GENERAL RADIO COMPANY
engineering department

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A TRANSFER-FUNCTION AND IMMITTANCE BRIDGE FOR THE 25-1500 Mc RANGE

The performance of most electrical devices and circuits is usually described by specifying input and output functions (impedance and/or admittance = "immittance") and transfer functions (ratios of output to input, or input to output, voltages and currents). The "alpha" and "beta" current ratios of transistors, the transconductance of vacuum tubes, the gain of amplifiers, and the loss of attenuators and filters are examples of widely used transfer functions. The New Type 1607-A Transfer-Function and Immittance Bridge[1] can measure *all* these types of functions over the frequency range from 25 Mc to about 1500 Mc. Measurements can be made on two-, three-, or four-[2] terminal networks with d-c bias supplied to all terminals and three- and four-terminal networks terminated in either an rf short or open circuit. Examples of complex impedance, admittance, and transfer-functions that can be measured directly are given in the table below:

[1]Originally described in a paper presented at the 1956 IRE Annual Convention and subsequently published in the 1956 IRE Convention Record, Part 5, pp. 3-7: "A Transadmittance Meter for VHF-UHF Measurements," by William R. Thurston. The name of the instrument has been changed to Transfer-Function and Immittance Bridge so as to indicate more completely its nature and uses.

[2]Having one input terminal and one output terminal grounded.

TRANSISTORS	VACUUM TUBES	THREE- AND FOUR-TERMINAL NETWORKS	DIODES	LUMPED COMPONENTS	COAXIAL LINES
α, β, h_f, h_r, h_i, h_o, r'_b, all short-circuit admittance and open-circuit impedance parameters.	Y_m (Y_{21}), Y_{12}, Y_{11}, Y_{22}, etc.	Z_{11}, Z_{22}, Z_{21}, Z_{12}, Y_{11}, Y_{22}, Y_{21}, Y_{12}, I_2/I_1, I_1/I_2, E_2/E_1, E_1/E_2	Z, Y, R, C	R, L, C	Z, VSWR

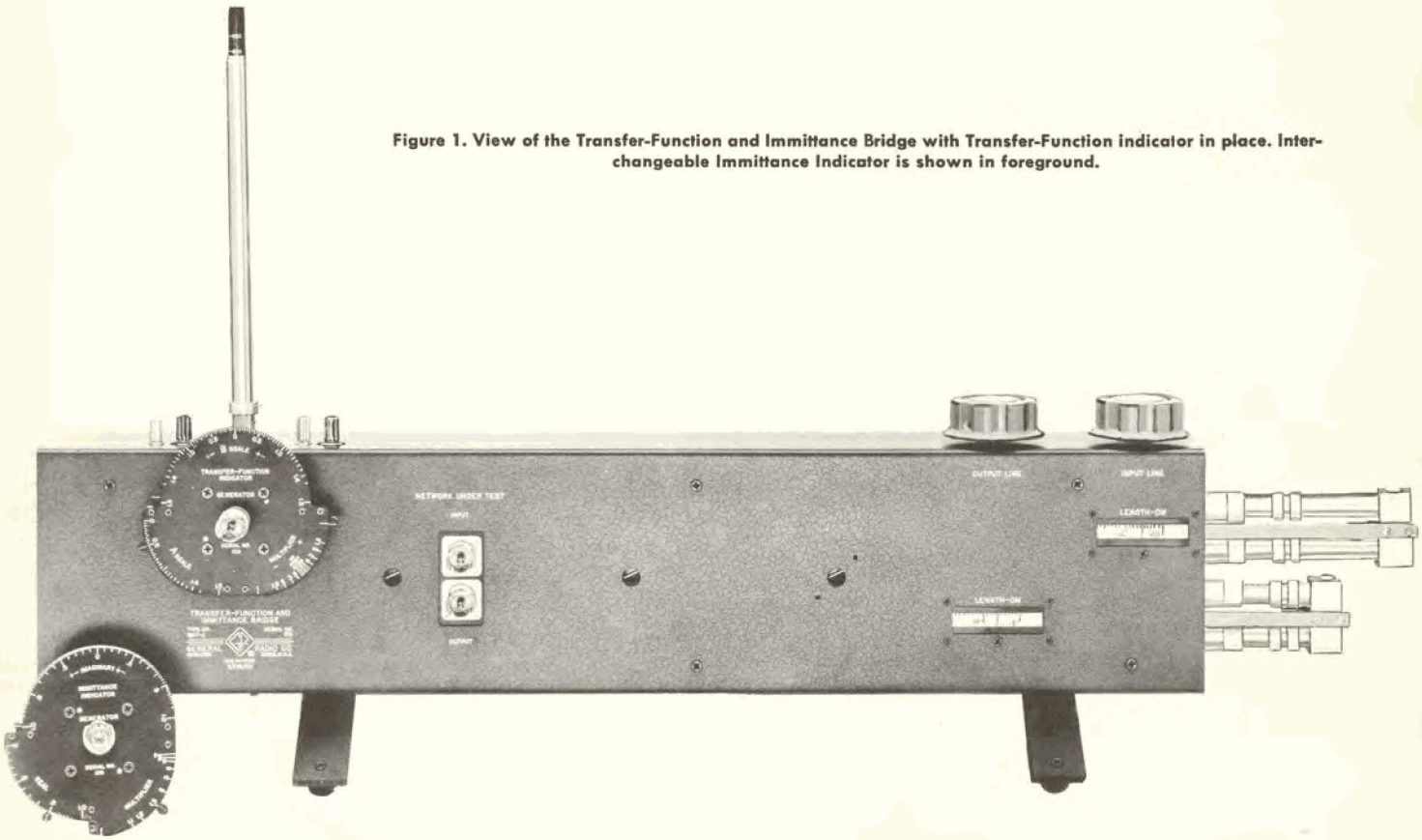


Figure 1. View of the Transfer-Function and Immittance Bridge with Transfer-Function indicator in place. Interchangeable Immittance Indicator is shown in foreground.

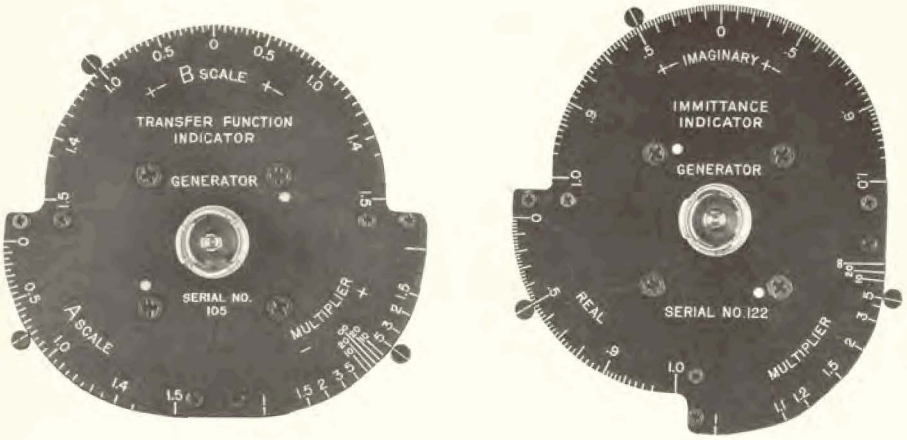


Figure 2. View of the two indicators. Calibrations are normalized with respect to coaxial line characteristic impedance (50 ohms) and admittance (20 millimhos).

Answers, direct reading except for a multiplying factor, are obtained in terms of complex components by a null method. The phase information provided by measurement of complex components is especially valuable at these high frequencies, where effects of transit time, electrode resonances, and stray capacitances usually dominate the over-all performance of a device.

The Transfer-Function and Immittance Bridge is a basic measuring tool, and has very important specific uses for transistor, diode, and vacuum-tube measurements. It is well suited for laboratory measurements because of its versatility, accuracy, and wide frequency range. It can also be set up for rapid, routine, production tests on transistors, vacuum tubes, amplifiers, or networks, and a high degree of skill or knowledge on the part of the operator is not required. Several specific applications, with results of measurements, are described later in this article.

Interchangeable Indicators

Two different indicator units, shown in Figures 2 and 3, are furnished with the bridge, one for transfer-function measurements and the other for immittance measurements. Each is an assembly of a casting with three rotatable loop units, control-indicator arms, and calibrated scales. They are held in place by four screws and are easily interchanged. Locating pins permanently preserve alignment and factory calibration.

THEORY OF OPERATION FOR TRANSFER-FUNCTION MEASUREMENTS

To measure a transfer function of a network, it is necessary to supply to it an input driving signal and to measure the resulting output signal in terms of the input signal. It is also necessary to terminate the network output in an open circuit if the desired output signal is a voltage, or in a short circuit if the desired output signal is a current. If the network were terminated otherwise, the answer obtained would depend on the network output impedance or admittance as well as on its transfer functions[3] and would, consequently, be less useful for general calculations.

