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Home-Brew Rf Impedance Bridge

— indispensable tool for antenna fans

In the construction and adjustment of HF antennas, an undesirable standing wave ratio may be experienced even though the antenna appears to be operating at resonance. The exact antenna impedance may be unpredictable because of interaction with other objects, or variations in physical configuration as a result of mechanical restrictions. The use of a simple impedance measuring device can eliminate the uncertainty of estimating antenna impedances and allow an intelligent approach to antenna matching. This article describes the construction of a high-frequency rf impedance bridge capable of measuring resistive impedances of 5 to 500 Ohms at frequencies up to 30 MHz. Calibration and operating instructions are included.

Theory of Operation

Fig. 1 shows the simplified schematic diagram for the impedance bridge. The meter compares the voltage at the unknown R with the voltage at the variable R when rf voltage is applied. If the variable R is adjusted for a minimum meter indication, the voltage at the wiper of the variable R is equal to the voltage at the junction of the fixed R and unknown R, and the bridge is balanced. Now the voltage division ratio of the variable R is equal to the voltage division ratio of the other two resistors. Since the fixed R resistance is known and the variable R resistance can be calibrated, the unknown R can be determined. In practice, the dial of the variable R is marked with resistance values while various known-value resistors are substituted for the unknown R when the bridge is balanced.

Design Points

Fig. 2 shows the schematic diagram of the impedance bridge. A 250-Ohm potentiometer is smaller and less expensive than a differential capacitor. The use of two separate diode detectors, D1 and D2, provides convenience of operation, since the zero-center meter will indicate the direction of the null even when pinned. This also eliminates the need for a sensitivity control, since D3 and D4 will limit the voltage across the meter and its series resistor.

The use of two 2-Watt, 100-Ohm resistors for the fixed 50-Ohm element provides for power dissipation. The 250-Ohm value for the potentiometer was also selected for power considerations. A nominal 5-Watt (53-Ohm) input results in a sharp null with moderate component heating. The use of a hot-carrier diode such as the 1N5711 for D1 and D2 may seem indicated, but diodes can be selected for matched characteristics at less expense, and errors can be calibrated out. It was decided not to include reactive measurements in the impedance bridge since this would add expense, increase size, and complicate calibration. If the unknown antenna can be first tuned to a resistive impedance by using a grid-dip oscillator,

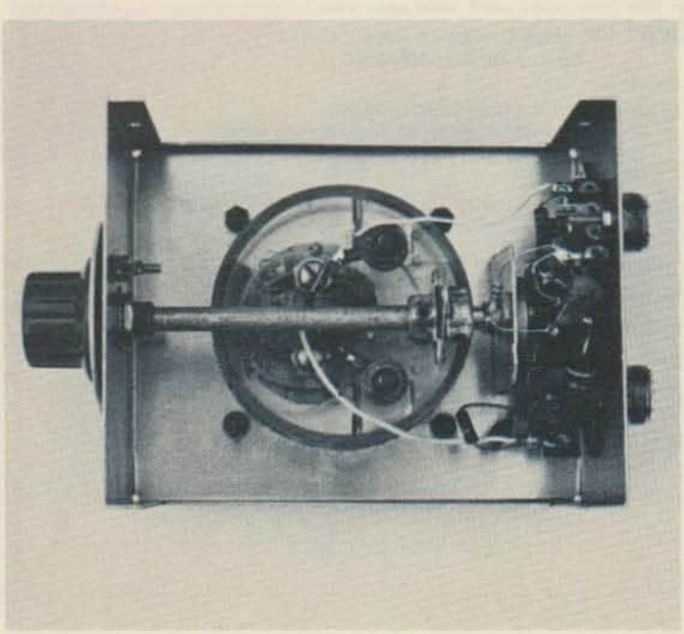


Photo A.

