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ELECTRICAL MEASUREMENTS AND THEIR INDUSTRIAL APPLICATIONS

A DIRECT-READING IMPEDANCE-MEASURING INSTRUMENT FOR THE U-H-F RANGE

Also IN THIS ISSUE

INTRODUCTION

Now that television is getting ready to move into the u-h-f range, the need for direct-reading measuring equipment that will give accurate results quickly is becoming increasingly evident. For impedance measurement, specifically, there is a need for a null-type device that will be as convenient and rapid to use as are the bridges that have been developed for lower frequencies.[1, 2, 3, 4]

[1]D. B. Sinclair, "The Twin-T—a New Type of Null Instrument for Measuring Impedance at Frequencies up to 30 Megacycles," *Proc. I.R.E.*, July, 1940.

[2]D. B. Sinclair, "A Radio-Frequency Bridge for Impedance Measurements from 400 Kilocycles to 60 Megacycles," *Proc. I.R.E.*, November, 1940.

[3]R. A. Soderman, "A New Bridge for Impedance Measurements at Frequencies between 50 Kilocycles and 5 Megacycles," *General Radio Experimenter*, March, 1949.

[4]R. A. Soderman, "A New Bridge for the Measurement of Impedance between 10 and 165 Mc," *General Radio Experimenter*, February, 1950.

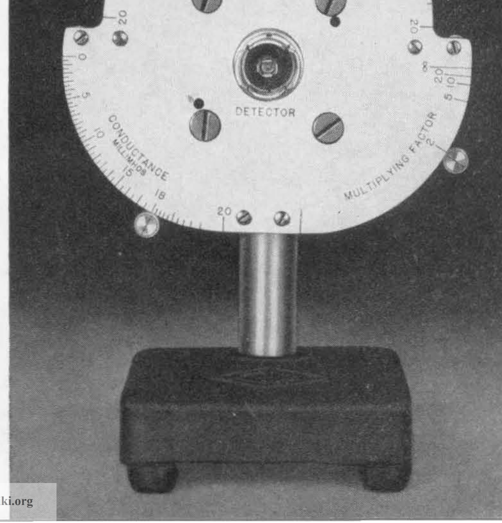
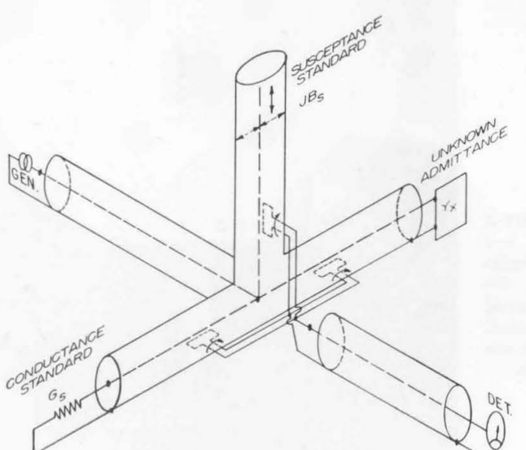


Figure 1. Front view of the Type 1602-A Admittance Meter, showing dial and sliding indicators. The extreme simplicity of operation is evident from this photograph. The indicators are moved along the scales until a null is obtained, and the conductance and susceptance are then read directly from the dial.

At these lower frequencies, it is not difficult to design and construct a bridge to perform a specific task. As the frequency increases, however, it becomes more and more difficult to isolate specific impedances and to arrange them in a predictable system. It has been found, in fact, that lumped-parameter elements cannot generally be connected satisfactorily in conventional bridge circuits above about 150 Mc, and that new arrangements based on coaxial-line techniques offer greater promise.

The TYPE 1602-A U-H-F Admittance Meter is a null device based on these techniques. Through adjustable loops, it samples the currents flowing in three coaxial lines fed from a common source at a common junction point. The outputs of the three loops are combined and, when the loops are properly oriented, the combined output becomes zero. The device therefore balances in the same manner as a bridge. It indicates conductance and susceptance on direct-reading dials, the calibrations of which are independent of frequency, and the null settings for both components are completely independent.