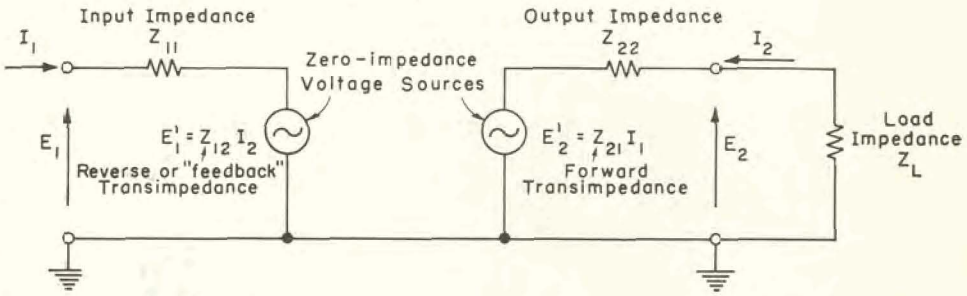
Nevertheless, there are undoubtedly applications where one wishes only to determine the over-all performance of a network working into a *specific* load impedance. In these cases, it is necessary to include the termination as a part of the network under test. Where output current is of interest, the termination must be in series, and where output voltage is of interest, the termination must be in shunt.

Forward transfer functions are, of course, measured by driving the normal input terminals of a network under test, while reverse, sometimes called "feedback," transfer functions are measured by reversing the network and driving the normal output terminals.

In the Transfer-Function and Immittance Bridge there are three identical loops, as shown in Figure 4, driven in parallel by an external generator adjusted to the desired frequency of measurement. The currents, I_L, in all three loops are equal in magnitude and phase. Each loop is loosely coupled, through electrostatically shielding slots, to an associated coaxial line. In Figure 4, only the inner conductors of these lines are shown. Each loop can be rotated independently of the others so as to vary its coupling, or mutual inductance, to its associated line. The mutual inductances are designated M_G, M_B, and M_X. The series voltages induced in the three lines by virtue of the couplings to the associated loops are: $E_G = -j\omega M_G I_L$, $E_B = -j\omega M_B I_L$, and $E_X = -j\omega M_X I_L$.

The outer end of the left-hand line, called the G line, is terminated in a known, standard conductance, Y_0 (20 millimhos). The characteristic admittance of the coaxial lines and TYPE 874 Connectors used in the instrument and associated components is also equal to 20 millimhos (characteristic impedance, Z_0, is 50 ohms). The outer end of the upper line, called the B line, is terminated in a known, standard susceptance of $+jY_0$ at frequencies below

[3]Example: Equivalent circuit using impedance parameters:



Measured forward transimpedance =

$$\frac{E_2}{I_1} = \frac{E'_2/I_1}{1+\frac{Z_{22}}{Z_L}} = \frac{Z_{21}}{1+\frac{Z_{22}}{Z_L}} \cong Z_{21}, \text{ if } Z_L \gg Z_{22}$$

From circuit and equations given, it is seen that the measured transimpedance equals the value of Z_{21} only if the load impedance Z_L is very large compared to the network output impedance, Z_{22}. Otherwise the measured value is in error, and the error can be in phase angle, magnitude, or a combination of both, depending on the phase angles of Z_L and Z_{22}.

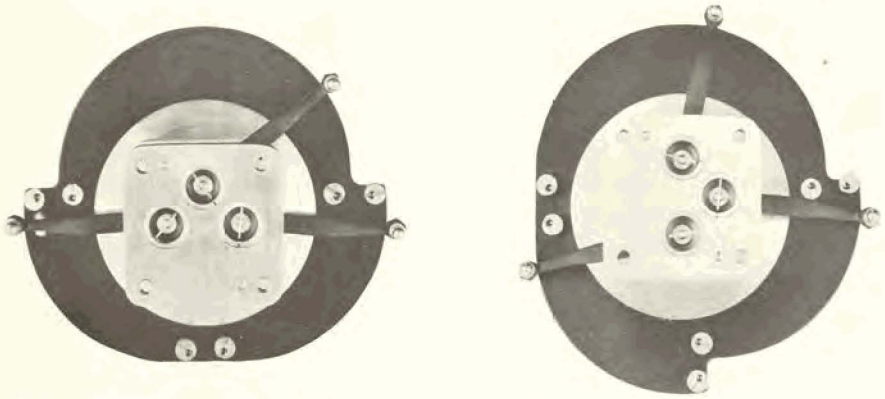


Figure 3. Rear view of indicator units showing different loop locations and consequent differences in scale plate shape.

150 Mc (adjustable capacitor), $-jY_0$ between 150 Mc and 450 Mc (adjustable stub set to $\frac{\lambda}{8}$), and $+jY_0$ above 450 Mc (stub set to $\frac{3\lambda}{8}$). The far end of the right-hand line, which is adjustable in length and is called the *Network Input* line, is connected to the input of the network under test, and its electrical length is always set to equal either an odd or an even multiple, n_1, of a quarter wavelength, depending on which type transfer function is to be measured.

The near end of the *Network Input* line terminates in a short circuit. The inner ends of the B and G lines come together in a junction with two other lines not previously mentioned, as shown in Figure 4. One of these latter lines is connected to an external detector. The other, which is adjustable in length and is called the *Network Output* line, is connected to the output of the network under test. Its electrical length is always set to equal either an odd or an even multiple, n_2, of a quarter wavelength, depending on which type transfer function is to be measured, but not necessarily the same multiple as that to which the *Network Input* line is set.

The process of measuring complex quantities involves the balancing of the instrument by adjustment of the loop couplings until the external detector indicates a null condition. At null, the voltage at the junction of the four coaxial lines is zero, and the three currents, I_G, I_B, and I_X, that enter the detector junction from, respectively, the G, B, and *Network Output* lines, must add up to zero. These line currents are readily calculated, because, for this purpose, the zero-voltage condition at the detector junction can be considered equivalent to a short circuit. For the purpose of simplifying the explanation, the lengths of the *Network Input* and *Network Output* lines will first be assumed to be zero. Under these conditions, $E_1 = E_X$ and $I_2 = I_X$.

The current, I_G, equals the induced voltage, E_G, times the admittance of the G line, which is the known, standard conductance, Y_0. That is,

$$I_G = Y_0 E_G = Y_0(-j\omega M_G I_L)$$
$$= Y_0 M_G(-j\omega I_L)$$

The current, I_B, equals the induced voltage, E_B, times the admittance of the B line, which is the known, standard susceptance, $\pm jY_0$. That is,

$$I_B = \pm jY_0 E_B = \pm jY_0(-j\omega M_B I_L)$$
$$= \pm jY_0 M_B(-j\omega I_L)$$

The current, I_X, equals the product of the induced voltage in the *Network Input* line, E_X, and the transadmittance of the network, Y_X. Therefore,

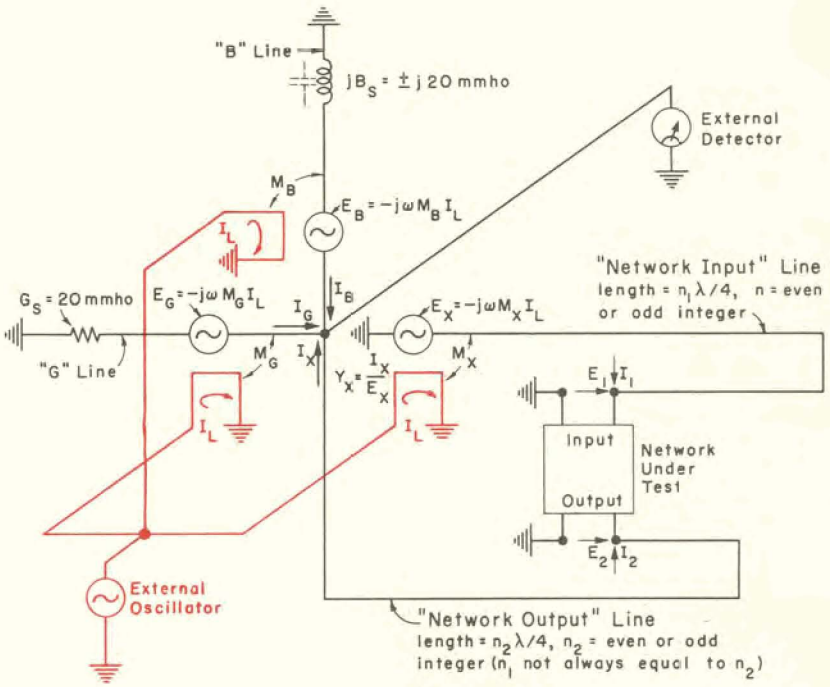
$$I_X = Y_X E_X = Y_X(-j\omega M_X I_L)$$
$$= Y_X M_X(-j\omega I_L)$$

When the sum of I_G, I_B, and I_X is equated to zero, which is the balance condition, the common $-j\omega I_L$ term is eliminated, and the basic balance equation for the instrument is obtained:

$$\frac{Y_X}{Y_0} = \frac{M_G}{M_X} \pm j\frac{M_B}{M_X}$$

The above equation is normalized with respect to the characteristic admittance of the line and corresponds to the dial calibration, which is normalized because impedances as well as admittances must be measured. As indicated above, the instrument actually measures the real and imaginary parts of the normalized transadmittance, $\frac{G_X}{Y_0}$ and $\frac{B_X}{Y_0}$, of the network connected directly between the input and output terminals of the instrument:

Figure 4. Schematic diagram of r-f circuits of the Transfer-Function and Immittance Bridge for transfer-function measurements.



$$\frac{G_X}{Y_0} = \frac{M_G}{M_X}$$

$$\frac{B_X}{Y_0} = \frac{M_B}{M_X}$$

Since the connecting line lengths are assumed to be zero, $Y_{21} = Y_X$, $G_{21} = G_X$, and $B_{21} = B_X$. The mutual inductance, M_X, is the denominator in both the above equations and hence is a common multiplier. The values of the mutual inductances, M_X, M_G, and M_B, depend on the angular positions of the loops and hence can be adjusted from zero to a maximum value by rotation of the loops. The angular position of the G loop can therefore be calibrated directly in normalized transconductance, the B loop in normalized transsusceptance, and the X loop in a common multiplier. Figure 2 shows these calibrations, which are independent of frequency and which, by virtue of the positive and negative ranges for two of the three loops, allow measurements to be made in all four quadrants of the complex plane. The scale associated with the G loop is labeled the A scale and is calibrated from 0 to 1.5. The scale associated with the B loop is labeled the B scale and is calibrated from 0 to $\pm$ 1.5. The multiplier is calibrated from $\pm$ 1 to infinity.

