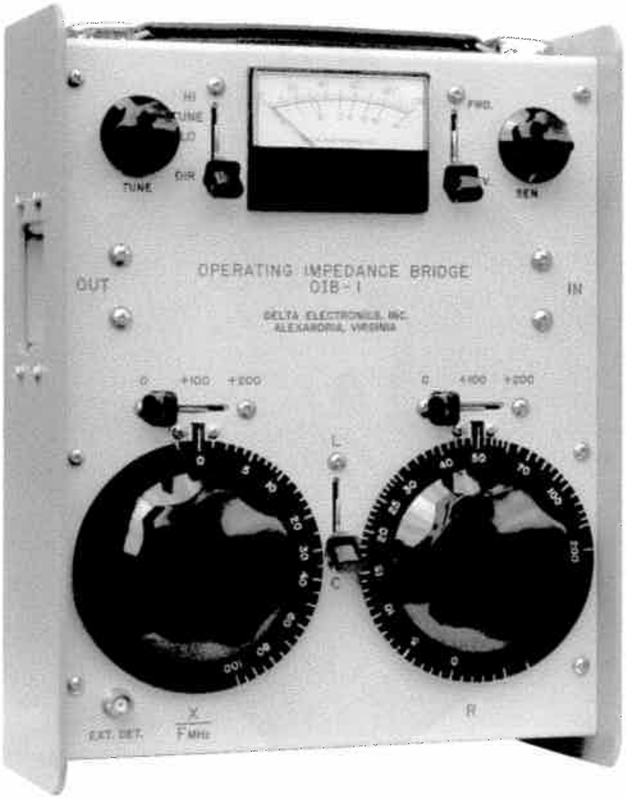
APPLICATION BULLETIN NO. 3

USE OF THE OPERATING IMPEDANCE BRIDGE



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Talk Given Before The
Georgia Association Of Broadcasters
On Operating Impedance Measurements

(June 16, 1964)

Operating Impedance

It has come as a rude shock to many engineers that the impedance of a circuit, as measured with a bridge, and the actual operating impedance of the circuit are sometimes two very different quantities. In the paper we shall take a second look at this quantity "operating impedance" and investigate the use of a new measuring tool developed for the purpose of measuring this elusive parameter.

In the rawest basic, operating impedance is the vector ratio of a circuit IN ITS NORMAL OPERATING CONDITION.

There are several reasons why the operating impedance of a circuit varies. The circuit varies. The circuit may be non-linear with power or voltage; for example, the incandescent light bulb, or even (unfortunately) most transmitter dummy loads. Or, as in the case of a directional antenna, the circuit may be so complex that it is impossible to introduce a conventional bridge into the circuit without modifying the circuit parameter.

Directional Antennas

A diagram of a simple two-tower directional antenna is shown in Figure 1A. The "T" equivalent circuit for the array is shown in Figure 1B.