As a null instrument, the U-H-F Admittance Meter can be used to measure conductances, and susceptances of either sign, from 1 millimho to 400 millimhos (1,000 Ω to 2.5 Ω) over a frequency range from 70 Mc to 1000 Mc. It can also be used as a comparator to indicate equality of one admittance to another, or degree of departure of one from the other. As a direct-indicating device, in addition, it can be used to determine the magnitude of the reflection coefficient of a coaxial system, or the magnitude of an unknown admittance, from ratios of output voltages read on a meter.



PRINCIPLE

Figure 2 shows the functional arrangement of the admittance meter with standards connected. The standard conductance, G_s, is a resistor having a value equal to the characteristic impedance, Z_o, of the line, and the standard susceptance, jB_s, is an adjustable stub which is set to one-eighth wavelength at the operating frequency.

Since the voltage from the generator is common to all three lines, the sending-end current in each line is proportional to the sending-end admittance. This admittance is Y_x for the line terminated in the unknown, $G_s = \frac{1}{Z_o}$ for the line terminated in the standard conductance, and $jB_s = -j\frac{1}{Z_o}$ for the line terminated in the eighth-wave stub.

The induced voltage in each loop is proportional to the mutual inductance (M_X, M_G, or M_B), and to the current in the corresponding line. Thus, the induced voltage in the loop associated with the unknown admittance is proportional to the product,

$$M_X Y_X = M_X G_X + jM_X B_X;$$

the induced voltage in the loop associated with the standard conductance is proportional to the product, $M_G G_S$; and

Figure 2. Schematic diagram of admittance meter circuit, with standards, generator, and null dectector connected for admittance measurements.

the induced voltage in the loop associated with the standard susceptance is proportional to the product, $jM_B B_S$. It follows that these three induced voltages add up to zero and produce a null when the couplings of the three loops have been adjusted to have the following relations:

$$G_X = -\frac{M_G}{M_X} G_S, \text{ and } B_X = -\frac{M_B}{M_X} B_S.$$

G_S and B_S are constants, so the M_G scale can be calibrated in terms of G_X, the M_B scale in terms of B_X, and the M_X scale in terms of a multiplying factor to be applied to the other two scale readings. Since each coupling can be varied through zero, the two balance equations show that the theoretically measurable ranges of conductance and susceptance extend from zero to infinity. However, the percentage accuracy of reading the scales naturally decreases as the position of zero coupling is approached, and the 1 millimho to 400 millimhos range is found practical for reading and setting.

The loops associated with the unknown admittance and the standard conductance can each be rotated through an angle of 90°, but the loop associated with the standard susceptance is arranged to be rotatable through an angle of 180°, thus allowing the measurement of positive as well as negative values of unknown susceptance with a single susceptance standard. Figure 1 is a detailed view of the calibrated scales.

A unique feature of the U-H-F Admittance Meter, which distinguishes it from bridges and other null devices, is that the susceptance scale, as well as the conductance scale, is independent of frequency. This comes about because the stub that forms the susceptance standard is always adjusted to one-eighth wavelength at the operating frequency and therefore presents a constant susceptance.

CONSTRUCTION

Various views of the external and internal appearance of the admittance meter are shown in Figures 1, 3, 4, and

Figure 3. Rear view of the admittance meter, showing the four lines making up the generator junction assembly. The three arms for the sliding indicators can also be seen.

