INSTRUCTION BOOK

for

MODEL OIB-1

OPERATING IMPEDANCE BRIDGE

DELTA ELECTRONICS

DELTA ELECTRONICS, INC.
5730 GENERAL WASHINGTON DRIVE
ALEXANDRIA, VIRGINIA 22312

D93-15

ISSUE DATE: 4 OCTOBER 1966

TECHNICAL MANUAL

MODEL OIB-1

OPERATING IMPEDANCE BRIDGE

Manufactured Under
U.S. Patent No.
3,249,863

WARNING: *Dangerous radio frequency voltages may be encountered when measuring high power active circuits. Exercise care in grounding the instrument before applying power.*

D93-15

ISSUE DATE: 4 OCTOBER 1966

TABLE OF CONTENTS

INSTRUCTION BOOK - MODEL OIB-1

INSTRUCTION BOOK
MODEL OIB-1
OPERATING IMPEDANCE BRIDGE

I. GENERAL INFORMATION

1.1 General Description

The Delta Electronics, Inc. Model OIB-1 Operating Impedance Bridge is an impedance measuring instrument based on a new bridge principle. It permits the measurement of impedance under power, with a minimum of insertion effects on the circuit being measured. The bridge will handle a through power of up to 5,000 watts at moderate standing wave ratios. Resistance and reactance values are read directly from two dials located on the front of the panel. An internal detector is provided so that when the bridge is operating in a power circuit, no other instrument is required. The instrument's specifications are:

Frequency Range: 500 kc to 5 mc
Maximum Through Power: 5 kw at VSWR 3:1
10 kw intermittent duty below 1.7 mc
Resistance Range: -400 to +400 ohms
Reactance Range: -300 to +300 ohms at 1 mc
Resistance Accuracy: 2% ±1 ohm
Reactance Accuracy: 2% ±1 ohm

1.2 Operating Impedance

The term "operating impedance" is defined as the complex ratio of the voltage applied to a load to the current flowing in the load when it is operating under normal power and in its normal environment. In many cases, this impedance differs substantially from the "self-impedance" or "cold impedance" of the load. In antenna systems, for example, a separate radiator has a self-impedance when operating in free space. When it is combined in an antenna array, its operating impedance differs from its self-impedance by the coupled impedances from adjacent radiator elements; or its image.

Many loads have an operating impedance which differs with applied power level. In dielectric heating applications, for example, the operating impedance of the dielectric varies substantially with applied power. Meaningful impedance measurements must, therefore, be made at normal power level.

1.3 Differences Between Bridges

The Delta Electronics, Inc. Model OIB-1 Operating Impedance Bridge differs from bridges based on classical design in that the bridge can handle a substantial power level and causes a minimum of insertion effects. This permits the direct measurement of operating impedance as defined above, the Model OIB-1 can be inserted directly in the circuit and the operating impedance of the load measured under normal power. Bridges of a classical design are ordinarily incapable of handling large amounts of power. They measure the "cold" impedance of the load. When the matching circuits are adjusted from these measurements, it is found that a satisfactory match is not obtained when power is applied.

In measuring the operating impedance of various elements of a complex directional antenna, the installation of a normal bridge within the antenna circuit completely disturbs the relative magnitude and phase of the currents in the various radiators. The element under measurement, therefore, does not have the normal coupled impedance, and the measurements made do not give an impedance value which can be used to adjust the feeding system of the antenna. The Model OIB-1 impedance bridge, on the other hand, can be installed directly in the circuit of each element, each transmission line, each matching network, etc., and the operating impedance level throughout the system can be determined. The data thus obtained can be used to match the entire antenna system and determine the power level throughout the complete system. Another distinct advantage of the OIB-1 is that a signal generator of substantial power can be used with the bridge for making antenna impedance measurements. The interference effects from adjacent antennas in operation, or from strong signals on nearby frequencies, can thus be minimized.

