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Direct Measurement of Impedance in the 50-500 MC Range

THE frequency range from 50 to 500 megacycles, being too high for accurate use of conventional bridges and too low for economical construction of slotted line equipment, has heretofore been a difficult region for measuring impedance.

The new -hp- Model 803A Bridge[1] measures impedance with good accuracy over this 50-500 mc range. Measurements can be made over the much wider range from approximately 5 to 700 mc with relaxed accuracy and reduced phase angle range. The bridge reads directly in impedance magnitude over a range from 2 to 2000 ohms and is also calibrated in impedance phase angle at 100 mc. Phase angles between −90 and +90 degrees can be determined at any frequency above 50 mc. Because of its wide impedance range, the bridge is capable of measuring almost any of the devices and components usually encountered in high-frequency work. In addition, the impedance range of the bridge can be extended with some reduction in accuracy by using a known length of transmission line.

The usefulness of this new bridge in the modern laboratory can hardly be over-emphasized. Measurements of impedance of high-frequency components, connectors, terminations, antennas, amplifier input circuits, and transmission lines are all possible with the -hp- 803A. The operation of the instrument is so convenient that accurate measurements can ordinarily be made at the rate of one per minute. In our laboratories, -hp- engineers have found the bridge to be more convenient and more accurate to use than slotted line equipment for the same frequency range.

Also available for use with the bridge is the new -hp- Model 417A VHF Detector—a well-shielded, high sensitivity receiver that has been specifically designed for use as a detector for the bridge over the range from 10 to 500 mc. This receiver is regarded as a very useful piece of general laboratory equipment, for it is quite small, has a very wide range, and has approximately 5 microvolts sensitivity over the entire range.

Figure 1. *-hp- Model 608A VHF Signal Generator Used with New -hp- Models 803A VHF Bridge and 417A VHF Detector.*

[1]Based on a principle suggested by Mr. John F. Byrne of the Airborne Instruments Laboratory, Inc.

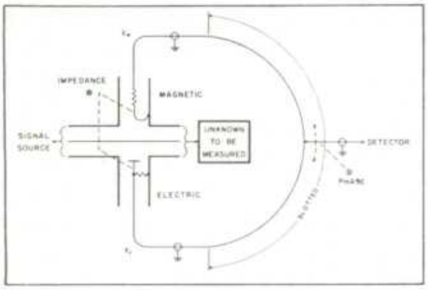


Figure 2. *Basic Circuit of -hp- Model 803A VHF Bridge.*

CIRCUIT DESCRIPTION

The basic circuit for the bridge is shown in Figure 2. Power of the desired VHF frequency is fed through a coaxial line to the unknown impedance to be measured. To determine the voltage-to-current ratio E/I (and thus the impedance) at the terminals of the unknown, a magnetic and an electrostatic probe are located as close as possible to the end of the main line. The voltage induced in the magnetic probe circuit is proportional to the current flowing at the sampling point, while the voltage in the electrostatic probe circuit is proportional to the voltage at the sampling point. Thus, two small voltages E_m and E_e that have a definite relationship to the unknown impedance are available externally for comparison purposes.

In operation, the probe-to-line coupling of the two probes is adjusted by means of ganged controls so that the induced voltages are equal in magnitude. The magnitude of the impedance being measured can then be read directly from the settings of these probes. The control that operates the probes is provided with a single dial calibrated directly in impedance magnitude.

The phase angle of the unknown impedance can be determined from the angle between E_m and E_e. If the current and voltage in the main coaxial line are in phase (resistive unknown), E_m and E_e will be out of phase and a null will exist at the center of the external loop when E_m and E_e are adjusted to be equal in magnitude. If the current and voltage in the main line are not in phase (reactive unknown), the null will be displaced to one side or the other of the center of the loop. The amount and direction of this displacement in electrical degrees is proportional to the phase angle and sign of the unknown. To measure the displacement, the external loop is slotted and the slot searched with a probe operated by a panel control. This control can be calibrated directly in phase angle at any one frequency. The phase angle at any other frequency is modified by the ratio of the second frequency to the first. To facilitate calculation, the phase dial is calibrated for a frequency of 100 mc and at other frequencies the phase angle θ obtained from the expression θ=(frequency used/100 mc) $\times$ dial reading.