The assumption of zero length of lines between the instrument and network made in the preceding analysis cannot be realized in practice, since the effective measurement points are located *within* the instrument. However, by the adjustment of the *Network Input* and *Network Output* lines to odd or even multiples of a quarter wavelength, the instrument can be made to indicate directly the transadmittance, transimpedance, complex transfer current ratio, and complex transfer voltage ratio of networks whose terminals are *not* directly the actual measurement terminals of the instrument. Each of the above measurements requires a different setting of the *Network Input* and *Network Output* lines and will be considered in detail in the following paragraphs.

In the following discussion, the term "half-wave setting" means that the line in question is set to an *even* multiple of a quarter wavelength, which is, of course, always a multiple of a half wavelength. A half-wave line has the property of "repeating" at one end all voltages, currents, and impedances appearing at the other end with 180 degrees of phase shift in voltages and currents for each half wavelength. Similarly, the term "quarter-wave setting" means that the line in question is set to an *odd* multiple of a quarter wavelength. A quarter-wave line has the property of "inverting" voltages into currents, impedances into admittances, and vice versa. The reversal of phase which occurs for each added half wavelength will be ignored, since it does not affect the basic theory of operation.

Transadmittance, Y_{21} and Y_{12}

The forward transadmittance of a network with its output terminals short-circuited is Y_{21}. In order to measure this parameter, the *Network Input* and *Network Output* lines are both adjusted to a half wavelength. Under these conditions the output terminals of the network under test are effectively short-circuited, because the half-wave *Network Output* line terminates at the detector junction, which under null conditions has zero voltage and can be considered to be a short circuit. The half-wave line produces a similar short circuit at the network terminals and makes $I_2 = I_X$. The input half-wave line makes $E_1 = E_X$. Therefore,

$$\frac{Y_{21}}{Y_0} = \frac{I_2/E_1}{Y_0} = \frac{I_X/E_X}{Y_0} = \frac{Y_X}{Y_0} = \mathrm{A} + \mathrm{jB}$$

where A and B are the A and B *scale* readings.

As previously shown, the instrument directly measures the normalized, real and imaginary components of Y_X, and from the above equation it is evident that it also indicates $\frac{G_{21}}{Y_0}$ and $\frac{B_{21}}{Y_0}$.

The reverse transadmittance, Y_{12}, can be measured by the same procedure as indicated for the forward transadmittance but with the input and output connections of the network interchanged.

Transimpedance, Z_{21} and Z_{12}

The forward transimpedance of a network with its output terminals open-circuited is Z_{21}. In order to measure this parameter, the *Network Input* and *Network Output* lines are both adjusted to a quarter wavelength. Under these conditions the output terminals of the network under test are effectively open-circuited, because the quarter-wave *Network Output* line inverts the equivalent short circuit at the detector junction into an open circuit at the network. Also, the output quarter-wave line "inverts" the voltage E_2 into a constant times the current I_X, and the input quarter-wave line "inverts" the voltage E_X into a constant times the current I_1. It can be shown that

$$\frac{Z_{21}}{Z_0} = \frac{E_2/I_1}{Z_0} = \frac{I_X/E_X}{Y_0} = \mathrm{A} + \mathrm{jB}$$

where Z_0 is the characteristic impedance of the coaxial lines, 50 ohms. Thus the instrument reads directly the normalized transimpedance of the network under test. The readings are in terms of the normalized network transresistance, $\frac{R_{21}}{Z_0}$, read on the A scale, and the normalized transreactance, $\frac{X_{21}}{Z_0}$, read on the B scale.

Reverse transimpedance, Z_{12}, is measured in a similar manner with the input and output network connections reversed.

Transfer Current Ratio, I_{21} and I_{12}

The forward transfer current ratio of a network with its output terminals short-circuited is I_{21}. For this measurement the *Network Output* line is adjusted to a half wavelength and the *Network Input* line to a quarter wavelength. The output terminals of the network under test are effectively short-circuited, because the half-wave *Network Output* line "repeats" the equivalent short circuit at the detector junction as a short circuit at the network. The half-wave line also makes $I_2 = I_X$. The quarter-wave *Network Input* line makes

$$E_X = \frac{jI_1}{Y_0}. \text{ Therefore,}$$

$$I_{21} = \frac{I_2}{I_1} = \frac{jY_X}{Y_0} = \mathrm{B} + \mathrm{jA}$$

Thus the instrument reads directly the real and imaginary components of the complex transfer current ratio of the network. The "j" term in the above equation interchanges the real and imaginary scales.

The reverse transfer current ratio, I_{12}, can be measured by reversing the input and output connections to the network.

Transfer Voltage Ratio, E_{21} and E_{12}

The forward transfer voltage ratio, E_{21}, is measured with the network output terminals open-circuited. In this case the *Network Output* line is adjusted to a quarter wavelength and the *Network Input* line to a half wavelength. The output terminals of the network are effectively open-circuited because the quarter-wave *Network Output* line "inverts" the equivalent short circuit at the detector junction into an open circuit at the network. Also, because of the quarter-wave *Network Output* line, $E_2 = \frac{jI_X}{Y_0}$, and because of the half-wave *Network Input* line, $E_1 = E_X$. Therefore,

$$E_{21} = \frac{E_2}{E_1} = \frac{jY_X}{Y_0} = \mathrm{B} + \mathrm{jA}$$

Here again, the instrument indicates the complex open-circuit transfer voltage ratio of the network under test with the real and imaginary component scales interchanged from those used for trans-admittance measurements because of the "j" term in the above equation.

Reverse transfer voltage ratio, E_{12}, can be measured by reversing the input and output connections to the network.

THEORY OF OPERATION FOR IMMITTANCE MEASUREMENTS

For immittance measurements with the Immittance Indicator (Figure 5), there are still three loops coupled to three coaxial lines, two of which are terminated, respectively, in a standard conductance and a standard susceptance, but the third loop couples to the bottom line (labeled "Network Output") instead of to the right-hand line (labeled "Network Input"). In the schematic diagram of Figure 5, the circuit is set up for measuring the output immittance of a four-terminal network. To measure network input immittances, the network is simply reversed. Note that the lower line, though labeled "Network Output" because of its use during transfer-function measurements, actually drives the network during immittance measurements. The upper line, labeled "Network Input" because of its use during transfer-function measurements, acts as either a short or open circuit at the other end of the network during immittance measurements and has no other coupling to the circuit, except to provide dc bias if required.

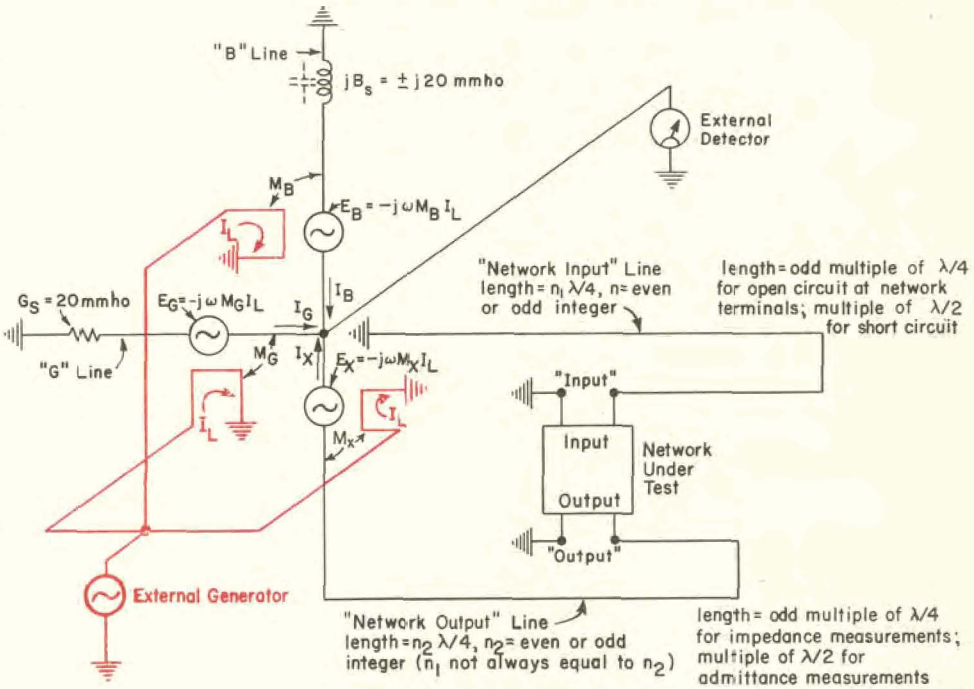
For measurements on two-terminal, grounded immittances, the unknown network is connected to the lower ("Output") terminals, and the upper line (labeled "Network Input") is not used at all.