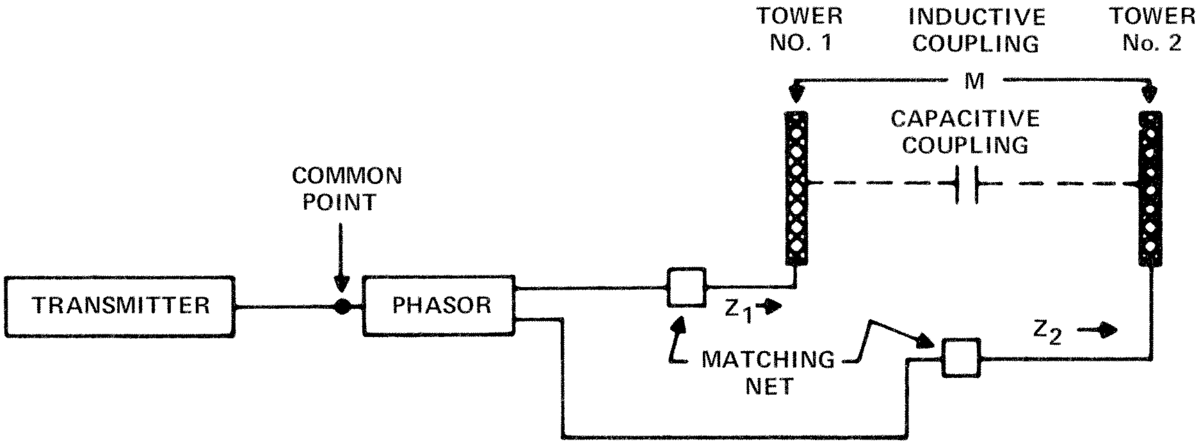

Figure 1A. Two Tower Antenna

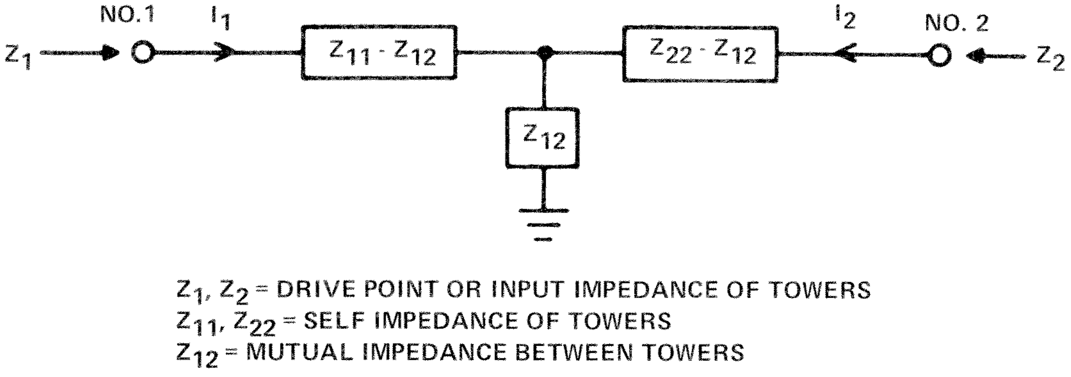

Figure 1B. Equivalent Circuit Of Antenna System

With the use of the simplified equivalent circuit of Figure 1B, we may see that measuring the input or drive point of a tower in an array is not a simple problem. If Tower No. 2 is disconnected and properly "floated" so that no current (I_2) is allowed to flow, or better yet, completely removed physically, then the input impedance Z_1 is equal to the self impedance (Z_{11}) and is easily measured with a conventional bridge. Note, however, that the requirement for $I_2 = 0$ quite often requires considerable effort to add tuning networks to all the elements in a poly-tower array in order to float all the towers except the one actually being measured.

In the operating configuration (Tower No. 2 connected into the circuit) the input impedance (or drive point impedance) of Tower No. 1 is given by the equation:

$$Z_1 = Z_{11} + Z_{12}\left(\frac{I_2}{I_1}\right)$$

Where, $Z_{12}\left(\frac{I_2}{I_1}\right)$ is the coupled impedance Z_C.

The mutual impedance, Z_{12}, is a function of the physical configuration of the towers and is constant for a given array. The current ratio, I_2/I_1, is a complex vector ratio and is a function of the self and mutual impedance (Z_{11}, Z_{22}, and Z_{21}) and the circuitry in the current paths (which include the matching networks, transmission lines, phasor, etc.).

Since the feed circuit for Tower No. 2 is connected through the phasor to Tower No. 1, the input impedance to Tower No. 1 affects the current in Tower No. 2 (I_2). Thus, placing any impedance in the feed to Tower No. 1 not only changes the current in that tower (I_1), but also changes the current in the other tower (I_2), through the interaction in the phasing equipment. From the equation, it is obvious that a change in the vector ratio of I_2 and I_1, results in a change of the coupled impedance and thus the imput impedance Z_1.

Introducing a conventional bridge into the circuit so radically changes the value of Z_1 that any measurements made this way are useless. As a matter of fact, the only place a conventional bridge may be introduced into a directional array without changing the array parameters is at, or before, the common point.