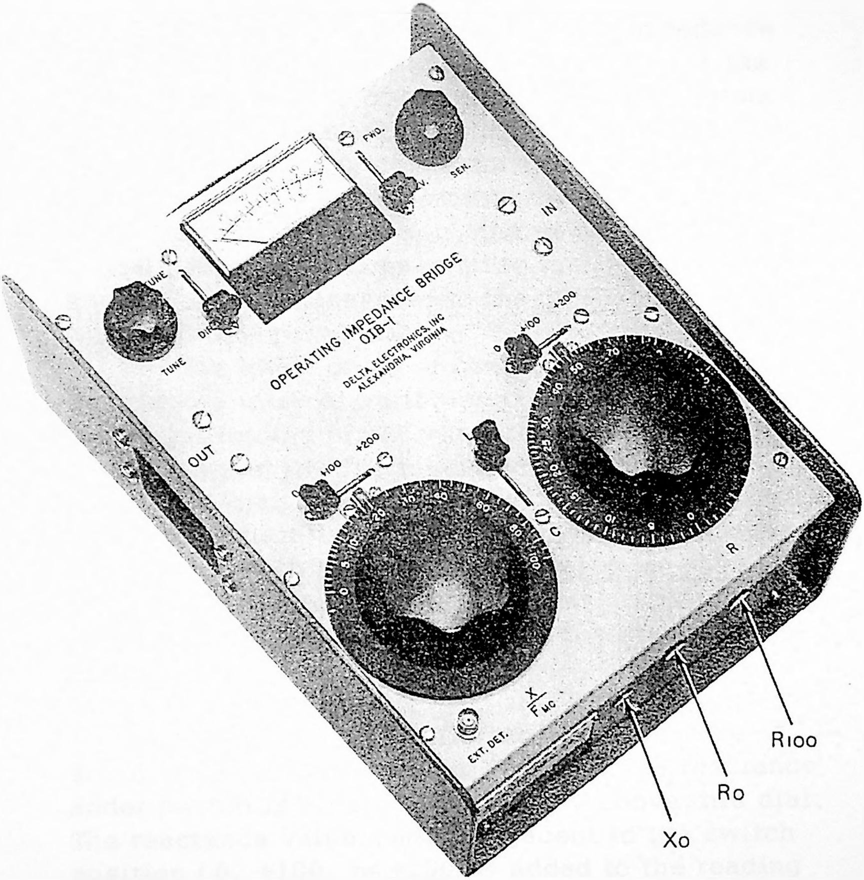


Figure 1. OIB-1 OPERATING IMPEDANCE BRIDGE

II. OPERATING INSTRUCTIONS

2.1 Identification of Controls

Figure 1 is a photograph of the impedance bridge. A large UHF connector is mounted in the recess on each side of the case. The connectors are identified by markings directly above them on the front panel. The connector on the right is marked IN and the connector on the left is marked OUT. In normal operation, the power source or signal generator is connected to the IN connector, and the load is connected to the OUT connector.

The lower group of controls on the panel operate the internal variable standards. The right dial is calibrated directly in ohms resistance, this dial is marked R. The lever switch immediately above this dial is the resistance adder switch. When the adder switch is in the O position it is inactive. When the switch is positioned on +100 or +200 the value indicated (100 or 200 ohms) is added to the reading of the R dial to obtain the resistance of the load.

The left dial is calibrated in ohms of reactance at 1 mc and marked X/FMC. The reactance adder-switch is located immediately above this dial. The reactance value marked adjacent to the switch position (0, +100, or +200) is added to the reading of the dial to obtain the reactance at 1 mc. When measurements are made at frequencies other than 1 mc, the reactance reading must be corrected by multiplying the value read by the frequency in megacycles.

For example, if measurements are made at 1.5 mc, and the total of the adder switch and the dial reads 250 ohms, the actual load reactance will be:

$$1.5 \times 250 = 375 \text{ ohms}$$

The switch marked L - C between the two dials in the center of the panel is for the selection of positive or negative reactance loads. If the load is inductive, the switch must be in the L position to obtain a null, and the reactance values read from the reactance dial are +j values. When the load is capacitive, the switch must be in the C position, and the reactance values are -j values. A bridge null can be obtained only when the switch is in the correct position.

