses firecracker-shaped, sealed, foil-and-paper capacitors having a viscous impregnant. These capacitors have the following improved characteristics:

1. Adjustment accuracy of capacitance increments from zero position is changed to ±1.5% (from ±2%) of the indicated value for any setting.
2. Dissipation factor is reduced to less than 0.005 (from less than 0.01).
3. Insulation resistance is increased to $>10^{10}$ ohms (from 10^8) at 100 v, 25°C, 50% RH, and after 5 minutes' electrification time.
4. Temperature coefficient is +180 ppm/°C nominal.
5. Maximum operating voltage (dc or peak) is raised to 500 (from 300).
6. Frequency limit for maximum voltage is up to 2 kc (from 1 kc).
7. Maximum operating temperature is up to 90°C (from 65°C).
8. The stability of all characteristics is considerably improved.

The use of the sealed firecracker units prevents increase of both capacitance and dissipation factor, which would result from moisture contamination. Further, the use of the viscous impregnant (rather than a liquid one), immobile at operating temperatures, improves capacitance stability since the relative positions of conductors and insulation will not change appreciably as a result of shock, vibration, change of position, or temperature variations.

— P. K. McElroy

Type		*Code Word*	*Price*
1419-M	**Decade Capacitor**	FORAY	**$145.00**
980-J	**Decade-Capacitor Unit, 100 pf per step**	ADIEU	**48.00**

Dimension drawings of all Type 980 Decade-Capacitor Units are available on request.

NEREM — 1960

Boston, Massachusetts — November 15-18, 1960

Come to NEREM, and when you do, drop in at Booths 9 and 10 at the exhibits in the Commonwealth Armory. Our engineers will welcome your call and will be glad to show you the new instruments that we shall have on display, among them:

An electronic frequency meter, direct reading to an accuracy of 0.1% and capable of measuring incidental fm to 1 part in 10^6.

A calibrator for accelerometers and other vibration pickups.

The Type 1531-A Strobotac®, described in the September *Experimenter*

plus

many other instruments displayed in interesting and significant uses.

General Radio Company

THE GENERAL RADIO EXPERIMENTER

VOLUME 34 Nos. 11 & 12 NOVEMBER-DECEMBER, 1960

IN THIS ISSUE

- Vibration Calibrator
- Vibration Pickup
- New Variac® Autotransformers
- New Decade Resistance Boxes
- Quartz-Crystal Discriminator

THE GENERAL RADIO EXPERIMENTER

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GENERAL RADIO COMPANY

West Concord, Massachusetts

Telephone: (Concord) *EMerson 9-4400;* (Boston) *CLearwater 9-8900*

NEW YORK: **Broad Avenue at Linden, Ridgefield, New Jersey**
Telephone — N. Y., WOrth 4-2722
N. J., WHitney 3-3140

CHICAGO: **6605 West North Avenue, Oak Park, Illinois**
Telephone — VIllage 8-9400

PHILADELPHIA: **1150 York Road, Abington, Pennsylvania**
Telephone — Phila., HAncock 4-7419
Abington, TUrner 7-8486

WASHINGTON: **8055 13th St., Silver Spring, Maryland**
Telephone — JUniper 5-1088

LOS ANGELES: **1000 North Seward St., Los Angeles 38, Calif.**
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CANADA: **99 Floral Parkway, Toronto 15, Ontario**
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COVER

Calibrating the Type 761-A Vibration Meter with the Type 1557-A Vibration Calibrator.

LITTLE DITHERS

A Small, Self-Contained, Self-Excited Vibration Calibrator

The accuracy of sound and vibration measurements in the field is greatly enhanced if the calibration of the measuring system can be checked against a stable, known source immediately before and after the measurements. The Type 1552-B Sound-Level Calibrator[1] is widely accepted as such a reference source for sound measurements. The new Type 1557-A Vibration Calibrator, shown in Figure 1, now performs a similar function for vibration measurements.