The foregoing brief description shows that this impedance-measuring device is not a true bridge, although its measurements are based on null methods and it is otherwise operated like a bridge.

HIGH FREQUENCY CONSIDERATIONS

At frequencies above 100 mc, the distance from the sampling point to the end of the unknown terminal becomes important. This distance is approximately 3 cm or 1/100 wavelength at 100 mc. If the unknown is different from 50 ohms, therefore, it is transformed by 3 cm of line. This will reduce the apparent impedance of capacitive unknowns and increase that of inductive unknowns. The effect can be avoided only by having an insignificantly short distance between the sampling point and the end of the connector.

To aid in determining the untransformed or actual load impedance quickly, a chart like that shown in Figure 3 is supplied with each bridge. The arcs centered on the horizontal line in the chart are constant-impedance contours; those centered on the vertical line are constant-angle. To use, the bridge reading is located on the chart and the chart then rotated clockwise an amount corresponding to the electrical length of 3 cm in a manner similar to the use of a Smith chart. The value obtained is the actual value of the unknown. An example is shown in the figure. Point A is the bridge reading of 45/70° ohms. At a frequency of, say, 500 mc, 3 cm is equal to 18 electrical degrees. The value at A is thus transformed on an

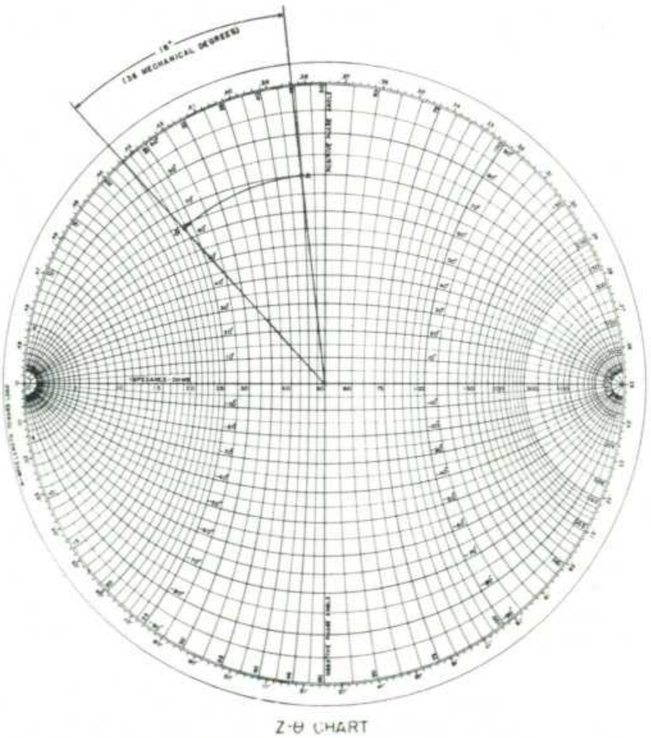


Figure 3. *Z-Theta Chart Supplied with Bridge.*

arc centered at the center of the chart to B, the corrected value.

This chart is extremely useful when measuring loads that are located a finite distance away from their input connector – the usual case. In such applications the chart will quickly tell the length of line between the sampling point and the unknown by the following procedure: a short placed at the actual load can be measured by the bridge; but, instead of reading zero impedance, the bridge will give a larger reading owing to line transformation of the short. This reading, when located on the chart, is the fraction of a wavelength away from the short indicated by the calibration around the periphery of the chart. Therefore, when the short is removed and readings made of the load impedance through the same cable, these readings are transformed by the length of line determined in the short-circuit measurement. A common example where this system is useful is in measuring the impedance of antennas that must necessarily be measured through a length of cable. A short placed at the antenna end of the cable, when read on the bridge and located on the chart, will tell the significant fraction of a wavelength between the sampling point and the antenna. The actual antenna impedance can then be quickly found.

Two copies of this chart on transparent film suitable for making dry-process prints are supplied with each bridge. One copy is as shown in Figure 3; the other is the same except that the impedance values are normalized to 50 ohms.

HIGH MEASUREMENT ACCURACY

The specifications for the bridge state that its measurements are accurate within 5% for impedance magnitude and within 3 degrees for phase angle. However, these accuracy ratings are necessarily stated conservatively and do not take into account the important factor of bridge technique.

