THE General Radio EXPERIMENTER

ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

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TRANSISTOR MEASUREMENTS WITH THE VACUUM-TUBE BRIDGE

Also IN THIS ISSUE

● **WHILE FOR MANY YEARS** the Type 561-D Vacuum-Tube Bridge has been used mainly for measuring vacuum-tube coefficients, it has also proved useful for determining the characteristics of more complex circuit arrangements under different load conditions.[1] The advent of the transistor emphasizes the versatility of this bridge. Low-frequency coefficients are as easily determined for transistors as for vacuum tubes.[2] The bridge indicates the input and output resistance of transistors, their forward and reverse transfer conductance, and their voltage-amplification factors. The current-amplification factor is the product of two of the coefficients indicated by the bridge.

When vacuum-tube coefficients are being measured, the plate resistance, forward transconductance, and forward voltage amplification are the only coefficients of interest, because the input (grid) resistance is essentially infinite at the measuring frequency (1000 cycles); the reverse transconductance and reverse amplification are negligible. The forward and reverse parameters of the transistor are much more interdependent. The input resistance can be quite low, and its value is definitely a function of the load at the output terminals. Gain in both directions is also important. Indeed, under carefully chosen operating conditions,

[1]Edward H. Green, "A Precise Laboratory Exercise Using a Vacuum-Tube Bridge," *American Journal of Physics*, Vol. 16, No. 3, pp. 151–155, March, 1948.

[2]L. J. Giacoletto, "Transistor Characteristics at Low and Medium Frequencies," *Tele-Tech*, March, 1933.

Figure 1. Functional diagram of a four-terminal transducer.

equal power gains in the two directions are feasible,[3] though admittedly this is not the usual circuit application. However, to obtain sufficient design information even for normal applications, both the forward and the reverse coefficients of the transistor are needed.

In spite of the tremendous range in parameters found for the various types of transistors, the Type 561-D Bridge is entirely adequate. It will measure resistance (input or output) from 10 ohms to 100 Megohms; the transconductance range is from 0.001 to 100,000 micromhos; the voltage amplification range is from 0.0001 to 10,000.

The transistor, the vacuum tube, the amplifier (single- or multi-stage), the attenuator can each be represented as a four-terminal transducer (Figure 1). When known voltages are applied to the terminals and the resultant currents are noted, two equations are sufficient to define the characteristics of the transducer. The impedance or admittance parameters that interrelate the voltages and currents are useful for intercomparing transducers and for devising circuits to use them.

In standardizing methods for testing tubes,[4] the Institute of Radio Engineers adopted the nodal form of equations and expressed the parameters as admittances. At the low frequency (1000 cycles) used for the Type 561-D Bridge, the conductance component is of primary interest. The equations are, then,

$$i_1 = g_{11}v_1 + g_{12}v_2$$
$$i_2 = g_{22}v_2 + g_{21}v_1$$

g_{11} and g_{21} are the input conductance and the forward transconductance obtained with the output terminals shorted. g_{22} and g_{12} are the output conductance and the reverse transfer (feedback) conductance obtained with the input terminals shorted.

When these parameters are measured on the Type 561-D Bridge, the reciprocals of the input and output conductances are obtained (r_p on the bridge). The bridge is not limited to resistance (or conductance) measurements of networks with short-circuit terminations, however. It is immaterial to the bridge what the termination is.

The forward and reverse transconductances (g_m on the bridge) and the voltage-amplification factors for both directions (μ) are indicated directly at bridge balance.

The various amplification factors can be derived from the conductance values as follows:

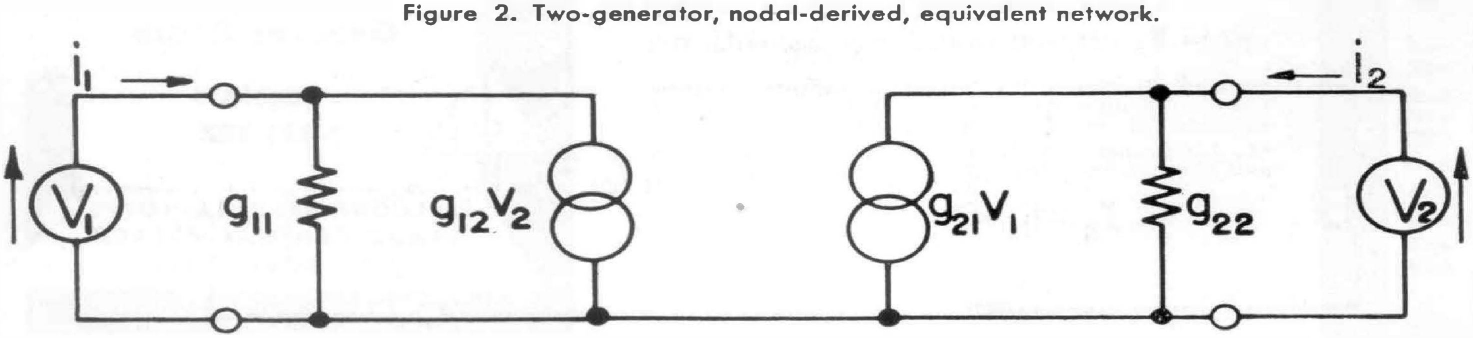
Forward current-amplification factor,

$$\alpha_{21} = -\frac{g_{21}}{g_{11}}$$

[3] R. M. Ryder and R. J. Keicher, "Some Circuit Aspects of the Transistor," *B.S.T.J.*, Vol. XXVIII, pp. 367–401, July, 1949.

[4] "Standards on Electron Tubes: Methods of Testing," *Proceedings of the I.R.E.*, Vol. 38, Nos. 8 and 9, August and September, 1950.

Figure 2. Two-generator, nodal-derived, equivalent network.



Reverse current-amplification factor,

$$\alpha_{12} = -\frac{g_{12}}{g_{22}}$$

Forward voltage-amplification factor,

$$\mu_{21} = -\frac{g_{21}}{g_{22}}$$

Reverse voltage-amplification factor,

$$\mu_{12} = -\frac{g_{12}}{g_{11}}$$

Forward power-amplification factor,

$$\phi_{21} = \frac{(g_{21})^2}{4\, g_{11} g_{22}}$$

Reverse power-amplification factor,

$$\phi_{12} = \frac{(g_{12})^2}{4\, g_{11} g_{12}}$$

The current-amplification factor is a significant coefficient of the transistor, just as the voltage-amplification factor is important in the vacuum tube. The current-amplification factor of a junction-type transistor, common-base connected, is usually very nearly unity. For a point-contact-type transistor, it is sometimes between two and three.

The vacuum tube can be operated with grounded cathode, grounded grid, or grounded plate (cathode-follower). Similarly, the transistor can be connected with grounded emitter, grounded base, or grounded collector. The Type 561-D Bridge can be used to measure the transistor coefficients for any of these circuit connections. If the coefficients have been determined for any one circuit arrangement, the coefficients for the other circuit arrangements can be computed from simple transformation equations.[5]

When a picture of the equivalent circuit of a transducer is attempted, the nodal equations lead to a two-generator network as shown in Figure 2.

The parameters of the nodal equations can be transformed very simply[5] to new parameters that are depicted by a one-generator π-network.

In the measurement of vacuum-tube coefficients with the Type 561-D Bridge, the third significant figure can usually be determined unless the tube under measurement is very noisy. Transistors have acquired the reputation of being noisier than tubes, though noise measurements on some newer designs indicate definite improvements. However, many junction-type transistors have noise figures of about 20-25 db and the figure for point-contact-type transistors is around 40-50 db. It is gratifying, therefore, to find that even point-contact-type transistors are readily measured on the Type 561-D Bridge and yield results that are entirely satisfactory for design-information purposes.

While the junction transistor is very stable, the point-contact type, because of inherent positive feedback, can be unstable. Stable operation is obtained either by confining operation to known stable circuit conditions or by introducing some positive external resistance in series with one of the electrodes to counteract the effects of the internal negative resistance. Manufacturers usually advise 500 to 1000 ohms.

[5]See the recent issue of the Operating Instructions for the Type 561-D Vacuum-Tube Bridge.