This calibrator generates a monitored vibration level of 1 g, rms, acceleration at 100 cycles per second for the calibration of any vibration pickup that is attached to it. It was originally developed to calibrate the Type 761-A Vibration Meter, as illustrated on the cover of this issue, or the Type 1560-P11 Vibration Pickup System.[2] It will serve equally well to calibrate most of the one-hundred-plus types of piezo-electric accelerometers now available or moving-coil velocity pickups weighing 300 grams or less. It can provide on-the-spot calibrations of vibration measuring systems immediately before and after important measurements and also can be used to compare transducers or to calibrate working transducers against a laboratory standard transducer.

Figure 1. Panel view of the Vibration Calibrator.

DESCRIPTION

The Type 1557-A Vibration Calibrator is a small shaker driven by an internal, transistorized, electromechanical oscillator. The functional diagram, Figure 2, shows both design and construction. The moving part, M_1, is concentrically and resiliently mounted within the cylindrical main body, M_2, of the shaker, which is in turn resiliently mounted to the calibrator case. The transistor amplifier supplies energy to the drive coil of M_1, while the pickup coil feeds back energy to maintain oscillation and operates the indicating meter. The shaker motion is sinusoidal, and the frequency of the electromechanical oscillator is 100 cps, but the main shaker body, M_2, with its suspension resonates below 10 cps. Small changes in the mass of M_2 caused by addition of the mass of a vibration pickup, for example, have a negligible effect on the motion of M_1, while the motion of M_2 is determined by the ratio of M_1 to M_2. The mass of M_2 is always more than 10 times the mass of M_1 and so, for 1 g acceleration of the shaker body, M_1 must shake in excess of 10 g. When the mass of the shaker body is increased by that of a vibration pickup,

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[1] Gross, E. E., "An Improved Sound-Level Calibrator," *General Radio Experimenter*, 30, 1, June, 1955.

[2] See page 5 this issue.

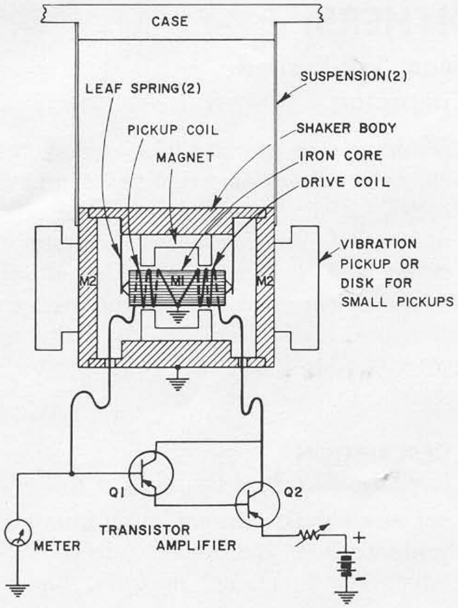

Figure 2. Functional diagram of the calibrator.

the motion of M_1 must be increased to maintain the acceleration of M_2 at the 1 g level. The motion of M_1 is monitored by the panel meter, which is calibrated to register the motion of M_1 that is required to maintain M_2 at 1 g as a function of the added load. The scale reads directly in shaker load from 100 to 300 grams. The load is made up of two removable 50-gram discs and/or the vibration pickup or pickups being calibrated.

OPERATION

Operation of the calibrator is simple. A pickup of known mass is attached to the shaker, either in place of one of the removable 50 gram discs or to one of the discs by means of double-faced pressure-sensitive tape.[3] The calibrator is turned on, and the output is set to 1 g rms by adjustment of the LEVEL control until the panel meter indication corresponds to the mass, in grams, of the total external load on the shaker. For example, in the calibration of a tiny accelerometer weighing 20 grams, the accelerometer is attached to one of the discs with double-faced pressure-sensitive tape, and the LEVEL control is adjusted so the meter reads 120 (the mass of the accelerometer plus the mass of the two 50 gram discs).

When the General Radio TYPE 1560-P51[2] Pickup (50 grams) is calibrated, one disc is replaced by the pickup and the meter reading is set to 100. For the General Radio TYPE 761-P1/759-P35 Pickup (215 grams), both discs are removed and the correct meter reading is 215.