Immediately to the right of the meter is a switch marked FWD - REV. This switch must always be in the REV position for impedance measurements. The use of the FWD position will be discussed later. For impedance measurements, a meter null is obtained by adjusting the resistance and reactance controls for a minimum reading on the meter. Immediately to the left of the meter is the meter TUNE - DIR switch. In the DIR position the output of the bridge is connected directly to the meter circuit without tuning. In the TUNE position a resonant circuit is inserted between the bridge output and the meter for increased sensitivity. This circuit is tuned to the desired frequency by a variable capacitor operated by the TUNE knob to the far left of the meter.

To the far right of the indicating meter is a sensitivity control (SEN) which adjusts the sensitivity of the meter. The sensitivity is increased by turning this knob in a clockwise direction.

2.2 In-Line Impedance Measurement Under Power

The simplest measurement that can be made with the bridge is the impedance level at a point along a coaxial transmission line. For this measurement, the line is interrupted; the end of the line coming from the source is connected to the IN connector and the end of the line towards the load is connected to the OUT connector. A power level of up to 5,000 watts can be applied to the bridge with such connections. The controls are then adjusted, as follows: Meter switch in DIR position; FWD - REV switch in REV position; SEN control at minimum (full counterclockwise); R dial at zero; X dial at zero; L-C switch in L position and both adder switches to O. Power is then applied to the circuit and the gain control is advanced until an upscale indication on the meter is obtained. The R and X dials are then adjusted for a minimum reading on the meter.

If the reading on the meter is decreased when the X dial is advanced from zero, the load is inductive and a null can be obtained. If the reading is increased when the X dial is advanced from zero, the load is capacitive and the L-C switch must be changed to the C position. After a minimum has been obtained on the meter, the gain control is further advanced and further adjustments are made on the R and X dials until a deep, sharp null is obtained. The R and X readings are noted and the X reading is corrected for frequency, as described above.

If either the R or X dial is advanced to its maximum value before a null is obtained it will be necessary to switch in one or both of the adder switches. When a null is obtained by the use of these switches, the values marked on the adder switches are added to the reading on the dials to obtain the load impedance.

Since the bridge will usually not be inserted directly into a line equipped with the proper connectors, a set of heavy clip leads is supplied for connecting the bridge into the antenna or matching network circuit. Both of the clip ground leads should be grounded when these leads are used.

2.3 Increased Detector Sensitivity with "Tune" Circuit

When the power level is not high, it may be desirable to increase the sensitivity of the indicating meter in order to obtain a more accurate null. This can be done with the TUNE circuit, as follows: The meter switch now is set to TUNE. The TUNE knob is rotated for a maximum meter deflection. Measurements are then made as before with increased meter sensitivity.

2.4 Operating With External Detector

At very low power levels, the meter sensitivity may not be high enough even when using the tuned circuit.

For this circumstance, an external detector connector is provided at the bottom left of the panel. A communications receiver can be connected by a well shielded coaxial cable to this connector and used as an external null detector. Impedance measurements are then made, as described above, using the S meter on the receiver, or by nulling an audible tone. For this mode of operation, a signal generator can be used as a power source, and the bridge used as a normal impedance bridge.

2.5 Improving Precision by Substitution Method

Occasionally, it will be found that accuracies better than the ± 5% accuracy of the bridge are desired. More accurate impedance measurements can be made by installing the bridge and adjusting for a null, as described above. The bridge is then removed from the circuit without disturbing the setting of the controls. A signal generator (tuned to the same frequency) is connected to the IN terminal and a communications receiver connected to the external detector jack. A variable composition resistor, such as a CTC RV4NAYSD102 is connected to the OUT connector. A null is then established by adjusting the X dial (which should adjust to approximately zero), and by rotating the variable resistor. The resistor is then disconnected, and its value measured on an accurate ohmmeter or a wheatstone bridge. Very accurate power determinations can be made in this fashion. Accurate reactance measurements may also be made using a variable capacitor across the output connector. In this case, a null is re-established by adjusting the R control on the bridge and by varying the capasitor.