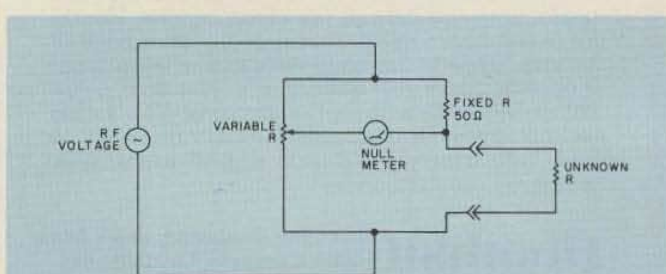
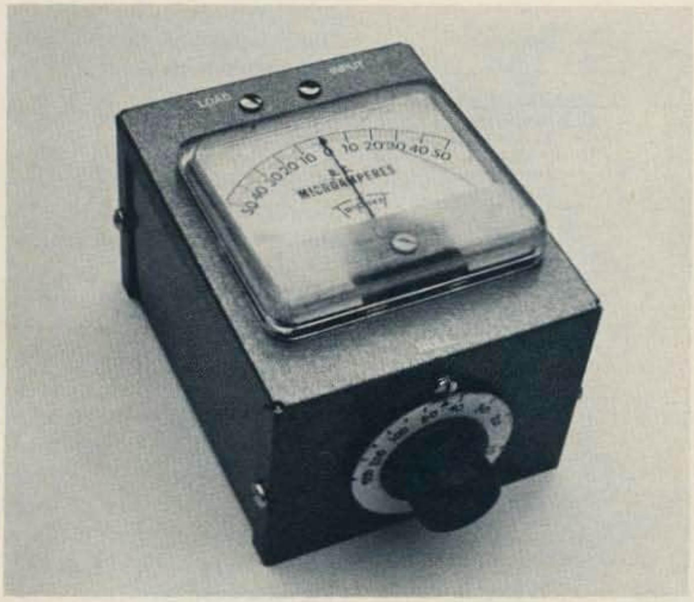


Fig. 1. Simplified schematic diagram.



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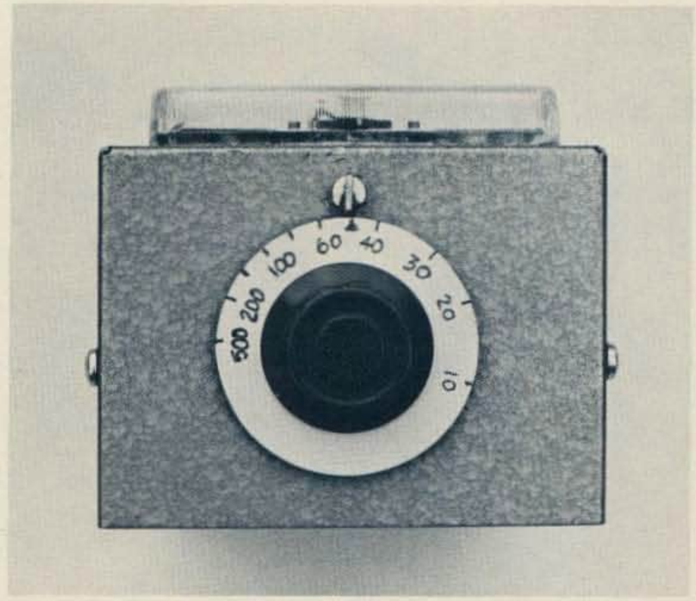

Photo C.

reactive measurements are unnecessary.

Construction

The impedance bridge is built in a California Chassis M-60 aluminum box. The most important mechanical consideration is to provide short connections for the portions of the device. The potentiometer is a Clarostat RV4NAYSD251A, and must be mounted near the two SO-239 connectors. A shaft coupling and extension allow a convenient location for the dial at the front of the meter movement location. A small aluminum bracket is used to mount the potentiometer. The meter is a Triplett 327-PL, 50-uA, zero-center (100-uA, end-scale) movement. The dial can be made from a knob with a large flat washer attached for a scale. The calibration marks are then written on the washer in pencil. A screw-head slot provides the index mark. Fixed resistors are half-Watt carbon unless otherwise indicated in Fig. 2. The capacitors are disc ceramic.