Life tests on the calibrator indicate that it will operate continuously at maximum output for over 1000 hours. Since normal operation will usually be below the maximum and will not be continuous, the unit should give trouble-free service for many years.

The rms velocity at 100 cps for 1 g rms acceleration is 0.614 inch per second and the corresponding rms displacement is 0.000978 inch. The total excursion (peak-to-peak displacement) of the shaker body or pickup is 0.00277 inch.

EXTERNAL FIELDS

The magnetic fields measured near the calibrator are maximum at the right-hand side of the instrument as one looks at the panel. The dc field is 100 gauss or lower when the right-hand 50 gram disc is removed. Under the same conditions the ac field is less than 1 gauss. The measured stray magnetic fields are somewhat lower at the left-hand side of the instrument, and so one should mount pickups that may be susceptible on that side.

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[3] Angiers Adhesives, Division of Interchemical Company; Scotch Brand, Minnesota Mining and Manufacturing Company.

ACKNOWLEDGMENT

The TYPE 1557-A Vibration Calibrator is an extension of an original design by D. V. Noiseux of Bolt, Beranek, and Newman, Inc. The present mechanical and magnetic design was engineered by P. K. McElroy.

— E. E. GROSS, JR.

SPECIFICATIONS

Output: Acceleration, 1 g rms ±10%.
Velocity, 0.614 in./sec.
Displacement, 0.000978 in., rms, 0.00277 in., peak to peak.

Frequency: 100 c ±1%.

Battery: 4 RM-4 Mercury cells or equivalent.

Battery Life: 100 hrs. of continuous operation.

Accessory Supplied: Leather carrying case.

Dimensions: 4 by 8 by 4 inches (102 by 204 by 102 mm).

Weight: 3¼ pounds (1.5 kg), including leather carrying case.

Type		*Code Word*	*Price*
1557-A	**Vibration Calibrator.........................**	VIVID	**$225.00**

TYPE 1560-P11 VIBRATION PICKUP SYSTEM

New Ceramic Pickup — New Control Box for Use with Type 1551 Sound-Level Meters

A new barium-titanate accelerometer (TYPE 1560-P51) with excellent characteristics is now available as an accessory input transducer for the sound-level meter. A new control box (TYPE 1560-P21) to complement the electrical characteristics of the pickup has been designed. It mounts on the end of the sound-level meter and provides storage for the pickup, extension probe, tips, and cable. The combination is called the TYPE 1560-P11 Vibration Pickup System and is shown in Figure 1.

USES

The Vibration Pickup System converts the sound-level meter to a general purpose Vibration Meter. For a very modest investment, one can now put the precision attenuators, amplifiers, and metering circuit of his sound-level meter to work in the field of vibration measurements. As modern production machinery and vehicles are designed to go faster and last longer, vibration studies during developmental and testing stages are becoming more and more important. Operator comfort and safety as well as machinery or vehicle life depend to a large extent on smooth, vibration-free operation. The TYPE 1560-P11 Vibration Pickup System is a convenient means for making these measurements. The pickup system also increases the usefulness of the sound-level meter as a noise-control instrument. Noises caused by solid-borne vibrations can be more easily tracked down. Detection of excessively noisy or worn machinery is often possible, even in

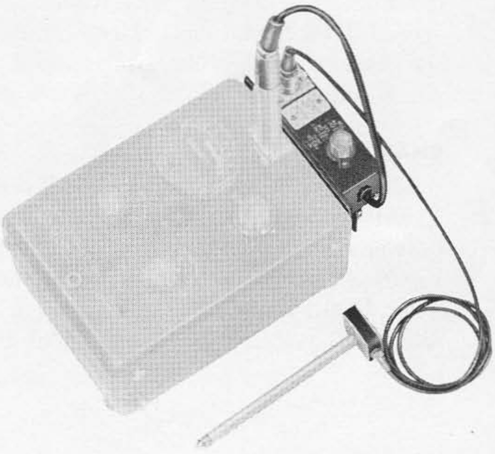

Figure 1. View of the Vibration Pickup System attached to the Type 1551-B Sound-Level Meter.

