APPLICATION BULLETIN NO. 1

NEW MEASUREMENTS YOU CAN MAKE WITH THE OIB-1 OPERATING IMPEDANCE BRIDGE

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I. DESCRIPTION OF OPERATING IMPEDANCE BRIDGE

The Delta Electronics Model OIB-1 Operating Impedance Bridge is an instrument for impedance measurement and has two main characteristics that make it unique. These characteristics are, (1) its ability to handle a large through power (up to 5 kW with modulation, 10 kW unmodulated); and, (2) its very low insertion effect in the circuit being measured.

It is a characteristic of directional antenna systems that the impedance at each point throughout the antenna system varies according to the tuning of the antenna system. When an ordinary bridge is inserted in such a system, the impedance measured with that bridge is not the actual operating impedance since the insertion of the bridge greatly detunes the system. The OIB-1, on the other hand, can be inserted at any point throughout a directional antenna system. The insertion effect is so low (equal to 9" of 150 ohm line) that the antenna continues to function without significant detuning.

A description will be given below of several of the measurements that can be made with this bridge that cannot be made with an ordinary bridge. There are, of course, many other unique measurements that can be made, as well as measurements that can be made by both types of bridges.

II. FRONT PANEL CONTROLS OF THE OIB-1

The cover is a photograph of the front panel of the operating impedance bridge. The controls on the lower half of the front panel are for the measuring section of the bridge. Those on the upper half are for the detector section. The large dial on the lower right is the resistance dial. The dial on the lower left is the reactance dial. When a null is obtained by adjusting these two dials, the resistance and reactance can be read directly from the engravings on the dials. The lever switch between these two dials is the L-C switch. This switch must be in the L position for inductive loads, and in the C position for capacitive loads. The two lever switches immediately above the R & X dials are adder switches. When an adder switch is thrown in the +100 position, the measured value is the dial reading plus 100 ohms.

The meter in the top center is the null indicating meter. The sensitivity control for this meter is the knob to the right of the meter. The lever switch between this control and the meter is the Forward-Reverse switch. This switch is always in the "Rev." position, except during the SWR measurements described later. The lever switch immediately to the left of the meter is the Tune-Direct switch. When it is in the direct position, the null indicating meter is connected directly to the output of the bridge. When it is in the "Tune" position, a tuneable L network is inserted between the meter circuit and the bridge. This network is tuned by the "Tune" knob. Its use increases the sensitivity of the null measuring circuit.

Provision is made for attaching an external detector to the bridge. A BNC connector for this purpose is mounted on the lower left corner of the panel.

Two high power RF connectors are mounted in recess holes on either side of the bridge case. The connector on the right is the input connector and the one on the left is the output connector. It is to these connectors that the circuit to be measured is attached.

III. MEASURING OPERATING IMPEDANCE

Measurement of the operating impedance at any point in the antenna system can be accomplished as follows: the circuit to be measured is interrupted. A convenient way of doing this is the removal of a meter plug. The clip leads supplied with the bridge are attached to the input and output connectors on the bridge case. The bare leads from both sides are clipped to a good ground point. The insulated lead from the input connector is clipped to the meter jack terminal towards the transmitter. The other insulated lead is clipped to the terminal towards the antenna. Power is then applied to the circuit. The sensitivity control is advanced until an upscale reading is obtained on the null indicating meter. The R & X dials are then manipulated for a null. The sensitivity is then advanced and further adjustments of the dials are made to obtain a deep null. It will be found that the L-C switch must be placed in the proper position in order to obtain a null. It may also be found that one of the dials is rotated to its maximum position before a null is obtained. In this case, the adder switch must be used. When a null is obtained, the operating impedance looking towards the antenna is the dial readings plus the adder switch readings. The reactance value is positive with the L-C switch in the L position, and negative when in the C position. When measurements are made at 1 MHz, the reactance is the value indicated on the X dial (plus the adder switch). For frequencies other than 1 MHz, the reading must be multiplied by the measuring frequency in megahertz to obtain the actual load reactance.