This circuit for immittance measurements is the same as that used in the TYPE 1602-B Admittance Meter.[4] With the lower line (labeled "Network Output") set to a half wavelength or an integer multiple thereof, the instrument measures admittance. With the line set to a quarter wavelength or odd multiple, the instrument measures impedance. The scales are calibrated in normalized components, from 0 to 1, with a multiplier from 1 to ∞ as shown in Figure 2. For impedance measurements, the reference is 50 ohms, and for admittance measurements, 20 mmhos. The Transfer-Function and Immittance Bridge can measure everything that the Admittance Meter can measure, including reflection coefficient and VSWR of transmission lines and antennas. In addition, it has the built-in, calibrated, adjustable line for direct-reading immittance measurements, the second, short-circuited, calibrated, adjustable line for proper termination of four-terminal networks during input and output immittance measurements, and provisions for biasing active devices or networks. However, the Admittance Meter will, no doubt, still be preferred in a number of instances for two-terminal measurements because of its lower price, smaller size, and somewhat better basic accuracy (3% vs. 5%).

PHYSICAL DESCRIPTION

The physical arrangement of the parts of the Transfer-Function and Immittance Bridge corresponds closely to that shown in the schematics of Figures 4 and 5 and is illustrated further in Figure 6, in which the cover of the instrument has been removed and the coupling-loop or indicator assembly dismounted. The Transfer-Function Indicator is shown separated at the lower left. At the left of the main assembly in Figure 6 can be seen the main junction block, in which coupling slots are cut into the coaxial lines within the block. When in place, each of the three loops in the indicator assembly is centered over its respective slots and is coupled magnetically to the corresponding line. The *Network Input* and *Network Output* lines

Figure 5. Schematic diagram of the circuit for immittance measurement. For a diagram of the circuit for transfer-function measurement, see Figure 4.



[4] W. R. Thurston, "A Direct-Reading Impedance-Measuring Instrument for the U-H-F Range," *General Radio Experimenter*, Vol. 24, No. 12, May, 1950, pp. 1-7.

R. A. Soderman, "Improved Accuracy and Convenience of Measurements with TYPE 1602-B Admittance Meter in VHF-UHF Bands," *General Radio Experimenter*, Vol. 28, No. 3, August, 1953, pp. 1-6.

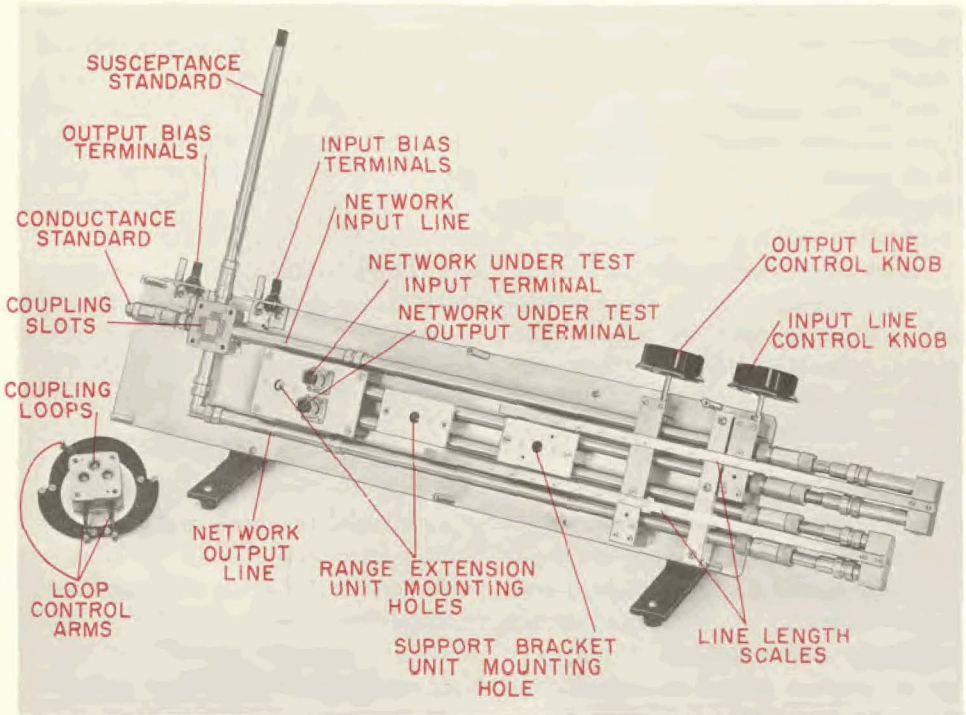


Figure 6. The Transfer-Function and Immittance Bridge partially disassembled to show details of design and construction. (Transfer-function indicator shown in left foreground.)

are of the constant-impedance, "trombone" type, driven independently by separate, rack-and-pinion drives having accurately calibrated scales to indicate total effective line lengths directly in cm. The lines are provided with locking sleeves to prevent accidental changes during prolonged work at a single frequency. All these parts are mounted on a heavy aluminum base plate.

In the measurement of active devices, especially transistors, it is important to keep the applied signal level low. In this instrument, the coupling loss of the loop between the external generator and the device under test is about 40 db at 500 Mc and decreases at a rate of 6 db per octave with increasing frequency. For tests on transistors, in which signal levels should be 5 millivolts or less, appropriate attenuators (874-G series) should be used to reduce the level of the signal supplied by the generator when necessary.

Since the external detector is usually of the heterodyne type with a local oscillator, it is important to prevent excessively high local-oscillator signals from appearing at the terminals of the unknown device. This problem is solved by the insertion of a tuned stub, or "trap," in parallel with the detector input and tuned to reject the local-oscillator frequency. This stub is supported horizontally behind the base plate of the instrument.

In measurements on active networks, d-c voltages or currents must be supplied without affecting the r-f circuits. In the Transfer-Function Meter, provisions are included for applying dc to both the input and the output of the network under test. The binding posts for connection to external power supplies are visible in Figure 6, and the internal filters and blocking capacitors are shown schematically in Figure 7. Built-in blocking capacitors isolate the measurement standards, the external detector, and the short circuit on the *Network Input* line. Filter networks, each comprising two chokes and two by-pass capacitors, allow insertion of d-c voltages and currents and prevent r-f leakage. Choke and capacitor ratings limit currents to 250 milliamperes and voltages to 400 volts. Higher currents may be used for short periods. The loading effect of the input filter on the *Network Input* line is negligible, because of its proximity to the short-circuited end of the line. The only loading effect of the output filter on the detector line is a small reduction in detector sensitivity.

The range of adjustment of the *Network Input* and *Network Output* lines is such as to allow continuous coverage for all types of measurements above 300 Mc, plus separated bands of coverage below 300 Mc. In order to allow continuous coverage below 300 Mc, a set of extension lines is provided. When needed, these lines and their supports can be snapped into place by means of quarter-turn fasteners, as shown in Figure 8. This photograph also shows the shielded, variable capacitor used as the susceptance standard at low frequencies in place of the stub used at high frequencies.

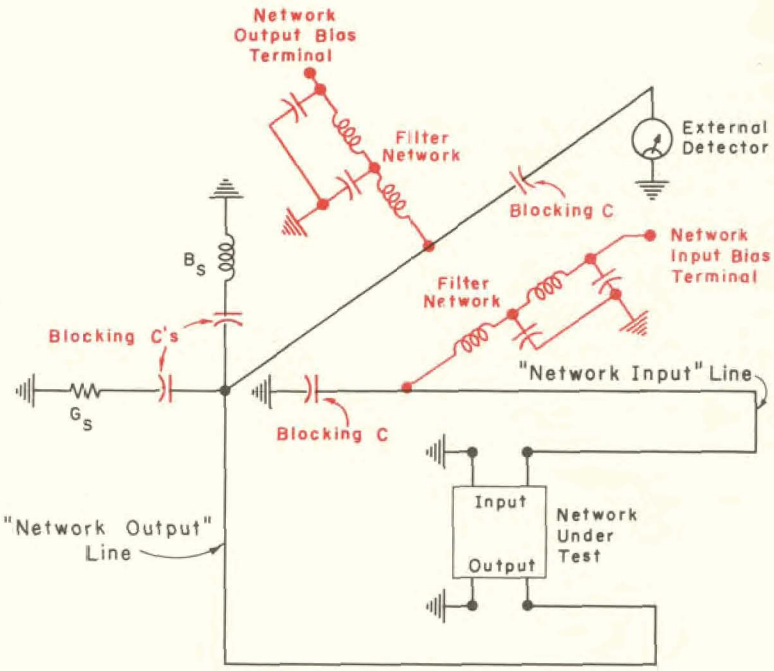


Figure 7. Schematic diagram of d-c circuits of the Transfer-Function Meter.