When the actual load is inductive, an initial balance is obtained on the L position of the L-C switch. It will be necessary to change this switch to the C position to re-establish the null with a variable capacitor. In this case, the reactance of the capacitor after the null is re-established will equal the inductive reactance of the load.

2.6 Measuring Negative Impedances

Quite often, in complex antenna systems, it is found that one or more of the elements has a negative operating impedance; that is, the total of the coupled impedance from all other elements exceeds the self-impedance of that element, and the element actually returns power to the transmitter. It is necessary to know the magnitude of this negative impedance in order to match the feed system of the element, and to determine the total power in all of the elements. This can be measured by simply reversing the connections to the bridge; that is, the source is connected to the OUT connector, and the load to the IN connector. The bridge is operated in the normal manner and the impedance read from the dials of the bridge. The actual impedance of the load for this case is the negative of the impedance indicated.

2.7 SWR Measurements

The null indicator meter has a standing wave ratio scale. The bridge can be used to measure the SWR on a transmission line. The bridge is connected in a normal fashion, as described in section 2.2.

The reactance dial is adjusted to zero, and the resistance dial is adjusted to the Z_o of the transmission line to be measured. The FWD - REV switch is switched to the FWD position and the meter sensitivity is adjusted for a full scale reading. The FWD - REV switch is then changed to the REV position and the SWR is read directly from the indicating meter. It will be noted that SWR measurements can be made on lines having quite a range of characteristic impedance. SWR measurements can be made with reference to a complex impedance by simply adjusting the resistance and reactance dials to that reference. In this case, the frequency dependence of the reactance dial must be accounted for, as described above. (The external detector is wired directly to the output of the coupler box, and does not through the FWD - REV switch. SWR measurements with an external detector are, therefore, not possible with this bridge.)

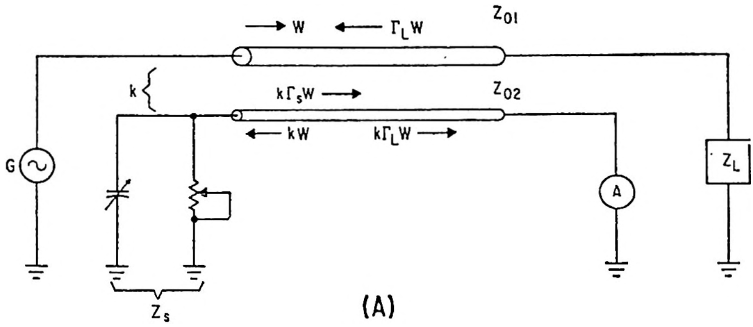
Note: The SWR scale is calibrated for a linear diode characteristic. The absolute value of SWR will thus be accurate only when the readings can be obtained with the gain control near minimum (thus a large diode voltage).

III. OPERATING PRINCIPLES AND CIRCUIT DESCRIPTION

3.1 Theory of Operation

Figure 2A is a simplified schematic, illustrating the operating principles. The circuit between the generator , G, and the load, Z_L is, interrupted by a short length of transmission line having a characteristic impedance of Z_{01}. To this short length of transmission line is lightly coupled a second section of transmission line having a characteristic impedance of Z_{02}. The coupling coefficient between the two lines is k. Across the secondary line nearest the load is a meter circuit. Across the end of the secondary nearest the generator is a variable standard resistance and a variable standard reactance. The combination of these standards is identified as Z_s.

There will be two waves on the main transmission line: one direct wave carrying energy from the generator to the load, identified as W, and a reflected wave identified as Γ_L W. Quantity ΓL is the reflection coefficient of the load impedance Z_L for the characteristic impedance of Z_{01}. Because of the coupling, k, these two waves induce waves in the secondary line. One wave is induced traveling toward Z_s, of magnitude kW, and another wave is induced traveling toward the meter of magnitude k Γ_LW. If the load impedance, Z_s, is not equal to Z_{02}, a third wave will exist on the line of magnitude, k Γ_sW. The direction of travel of this wave will be toward the meter. Γ_s is, of course, the reflection coefficient of the impedance Z_s for the characteristic impedance Z_{02}.