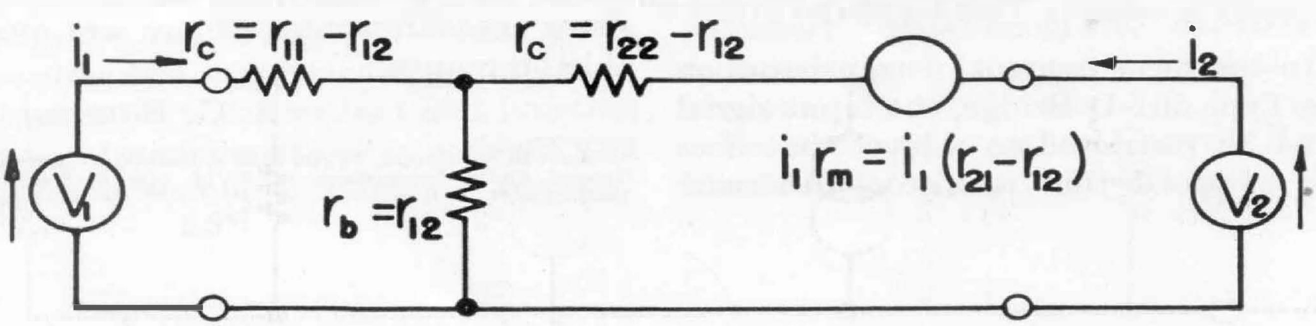


Figure 3. One-generator, loop-derived, equivalent network.

This external resistor is a factor which led to the early adoption of measurement methods that stressed constant current at the transducer terminals rather than constant voltage. The voltage-current equations are then of the loop (mesh) variety; parameter measurements are under open-circuit-termination conditions, the parameters are expressed as impedances (or resistances at low frequencies), and the equivalent one-generator circuit is a T-network as in Figure 3.

The measurement of these parameters becomes difficult because the equations assume open-circuit-termination conditions. This can be accomplished, however, by the use of parallel-feed choke coils that are of sufficiently high impedance at 1000 cycles or by feeding through the plate circuit of a pentode which has a very high plate resistance. The supply voltage must, of course, be relatively high.

Fortunately, the junction-type transistor will very likely be the preferred type for use in oscillators and amplifiers. Since it is, in many respects, analogous to the vacuum tube, it can be expected that the equivalent network adopted by the IRE Standards for the vacuum tube will also be found most useful for transistor applications. In any event, it is a simple matter to translate from one form of equivalent circuit to the other:

Nodal	*Loop*
$g_{11} = r_{22} \div \Delta r$	$r_{11} = g_{22} \div \Delta g$
$g_{12} = -r_{12} \div \Delta r$	$r_{12} = -g_{12} \div \Delta g$
$g_{21} = -r_{21} \div \Delta r$	$r_{21} = -g_{21} \div \Delta g$
$g_{22} = r_{11} \div \Delta r$	$r_{22} = g_{11} \div \Delta g$
$\Delta r = r_{11}r_{22} - r_{21}r_{12}$	$\Delta g = g_{11}g_{22} - g_{21}g_{12}$

In the measurement of transistors on the Type 561-D Bridge, the input signal must be restricted to a level that does not overload the transistor; otherwise the indicated value of coefficient will be in error. This is also true in vacuum-tube measurements. The obvious way to determine the safe level is to apply increments of voltage and note the level at which the measured coefficient no longer remains constant. This method, though correct, can be tedious and time-consuming. A quicker method is to obtain an approximate balance and to advance the voltage level to a point where distortion just becomes noticeable (in the detector headphones). This has been found to be a safe operating level.

Incidentally, when noisy transistors are being measured, the high sensitivity of the ear to the signal in the presence of noise yields surprisingly satisfactory results. The use of filters is less trying on the operator but does not greatly improve the balance condition. The new Type 1212-A Unit Null Detector[6], when used with phones, provides an excellent detection system since the clipping inherent in the logarithmic response reduces the noise but does not affect the low level signal at balance.

A recommended signal source is the General Radio Company Type 1214-A Unit Oscillator. Since the d-c voltages required for measuring the transistor are low and current drain is small, the use of batteries as power supplies is feasible. Sockets for the transistors can easily be mounted on the universal adapter plate furnished with the bridge.

The operating instructions for the Type 561-D Vacuum-Tube Bridge have been expanded considerably to include much information pertinent to transistor measurements. Copies are available on request.

— A. G. Bousquet

[6]Robert B. Richmond, "Type 1212-A Unit Null Detector," *General Radio Experimenter*, XXVII, No. 9, February, 1953.

MODERNIZATION OF VACUUM-TUBE BRIDGES

In the course of the last few years, several changes have been made in the Type 561-D Vacuum-Tube Bridge in order to meet the test requirements of the latest types of vacuum tubes. Our Service Department is equipped to make these changes in existing older-type bridges or to supply kits and directions to the user who wishes to do the work in his own shop. Write to the Service Department for further information.

1953 RADIO ENGINEERING SHOW

General Radio will be in the same location as in previous years in the Radio Engineering Show at Grand Central Palace, March 23–26.