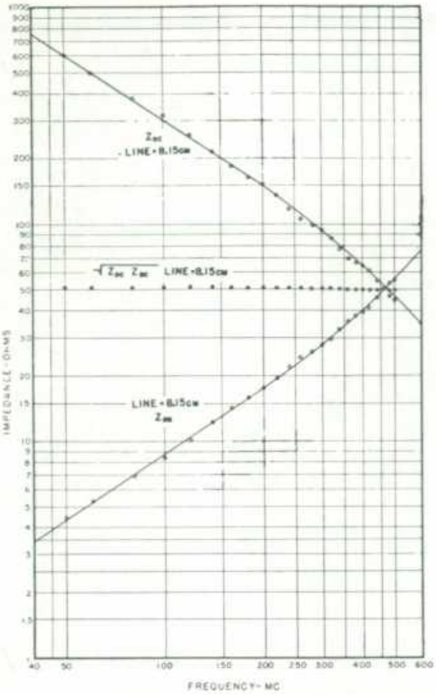


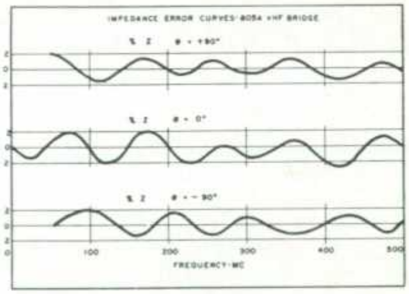
Figure 4. *Open- and Short-Circuit Measurements of Air-Filled Line.*

Figure 4 illustrates this matter. The curves in Figure 4 show measurements of open-circuit and short-circuit impedance of a section of *air*-dielectric 50-ohm rigid line. The impedance of the line ($Z_0 = \sqrt{Z_{oc} Z_{sc}}$) is shown in the series of heavy dots across the center.

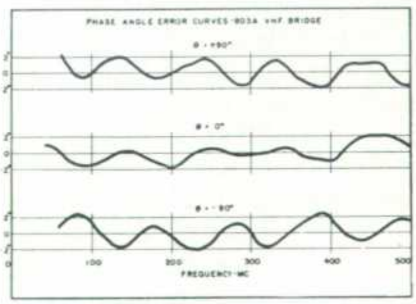
An examination of the heavy dots shows that this measurement is accurate within approximately 1% over the entire 50-500 mc range. Referring to the short-circuit measurement as given by the lower curve in Figure 4, the actual measured values are enclosed by small circles. These circles vary about the solid line in cyclic fashion, and this variation indicates the error of the bridge. Looking at the upper curve Z_{oc}, it can be seen that these same variations are present in the open-circuit measurements, but are out of phase with those in the short-circuit measurement. Thus, these errors, which are in the order of a few per cent, tend to cancel in a measurement of this type, giving approximately 1% accuracy.

Figure 5 shows these errors in magnified form for a typical bridge. Curves of this type are supplied for each instrument to allow maximum accuracy to be obtained by the user. Figure 5 (a) shows the error in magnitude readings at three phase angles; figure 5 (b) shows the error in phase angle readings at three phase angles. The importance of these curves is that the error of measurement can be estimated for nearly any reading of the bridge or can be made directly for what is probably the three most important cases: a resistive, totally capacitive, or totally inductive unknown. For example, in Figure 5 (a), the error at 100 mc at a phase angle of −90 degrees is +2%, while at 0 degrees the error is 0%, and at +90 degrees about −1.3%.

Use of these correction curves significantly increases the accuracy of measurements and it is believed that measurements can be made within



Magnitude
(A)



Phase Angle
(B)

Figure 5. *Typical Correction Curves Supplied with Bridge.*

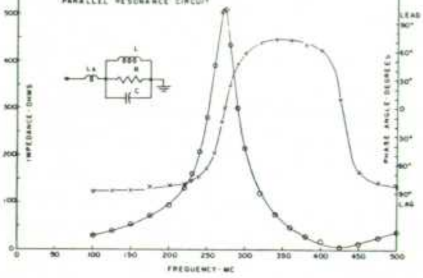


Figure 6. *Magnitude and Phase Measurement of Parallel Tuned Circuit.*

approximately 2% in every case—and often within approximately 1%. By contrast, such high accuracies correspond to a slotted line system having a residual VSWR of less than 1.01-1.02—a seldom-achieved condition.