Alignment

Table 1 lists the test equipment used in the preparation of this article. Connect the equipment as shown in Fig. 3. Adjust the rf source for a five-Watt power meter indication. Connect a 50-Ohm (approximately) calibration resistor to the impedance bridge LOAD terminal. Set the impedance bridge NULL potentiometer to each end of its range and verify an impedance bridge meter indication of approximately 50 uA at each end of the meter scale. The most convenient use of the impedance bridge will result if the meter is connected so that a clockwise NULL control setting will cause a positive meter deflection. Change the meter connections if required. If a symmetrical meter indication cannot be obtained while manipulating the NULL control, try changing any of the diodes. Diodes have been found to be shorted, "weak," or accidentally marked with reversed polarity.

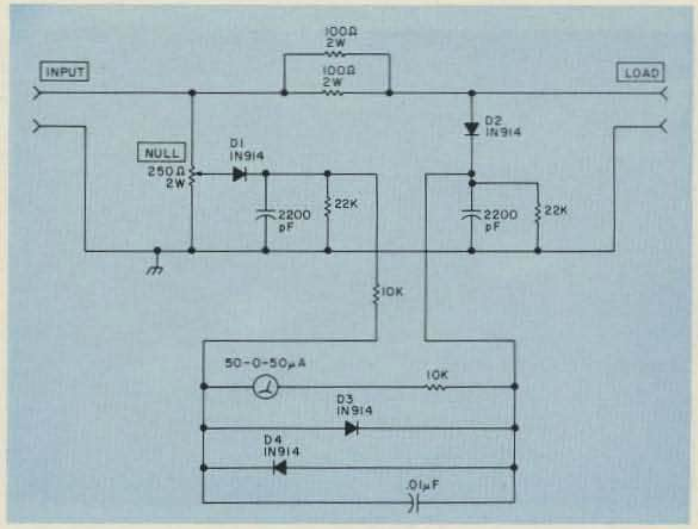

Fig. 2. Schematic diagram. Capacitors are disc ceramic; resistors are ½-Watt unless otherwise indicated. Boxes indicate panel markings. Connect meter polarity so that clockwise rotation of NULL potentiometer causes positive meter deflection.

Name	Application	Model/Part no.
Rf source	Drive impedance bridge and swr bridge	Heathkit HW-32
Swr bridge	Antenna measurements	Heathkit HM-2102
Grid-dip oscillator	Resonate antenna	Heathkit GD-1B
Calibration resistors	Calibrate impedance bridge and swr bridge	2-Watt Carbon, P/N RCR42 (assorted)
Volt ohmmeter	Check Calibration resistors	Micronta 22-204A
Dummy load	Load for rf source (50-Ohm nominal)	Heathkit HN-31
Precision resistor	Resistance calibration standard	P/N RN-, RLR-, RD-, or RBR- prefixes
Power meter	Measure rf source output	Swan WM-1500

Table 1. Equipment requirements. (Selection of these items does not indicate a product endorsement or evaluation of their performance. Use of other equipment may result in perfectly satisfactory results in the procedure.)

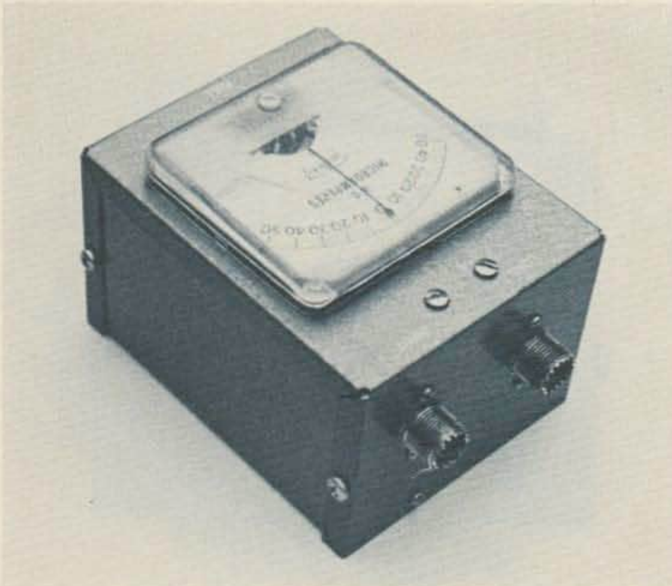

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Photo E.