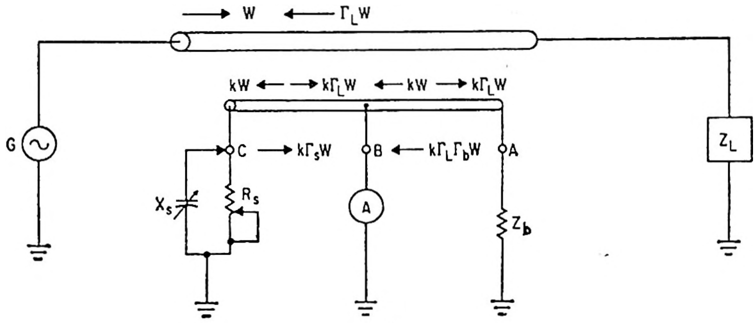


Figure 2
Simplified Schematic

Therefore, two waves arrive at the meter circuit. They are $k\Gamma_s W$ and $k\Gamma_L W$. If these two waves are of equal magnitude and opposite time phase, the meter indication will be zero. The null condition of the bridge will be:

$$k\,\Gamma_L W = -k\,\Gamma_s W \tag{1}$$

Or,

$$\Gamma L = -\Gamma s \tag{2}$$

The reflection coefficients Γ_L and Γ_s are:

$$\Gamma L = \frac{Z_L - Z_{01}}{Z_L + Z_{01}} \; ; \quad \Gamma s = \frac{Z_s - Z_{02}}{Z_s + Z_{02}} \tag{3}$$

Replacing Γ_L and Γ_s in Eq. 2 with these definitions and solving for Z_L

$$Z_L = \frac{Z_{01} \quad Z_{02}}{Z_s} \tag{4}$$

Or,

$$Z_L = Y_s \;(Z_{01} \quad Z_{02}) = Y_s C \tag{5}$$

The load impedance is directly proportional to the shunt admittance of the standard circuit. The constant of proportionality C is the product of the characteristic impedance of the main transmission line and the auxiliary transmission line. This constant has first-order independence of frequency. A standard circuit, using a parallel-connected variable resistance and variable reactance, can be calibrated directly in the series equivalent load impedance.

The simplified circuit is useful for many purposes, but has several limitations as a general-purpose measuring instrument. For example, if the load impedance Z_L is zero, the standard shunt resistance must be infinite. Also, if the reactive component of the load is inductive, a variable capacitor can be used as a standard. On the other hand, if the load is capacitive a variable inductor is required for the standard. A satisfactory variable inductor of sufficiently high Q is not obtainable.

BIASING CIRCUIT - These limitations may be removed by adding a biasing circuit. Figure 2B shows a simplified schematic similar to Figure 2A, with the biasing circuit. A short length of transmission line is inserted between the generator and the load impedance to be measured, and the secondary line is lightly coupled. Three connections are brought from the secondary line, indicated by terminals A, B and C. The line between terminals C and B is used as the secondary line shown in Figure 2A. The line section between terminals B and A is the bias section. As before, the variable standards are parallel-connected across terminal C and an r-f meter circuit is connected across terminal B. A biasing impedance is connected across terminal A. The waves induced on the two secondary line sections from the direct wave W and the reflected wave $\Gamma_L W$, are shown in Figure 2B. The total of the waves arriving at the meter circuit is equated to zero:

$$\Gamma_s + \Gamma_L + 1 + \Gamma_L \Gamma_b = 0, \qquad (6)$$

where Γ_b is the reflection coefficient of Z_b terminating the bias line.

