TYPE 1607-A TRANSFER-FUNCTION AND IMMITTANCE BRIDGE

NEW FUNCTIONS, NEW NAME, AND NEW TEST MOUNTS

An unusual new instrument, identified as the TYPE 1607-A Transfer-Function Meter, was described in this publication a little over one year ago.[1] It could measure all the complex transfer functions[2] of three- and four-terminal[3] devices and networks, such as transistors, vacuum tubes, amplifiers, filters, and attenuators, over the 60:1 frequency range from 25 Mc to 1500 Mc.

New Functions

Stimulated by comments of people seeing the instrument for the first time, e.g., "That's fine, but isn't there some way of making it measure *two*-terminal impedances and admittances, too? Then it would measure everything," we looked further and found a simple way to do just this.[4] Although the changes necessary to incorporate the added functions involved cutting a fourth set of slots in the instrument's main junction block and the addition of a new indicator assembly, we were fortunately able to catch the first production lot of instruments just in time to include these new features, starting with the first instrument sold. Therefore, all instruments in use are up to date, except that on the earliest units the engraving shows the old name. The instrument will now measure the input or output impedance or admittance of two-, three-, or four-terminal networks with dc bias supplied to all terminals and with three- and four-terminal networks terminated in either an rf short or open circuit.

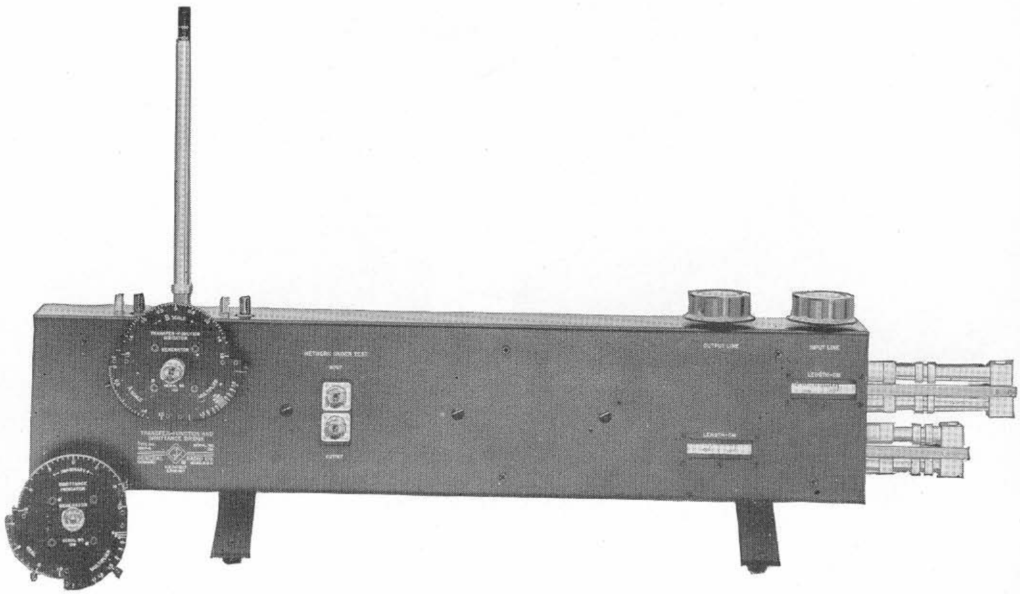
[1] W. R. Thurston, R. A. Soderman, "A Transfer-Function Meter for the VHF-UHF Range," *General Radio Experimenter*, Vol. 32, No. 10, March, 1958, pp. 3-15.

[2] Forward and reverse transadmittance, transimpedance, transfer voltage ratio, and transfer current ratio.

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

[4] Not "everything," of course — just 2, 3, and 4-terminal networks.