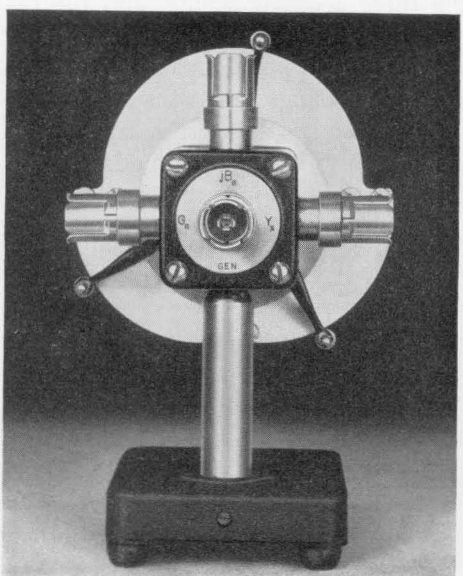
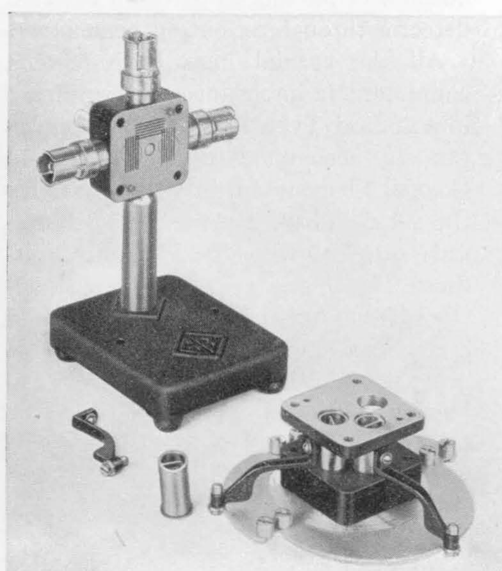


Figure 4. View showing internal parts of the admittance meter. The pickup-loop assembly has been removed from the generator junction assembly to show the coupling slots and the coupling loops.



5. The instrument consists basically of a generator-junction assembly, a pickup-loop assembly, and a detector-junction assembly. The generator-junction assembly is made up of four coaxial lines coming together in a common junction. Three of these lines are arranged in a "T" configuration that can be excited through the fourth line, which is perpendicular to the plane of the "T." At their outer ends the lines are terminated by coaxial connectors, so that unknown and standard admittances and a generator can be readily connected.

The pickup-loop assembly comprises three loops, each of which couples through slots to the magnetic field in one of the three coaxial lines making up the "T." Each loop can be rotated by means of an arm to vary its coupling, and the position of the end of the arm with respect to a fixed scale is used to indicate degree of coupling. The maximum values of coupling of all three loops are the same, and the loops are carefully shielded from one another so that they pick up voltage only from the line to which they are directly coupled.

The detector-junction assembly consists of a connection of all three loop outputs in parallel to drive an external detector through an output connector.

All the coaxial lines have 50-ohm characteristic impedance and terminate in standard TYPE 874 Coaxial Connectors to accommodate the TYPE 874 Coaxial Elements already developed for the v-h-f and u-h-f ranges.[5] The standards supplied with the U-H-F Admittance Meter are a TYPE 874-WM 50-Ohm Termination for conductance, and TYPE 874-D20 and 874-D50 Adjustable Stubs, modified by the addition of frequency scales, for susceptance.

[5]W. R. Thurston, "Simple, Complete Coaxial Measuring Equipment for the U-H-F Range," *General Radio Experimenter*, January, 1950.

ERRORS AND CORRECTIONS

Errors in the U-H-F Admittance Meter can be classified generally as (1) errors arising from departures from perfection in fabrication and (2) errors resulting from the practical geometry of the system.

Errors of the first kind are principally caused by necessary manufacturing tolerances and are small enough to be ignored at frequencies up to 1000 Mc within the accuracy limitations specified.

Errors of the second kind are amenable to systematic correction. They are caused by the physical requirements that (1) the pickup loops cannot be located exactly at the junction of the three lines that form the "T," and that (2) the conductance and susceptance standards, and the unknown admittance, cannot be connected to the lines at a point directly under the corresponding pickup loop.

The first of these errors is minimized by making the outer-conductor diameter of the line sections between the coupling points and the junction point only slightly larger than the inner-conductor diameter. The resulting very low impedance of the connecting sections prevents large voltage differences among the three coupling points, and the decreased diameter of the sections relative to their length prevents appreciable unwanted couplings across the junction.