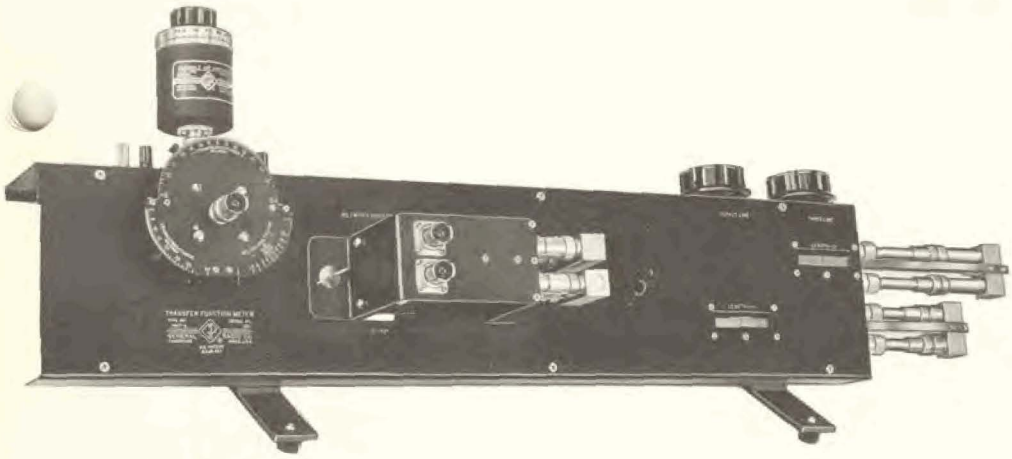


Figure 8. View showing Range Extension Unit and low-frequency susceptance standard.

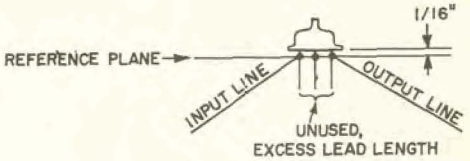


Figure 9. Sketch of connections to transistor, showing the reference points of measurement.

Generator and Detector

General Radio Unit Oscillators are recommended for use as generators with the Transfer-Function Meter. The recommended detector is the General Radio Type DNT, a heterodyne type that combines high sensitivity with wide frequency range. Both generators and detectors are listed on page 12.

Transistor Mounts

At very-high and ultra-high frequencies, the method of connecting an unknown device to a measuring instrument of any kind is critical. Reproducible answers can be obtained in different measurements by different people using different equipment only if the same, standard method of making connections is used in all cases, with details of configuration and dimension being precisely the same. Furthermore, the necessity of applying bridge voltages or currents to transistors or other active devices, of accurately compensating stray capacitances and inductances, and of suppressing spurious oscillations makes the design of suitable mounts more than a minor job, even for an engineer skilled in vhf-uhf design techniques.

To help avoid these problems in transistor measurements, standard mounts have been designed, two of which are presently available and two more which are approaching completion in development. Additional types will be added from time to time in response to user demand. Those available now are for JETEC basings, 0.200-inch-pin-circle triode, with common base (1607-P101) or common emitter (1607-P102). Those in development are for 0.200-inch-pin-circle tetrodes (1607-P401) and 0.100-inch-pin-circle triodes with common base (1607-P111). Leads of units to be measured can be any length between 3/32 and 5/16 inch, and lead diameters up to 0.035 inch can be accommodated. In the Transfer-Function and Immittance Bridge all characteristics of a given transistor with a given common electrode are measured with a single mount, thus insuring consistency of results at high frequencies.

These transistor mounts incorporate several refinements that result in accurate and reproducible measurements:

(a) The reference point of measurement on the transistor leads is only 1/16" from where they emerge from the header, as shown by Figure 9. Therefore, the measured characteristics are those of the transistor elements in their housing and with 1/16" leads. This measurement environment is very close to the best that can practically be done in actual circuit use of transistors.

(b) The input and output lines leading to the reference plane are accurately compensated to maintain a 50-ohm characteristic impedance level with very low reflections due to discontinuities.

(c) A removable 50-ohm resistor, with bias blocking capacitor, is supplied to suppress spurious oscillations. This resistor is shunted across either the input or the output of a transistor, depending on the type of measurement being made, and has no adverse effect on measurement accuracy.

(d) The input and output circuits within the mounts are very well shielded, so that coupling between them external to the transistor is negligible.

Transistors with 0.072-inch-pin circles will be easily measurable in the 0.100-inch-pin-circle mount (available later) if the leads are bent the slight amount required, by use of the lead alignment holes provided in the top of the mount.

Figure 10 is a photo of Type 1607-P101 Transistor Mount.

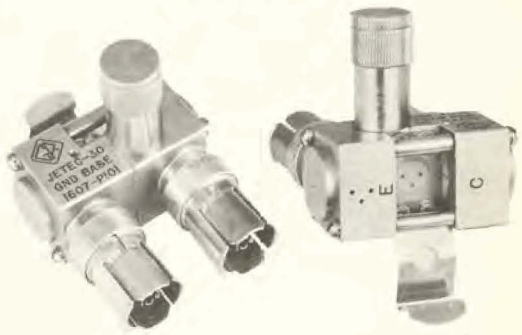
Tube Mount

One tube mount is available so far, and others are in development. The one now available is designed for common-cathode measurements on seven-pin miniature tubes such as 6AF4, 6AF4A, 6AN4, 6T4, and other tubes having the same pin connections. The tube is measured in the socket of the mount, so that measured values will include socket effects and will be those of greatest use in circuit design. The Type 1607-P201 Tube Mount, with tube and shield installed, is shown in Figure 11.

Diode and Component Mounts

Active and passive 2-terminal components, such as diodes, resistors, capacitors, inductors, thermistors, etc., can readily be measured either with one terminal grounded or with neither terminal grounded. Ungrounded measurements are often desirable to avoid the

Figure 10. Two views of the Type 1607-P101 Transistor Mount showing the damper unit projecting from the side. In the right-hand view the lead alignment holes can also be seen.



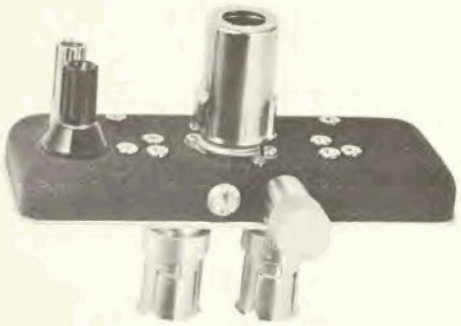


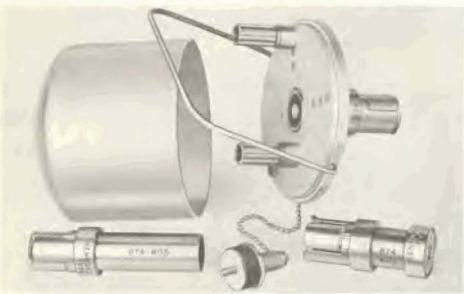
Figure 11. View of the Type 1607-P201 Tube Mount with tube and shield installed and damper unit projecting from side. Binding posts at left are for heater connections.

effects of the stray capacitances between the component terminals and ground. The Type 874-M Component Mount is available for measuring grounded components, and the Type 1607-P601 Ungrounded Component Mount will be available soon for measuring ungrounded components. Both mounts incorporate versatile means for connecting to many sizes and shapes of components and are supplied with a cover for complete shielding of the unknown if desired. The electrical design of these mounts minimizes lead reactance and stray capacitance. The Type 874-M Mount is shown in Figure 12, and the appearance of the Type 1607-P601 Mount is similar, except that it has two coaxial connectors side by side instead of one.

MEASUREMENT PROCEDURE

The equipment is set up by connecting generator, detector, and d-c supplies, if needed, to the Transfer-Function and Immittance Bridge, and making the necessary adjustments for desired operating frequency and d-c levels. The calibrated susceptance standard is also set to the operating frequency.

Figure 12. The Type 874-M Component Mount for measuring grounded components.



If isolation of the local-oscillator signal is desirable, as in measurements on transistors, the "trap" stub is included in the setup and is adjusted for maximum attenuation of the local-oscillator voltage.

Next, the *Network Input* and *Network Output* lines are set to the proper length, in accordance with the type of transfer function or immittance to be measured. An appropriate component mount is plugged into the *Network Under Test* connectors, and the unknown device or network is plugged into the mount. The three loop-control arms are then adjusted until the detector indicates a null, and the desired answer is read directly from the scale settings.

If several units of the same type are to be checked at a given frequency, as in the case of production testing of transistors or tubes, each unit successively is plugged into the mount (with due precautions regarding the d-c supplies), the control arms are set for a null, and the answer is read off the scales. This operation can be performed very rapidly by relatively unskilled personnel.

Terminals

The terminals used on the Transfer-Function Meter are Type 874 Coaxial Connectors. General Radio oscillators and detectors are also equipped with these terminals. When generators and detectors having other types of terminals are used, the Type 874-Q series of adaptors provides a convenient means of connection.

For special types of measurements requiring the construction of special mounts to connect the device being measured to the measuring terminals, Type 874 Coaxial Connectors to fit rigid line, panel, and cable are available for building into these mounts.

Both adaptors and connectors are listed on page 12.

Sources of Error

The major sources of error are incidental losses and small reflections in the *Network Input* and *Network Output* lines. The minor sources of error are similar to those in the Type 1602-B Admittance Meter[4] and are spurious cross-couplings between the coupling loops and their associated lines, inductances between the junction center and the coupling points, incidental losses in the susceptance standard, and small reflections in the conductance standard.