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



New Name

With the capabilities of the instrument increased to cover many additional applications, the old name, "Transfer-Function Meter," was not completely descriptive. The new name is "Transfer-Function and Immittance Bridge," the word "Immittance" denoting both *im*pedance and ad*mittance*. Because of its convenience, this word is gradually coming into more common use in connection with transmission lines, networks, and certain types of measuring instruments, such as the slotted line.

The change of the last word from "Meter" to "Bridge" is intended to improve further the descriptive accuracy of the name. Passive, null-type circuits used with generator and detector to measure accurately the real and imaginary components of an unknown in terms of resistive and reactive standards are commonly called "bridges," whether or not the classic, bridge, diamond form is apparent without topological juggling.

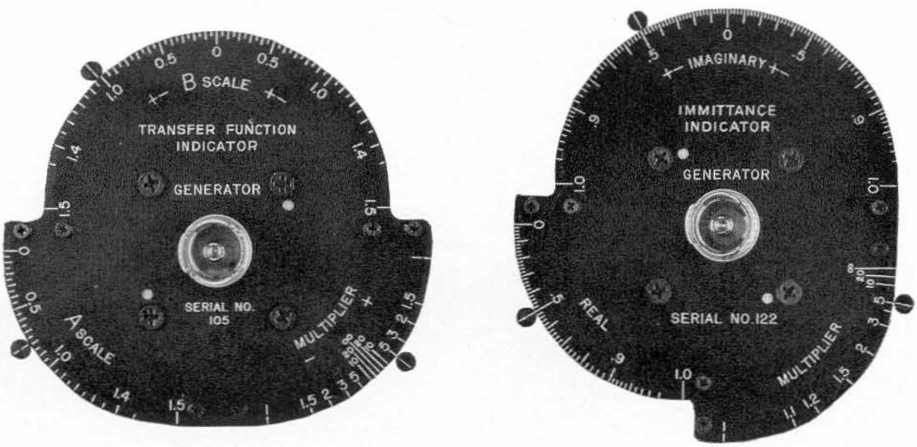
Interchangeable Indicators

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.

Circuit for Immittance Measurements

The operating principles and circuit for transfer-function measurements were fully described in the earlier article,[1] to which reference is made for basic description and features. For immittance measurements with the Immittance Indicator (Figure 4), 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 4, the circuit is set up for measuring the output immittance of a four-terminal network. To measure network input im-

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



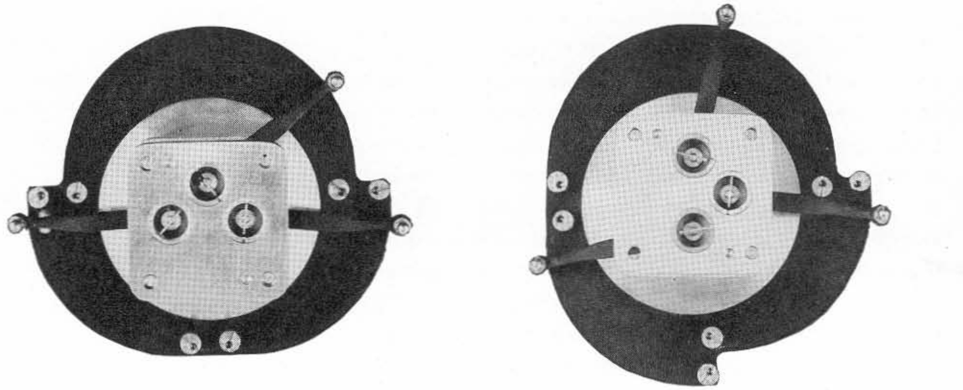


Figure 3. Rear view of indicator units showing different loop locations and consequent differences in scale plate shape.

mittances, 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.[5] 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,

[5]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.