When these reflection coefficients are replaced by their defining impedance ratios, and the resulting equation is solved for Z_L, then

$$Z_L = \frac{C}{2} Y_s - \frac{C}{2} Y_b \quad (7)$$

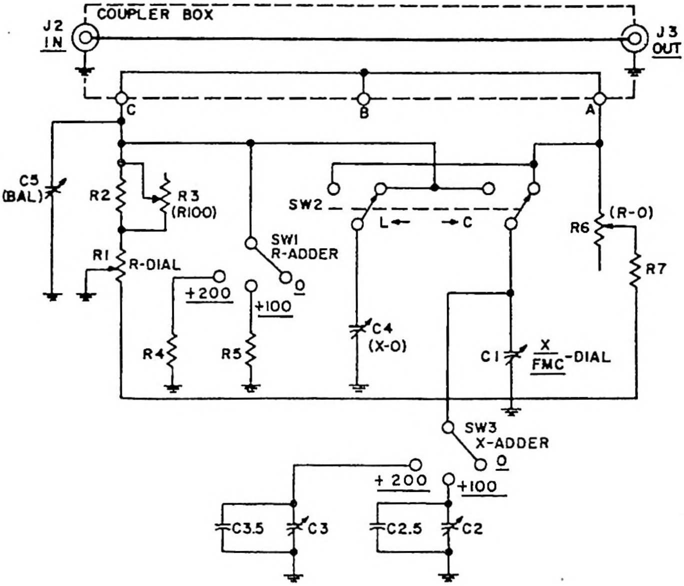
This result is obtained, assuming an exact centertap of the secondary line. Other tap ratios may be used, but they will modify this equation. Equation 7 is similar to Eq. 5, except that a negative term has been added. This means that the negative of the bias admittance Y_b is effectively in parallel with the admittance of the standard Y_s. The two limitations of the circuit in Figure 2A are now circumvented, and the requirement for an infinite resistance standard no longer exists. When Z_L is zero, it is only necessary that Y_s and Y_b be equal. Neither is required to be zero. It is not necessary to have a variable inductor for capacitive loads. The variable capacitor standard can be switched from terminal C to terminal A. Equation 7 shows that this has the effect of reversing the sign of the susceptance of this standard.

3.2 Circuit Description

Figure 3 is the schematic diagram for the bridge measuring circuit. The Coupler Box consists of a heavy rod suspended directly between the IN and OUT connector. This center conductor along with the shielding box forms the primary line and has a characteristic impedance of approximately 150 ohms. The secondary line is formed by a small rod mounted from the cover of the shielding box by three shielded teflon feed-through terminals, these terminals are the A, B, and C points shown in Figure 2B. The shielding box should never be opened in the field since this will affect the primary calibration of the bridge.

The components in the Standards Circuit are selected for both their RF characteristics and long term stability. The variable R dial resistor (R1) is a special precision, low noise, ceramet potentiometer. The resistance adder resistor (R4 and R5) are high stability metal film units of values individually selected to calibrate each bridge.

The Meter Circuit is a straight forward R.F. detector circuit using an "L" matching section for increased sensitivity in the TUNE position.



STANDARDS CIRCUIT

METER CIRCUIT

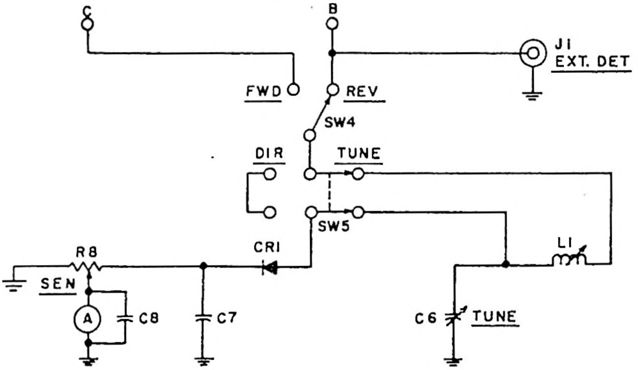


FIGURE 3

SCHEMATIC DIAGRAM

IV. MAINTENANCE

Due to the complexity of the RF distributed circuit and the interaction of all controls it is recommended that field maintenance not be attempted on this unit. If the unit is damaged or ceases to function, it should be returned to the factory for maintenance and calibration.

Note: A precision ceramet potentiometer is used as a variable standard resistance in this bridge. A relatively high contact resistance is a characteristic of precision potentiometers. For this reason, the user may notice an apparent "noise" when obtaining a deep null with an external detector. This is normal and does not affect the rated accuracy of the instrument.