In most measurements, the instrument dial readings can be used directly without any corrections and will be accurate within the limits given in the specifications at the end of this article.

Some of these errors become appreciable under certain conditions, but corrections can be made for them.

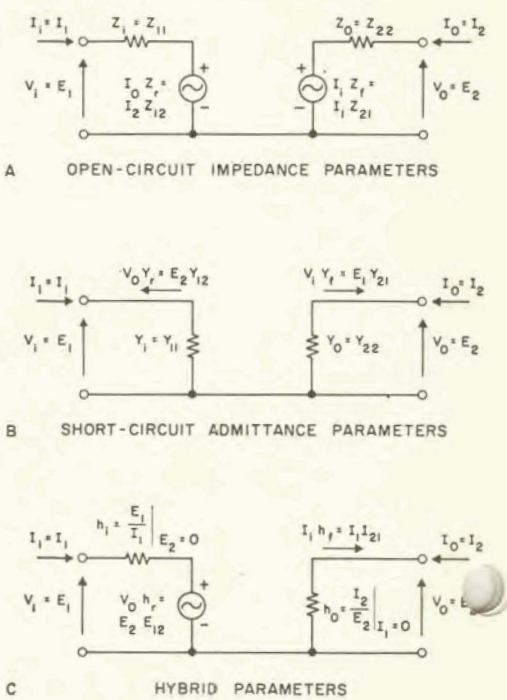
APPLICATIONS

Transistor Measurements

Several different network representations are used for transistors, the most common of which are shown in Figure 13. All of the transfer parameters indicated in these circuits can be directly measured with the Transfer-Function Meter at frequencies between 25 and about 1500 Mc.

Since many transistors operate at very low voltage levels, it is important that all applied signals be kept small during the measurements. As previously mentioned, the r-f signal level can be held below 5 mv, which has been found to be a satisfactory limit.

Figure 13. Equivalent network representations of transistors. Left-hand set of symbols is from "IRE Standards on Electron Devices; Methods of Testing Transistors," *Proc. IRE*, Vol. 44, pp. 1542-1561, November, 1956. Right-hand set of symbols corresponds to those of this article.



For measurement of the complex current ratios, α (or $-h_f$), the *Network Input* line is set to a quarter wavelength and the *Network Output* line to a half wavelength, as outlined in a previous paragraph. The local-oscillator trap is adjusted, with interchange of the generator and detector connections, by adjustment of the stub line until minimum output is observed on the meter of the detector. The normal connections are restored and the transistor mount plugged into the coaxial connectors on the panel of the instrument. The meter is then balanced by adjustment of the three arms, and the real and imaginary components of the current ratio are indicated directly on the dial scales. The α-vs.-frequency characteristics of an experimental, Bell Telephone Laboratories, diffused-base, germanium transistor in a common-base connection are shown in Figure 14.

The hybrid feedback factor h_r ($= E_{12}$), can be easily measured by reversal of the coaxial-line connections between the common-base mount and the instrument,

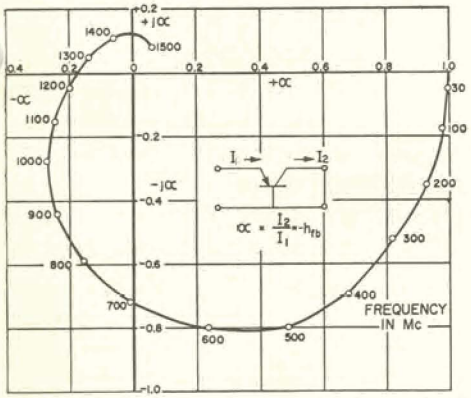
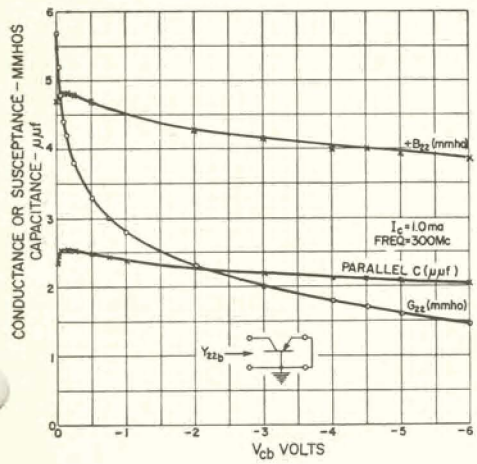


Figure 14. Plot of α, or $-h_{fb}$, versus frequency for a diffused base transistor.



NETWORK PARAMETER MEASUREMENTS ON A HIGH-FREQUENCY TRANSISTOR AT 300 Mc

FREQUENCY = 300 Mc, V_{cb} = -4.5 v, I_c = 1.0 ma, SHELL GROUNDED

COMMON BASE			COMMON EMITTER		
	HYBRID	SC ADMITTANCE mmhos	HYBRID	SC ADMITTANCE mmhos	
α_f	h_{fb}	Y_{21b}	h_{fe}	Y_{21e}	β_f
0.79 - j 0.53	-0.79 + j 0.53	-3.4 + j 10.2	-0.68 - j 1.5	2.0 - j 12.0	-0.68 - j 1.5
α_r	h_{rb}	Y_{12b}	h_{re}	Y_{12e}	β_r
0.32 - j 0.18	0.04 + j 0.14	-1.4 - j 1.0	0.12 + j 0.09	-0.4 - j 1.0	-0.215 - j 0.02
	h_{ib}	Y_{11b}	h_{ie}	Y_{11e}	
	67.0 + j 53.8 ohms	9.1 - j 6.9	115 - j 75 ohms	5.9 + j 4.1	
	h_{ob}	Y_{22b}	h_{oe}	Y_{22e}	
	0.2 + j 4.25 mmhos	1.8 + j 4.2	3.2 + j 3.0 mmhos	1.9 + j 4.3	

which is accomplished by 180° rotation of the mount, reversal of the d-c connections, and use of the procedure outlined for voltage-ratio measurements. Under these conditions the input is applied to the collector and the output is obtained from the emitter.

With this instrument transistors can be measured in either the common-base or common-emitter connection; and a *complete* set of measurements can be made in either connection without calculation of any of the parameters from measurements made in another connection. This factor is important at high frequencies, where connection changes can cause changes in the effects of stray capacitances and inductances.

The chart on page 9 shows a typical set of measurements made on a high-frequency transistor. All the values were directly measured with the exception of the h_o parameters. For the h_o measurement, the output admittance must be determined with the input circuit open circuited, a condition which is easily obtained with the bridge. However, with the open-circuit connection, the damping units cannot be used, and in some cases regeneration or oscillation can occur. In these cases, h_o can easily be calculated from the formula:

$$h_o = Y_{22} + \frac{h_f h_r}{h_i}$$

The variations in some of the above transistor parameters with collector

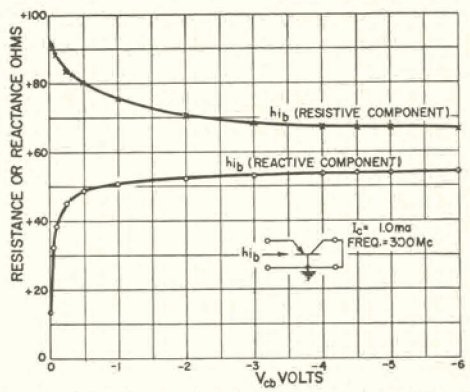


Figure 15. Variation of parameters of a diffused-base transistor as a function of collector voltage.

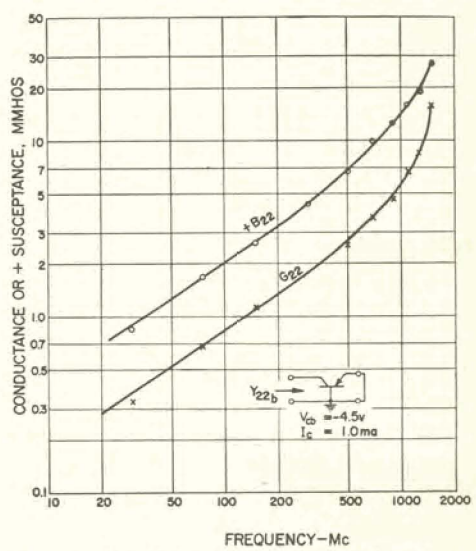


Figure 16. Plot of short-circuit output admittance as a function of frequency for a diffused-base transistor.

NOTE: All schematics show *rf* connections only, with biasing connections omitted.

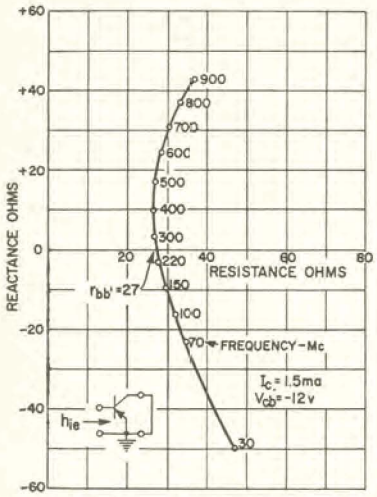


Figure 17. Plot of input reactance versus input resistance, with output short circuited, for a low-frequency transistor.

voltage are plotted in Figure 15. Figure 16 shows the results of measurements of the short-circuit output admittance, Y_{22}, on a similar transistor.

