OPERATING INSTRUCTIONS

TYPE 1603-A

Z-Y BRIDGE

1603-A

1603-A

GENERAL RADIO COMPANY

G

Type 1603-A
Z-Y BRIDGE

Serial No.____________

F

GENERAL RADIO COMPANY
West Concord, Massachusetts U.S.A. 01781
Form 1603-0100-F
August, 1968
ID-0100

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SPECIFICATIONS

RANGES OF MEASUREMENT

Frequency: 20 Hz to 20 kHz.

Impedance and Admittance: $-\infty$ to $+\infty$.

Unknown is measured as an impedance if the resistance is less than 1000 Ω and the reactance is less than 1000 (f_o/f)Ω.

Unknown is measured as an admittance if the absolute conductance is less than 1000 μ℧ and the absolute susceptance is less than 1000 (f/f_o)μ℧.

ACCURACY (with unknown grounded)

R: ±1% ± (2 Ω on main dial or 0.2 Ω on ΔR dial) ±0.0002 $f_{kHz}X$.

G: ±1% ± (2 μ℧ on main G dial or 0.2 μ℧ on ΔG dial) ±0.0002$f_{kHz}B$.

X: ±1% ± ($2f_o/f$ Ω on main X dial or $0.2f_o/f$ Ω on ΔX dial) ±0.0002$f_{kHz}R$.

B: ±1% ± ($2f/f_o$ μ℧ on main B dial or $0.2f/f_o$ μ℧ on ΔB dial) ±0.0002$f_{kHz}G$.

These expressions are valid for R and G up to 20 kHz; for X and B the 1% term is valid up to 7 kHz; above 7 kHz it becomes 2%, above 15 kHz, 3%. Slightly larger errors occur at high frequencies for direct or delta measurements.

GENERAL

Accessories Supplied: 274-NP Patch Cord, 874-R34 Patch Cord.

Accessories Required: Generator and Detector. 1240-A Bridge Oscillator-Detector recommended.

Generator: 1311-A Oscillator recommended or 1210-C or 1310-A. Max safe voltage on bridge is 130 V rms, giving <32 V on unknown.

Detector: 1232-A recommended.

Mounting: Lab-Bench Cabinet.

Dimensions (width x height x depth): 12½ x 13½ x 8½ in. (320 x 345 x 220 mm).

Weight: Net, 21½ lb (10 kg), shipping, 31 lb (14.5 kg).