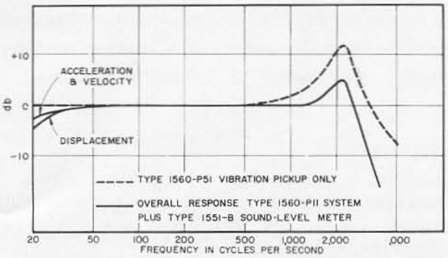

Figure 2. Frequency response of the pickup (dotted curve) and the complete system (solid curve).

the presence of high ambient noise levels, by use of a vibration pickup in place of the microphone on the sound-level meter. Vibration measurements are also often used for production noise testing of silent small mechanisms and motors where airborne noise tests are impossible even with very low ambient noise levels. Routine vibration-level checks on operating machinery are an aid to preventive maintenance on machinery when vibration levels begin to climb, but before excessive wear that causes noise and failure occurs.

Vibration measurements can be used to supplement sound-level measurements made for noise control purposes in buildings. Floors, walls, piping, ventilating ducts, all are sources of noise that can be sought out by using a vibration pickup.

Other uses include the measurement of all types of machinery vibration to determine the need or effectiveness of special shock mountings or to determine the motion of large panels or supports which could cause noise.

CHARACTERISTICS

The frequency response of the Type 1560-P51 Pickup for constant acceleration is shown by the dotted curve of Figure 2. The over-all response of the Type 1560-P11 system for constant acceleration, velocity, or displacement is shown by the solid curves of Figure 2. As indicated, the response of the system is flat within ±1 db (±12%) from 30 to 1500 cps.

The nominal sensitivity of the pickup is 40 mv/g. The control box provides a gain control (set at the factory to match the pickup sensitivity to that of the sound-level meter) plus integrating circuits to convert the acceleration response to velocity and displacement. The factors for converting decibel readings to vibration quantities are indicated on the control box name-plate as are the data relating pickup and control box to the proper sound-level meter. Conversion charts are supplied in the instruction booklet so that decibel readings for acceleration, velocity, or displacement are readily translated to rms inches per sec,[2] inches per sec, or inches.

The maximum acceleration that can be measured before the pickup becomes non-linear is 100 g (38,600 inches/sec^2 or just under 132 db reading on the sound-level meter).

The maximum velocity and displacement readings are a function of frequency and are determined by the 100-g limit on the pickup. At 20 cps, for example, the maximum velocity would be 307 inches/sec (approx. 130 db) and the maximum displacement would be 2.44 inches (approx. 118 db).

The minimum acceleration measurement (sound-level meter reading of 30 db) is 0.32 in./sec^2 or .008 g. The corresponding minima for velocity and displacement are .003 in./sec and 100 μ inches respectively.

Safe operating temperature for the pickup extends from 0 to 200°F. Over the temperature range of 30 to 180°F., the sensitivity remains constant within ±10%.

Except for temporary surface leakage

across the ceramic unit, cables, and high value resistors in the control box, high humidity has no serious effect on the operation of the system. Dry atmospheres have no ill effect.

CALIBRATION

Absolute sensitivity of the pickup is measured at low frequencies on an electrodynamic shaker. The displacement of the shaker is accurately determined with a measuring microscope and stroboscopic illumination of fiduciary marks on the shaker table. At frequencies above 100 cps, the response of the pickup is measured on a small piezo-electric shaker. The response of each pickup is checked over the frequency range of 10 cps to 5 kc. The electrical responses of the networks in the control box are also carefully checked over the frequency range of 20 cps to 5 kc. The system can be readily checked with the TYPE 1557-A Vibration Calibrator (see page 3). This new TYPE 1560-P11 Vibration Pickup System replaces the TYPE 759-P35 Vibration Pickup and TYPE 759-P36 Control Box which have been supplied for many years as an accessory input system for sound-level meters.

— E. E. GROSS, JR.

SPECIFICATIONS

Calibration: The db readings of the sound-level meter can be converted into absolute values of displacement, velocity, or acceleration by means of calibration data supplied.

Range: The range of measurement of the pickup and control box when used with the TYPE 1551-B, TYPE 1551-A, or the TYPE 759-B Sound-Level Meter is approximately as follows:

Rms Displacement — 100 micro-inches (minimum).