The GR Display will include a demonstration of the remarkable overload characteristics of the Variac® autotransformer, resulting from General Radio's new Duratrak process for stabilizing the brush track. Also on display will be the new Type V-2 Variac® autotransformer, a new 2-ampere model.

The Type 1602-A Admittance Meter will be set up for operation at ultrahigh frequencies, with all necessary accessories for impedance measurements on receiver input circuits, components, lines, antennas, etc. If you are working with u-h-f TV receiving or transmitting circuits, be sure to see it and operate it. No other impedance-measuring device combines the accuracy and convenience of the admittance meter.

Unit Instruments, an impressive line of high quality, low-priced items for the laboratory, will be displayed. These building-block instruments now number some ten different models with several more soon to be announced.

Transistors — the Type 561-D Vacuum-Tube Bridge will be set up to measure the characteristics of transistors, both point-contact and junction types. Measurements of impedance and gain of a complete transistor amplifier will also be demonstrated. An experimental transistor oscillator will be set up for operation with General Radio Decade Capacitors and Inductors as the frequency-determining elements.

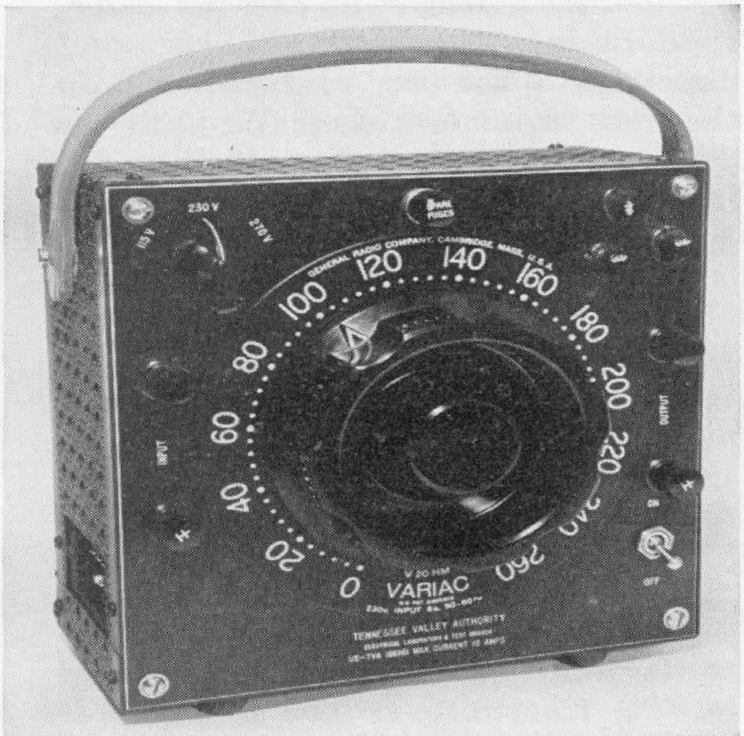
Type 874 Coaxial Elements, including many types of adaptors, will be displayed. Be sure to see the new adaptors to the u-h-f and v-h-f coaxial lines used on TV transmitters. The low VSWR of these adaptors is typical of GR Coaxial Elements, designed for accurate measurements over wide ranges of frequency.

Limit bridges for production testing — the Type 1652-A Resistance-Limit Bridge for d-c resistor measurements and the Type 1604-A Comparison Bridge for audio frequency measurements on capacitors, inductors, and resistors are convenient, rapid, test instruments for production line or laboratory that will speed up the selection of close-tolerance components for electronic circuits.

GR's famous TV Monitor, for checking the frequency of both transmitters and the modulation percentage of the aural transmitter, will also be on display. This monitor, for both v-h-f and u-h-f stations, has had a wide acceptance of transmitter manufacturers and station engineers. This accurate, dependable monitor is used by some 95% of all TV stations now on the air.

See these outstanding General Radio instruments at Booths 1-121 and 1-122.