The extrinsic base resistance, $r_{bb'}$, of a transistor is often determined[6] from measurements of the common-emitter input impedance with the collector short circuited, h_{ie}. In this case, the $r_{bb'}$ is approximately equal to the input resistance obtained at a frequency at which the reactance is zero. Figure 17 shows a plot of h_{ie} measured on a relatively low-frequency transistor, indicating a base resistance of 27 ohms. At frequencies above the zero-reactance point, the reactance becomes positive owing to the inductance of the leads inside the transistor body and that of the short length of pin between the seal and the point at which the measurements are made. At much higher frequencies, this lead inductance can be in paralled resonance with the stray capacitance to the shell and ground, as shown in Figure 17.

In high-frequency transistors, the zero-reactance point occurs at a much higher frequency, and the impedance at this point may be affected by stray lead reactances. A typical measurement is shown in Figure 18. Measurements were also made on a slotted line in order to check the values measured on the Transfer-Function and Immittance Bridge. These measurements are plotted on the same figure, and it is evident that they agree very closely with the Transfer-Function and Immittance Bridge measurements.

[6]R. P. Abraham and R. J. Kirkpatrick, "Transistor Characterization at VHF," *Proc. Nat. Elec. Conf.* 13, pp. 385-402, 1957.

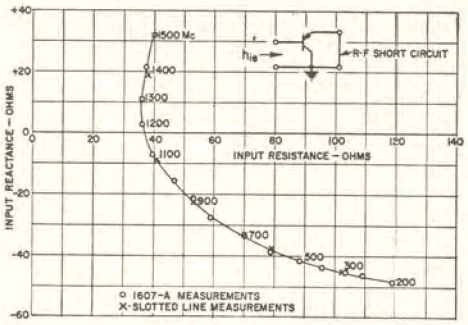


Figure 18. Plot of input reactance versus input resistance, with output short circuited, for a high-frequency transistor. Comparison with slotted-line measurements.

Tube Measurements

The high-frequency, complex, forward and reverse transadmittances of vacuum tubes can also be easily measured under dynamic conditions with the Transfer-Function Meter. D-C plate and bias voltages can be applied to the input and output terminals in the same manner as with transistors. Filters must be provided in the tube mount for heater and screen voltages. However, these filters are not so critical as are the filters associated with the input and output circuits. As with transistors, the mount must be carefully designed in order to give significant and reproducible results. The measured transadmittance of a 6AF4 in the grounded-cathode connection is plotted in Figure 19. The effective transadmittance first increases with frequency, apparently as a result of a resonance between the grid-cathode capacitance and cathode-lead inductance. At higher frequencies, other resonances are apparent, the largest one of which is probably a result of the grid-plate capacitance and plate lead inductance resonance. The large values of transadmittance shown do not result in correspondingly large magnitudes of gain when this tube is used in an amplifier, since the input impedance decreases rapidly as the resonances are approached.

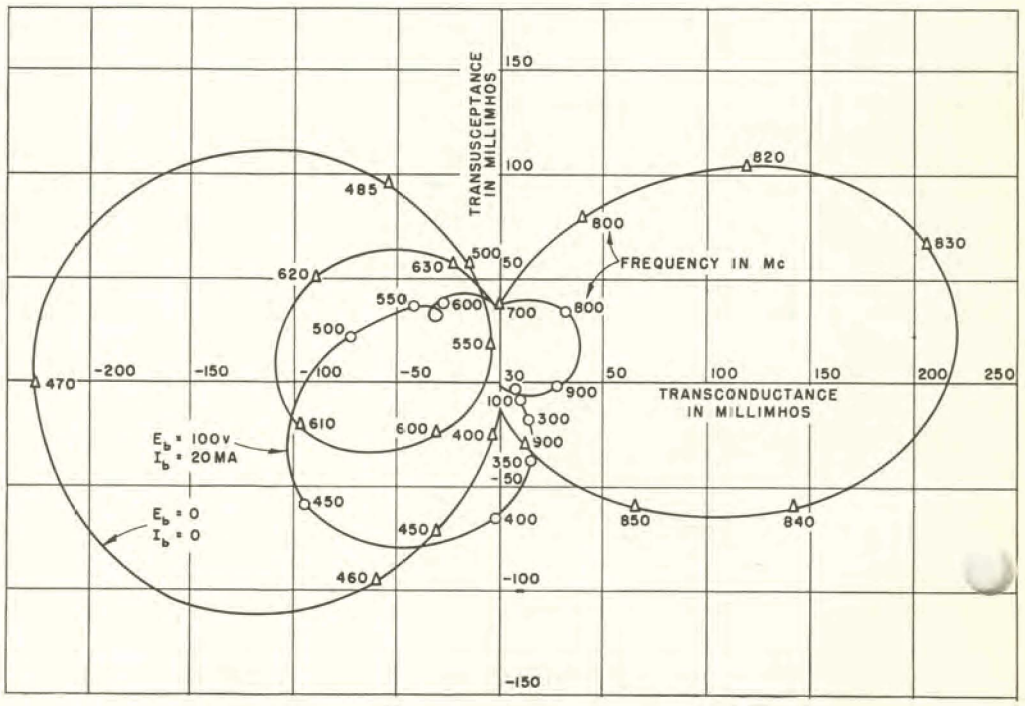
Coaxial-Component Measurements

The Transfer-Function Bridge can measure the transfer admittance or impedance and attenuation of circuits fitted with coaxial connectors. Figure 20 shows the results of short-circuit, current-ratio measurements made on a TYPE 874-G10 Attenuator Pad, and Figure 21 shows transadmittance of the same pad. Other possible applications are for filters, coupling networks, amplifiers, and other four-terminal coaxial devices.

Two-Terminal Component Measurements

As mentioned earlier, measurements on diodes and other lumped, 2-terminal components can readily be made either grounded or ungrounded. The grounded measurement is made in the same manner as with the Type 1602-B Admittance Meter, and the capacitance from the

Figure 19. Transadmittance versus frequency for a grounded-cathode 6AF4 vacuum tube.



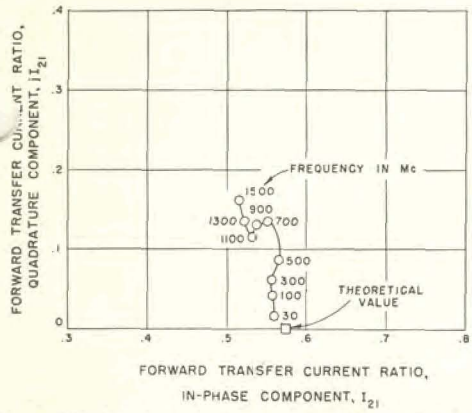


Figure 20. Forward transfer current ratio versus frequency for a Type 874-G10 Attenuator Pad.

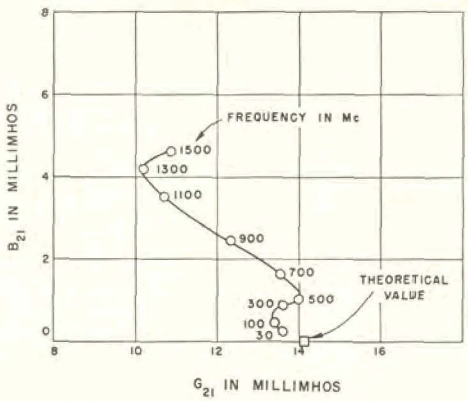


Figure 21. Forward transadmittance versus frequency for a Type 874-G10 Attenuator Pad.

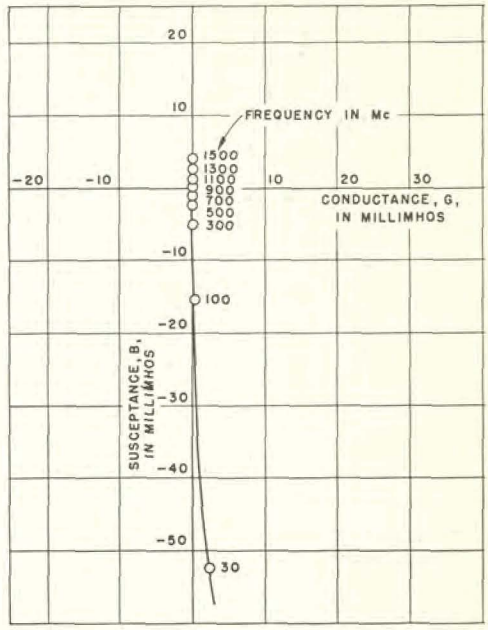


Figure 22. Admittance versus frequency for a 0.1-microhenry inductor.

"high" side of the component to ground is effectively in parallel with the impedance of the component. The ungrounded measurement is not affected by impedances from *either* side of the unknown component to ground and is very useful for determining the characteristics of floating resistors, rf chokes, capacitance between two ungrounded terminals, and many other 3-terminal circuits. Figure 22 shows the direct (ungrounded) admittance of one of the chokes used in the d-c supply filter of the Transfer-Function and Immittance Bridge.

Advantages of the Transfer Function and Immittance Bridge

The Transfer-Function and Immittance Bridge has a number of very important advantages over other methods of measuring transistor characteristics in the VHF-UHF range.