Rms Velocity — 3000 micro-inches per second (minimum). The upper limit of velocity and displacement measurements is dependent on the frequency and is determined by the maximum acceleration permissible before nonlinearity occurs (100 g).

Rms acceleration — 0.3 to 39,000 in./sec/sec (100 g).

Net Weight: TYPE 1560-P51 Vibration Pickup, 1.6 ounces (45 g) (pickup only); pickup plus 5-foot cable probe, and tips, 8 ounces (0.3 kg); TYPE 1560-P21 Control Box, 1 pound, 3 ounces (0.6 kg).

Type		*Code Word*	*Price*
1560-P11	**Vibration Pickup System**	PIKUP	**$130.00**

NEW INSTRUCTION BOOK FOR THE TRANSFER-FUNCTION BRIDGE

We have recently prepared a revised version of the operating instructions for the TYPE 1607-A Transfer-Function and Immittance Bridge. This new and greatly enlarged edition contains a great deal more operating information than does the first edition, including a complete section on tunnel-diode measurement. Single copies will be gladly furnished without charge to users of the instrument. Requests should include the serial number of the instrument with which the book is to be used.

STANDARD INDUCTOR

From last month's article on new standard inductors, the following identification and price data were inadvertently omitted.

Type		*Code Word*	*Price*
1482-A	**Standard Inductor, 50 μh**	INDUCTOGAP	**$125.00**

NEW METERED VARIAC® AUTOTRANSFORMERS

Metered Variacs are portable testing devices, each consisting of a Variac autotransformer, a voltmeter, and an ammeter or a wattmeter or both. Switching, fuses, and 3-wire power cord are also provided. These handy, compact assemblies have many uses both in the laboratory and on the test bench, among them overvoltage and undervoltage tests, trouble shooting, and measurements of voltage, current, and power.

Meters are shielded from the transformer stray field, permitting an over-all accuracy of 3% of full scale. The on-off switch disconnects both sides of the line. Make-before-break switches permit the dual-range ammeters and voltmeters to be switched under load.

Three new models are now available, in addition to the two (Types W5MT3A and W5MT3W) previously announced.[1] For convenient reference, all five available models are listed below.

The new Type W10MT3A and Type W10MT3W duplicate in the 10-ampere rating the features of the 5-ampere models previously announced. The Type W5MT3AW offers the advantage of all three meters — reading load volts, amperes, and watts — in a single assembly.

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[1] "New Metered Variacs, Types W5MT3A, W5MT3W," *General Radio Experimenter*, 33, 5, May, 1959.

Type	*Input Voltage*	*Output Voltage**	*Output Current (Amperes)*	*Meter Ranges*		*Code Word*	*Price*
				Amperes	*Watts*		
W5MT3A	120	0-140	0-5	0-1 0-5	None	CABAL	**$89.00**
W5MT3W	120	0-140	0-5	None	0-150 0-750	CABOB	**112.00**
W5MT3AW	120	0-140	0-5	0-1 0-5	0-150 0-750	CABEX	**150.00**
W10MT3A	120	0-140	0-10	0-2 0-10		DOGEN	**110.00**
W10MT3W	120	0-140	0-10		0-300 0-1500	DOGID	**138.00**

*Voltmeter range is 0-150

Type W5MT3AW Metered Variac.

Type W10MT3A Metered Variac.

TYPE W5LMT3 VARIAC® AUTOTRANSFORMER

The popular Type W5L Variac® Autotransformer is now available in a portable model, Type W5LMT3, with case, handle, on-off switch, overload protector, 3-wire cord and plug, and 3-wire outlet. Maximum output voltage is limited to input line voltage, which permits a maximum current of 9.2 amperes and an output rating of 1.1 kva. Rated current of 7.1 amperes can be drawn at any point on the winding: maximum current can be drawn at, or near, maximum voltage only. A load drawing not more than maximum current at maximum voltage can be controlled over the full range of output voltage (0 to 120).

The combination of portability, high rating, 3-wire plug, and built-in overload protector make this Variac a most useful device for general testing in the laboratory and shop.