Catalog Number	Description
1603-9701	**1603-A Z-Y Bridge**

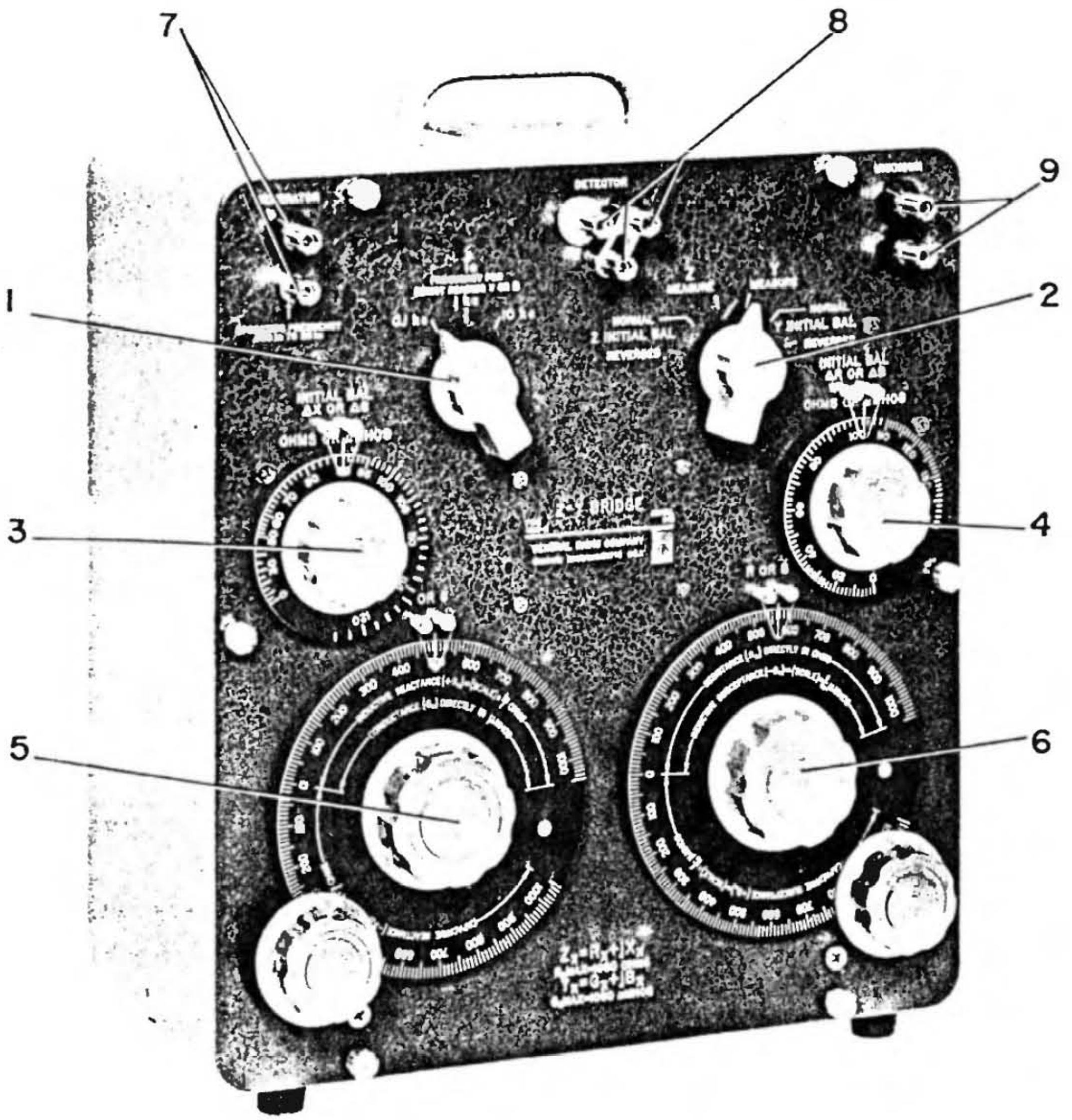


Figure 1-1. Panel view of the Type 1603-A Z-Y Bridge.
(For legend, see page 2).

SECTION **1**

INTRODUCTION

1.1 PURPOSE.

The Type 1603-A Z-Y Bridge (Figure 1-1) is an audio-frequency bridge that can measure any impedance connected to its terminals. From short circuit to open circuit, real or imaginary, positive or negative, a bridge balance can easily be obtained. Good accuracy is obtainable over a very wide range.

The Z-Y Bridge measures the Cartesian coordinates of complex impedance in ohms (series resistance and reactance, each carrying the same current; see Figure 1-2) or the Cartesian coordinates of complex admittance in micromhos (parallel conductance and susceptance subjected to the full terminal voltage; see Figure 1-3).

1.2 DESCRIPTION.

1.2.1 GENERAL. The Type 1603-A Z-Y Bridge uses a conventional resistance-capacitance bridge circuit (see Figure 1-4) and operates in the frequency range from 20 cps to 20 kc. A calibrated oscillator or suitable generator (such as the Type 1210-C Unit RC Oscillator) is required to drive the bridge and a null-balance detector (such as the Type 1232-A Tuned Amplifier and Null Detector) is required to indicate bridge balance. A Type 274-NP Patch Cord and a Type 874-R34 Patch Cord are supplied to connect the bridge to the generator and detector.