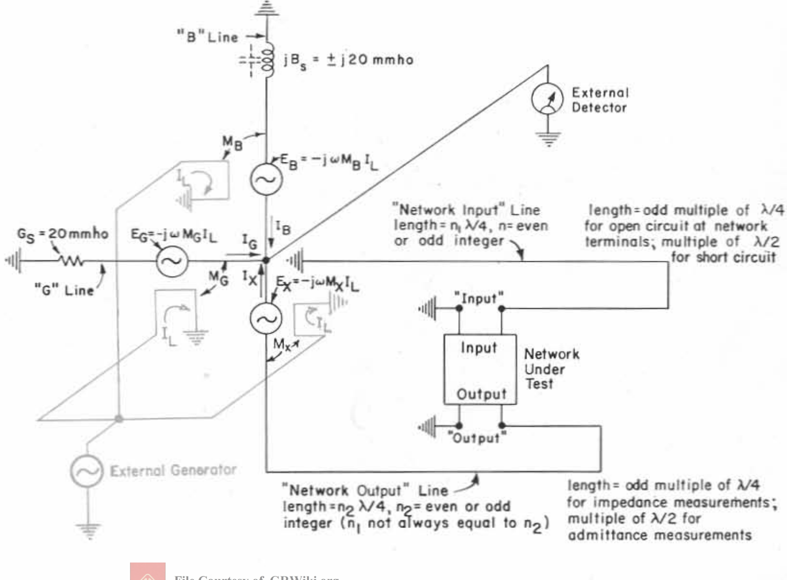


Figure 4. Schematic diagram of the circuit for immittance measurement. For a diagram of the circuit for transfer-function measurement, see previous article.[1]

the instrument measures impedance. The scales are calibrated in normalized components, from 0 to 1, with a multiplier from 1 to ∞. 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%).

New 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.

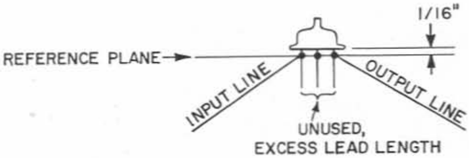


Figure 6. Sketch of connections to transistor, showing the reference points of measurement.

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 and 0.100-inch-pin-circle triodes with common base. 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:

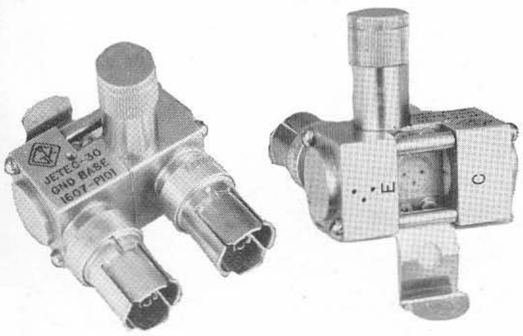


Figure 5. Two views of the Type 1607-P101 Transistor Mount showing the damper unit projecting from the side. In the right-hand view the lead alignment holes can also be seen.

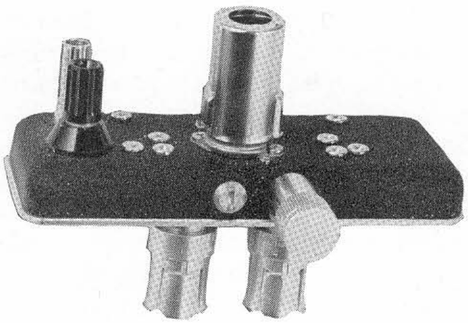


Figure 7. View of the Type 1607-P201 Tube Mount with tube and shield installed and damper unit projecting from side. Binding posts at left are for heater connections.

(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 6. 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 5 is a photo of TYPE 1607-P101 Transistor Mount.

Tube Mount

One tube mount is available so far. It 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 7.

Typical Measurements

With this instrument direct measurements can be made of the parameters of commonly used transistors, vacuum tubes, and passive networks. 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 8 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 voltage are plotted in Figure 8. Figure 9 shows measured values of forward current-transfer ratio for a diffused-base transistor. Figure 10 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 11 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 11.