The second of these errors is of significance for only the unknown admittance. For the line terminated in the conductance standard, $G_s = \frac{1}{Z_o}$, no error results from the spacing between the standard and loop because the line is matched. For the line terminated in the susceptance standard, $jB_s = -j\frac{1}{Z_o}$, no error results since the system is smooth through the connector and the total electrical length from loop to plunger is set at $\lambda/8$. For the line terminated in the unknown admittance, Y_x, however, a "lead correction" must be made to account for the short section of line between the loop and connector. This can be readily made through the use of a Smith Chart,[6] which can also be used to convert admittance parameters to impedance, if desired.

[6]Phillip H. Smith, "Transmission Line Calculator," *Electronics*, January, 1939, and January, 1944.

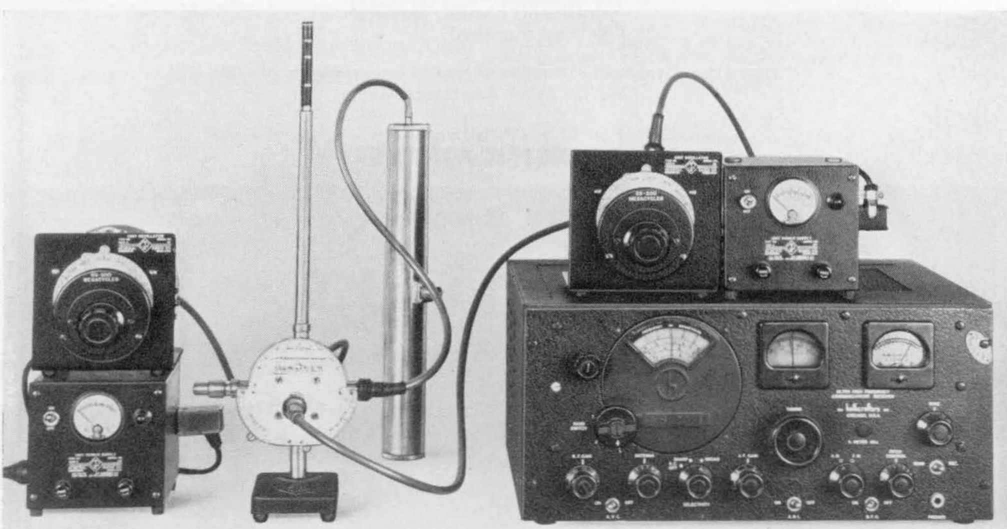
OPERATION

Equipment suitable for use as generator and detector with the U-H-F Admittance Meter has been developed and is described elsewhere in this issue. The Type 1208-A and Type 1209-A Unit Oscillators are particularly suited for use as generators and, when combined with the Type 874-MR Mixer Rectifier, as frequency converters to adapt conventional communication-type receivers for use as v-h-f and u-h-f detectors. The component instruments of this system are all fitted with Type 874 Coaxial Connectors and are easily interconnected by Type 874-R20 Patch Cords. The Type 1021-AV and Type 1021-AU Standard-Signal Generators also make satisfactory generators and, at frequencies above those covered by conventional communication-type receivers, the Type AN/APR-1 and Type AN/APR-4 Search Receivers also make excellent detectors.

In general, superheterodyne-type detectors are preferable to superregenerative types because their greater dynamic range makes it possible to locate the null quickly, without recourse to progressive adjustment of the input level over a wide range, and makes possible the use of a simple, inexpensive generator.

In addition to its use as a null device, the U-H-F Admittance Meter can be used as a direct-indicating device. It can, for instance, measure reflection-coefficient magnitude and impedance magnitude directly and simply by voltage-ratio methods. These measurements require the generator or the detector to have a calibrated attenuator or a calibrated indicator, and the answer is obtained from the ratio of two voltages

Figure 5. View of the admittance meter in use with standards and unknown connected. The generator is a Type 1208-A Unit Oscillator and the null detector is a communications-type receiver, with a second unit oscillator and Type 874-WM Mixer acting as a frequency converter. The unknown admittance being measured is an u-h-f transformer.

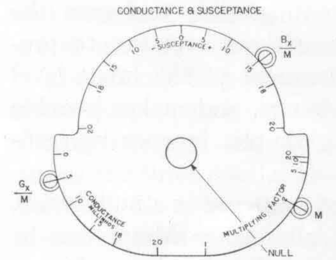


with the controls of the admittance meter set at two different positions. As with null measurements, there are no frequency corrections.