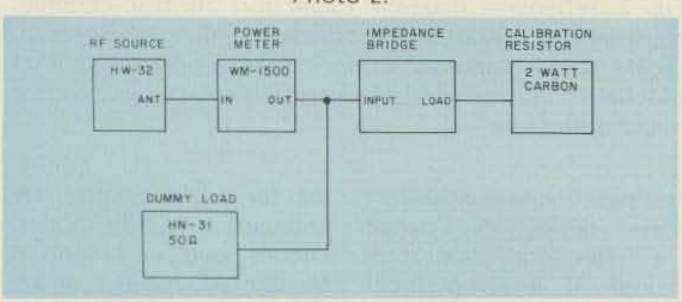


Fig. 3. Test configuration.

Calibration

Calibration is the periodic verification of essential performance parameters. Traceability of all measured values to a higher accuracy standard is essential. Fig. 4 shows a suggested flow of traceability for the impedance bridge. Note that the impedance bridge could be calibrated directly from the carbon calibration resistors. However, some type of testing is required to verify the accuracy of the calibration resistors since it is known that this type of resistor is not extremely stable or very precisely specified. Also note that *periodic* calibration of the impedance bridge is required since it is

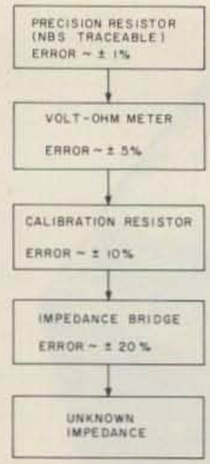


Fig. 4. Typical calibration traceability.

made from the same type of resistor. Check the calibration resistors with a calibrated volt ohmmeter and mark the resistors with their indicated values. Check the volt ohmmeter with a precision resistor. The precision resistor can be any of the marked film or wire-wound resistors. If the resistor is purchased new and undamaged, calibration traceability in the manufacturing process is (hopefully) assured. Part numbers for precision resistors beginning with RN-, RNR-, RLR-, or RBR- are excellent.

Connect the equipment as shown in Fig. 3. Connect a calibration resistor to the impedance bridge LOAD terminal and adjust the impedance bridge NULL control for a zero (center) impedance bridge meter indication. Mark the calibration resistor value on the impedance bridge NULL dial. Repeat this procedure for all resistance values desired.

Note: The swr bridge also can be calibrated by this method. Standing wave ratio is given by: swr = Z_1/Z_2, where Z_1 and Z_2 are the impedances of the source (swr bridge) and the calibration resistor. The larger resistance value is used for Z_1 so that the swr will be a number greater than one. The swr measurement will give the ratio of the resistances, but will not indicate which is larger.

Typical Applications

A shortened 20-meter vertical ground-plane antenna was constructed to demonstrate the use of the impedance bridge. Impedances of vertical antennas of varying length are well known[1] and provide some indication of the impedance bridge's performance.

The ultimate objective was to construct a 20-meter antenna from a 12-foot length of aluminum tubing. Fig. 5 shows the results of various configurations. The following procedure was used to adjust the antenna:

1) Make rough adjustments for antenna resonance by using the grid-dip oscillator coupled to a loop of wire at the antenna base.

2) Make fine adjustments with the swr bridge by varying the rf source frequency and observing where the minimum swr is.

3) Measure the resistive base impedance of the antenna with the impedance bridge.