DO NOT attempt to break the seal on the potentiometer for cleaning purposes.

APPENDIX I.

Because of a light interaction between the resistance and reactance measuring components, a correction must be made to the resistance measurement of a high Q circuit (low resistance and high reactance). The correction factor C_R can be computed from the following equation:

$$C_R = xf\ (.009 - .00014R)$$

Where: X is dial reactance before frequency correction.

Bridge Dial Readings

Example: 10 -j100 at 680 kc (.68 mc)

$$C_R = -100f\ [.009 - .00014\ (10)]$$
$$= -100f\ [.009 - .0014]$$
$$= -100f\ [.0076] = -.76\ f$$

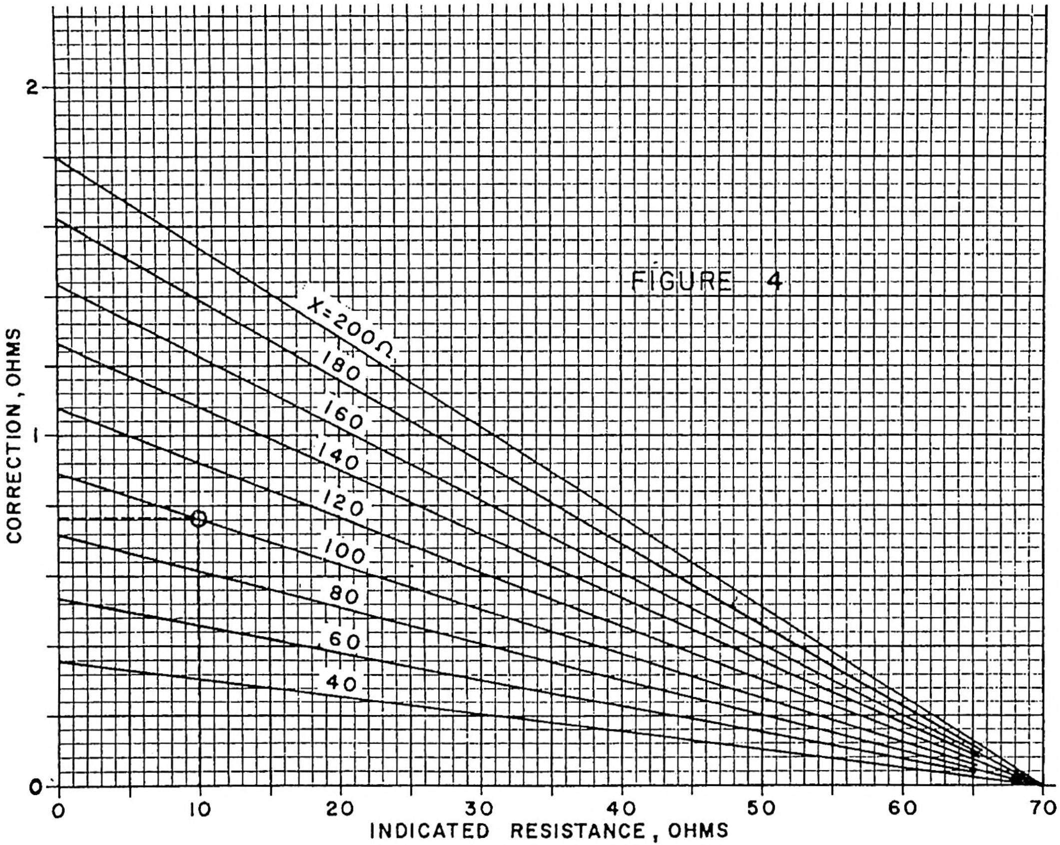
Correcting for frequency

$$-.76\ (.68) = -.52$$

True Resistance: 10 -.52 = 9.48

Note that the correction is negative for capacitor loads and positive for inductor loads.

The correction equation has been plotted in Figure 4. The correction can be read directly from this figure. The example above is illustrated by the dotted lines on the graph. The correction read from the graph must be multiplied by the frequency in mc. These corrections are usually not significant for resistances above about 50 ohms.



CORRECTION FACTOR