PORTABLE TEST AUTOTRANSFORMERS



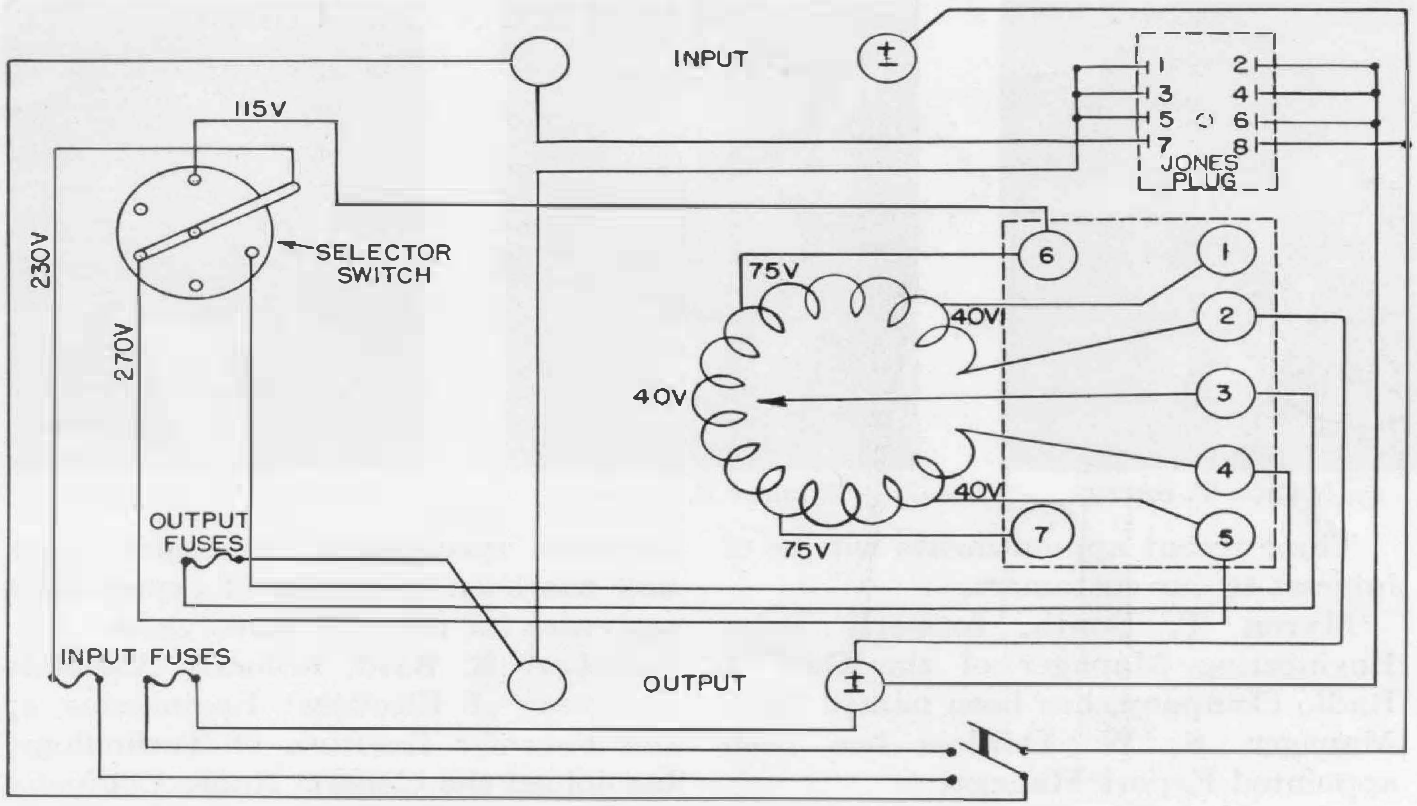
A source of manually controlled variable low voltage is required for many tests and maintenance activities associated with the operation of a power system. Over the past several years the Tennessee Valley Authority has purchased a number of continuously variable autotransformers to meet such needs in its power organization. Most of them have been in the 2.4-kva class although some smaller ones are used on light test work.

The General Radio Type V-20HM Variac is one type of variable autotransformer that has been made into a convenient, portable, general test instrument, as shown in the attached photograph by the Authority's development laboratory. Input and output connections are brought out to terminal posts to provide adequate facilities for connections. A voltage selector switch is installed to reduce the chances of incorrect connections in a test setup. Input and output connectors are also made to a Jones plug, which allows rapid, complete connections of the Variac into a standard relay test setup by merely plugging in a multiconductor test cable. Full fuse protection is provided, using slow-blow fuses in both input leads and in the brush lead. The slow-blow-type fuse takes care of the surge current when power is turned on, yet protects the Variac from overloads. A special magazine-type spare fuse holder keeps proper size replacement fuses at the test engineer's finger tips. The whole instrument is protected from mechanical damage by a metal enclosure, which also provides suitable mounting for a convenient carrying strap.

It has been found that fusing these devices has reduced burn-outs to practically zero whereas, previous to the time fuses were installed, burn-outs occurred rather regularly mainly because of improper connections into test circuits.