4) Use the best available means to match the antenna impedance, or,

5) Change the antenna tuning method to change the base impedance and allow application of the matching devices available, and,

6) Repeat steps 1 through 5 until the antenna is matched.

Fig. 5 shows that a perfect match for a 53-Ohm system was not found. To illustrate a simple matching system, ¼-wavelength transmission-line matching sections were applied. The length (in feet) of a ¼-wave coax section is $\lambda/4 = 246(V)/F$, where V is the transmission line velocity factor (0.66 for RG-58 and RG-59) and F is the frequency in MHz.[2] The impedance, looking into the end of a terminated section is $Z = (Z_o)^2/Z_L$, where Z_o is the matching-section characteristic impedance and Z_L is the termination impedance at the other end of the section. Manipulation of the equation shows that a good match to a 73-Ohm system can be obtained with a 53-Ohm matching section for the antennas of Fig. 5(b) and (d). This is a popular matching technique for vertical antennas. The Fig. 5(a) antenna could be matched with a 4:1 toroidal transformer (2:1 turns ratio).

To accomplish a match to a 53-Ohm system, two matching sections were used. Fig. 6 shows this approach. This method provides a good match to the antennas of Fig. 5(e) and (c). The Fig. 5(e) approach was finally settled upon since the capacitive top loading allowed the use of a very small base-loading inductance, thus increasing antenna efficiency. A large base inductance will cause loss since it is used at a high-current point. The amount of capacitive and inductive loading was adjusted while keeping the antenna resonant (one was balanced against the other), until the desired base impedance was obtained. Actual measured values are shown in parentheses in Fig. 6.

For the record, the capacity hat for Fig. 5(e) was four 30-inch pieces of 3/8-inch diameter tubing. The inductor was two turns of #18 wire, ¾-inch in diameter, and ¼-inch long. The antenna vertical element was a 12-foot length of 2-inch diameter tube, and radials were made from six 17-foot lengths of #18 wire spread around the roof. The antenna was mounted with two chain-link fence clamps bolted into a piece of plywood nailed to the gable of the roof. The bottom of the antenna was insulated with plastic tape. A California Chassis box was used to cover the base of the antenna, which extended through a hole in the top of the box. The hole was insulated with a free sample of caterpillar grommet from Weckesser. UHF connectors (PL-259, etc.) were used to connect the coax sections for ease of measurement, but connections could be simple splices for permanent use.