MEASURING TECHNIQUES

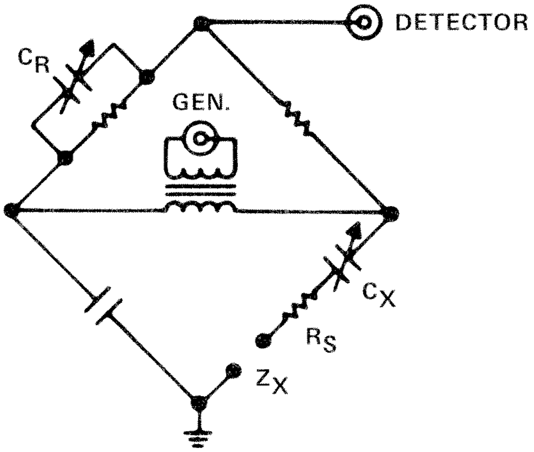

Figure 2. Impedance Bridge (GR Type 1606A)

The Impedance Bridge

The conventional impedance bridge (Figure 2) is a convenient and highly accurate method of measuring regular impedance. It uses a conventional bridge circuit to measure resistance by nulling the detector output with the variable capacitor, C_r, which is calibrated directly in ohms resistance. Reactance is measured by the substitution method: Decreasing the reactance of C_X for a capacitive unknown, or increasing the reactance of C_X for an inductive unknown. The reactance control, C_X, is calibrated directly in ohms reactance normalized to 1 MHz

An excellent feature of this configuration is the use of variable capacitors for measuring both resistance and reactance. The capacitor has many advantages for measuring resistance, including accuracy, linearity, and low contact noise when compared to presently available variable resistors.

A disadvantage of this bridge is that most of the components are above ground and thus are sensitive to stray ground capacities. This requires that these stray capacities be balance out with "initial balance" controls at each frequency before measuring. This is a very tedious and time consuming process when making frequency response measurements.

Although the accuracy of this bridge makes it an excellent choice for common point measurements in a directional array, its configuration makes it unsuitable for drive point measurements. The series and shunt elements between the generator or input connection and the unknown (Z_X) terminal completely disrupt any circuit into which the bridge is inserted. Naturally, this configuration is also incapable of handling any appreciable power.

Direct Impedance Measurements

Of the two common methods of directly measuring operating impedance, voltage distribution measurements are impractical at low frequencies due to the size of the slotted lines required. The voltage-current measuring technique has been the most practical method of measuring operating impedance, until the introduction of the operating impedance bridge.

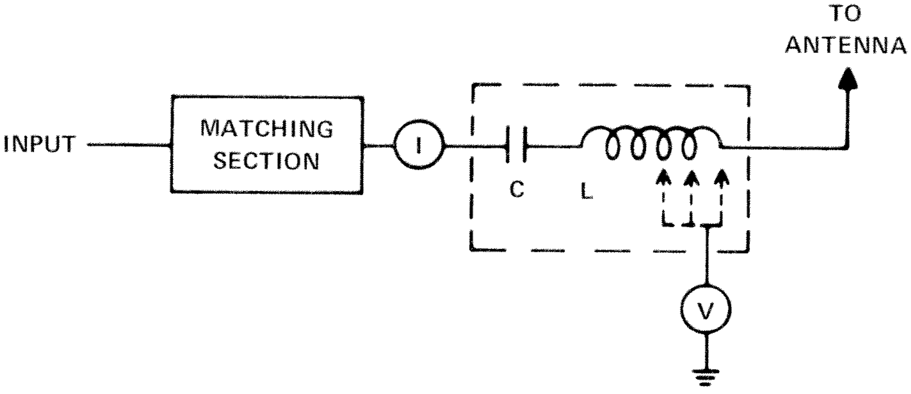

Figure 3. Voltage Current Measurement of Operating Impedance

To measure impedance with this system, the setup shown in Figure 3 is used. The induction (L) and capacitor (C) are set to be series resonance at the operating frequency, so as not to disturb the circuit into which they are inserted. The voltage measured directly across the base of the tower and the current gives the total impedance by: $Z = \frac{V_t}{I}$. However, this gives no phase data.

By measuring the voltage along the inductor (L), a minimum voltage will be found (V_m). (Note: It will be necessary to interchange the inductor and capacitor for an inductive tower in order for the voltage along the inductor to reach this minimum value.) The minimum voltage occurs where the inductor's reactance cancels the antenna's reactance, and this minimum voltage is a function of the antenna's resistance only. The antenna resistance may then be calculated by:

$$R = \frac{V_m}{I}$$

With R and Z known, the reactance, X, and the phase angle may be calculated. While this technique is slow and tedious, it has been used for many years due to the lack of any better procedure.