IV. INCREASING SENSITIVITY WITH TUNE CIRCUIT

It will be found that with transmitters of a low power, especially at low frequencies, that it is desirable to have more sensitivity in the null indicating meter. This can be accomplished by throwing the "Tune-Dir." switch to the "Tune" position and rotating the "Tune" knob for maximum meter indication. A substantial increase in sensitivity can be obtained using this circuit.

V. USE OF EXTERNAL DETECTOR

For very low transmitter powers, or when a signal generator is used in place of the transmitter, an external null detector can be used to get the required sensitivity. A well shielded communications receiver can be connected to the external detector jack by a coaxial cable and used as an external detector. Since it is required that the bridge operate with a large through power, the attenuation between the bridge input and the detector circuit has purposely been made large in order to protect the adjustable standards in the bridge. This attenuation places a rigorous requirement on the shielding of an external detector. The adequacy of the external detector shielding can be determined by disconnecting the receiver cable from the external detector jack and putting the body of the plug in contact with the body of the external detector jack. The output indication should be lower than the null value.

VI. MEASURING NEGATIVE IMPEDANCE
(Another Unique Feature of the OIB-1)

Occasionally it will be found that when the dials are manipulated for a null, a balance will be indicated below zero on the R dial. This indicates that that particular part of the antenna system has a negative operating resistance. This characteristic is frequently found in multi-element directional antenna systems. The value of the negative impedance can be measured with the OIB-1. It is accomplished merely by reversing the connection of the clip leads from the bridge. That is, the lead from the IN connector is connected to the circuit towards the antenna. The lead from the OUT connector is connected to the circuit near the transmitter. A bridge null is obtained in the normal manner and readings are taken from the bridge dials in the normal fashion. The actual impedance is the negative of the R & X values read from the bridge.

VII. ADJUSTING MATCHING NETWORKS

After the operating impedance of a single tower is obtained, proper values of network components can be computed by normal equations. When the network is installed, it is convenient to connect the bridge between the input of the network and the transmission line. With the power applied, the network impedance can be measured. The network components can then be trimmed to obtain an exact match for the transmission line. It will, of course, be necessary to re-establish the phase and current ratio each time a change is made in the matching network.

It has been found that if the networks and transmission lines are matched early in the directional antenna tuning procedure, a much better control is obtained with the antenna phasing equipment. This speeds the adjustment of the antenna parameters.

VIII. MEASURING THE COMMON POINT

Adjustments on the phasing equipment of the antenna system to obtain the desired pattern will, unfortunately, change the common point impedance of the system. This changes the input power to the antenna and leaves the engineer in the dark as to the actual radiated power during field measurements. It has been found quite convenient to connect the operating impedance bridge in the common point lead while adjustments are being made. When the phase and current adjustment is made, the engineer can observe the effect on the common point. If the common point resistance is changed substantially, it can be returned by adjusting the appropriate network components without removing the transmitter from operation. The engineer, therefore, has knowledge of the antenna power at all times during the antenna adjustment. Previously, it was often necessary to wait until midnight to determine the actual antenna power by conventional bridge measurements. On occasion it was found that the actual power differed so much from the required power that the field intensity measurements made that day were useless.

The final impedance measurements required by the FCC can be delayed until after the antenna is adjusted. These can, of course, be made in the usual manner with the usual equipment.

IX. LOCATING POWER LOSS

Quite frequently an antenna is adjusted and field intensity measurements reveal that the radiation in the main lobe is somewhat less than predicted. This can be due to several reasons, one of which is abnormal losses in the antenna networks. The Model OIB-1 is a very convenient tool for determining the source of these losses. The operating impedance of each radiator element is measured and the antenna current squared times the operating resistance of each element gives the power delivered to each tower. When these are all added they should very nearly equal the transmitter output power. If this is not the case, measurements can be made at successive points in the antenna system towards the transmitter. The total power at each point can be determined from the operating impedance and the current and the source of the power loss isolated.