(a) All measurements are made *directly*, with the transistor operating in the *proper environment* as defined by the parameter being measured. In most cases no calculations are required to obtain any desired short-circuit or open-circuit input, output, or transfer function. Direct measurements save time and avoid deterioration of measurement accuracy.

(b) All input, output, and transfer measurements on a given transistor with a given common electrode are made with the *same* mount, so that consistency between these different functions is assured. Furthermore, standard mounts are *available* and are not a design problem to the user.

(c) The unusually wide frequency range from 25 Mc to 1500 Mc is valuable in most applications and is of particular interest for today's new commercial transistors.

(d) The bridge can be operated with a very low rf level on the unknown, which is essential for the measurement of transistors and other nonlinear devices.

(e) First impressions notwithstanding, the bridge is *very simple*. The initial appearance of complexity is due to the *large number of different things that it can measure*, but each of these things *by itself* is measured in a straightforward and simple manner.

The bridge is completely passive, with stability of calibration dependent only on permanent, physical dimensions.

Finally, the instrument makes *basic* measurements of circuit characteristics that have been in use since the beginning of radio and that will continue to be used indefinitely into the future of electronics. Currently its most popular use is for the measurement of transistors and diodes, but its ability to measure any network, active or passive, indicates a much wider field of application.

Figure 23. View of the instrument storage box with accessories that are supplied with the Type 1607-A Transfer-Function and Immittance Bridge.

— W. R. Thurston
R. A. Soderman

CREDITS

The authors wish to express appreciation for the many helpful suggestions and other contributions of many individuals during the development of the Transfer-Function Meter, including Dr. J. M. Early and Mr. D. E. Thomas of the Bell Telephone Laboratories, and Mr. R. Wohl, Mr. S. Friedman, Mr. M. Zimet, and Mr. D. Youla of the Material Laboratory, New York Naval Shipyard.

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SPECIFICATIONS

Frequency Range: 25 to 1500 Mc, with reduced accuracy above 1000 Mc and when flexible cable is used in the lines. The use of this cable is required at frequencies below 150 Mc and is optional at other frequencies.

Measurement Range:	**Accuracy:** (up to 1000 Mc)
Voltage and Current Ratios	
(R) 0–30	$2.5\,(1+\sqrt{R})\%+0.025$
Transimpedance (Z_{21}) 0–1500 ohms	$2.5\left(1+\sqrt{\frac{Z_{21}}{50}}\right)\%+1.25$ ohms
Transadmittance (Y_{21}) 0–600 mmhos	$2.5\left(1+\sqrt{\frac{Y_{21}}{20}}\right)\%+0.5$ mmho
Impedance (Z_{11}) 0–1000 ohms	$2.0\left(1+\sqrt{\frac{Z_{11}}{50}}\right)\%+1.0$ ohm
Admittance (Y_{11}) 0–400 mmhos	$2.0\left(1+\sqrt{\frac{Y_{11}}{20}}\right)\%+0.4$ mmho

DC Bias: Terminals are provided for introducing dc bias from external sources. Maximum bias current, 250ma continuous; higher currents can be drawn for short periods. Maximum bias voltage, 400 volts.

Accessories Supplied: Range-Extension Unit; Transfer-Function Indicator; Immittance Indicator; 6 terminations (open, short, matched, etc.); standards; 10-db attenuator; 8 air lines (21.5 and 43 cm); 3 U-line sections; constant-impedance adjustable line; a special tee; 10 patch cords; carrying case with storage space for instrument and accessories.

Accessories Required: Generator, detector, and mount for unknown device. Unit Oscillators and Type DNT Detectors are recommended. For coaxial adaptors, see latest General Radio Catalog. See below for mounts available.

Other Accessories Available: Transistor, tube, and component mounts are listed in the price table below.

Case: The instrument, with accessories, is mounted in a wooden carrying and storage case.

Dimensions: Case — 11¼ x 14½ x 40 inches.

Net Weight: 63 pounds.

Type		*Code Word*	*Price*
1607-A	**Transfer-Function and Immittance Bridge**	HYDRA	**$1665.00**
1607-P101	**Transistor Mount (0.200-inch-pin-circle triode, common base)**	TRANSMOUNT	**60.00**
1607-P102	**Transistor Mount (0.200-inch-pin-circle triode, common emitter)**	TOPICMOUNT	**60.00**
1607-P201	**Tube Mount (7-pin miniature, grounded cathode, for 6AF4, etc.)**	TUBESMOUNT	**75.00**
1607-P111	**Transistor Mount (0.100-inch-pin-circle triode, common base)**	BASEYMOUNT	**65.00**
1607-P401	**Transistor Mount (0.200-inch-pin-circle tetrode)**	TETRAMOUNT	**65.00**
1607-P601	**Ungrounded Component Mount**	COMPOMOUNT	**25.00**
874-M	**Component Mount (grounded)**	COAXYMOUNT	**25.00**

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

COAXIAL CONNECTORS

Type 874-B Basic Connector, disassembled

BASIC CONNECTOR

The basic connector fits rigid, 50-ohm, air-dielectric coaxial line; ⅝″ OD and 9/16″ ID for outer conductor; 0.244″ rod for inner conductor.

Type 874-PB Panel Connector

PANEL CONNECTOR

The panel connector mounts with a flange and is available with rear fittings for commonly used RG-type cables. See the General Radio catalog for details. Connector listed below fits GR Type 874-A2 Cable, only.

Type		*Code Word*	*Price*
874-B	**Basic Connector**	COAXBRIDGE	**$1.25**
874-PB	**Panel Connector**	COAXAPPLER	**2.90**

GENERATORS*

Type	*Frequency Range*	*Code Word*	*Price*
1211-B	**0.5 — 50 Mc**	ATLAS	**$275.00**
1215-B	**50 — 250 Mc**	ADOPT	**190.00**
1209-BL	**180 — 600 Mc**	ADMIT	**245.00**
1209-B	**250 — 920 Mc**	AMISS	**245.00**
1218-A	**900 — 2000 Mc**	CARRY	**465.00**

*Require power supply below.

POWER SUPPLY*

Type		*Code Word*	*Price*
1203-B	**Unregulated**	ALIVE	**$40.00**
1201-B	**Regulated**	ASSET	**85.00**

*Plug-in type; supplies power to any one of the above oscillators.

DETECTORS

Type	*Frequency Range**	*Code Word*	*Price*
DNT-1	**40 — 530 Mc**	NALTO	**$626.00**
DNT-2	**40 — 280 Mc**	NERVO	**606.00**
DNT-3	**220 — 950 Mc**	NULLO	**659.00**
DNT-4	**870 — 2030 Mc**	NODDO	**879.00**

*Fundamental range. To cover a wider range than that listed for any one detector, harmonics of the local oscillator can be used. Thus Type DNT-2 will cover frequencies up to 1120 Mc if harmonics up to the 4th are used. Fundamental sensitivity is about 5 μv; 4th harmonic sensitivity, about 20μv. For this wide range, order also one Type 874-F1000 Low Pass Filter, price $14.00.

Another solution is to use the Type DNT-2 with an additional Type 1209-B Unit Oscillator (see Generators, above) and the Type 874-F1000 Filter. This covers the range with fundamental operation, which is, in general, more satisfactory. Harmonic operation is not recommended for measurement of active networks. Below 40 Mc, use a communications receiver.

COAXIAL ADAPTORS

Types QBJ and QBP

Type	*Fits*	*Code Word*	*Price*
874-QBJ	**BNC Plug**	COAXBOGGER	**$4.75**
874-QBP	**BNC Jack**	COAXBUNNER	**4.75**
874-QCJ	**C Plug**	COAXCOGGER	**4.75**
874-QCP	**C Jack**	COAXCUFFER	**6.25**
874-QNJ	**N Plug**	COAXNAGGER	**3.75**
874-QNP	**N Jack**	COAXNUTTER	**4.50**
874-QUJ	**UHF Plug**	COAXYUNDER	**4.00**
874-QUP	**UHF Jack**	COAXYUPPER	**4.25**
874-QHJ	**HN Plug**	COAXHAWSER	**6.50**
874-QHP	**HN Jack**	COAXHANGER	**6.50**
874-QLJ	**LC Plug**	COAXLITTER	**19.50**
874-QLP	**LC Jack**	COAXLUGGER	**30.00**

Adaptors are also available for connection to rigid air-dielectric lines.

GENERAL RADIO COMPANY

West Concord, Massachusetts Tel.: (Concord) EMerson 9-4400 (Boston) CLearwater 9-8900

- NEW YORK — Broad Ave. at Linden, Ridgefield, N. J. Tel. N.Y., WOrth 4-2722 N.J., WHitney 3-3140
- CHICAGO — 6605 West North Ave. Oak Park, Ill. Tel. VIllage 8-9400
- PHILADELPHIA — 1150 York Road Abington, Penn. Tel. HAncock 4-7419
- WASHINGTON — 8055 13th St. Silver Spring, Md. Tel. JUniper 5-1088
- SAN FRANCISCO — 1186 Los Altos Ave. Los Altos, Cal. Tel. WHitecliff 8-8233
- LOS ANGELES — 1000 N. Seward St. Los Angeles 38, Cal. Tel. HOllywood 9-6201
- CANADA — 99 Floral Pkwy. Toronto 15, Ont. Tel. CHerry 6-2171

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