The Operating Impedance Bridge

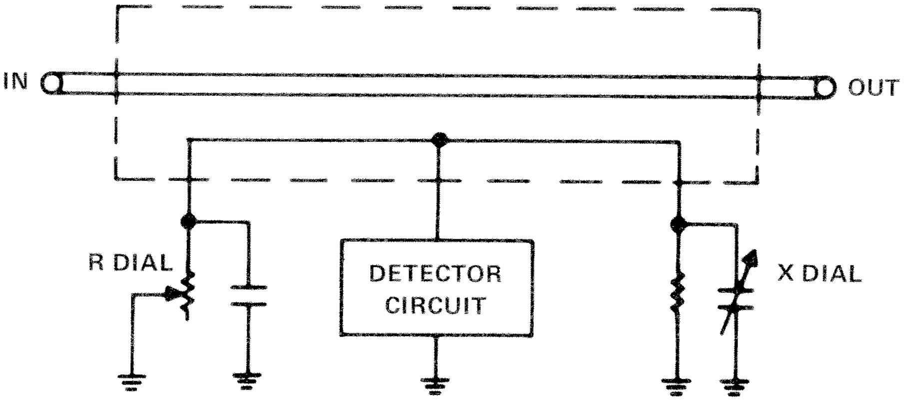

Figure 4. Simplified Schematic Of Operating Impedance Bridge

The Operating Impedance Bridge (OIB)[1] is a new measuring device (patent pending) utilizing distributed capacities and inductive coupling to the center conductor of a short length of coaxial line (Figure 4) to measure the voltage-current vector ratio on the line. The measuring circuit utilizes two controls in a null-balance circuit. The resistance control is calibrated in ohms normalized to 1MHz(The reactance dial is calibrated in $\frac{X}{F_{MHz}}$, and thus is **multiplied** by the frequency in megahertz to determine the actual reactance in ohms. This is opposite from a conventional bridge where the dial reading is divided by the frequency to determine the true reactance.

There are four prime advantages of the operating impedance bridge. First, since the measuring network is very loosely coupled to the circuit being measured, the insertion effect of the bridge is very small (approximately equal to 9" of 150-ohm coax.)[2]. The bridge may be inserted into any point of a directional antenna array with only negligible effect on the array characteristics.

Second, the bridge is designed to operate with considerable thru power (5 kW modulated, 10 kW carrier only with a 3:1 SWR)[2]. Not only does this allow measurements to be made while the system is operating under normal power, but it also allows the use of an internal null detector so that no external detector is required for power measurements.

Third, all of the measuring circuit components are in parallel to ground. This means that any stray capacities are in parallel with the measuring components and may be compensated. The practical result of this is that the circuit maintains balance throughout its operating range, and no "initial balance" controls are required.

Fourth, since the bridge is a "thru" measuring device, the power in the circuit being measured may flow in either direction. By reversing the input and output terminals, the bridge will measure NEGATIVE RESISTANCE directly. The only effect of this operation is the reversal of the "L-C" selector switch.

MEASUREMENTS WITH THE OPERATING IMPEDANCE BRIDGE

Conventional Antenna Measurements

Making accurate measurements on a conventional antenna is often difficult due to the co-channel and adjacent-channel interference received in the detector. This problem is easily overcome for initial tuneups by simply using higher power signal generators with the OIB. Even if transmitter level powers are not permissible due to FCC rules, a higher power signal generator and the use of an external detector with the operating impedance bridge will allow accurate measurements in the presence of the most persistent co-channel signal.

Adjusting Matching Networks

Once the rough setup on a directional array has been accomplished, it is desirable to adjust the tower matching networks to match the transmission line impedance. This is very important for several reasons: First, operating with the transmission line properly terminated provides the phasor with maximum control of the array parameters and minimum interaction of the phasor controls. Second, a high VSWR on the transmission line may easily exceed the line's ratings and cause a breakdown. Third, under mismatch conditions, component ratings in either the phasor or the matching network may be exceeded causing component breakdown.

The matching network may be readily set by measuring the operating impedance of the tower and then calculating the required values of the matching section components to give the impedance match and phase shift. The components may be set to their calculated values by operating the OIB as a conventional bridge with a low level signal and an external detector.