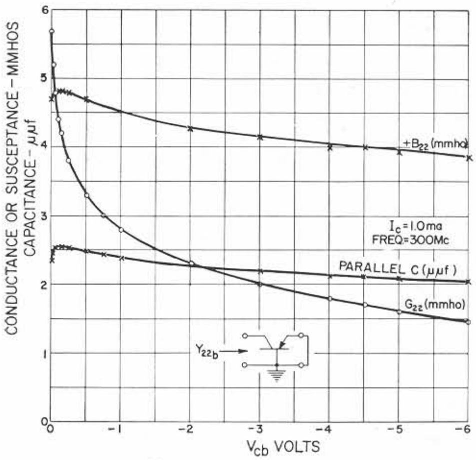
In high-frequency transistors, the zero-reactance point occurs at a much higher frequency, and the impedance at this point may be affected by stray lead reactances. A typical measurement is shown in Figure 12. Measurements were also made on a slotted line in order to check the values measured on the Transfer-Function and Immittance

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

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



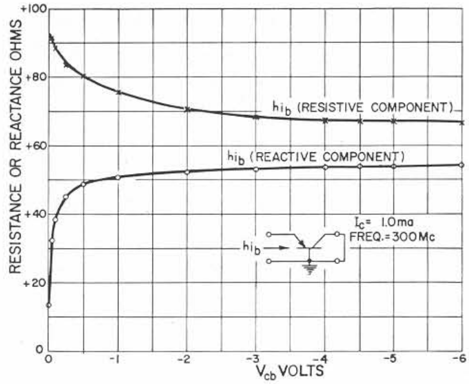


Figure 8. Variation of parameters of a diffused-base transistor as a function of collector voltage.

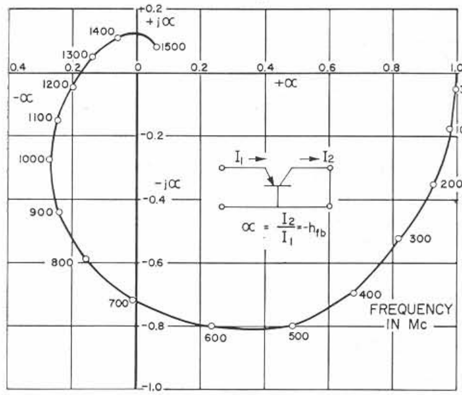


Figure 9. Plot of α, or $-h_{fb}$, versus frequency for a diffused base transistor.

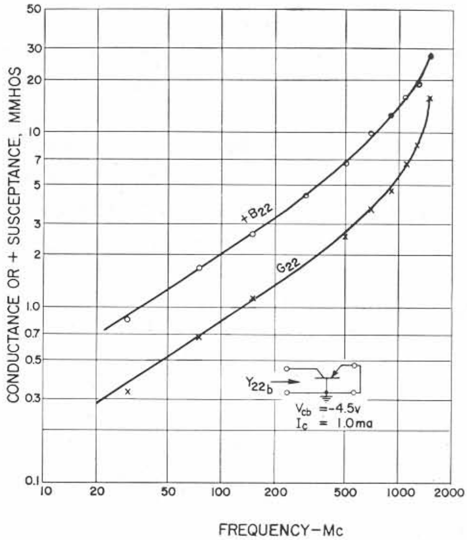


Figure 10. Plot of short-circuit output admittance as a function of frequency for a diffused-base transistor.

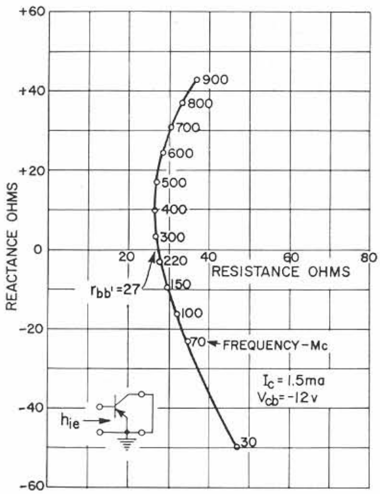


Figure 11. Plot of input reactance versus input resistance, with output short circuited, for a low-frequency transistor.