X. RENOVATING AN ANTENNA SYSTEM

Sometimes a station will wish to rebuild their antenna phasing gear, transmission lines and networks. The proper design of the new equipment requires a knowledge of the operating impedance of each element of the antenna system. These values can very easily be determined with the Model OIB-1 Operating Impedance Bridge, using the existing networks.

XI. SWR MEASUREMENTS

It is often desirable to measure and record the SWR on the transmission lines of an antenna system. This can be done with the operating impedance bridge by installing the bridge at the input of the transmission line, as described above. The R dial is set to the characteristic impedance of the line, and the X dial is set to zero. The "For. -Rev." switch is thrown to the "Fwd." position and the sensitivity control is advanced until a full scale reading is obtained on the meter. The switch is then returned to the "Rev." position. The SWR on the line can then be read directly from the SWR scale on the meter.

DELTA ELECTRONICS

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.

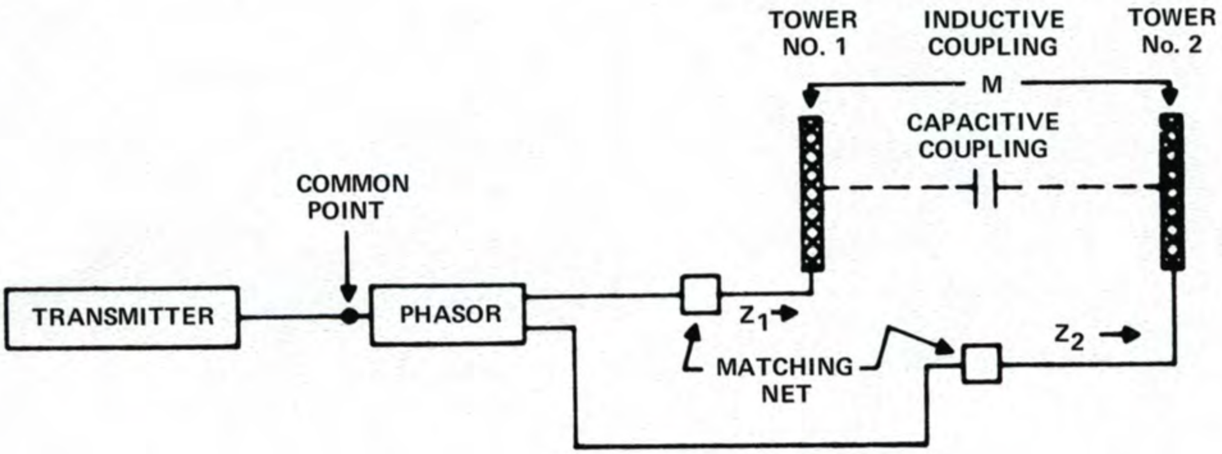
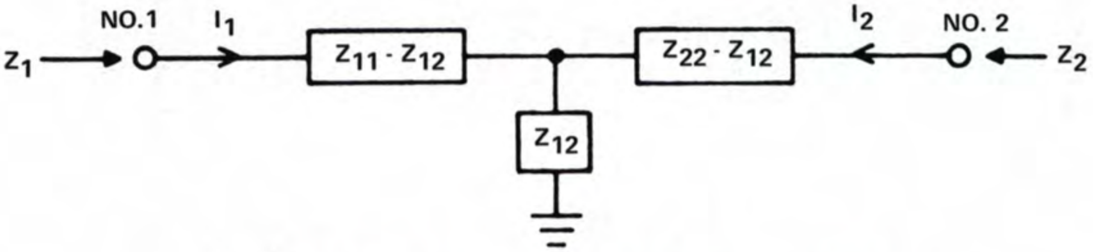