Figure 6 outlines the operating procedure to follow in making some of the many types of measurement of which the instrument is capable. Others will suggest themselves to the user as he becomes familiar with the instrument. The wide variety of applications illustrates the flexibility and adaptability of this new approach to u-h-f impedance measurements.

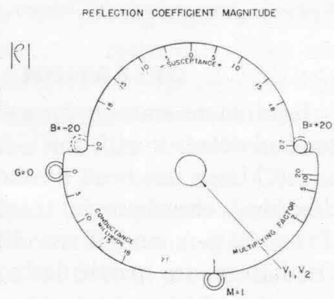
This flexibility of application combined with the simplicity and ease of operation of the instrument makes the U-H-F Admittance Meter well suited for measurements in the FM and TV bands including the proposed new u-h-f bands.

—W. R. Thurston



CONDUCTANCE AND SUSCEPTANCE

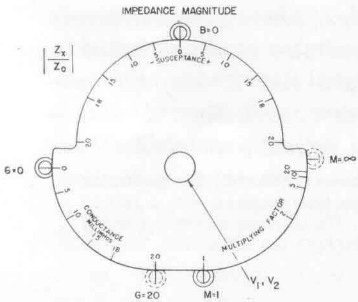
Set G and B controls to obtain null.
Read G and B scales and multiply by M.



REFLECTION-COEFFICIENT MAGNITUDE

Replace stub by 50-ohm termination.
Set $G = 0$ and $M = 1$. Set $B = -20$ mmhos.
Read output V_1. Reset B to $+20$ mmhos. Read output V_2.

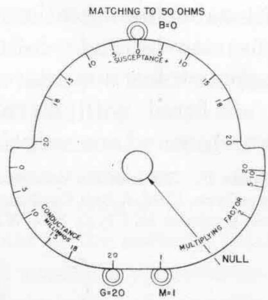
$$|\rho| = \frac{V_1}{V_2}$$



IMPEDANCE MAGNITUDE

Set $B = 0$, $G = 20$, and $M = \infty$. Read output V_1.
Reset G to 0 and M to 1.
Read output V_2.

$$\left|\frac{Z_x}{Z_0}\right| = \frac{V_1}{V_2}$$



MATCHING TO 50 OHMS

Set $B = 0$, $G = 20$ mmhos, and $M = 1$.
Adjust network to be matched until null occurs. Network is then matched.

Figure 6. Graphical illustration of typical measurements possible with the U-H-F Admittance Meter.

SPECIFICATIONS

Range: Theoretically, zero to infinity; practically, the lower limit is determined by the smallest readable increment on the scale which is 200 micromhos (0.2 millimho). The upper limit is 1000 millimhos. Range is the same for both conductance and susceptance, but susceptance can be either positive or negative, i.e., the susceptance dial is calibrated from −20 to +20 millimhos. Multiplying factors from 1 to 20 are provided, and factors from 20 to 100 can be determined approximately.

Frequency Range: 70 to 1000 Mc.

Accuracy: For both conductance and susceptance:

From 0 to 20 millimhos $\pm(5\% + 0.2$ millimho$)$

From 20 to ∞ millimhos $\pm 5\sqrt{M}\%$

Where M is the scale multiplying factor.

Accessories Supplied: Type 874-WM 50-Ω Termination, for use as conductance standard, and one each Type 1602-P1 and Type 1602-P2 Adjustable Stubs, for susceptance standards; two Type 874-R20 Patch Cords for connections to generator and detector.

Additional Accessories Required: Generator, covering desired frequency range and delivering between 1 volt and 10 volts, such as TYPE 1208-A, 65 – 500 Mc, and TYPE 1209-A, 250 – 920 Mc, Unit Oscillators with TYPE 1205-A Unit Power Supply, or TYPE 1021-A Standard-Signal Generator. Detector, with sensitivity better than 10 microvolts. Ordinary communications-type receivers can be used, in conjunction with a TYPE 1208-A or TYPE 1209-A Unit Oscillator and a TYPE 874-MR Mixer Rectifier. The receiver should have a bandwidth of at least 20 kc. An AN/APR-4 Receiver with TN-17 Tuning Unit for 75-300 Mc, or with TN-18 Tuning Unit for 300 – 1000 Mc, or AN/APR-1 Receiver with appropriate tuning units also is a satisfactory detector.