View of the Type W5LMT3 Variac® Autotransformer. The 3-wire to 2-wire adaptor shown at the right is furnished.

SPECIFICATIONS

Input Voltage: 120.

Output Voltage: 0-120.

Rated Current: 7.1 amperes.

Maximum Current: 9.2 amperes.

Load Rating: 1.1 kva.

Driving Torque: 10-20 ounce-inches (700-1400 gm-cm).

Case Dimensions: (Height) $6\frac{7}{16}$ x (width) $4\frac{7}{8}$ x (depth) $4\frac{1}{4}$ inches (168 x 124 x 108 mm), not including handle and cord.

Net Weight: $8\frac{1}{4}$ pounds (3.75 kg).

Type		*Code Word*	*Price*
W5LMT3	**Variac® Autotransformer**	COTOS	**$34.50**
VB-2	**Replacement Brush**..........................		**.75**

NEW RESISTANCE DECADE BOXES WITH IMPROVED SWITCHES

After having for several years fulfilled on a special basis many requests by customers for decade resistance boxes containing steps of 0.01 ohm, we are now adding to the line two new items, Type 1432-T: 1,111.1 ohms, 5 dials, in steps of 0.01 ohm, and Type 1432-U: 111.1 ohms, 4 dials, in steps of 0.01 ohm.

The 0.01-ohm-per-step decade greatly enhances the usefulness of a multi-dial decade resistor. If, in a particular application, the lowest decade is used as the last of several decades, its relative inaccuracy (±2%) is swamped out by the high resistance in series with it. Even when this lowest decade is used with only one or two others, it still can be very useful in making precise adjustment to a desired circuit condition, as, for instance, a null balance in an im-

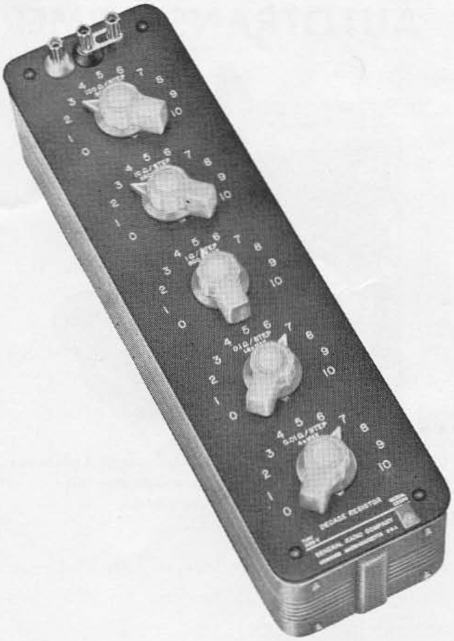

Figure 1. View of the Type 1432-T Decade Resistor.

pedance bridge. Used in an ac bridge to set the resistive balance, its high resolution permits a corresponding sharpening of the null, so that the desired reactive balance can be set with greater precision.

While the 0.01 ohm-per-step Type 510 Decade-Resistor Unit had been manufactured for some time on a special basis for selected uses, it became possible to catalog it for separate sale (as Type 510-AA) and to use it in decade resistance boxes only when the low-residual-resistance version of the Type 510 Switch, about to be described, came into production.

This basic change in the Type 510-P3 and -P3L Switches was made for the purpose of reducing the switch resistance, which is stated as being between 0.002 and 0.003 ohm in our current Catalog P. Use of two silver-bearing alloys as the materials from which to make the contact buttons, switch brushes, and take-off springs has resulted in a decrease of this resistance by a factor of three or four to one. This means that the switch resistance on a normal switch will not exceed one milliohm, even under extreme conditions of resistance variation.* (See Figure 2 for typical variation of resistance *vs.* time for old and new metal combinations.)