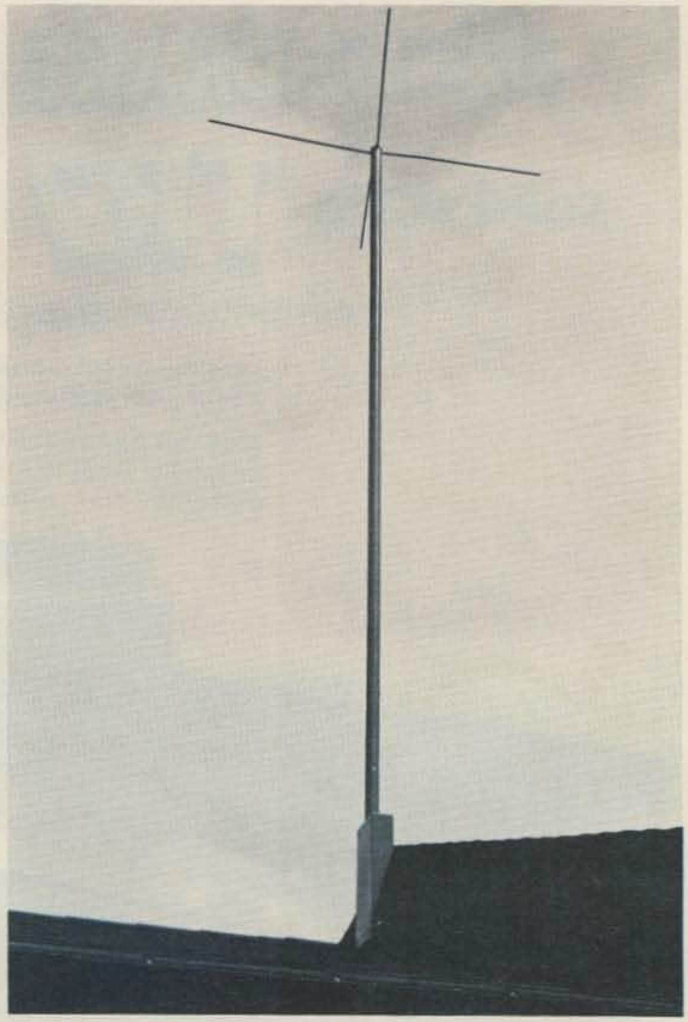
Conclusions

The previous exercise may seem pointless, but it serves as a good illustration of typical measurement and matching methods. Anyone would be most inclined to feed the ¼-wavelength antenna with 53-Ohm line and tolerate the 1.5:1 swr. Also, the antenna length could be increased to 0.28-wavelength[1] and tuned with a capacitor to match a 53-Ohm line. The point is that the use of a simple impedance bridge will allow the employment of all these techniques and provide verification of antenna theory application.

The Ben Lowe article[3] provides impedance measurements made with only an swr bridge, and performance of some calculations. It is felt, however, that many amateurs will prefer the use of the impedance bridge to avoid doing the calculations, particularly if many measurements are to be made. Also, many inexpensive ham and CB swr bridges don't have the resolution to make precise swr measurements since they are intended primarily to find 1:1 swr. ■

References

1. *Reference Data for Radio Engineers,* Howard W. Sams & Co., Inc. (ITT), Sixth Edition, pp. 27-8 (Fig. 6).
2. *The Radio Amateur's Handbook,* ARRL, Newington, Connecticut, November, 1978 (1979 edition), pp. 19-1 to 19-6.
3. Ben Lowe K4VOW, "Impedance Measurements Using an Swr Meter," *Ham Radio,* April, 1979, p. 80



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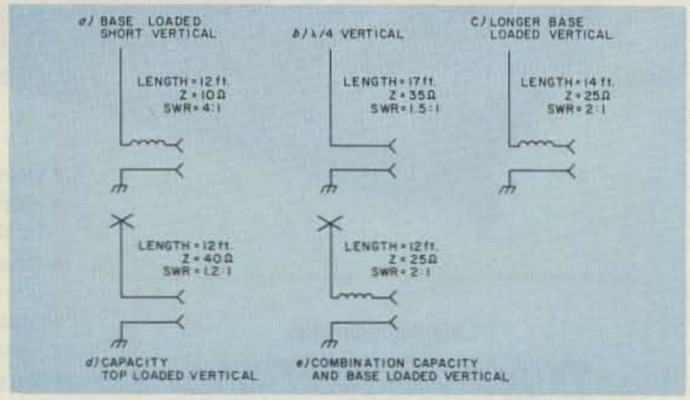

Fig. 5. Antenna measurements. Numbers are measured values; swr is referenced to 53-Ohm (nominal) system; frequency is 14.2 MHz. Measurement setup is shown in Fig. 3.

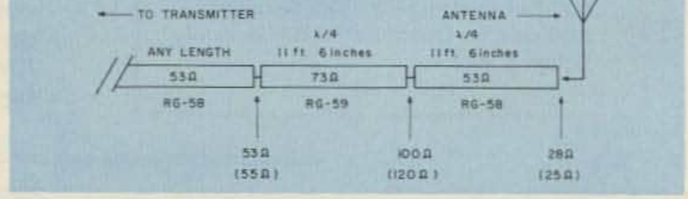

Fig. 6. Coaxial matching exercise. Values in parentheses are measured values; impedances are measured "looking toward" antenna with components to the transmitter end disconnected. Measurement setup is shown in Fig. 3.