Other Accessories Recommended: TYPE 874-WN Short-Circuit Termination.

Terminals: All terminals are TYPE 874 Coaxial Connectors, generator, detector, standards, and unknown. Adaptors are available for TYPE N Connectors.

Dimensions: 7½ x 5½ x 5½ inches without standards and unknown connected.

Net Weight: 8 pounds.

Type		*Code Word*	*Price*
1602-A	**U-H-F Admittance Meter***	HONEY	**$295.00**

*U. S. Patent 2,125,816. Patent Applied For.

V-H-F AND U-H-F UNIT OSCILLATORS

The TYPE 1208-A and TYPE 1209-A Unit Oscillators are compact, moderately priced, general-purpose power sources for the electronics laboratory. They cover the frequency ranges of 65 to 500 Mc and 250 to 920 Mc, respectively, and can deliver 100 to 500 milliwatts of power. Output terminals are TYPE 874 Coaxial Connectors, for connection to General Radio measuring equipment as well as to the wide variety of TYPE 874 Coaxial Elements previously described.[1]

These oscillators are recommended as power sources for the TYPE 874-LB Slotted Line, the TYPE 1601-A V-H-F Bridge,[2] and the TYPE 1602-A U-H-F Admittance Meter.[3] In conjunction with TYPE 874 Coaxial Elements such as attenuators, rectifiers, filters, terminations, modulators, and coupling devices, they can be adapted for a wide variety of uses in the laboratory which would otherwise require specialized and expensive equipment.

Three of these applications are described in detail below, and others will suggest themselves after a study of the complete list of TYPE 874 Coaxial Elements.[1]

The two unit oscillators cover very wide ranges in that part of the frequency spectrum that is beyond the region of conventional lumped circuit techniques and below the region of lines and cavities. Oscillators in that range cannot be

[1]W. R. Thurston, "Simple, Complete Coaxial Measuring Equipment for the U-H-F Range," *General Radio Experimenter*, Vol. XXIV, No. 8, January, 1950.

[2]R. A. Soderman, "A New Bridge for the Measurement of Impedance between 10 and 165 Mc," *General Radio Experimenter*, Vol. XXIV, No. 9, February, 1950.

[3]See first article in this issue.

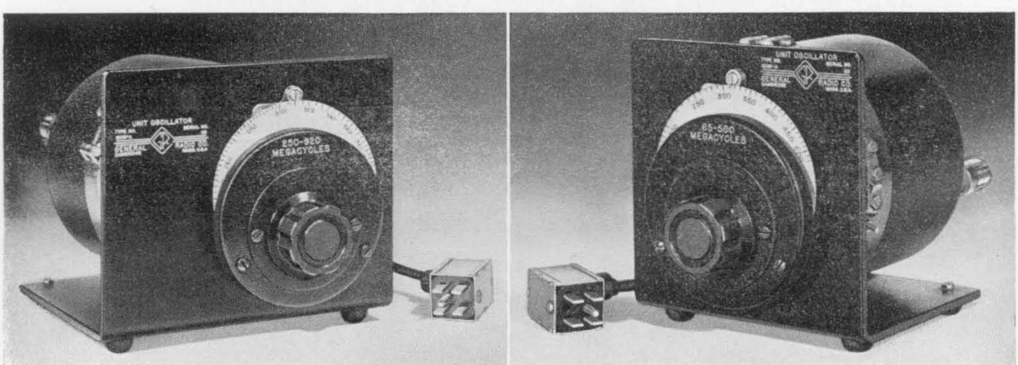


Figure 1. Panel views of the U-H-F and V-H-F Unit Oscillators.
***Left*, Type 1209-A; *right*, Type 1208-A.**