Since the two new alloys referred to above are high-copper alloys, having small silver additions rather than a large proportion of zinc, they appear redder in color than the earlier alloys. Because the high-copper alloys are more subject to corrosion by atmosphere or finger marking, a number of corrective measures have been taken. The brushes are nickel-plated, except on the contact surfaces, to maintain appearance. The take-off springs are silver-plated to assure persistence of the originally low contact

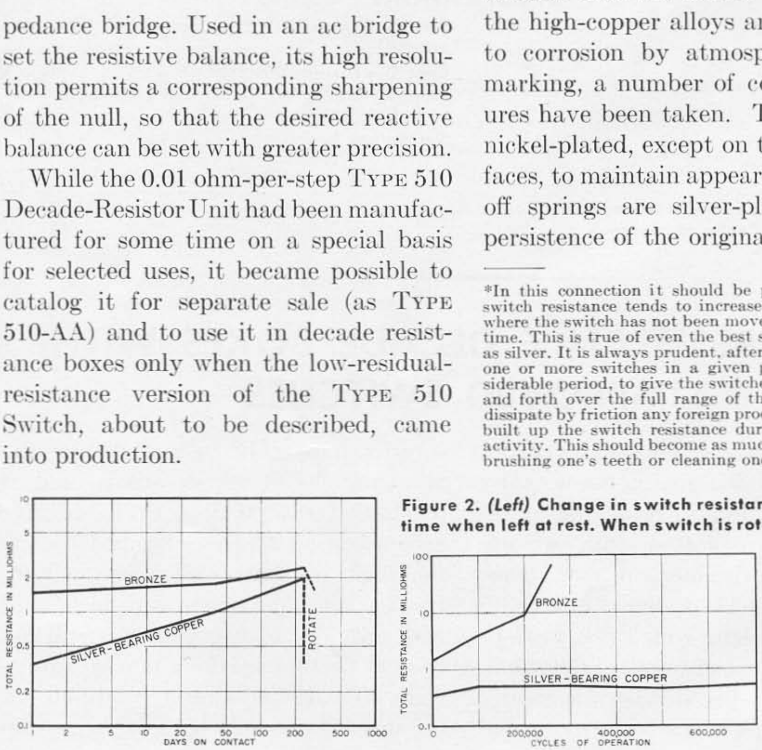

Figure 2. *(Left)* Change in switch resistance as a function of time when left at rest. When switch is rotated, the resistance drops immediately to its original value. *(Right)* Change in switch resistance as a function of cycles of operation for bronze and silver-bearing-copper alloys.

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*In this connection it should be pointed out that the switch resistance tends to increase under circumstances where the switch has not been moved for a long period of time. This is true of even the best switch materials, such as silver. It is always prudent, after a box has stood with one or more switches in a given position for any considerable period, to give the switches several swings back and forth over the full range of their motion. This will dissipate by friction any foreign products which may have built up the switch resistance during the period of inactivity. This should become as much a matter of habit as brushing one's teeth or cleaning one's spectacles.

resistance, which improves their solderability at the same time. New lubricants, otherwise similar to what had been in use, but having strong antioxidant properties, are employed. That used at the contact-button-brush interface is Master Lubricant's H101, available for maintenance purposes from our Service Department in four-ounce tubes at 75 cents per tube. This lubricant is equally satisfactory for use on older Type 510 Switches having phosphor-bronze brushes and Tobin-bronze contact buttons.

— P. K. McElroy

Type		*Code Word*	*Price*
1432-T	**1,111.1 ohms in steps of 0.01 ohm**	DEVIL	**$120.00**
1432-U	**111.1 ohms in steps of 0.01 ohm**	DEWIN	**95.00**

A QUARTZ-CRYSTAL FREQUENCY DISCRIMINATOR

Note: This discriminator is not built for sale by the General Radio Company. The description is published for the information of those who may wish to build their own. —Ed.

During the development of low-noise frequency-multiplier systems, a sensitive frequency discriminator was devised to measure the dynamic frequency modulation present in the output signal from the multiplier. The discriminator, which is described here, provides a sensitivity adequate for the measurement of deviations of $\pm 1 \times 10^{-9}$ or less when a narrow-band wave analyzer is used to select the modulation-frequency components.

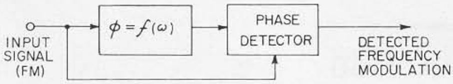

Figure 1. Block diagram of the discriminator.