USES CONVENTIONAL BRIDGE SET-UP

Impedance measurements with the new bridge require the same type set-up as with a conventional low-frequency bridge: a signal source, the 803A Bridge, the -hp- 417A VHF Detector or other suitable receiver, and the device to be measured (Figure 1). The signal generator should be a-m modulated and for best results should generate 0.25 volt or more across 50 ohms. The -hp- 608A VHF Signal Generator (10-500 mc) announced in last month's "Journal" is very well suited to this application.

An example of typical results obtained with the bridge is shown in Figure 6—a magnitude and phase curve of a parallel tuned circuit. A parallel-resonant point is shown at approximately 265 mc, while at 425 mc the inductance of the leads resonates with the equivalent series capacity of the circuit to cause a series-resonant condition. A full investigation of this type is easy and quick to make with the bridge.

—*Arthur Fong.*

SPECIFICATIONS FOR -hp- MODEL 803A VHF BRIDGE

FREQUENCY RANGE: Maximum accuracy, 50 to 500 mc. Useful from 5 to 700 mc. Maximum measurable phase angle at 5 mc is −9 to +9 degrees.

IMPEDANCE MAGNITUDE RANGE: 2 to 2000 ohms. Higher and lower values can be measured with some reduction in accuracy by using a known length of transmission line as impedance transformer.

PHASE ANGLE RANGE: From −90 to +90 degrees at 50 mc and above.

IMPEDANCE CALIBRATION: Directly in ohms.

PHASE ANGLE CALIBRATION: Directly in degrees at 100 mc. Can be readily computed at other frequencies (Actual Phase Angle = dial reading × Frequency/100 mc).

ACCURACY: Impedance magnitude, within 5%; impedance phase angle, within 3 degrees over 50 to 500 mc range.

EXTERNAL RF GENERATOR: Requires a-m signal source of at least ±1 mw. High signal level is desirable (-hp- 608A is ideal for this purpose).

RF DETECTOR: Requires well-shielded VHF receiver of good sensitivity. -hp- Model 417A VHF Detector is designed for this use.

CONNECTORS: Unknown terminal, female type N; Generator and Detector terminals, female type BNC.

MOUNTING: Cabinet Mounting.

SIZE: 14" x 14" x 8" deep.

WEIGHT: 25 lbs.; shipping weight, approx. 40 lbs.

PRICE: $495.00 f.o.b. Palo Alto, California.

Data subject to change without notice.

10-500 MC VHF DETECTOR

The -hp- Model 417A VHF Detector is a 10-500 megacycle a-m receiver having a sensitivity of approximately 5 microvolts through the entire range. A built-in speaker is included in the receiver as well as a jack for headphones.

The Detector is small, light, and well-shielded to prevent interference with measurements by other laboratory equipment or hum. Circuit-wise, the receiver is super-regenerative, which is ideal for this application because of the inherent high sensitivity and rather broad tuning of the circuit. In addition, the super-regenerative circuit can be used without a modulated signal source in some applications by tuning the receiver for a null in noise output. However, the use of an a-m signal generator gives in the order of a 20 db increase in sensitivity and is desirable in all cases.

For ease in tuning, a large 6-inch tuning dial driven through a 5:1 reduction drive is used. The receiver covers the 10-500 mc range in five bands: 10-20, 20-40, 40-90, 90-200, and 200-500 mc.

In addition to its use as a bridge detector, the receiver will be found useful for general-purpose work such as making quick frequency checks, checking spurious radiations, etc.

SPECIFICATIONS FOR -hp- MODEL 417A VHF DETECTOR

FREQUENCY RANGE: 10 to 500 megacycles in 5 bands; calibrated directly in mc.

SENSITIVITY: Approximately 5 microvolts over entire range (minimum discernible signal).

OUTPUT: Built-in speaker; output jack for headphones.

CONNECTORS: Input terminal, female type BNC.

CABLES SUPPLIED: 7' power cord permanently attached to unit.

DIMENSIONS: 9" wide, 10½" high, 8" deep.

POWER: Operated from nominal 115-volt, 50/60 cycle source. Requires approximately 30 watts.

WEIGHT: 17 lbs.; shipping weight, approx. 30 lbs.

PRICE: $200.00 f.o.b. Palo Alto, California.

Data subject to change without notice.