With the components set to their required values, the OIB is connected in series with the input to the matching section and final touchup of the components is made to give the exact match required. It is necessary, of course, to readjust the phases and current ratios at the phasor when a change is made in the matching network. This must be done before the final touchup of the matching network is possible, since the operating impedance of the tower will reflect any changes in the array parameters.

Locating Losses

The ability to measure operating impedance makes the OIB a natural tool for locating system losses. The operating resistance of the input to a network times the square of the current into the network gives the power input. The sum of the powers into the towers of the system should very nearly equal the transmitter output power. If there is a loss, it may be located by determining the power into and out of each circuit of the phasor and matching networks. Losses will often appear as intermittent conditions under power. These are the loose tower bolts, corroded joints, and poor ground joints that measure perfectly with low signal levels and can drive even the strongest of engineers to dispair. Monitoring the suspected circuit with an OIB with power applied, and then shaking and banging on the suspected joints, (insulated tools are advisable, of course) will usually detect even the most perverse of these intermittent conditions.

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[1] "Unique Bridge Measures Antenna Operating Impedance" by Charles S. Wright; "Electronics", Feb. 22, 1963.

[2] Specifications refer to the Delta Electronics, Inc. Model OIB-1, 0.5-5MHz Operating Impedance Bridge.

Monitoring The Common Point

Until the introduction of the Operating Impedance Bridge, one of the greatest difficulties involved in the final adjustment of a directional antenna system was the interaction between all of the phasor controls and the common point impedance.

Without monitoring an excessive number of field points, it is impossible to determine if a field strength change is due to a radiation pattern change, or to a change in the overall radiated power. Even the common method of ratioing field measurements against a non-directional radiation pattern is not useable unless the input impedances to both the phasor common point and the non-directional antenna's drive point are accurately known.

The high levels of co-channel interference that are commonly encountered today quite often preclude the measurements of common point impedances with conventional bridges until after midnight when the interfering stations have gone off the air.

Many consulting engineers have told us that by solving this problem, the OIB is one of their most valued tools. Continually monitoring the common point impedance with an OIB permits easy readjustment of the common point impedance, as required to maintain constant output power, thus eliminating this problem.

There is a special version of the OIB which is the Common Point Bridge (Delta Electronics, Inc., Model CPB-1), made especially for the purpose of permanent installation in a common point. A 50 kW version of this bridge (Model CPB-1A) is also available.

Measuring Techniques With The OIB

The OIB operates in a manner similar to other bridges with a few exceptions. First, the OIB is normally connected in circuits with high power and proper precautions must be exercised. A short circuit at 5 kW is much more spectacular (and expensive) than a shorted signal generator. Also, R.F. burns at this level are much more painful. If the OIB is accidentally ungrounded, very high R.F. voltage may be developed on the case.

Since the OIB is designed to operate with very large thru power, there is high attenuation between the measured circuit and the measuring circuit. This attenuation requires that extreme care be given to R.F. leakage when using an external detector, particularly at signal generator levels. If there is leakage into the receiver from other than the external detector connection on the OIB, the OIB null point will shift and the OIB reading will be incorrect. A well shielded receiver must be used and all interconnections must be made with well shielded coaxial cable.

An easy check for leakage is to disconnect the receiver cable from the OIB external detector jack and hold the body of the cable plug in contact with the body of the OIB jack (i.e., make the ground connection). The output of the receiver should be less than the output when the bridge is nulled.

When measuring tower operating impedances, it is easy to overlook shunting circuits feeding the tower – particularly the lighting circuits. The safest approach is to connect the OIB directly in series with the base current ammeter at the ammeter terminal. It has been found convenient to mount a "J" plug, or a second meter switch with appropriate terminals so that the OIB may be inserted into the circuit at any time without having to remove power from the circuit (again, exercise caution!).

SUMMARY

The Operating Impedance Bridge is capable of making many impedance measurements that heretofore have been very difficult, if not impractical. The OIB is not in competition with the conventional bridge, whose accuracy and usefulness has been proven over the years. Rather, the OIB makes available a new field of measurements that allow greater ease and efficiency of engineering operations.