A single fuse is installed in the brush lead of the Type V-5 Variac without external visual evidence of such addition to the Variac. For example, in the V-5HM Variac, the fuse holder is strapped to the central post of the base plate with the end of the holder accessible for replacing the fuse from the bottom of the Variac.

Probably one of the most important, and certainly the most frequent, uses to which this device is put is in the testing and adjusting of the many protective relays found on a power system. In many of these testing operations, the autotransformer supplies power directly to the relay up to its rated current-carrying capacity. When heavier currents are needed, the autotransformer is used to control a loading transformer, which may furnish current of 100



amperes or more to the relay under test.

In addition to the many general and usual uses to which these devices are put by the Authority are occasional out-of-ordinary uses such as its use with a special 4-prong test prod and milliammeter as a bar-to-bar tester in motor work. For a controllable source of 100 amperes at low voltage and minimum weight and space for use in a microohmmeter, a few turns of heavy conductor to serve as a secondary winding are added around an adjustable autotransformer's core over a non-used portion of the regular winding.

— R. F. Bennington

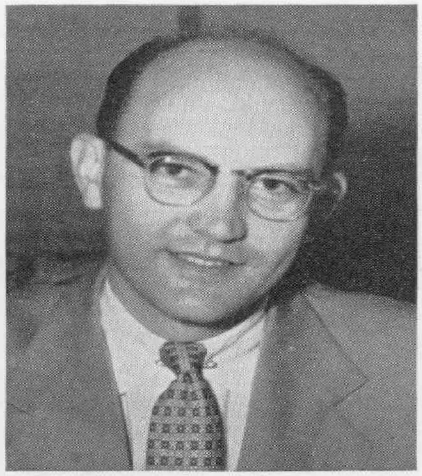
Mr. Bennington is Supervisor of Laboratories Section, Electrical Laboratory and Test Branch, Tennessee Valley Authority, Chattanooga, Tennessee. The publication of this material with the approval of the Tennessee Valley Authority does not constitute an endorsement of the General Radio Company's product by the Authority.

MISCELLANY

RECENT VISITORS to the General Radio Plant and Laboratories — Dr. Ing. Agostino Belotti of Ing. S. Belotti and Co. of Milan, our exclusive representative for Italy; Eric Monsted, Test Engineer, E.M.A.I.L., Sydney, Australia; Dr. Itaro Umeda and Mr. Katso Hogino of Oki Electric Engineering Co., Tokyo, Japan.

PAPERS — "Testing and Adjusting Speaker Installation with the Sound-Survey Meter," by William R. Thurston, at the Audio Fair, New York, 1952; "Steady-State Measurement — A Survey of Basic Methods," by William R. Thurston, at the Study Group on measurement techniques, New York Section, A.I.E.E., February 3, 1953; "Measurement and Its Place in Engineering," by William M. Ihde, at a meeting of the Student IRE Section, Valparaiso Technical Institute, December 11, 1952.

Myron T. Smith



Robert E. Bard

Stephen W. DeBlois

Three recent appointments will be of interest to our customers.

Myron T. Smith, formerly Sales Engineering Manager of the General Radio Company, has been named Sales Manager. S. W. DeBlois has been appointed Export Manager.

After his graduation from M.I.T. in 1931, Mr. Smith came with the General Radio Company as a development engineer. He served in this capacity until he was appointed manager of the New York district office. He subsequently managed the Los Angeles and Chicago districts, becoming Sales Engineering Manager in 1944.

Mr. DeBlois was graduated from Cornell University in 1936, and was later associated with Armco International. He served in the Signal Corps, U. S. Army, in the Mediterranean Theater during the war and was discharged a captain in 1945. He came to General Radio in 1946 as a sales engineer specializing in export work and has been in charge of export sales activities for the past three years.

Robert E. Bard, formerly Associate Professor of Electrical Engineering at the Fournier Institute of Technology, has joined the General Radio Company staff as Sales Engineer. Mr. Bard received his B.S. degree in Electrical Engineering from the Illinois Institute of Technology in 1942, after which he taught electrical engineering at that institution. He was associated with C. G. Conn, Ltd., as Engineer in the Research Department, leaving to enter the U. S. Navy, where he taught a course in Radar Fundamentals. From 1945 to 1948, he was employed by the American Phenolic Corporation as Senior Engineer in the Development and Research Divisions, and from 1948 to 1952 he has been on the faculty of the Fournier Institute of Technology.

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