The circuit makes use of the steep phase-*vs.*-frequency characteristic of a quartz crystal at series resonance to provide the required sensitivity. A balanced phase-detector circuit is used to reduce the effects of amplitude modulation. The block diagram of the circuit shows that it belongs to the class of frequency discriminators in which the input signal is applied to a phase detector through one channel with negligible phase shift and through a second channel with a phase shift that is a function of frequency.

The circuit is similar to the Foster-Seeley discriminator circuit insofar as the balanced phase-detector circuit is concerned. The inherent tuned-circuit phase shift, however, which is the basis of the operation of the Foster-Seeley discriminator, is negligible compared with the phase shift produced in the series-resonant crystal as the input frequency varies about the series-resonant frequency. The slope of the phase-shift characteristic in the quartz crystal branch is larger in comparison with that in the *LC* circuit by approximately the ratio of the *Q*'s of the resonant elements, or approximately $\frac{100{,}000}{100} = 1000$. Hence the phase characteristic of the quartz crystal dominates that of the inductance-capacitance circuit.

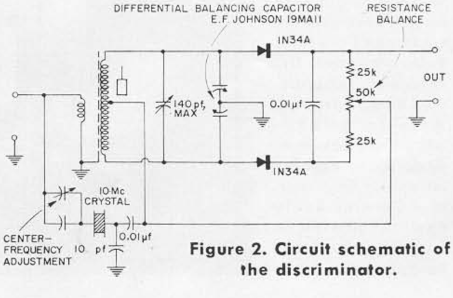

Figure 2. Circuit schematic of the discriminator.

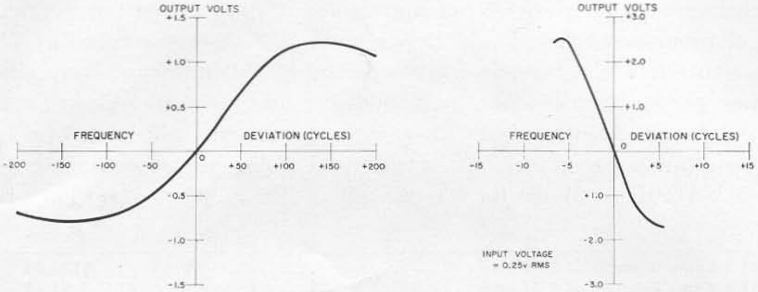

Figure 3. Response characteristic of *(left)* the 10-Mc discriminator and *(right)* the 1-Mc discriminator.

The principal series resonance of the crystal presents a very low impedance in the signal path, whereas the shunt resonance of the crystal with its own electrode capacitance presents a high impedance. Hence the shunt-resonant point, which would otherwise represent a possible spurious response, has negligible influence.

The frequency of the series-resonant response of the quartz crystal is adjustable by means of the adjustable series capacitor. The bandwidth of this response is affected by the shunt capacitor, connected between the center-top of the coil and ground. A large capacitor here produces a narrow-band response (maximum Q) as it does in any crystal filter circuit.

The response of the discriminator is limited to modulation frequencies within the pass band of the crystal branch. Modulation-frequency side bands beyond the bandwidth of the crystal element are not passed. The 10-Mc discriminator described has been used to measure 60-cycle and 100-cycle modulation, and to estimate 120-cycle modulation. It is not effective for higher modulation rates. A 1-Mc discriminator has also been built but is not effective for modulation rates above approximately 10 cycles/sec, and hence is not useful for the measurement of power-supply-related modulation.

— Frank D. Lewis

INTERKAMA 1960

View of the General Radio booth at Interkama 1960, the International Congress and Exhibition for Instrumentation Control and Automation, held at Düsseldorf, October 19 to 26. Shown at rear of the booth are *(left)* Dr.-Ing. Günter Nüsslein, General Radio representative in Germany, and *(right)* Peter J. Macalka, engineer from the General Radio factory. The ladies in the foreground are Miss Schuhmacher, Dr. Nüsslein's secretary, and Mrs. Macalka. Also in attendance were Robert A. Soderman, Administrative Engineer, and General Radio representatives from principal European countries.

General Radio Company

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