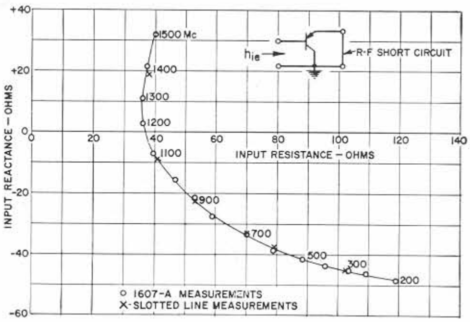


Figure 12. Plot of input reactance versus input resistance, with output short circuited, for a high-frequency transistor. Comparison with slotted-line measurements.

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

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.

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, but its ability to measure any network, active or passive, indicates a much wider field of application.

Acknowledgment

The authors wish to acknowledge the contributions of Peter D. Strum to the development of this instrument.

—W. R. Thurston
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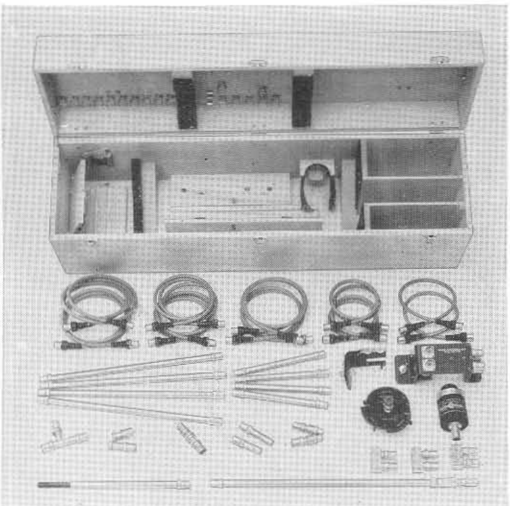

Figure 13. View of the instrument storage box with accessories that are supplied with the Type 1607-A Transfer-Function and Immittance Bridge.

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: Voltage and Current Ratios — **Accuracy:** (up to 1000 Mc)

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, 100 ma; 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: Type 1607-P101 Transistor Mount for JETEC-30 base arrangement, grounded base. Type 1607-P102 Transistor Mount for JETEC-30 base arrangement, grounded emitter. Type 1607-P201 Tube Mount, 7-pin miniature, grounded-cathode, for 6AF4, 6AF4A, and other tubes with same connections.

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 (JETEC-30, grounded base)**	TRANSMOUNT	**60.00**
1607-P102	**Transistor Mount (JETEC-30, grounded emitter)**	TOPICMOUNT	**60.00**
1607-P201	**Tube Mount, 7-pin miniature, grounded cathode**	TUBESMOUNT	**75.00**

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

NEW *METERED* VARIACS, TYPES W5MT3A, W5MT3W

The usefulness of the Variac® autotransformer as a laboratory tool can be considerably enhanced by the inclusion of meters in the assembly so that voltage, current, or power measurements can be made directly without the necessity of finding, and connecting, external meters. To this end, General Radio offers two instruments, similar in appearance and construction, and differing only in one respect. The Type W5MT3A Metered Variac reads volts and *amperes;* the Type W5MT3W Metered Variac reads volts and *watts;* both are metered in the output or load circuit.

The metal case houses a Type W5 Variac, the meters, a current transformer, and the necessary switching and meter shielding. This latter is sufficiently effective to reduce the Variac stray field to a point permitting an over-all accuracy of 3% (full scale) with 2% meters. Connections are made through a three-wire cord (line) and a three-wire outlet (load). A double-pole off-on switch disconnects the instrument from both sides of the line in the off position. A make-before-break range switch permits switching under load of the dual scale ammeter or wattmeter, as the case may be, from 1 ampere to 5 amperes, full scale, or from 150 watts to 750 watts, full scale,