Figure 1A. Two Tower Antenna



Z_1, Z_2 = DRIVE POINT OR INPUT IMPEDANCE OF TOWERS
Z_{11}, Z_{22} = SELF IMPEDANCE OF TOWERS
Z_{12} = MUTUAL IMPEDANCE BETWEEN TOWERS

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:

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

Where, $Z_{12}(\frac{I_2}{I_1})$ 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

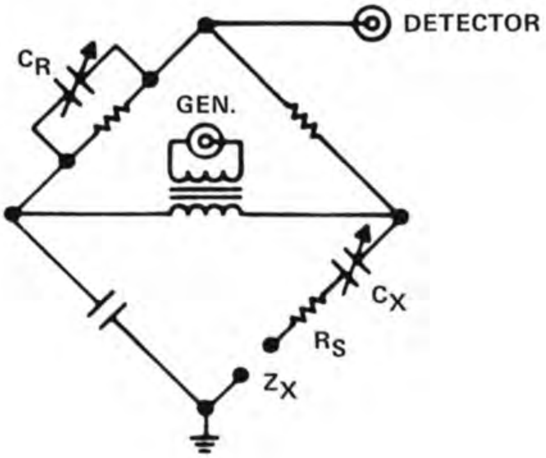


Figure 2. Impedance Bridge (GR Type 1606A)

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 imput 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.

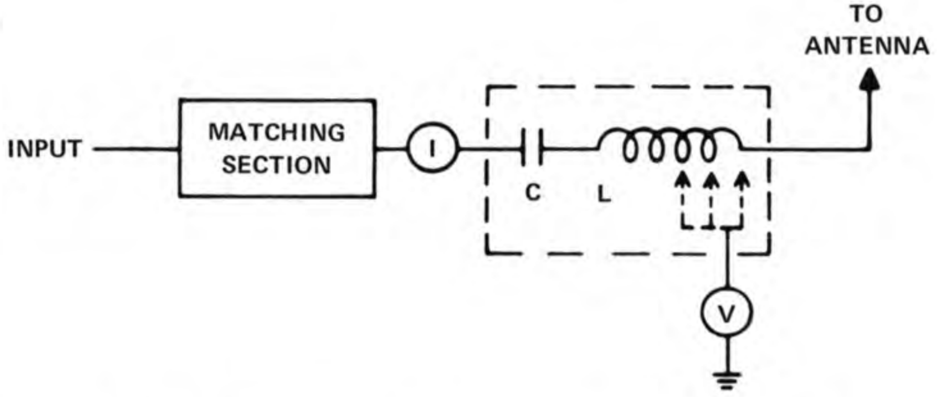


Figure 3. Voltage Current Measurement of Operating Impedance

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

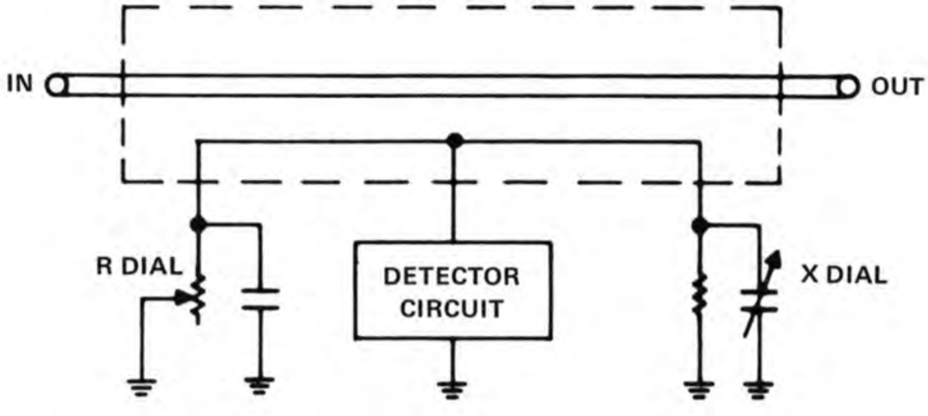


Figure 4. Simplified Schematic Of Operating Impedance Bridge

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.

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