1.2.2 SYMBOLS AND ABBREVIATIONS. The following symbols and abbreviations are used in this instruction book:

ac - alternating-current

B - susceptance, imaginary part of an admittance

C - capacitance

cps - cycles per second

D - dissipation factor, $D = \frac{1}{Q} = \frac{R}{X} = \frac{G}{B}$

dc - direct-current

emf - electromotive force

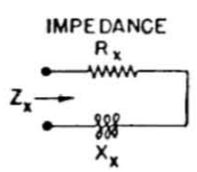


Figure 1-2.
Resistance R_x in series with inductive (positive) or capacitive (negative) reactance X_x.
Z_x *(ohms)* $= R_x + jX_x$

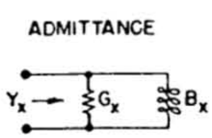


Figure 1-3.
Conductance G_x in parallel with inductive (negative) or capacitive (positive) susceptance B_x.
Y_x *(μmbos)* $= G_x + jB_x$

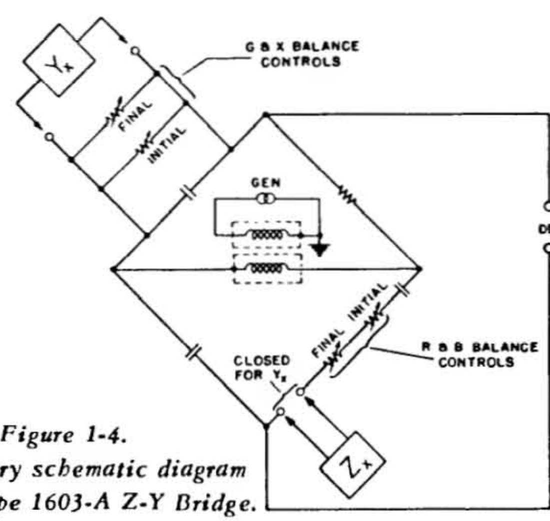


Figure 1-4.
Elementary schematic diagram of the Type 1603-A Z-Y Bridge.

f - frequency

G - conductance, $G = \frac{1}{R}$ (only if X = 0)

I - current

j - imaginary operator, $j^2 = -1$

K, k_1 k_2 - bridge constants

kc - kilocycles per second

kΩ - kilohms

L - inductance

M - correction factor

pf - picofarad, 1 pf = 1×10^{-6} μf = 1 μμf

PF - power factor, $PF = \frac{R^2}{R^2 + X^2} = \frac{G^2}{G^2 + B^2}$

Q - storage factor, $Q = \frac{1}{D} = \frac{X}{R} = \frac{B}{G}$

R - resistance, $R = \frac{1}{G}$ (only if B = 0)

r - resistance

X - reactance, imaginary part of an impedance

Y - admittance, Y = G + jB

Z - impedance, Z = R + jX

δ - change in

Δ - initial balance

θ - phase angle

μf - microfarad, 1 μf = 1×10^{-6} f

μh - microhenry, 1 μh = 1×10^{-6} h

μmho, μ℧ - micromho, 1 μ℧ = 1×10^{-6} ℧

π - 3.1416

Ω - ohm

ω - angular frequency, ω = 2πf

1.2.3 CONTROLS AND CONNECTORS. The following table lists the controls and connectors on the Type 1603-A Z-Y Bridge:

TABLE 1. CONTROLS AND CONNECTORS

Fig. 1-1 Ref No.	Name	Type	Function
1	f_o	3-position rotary switch	Changes the values of fixed bridge components by factors of ten to permit measurement at any audio frequency.
2	Measurement	6-position rotary switch	Selects conditions for initial Z or Y measurement, final Z or Y measurement, and normal or reversed measurement.
3	*INITIAL BAL ΔX OR ΔG*	Continuous rotary control with dial	For normal substitution measurements, sets initial balance of X or G component.
4	*INITIAL BAL ΔR OR ΔB*	Continuous rotary control with dial	For normal substitution measurements, sets initial balance for R or B component.
5	*X OR G*	Continuous rotary control with dial and vernier	For normal substitution measurement, sets final balance for X or G component.
6	*R OR B*	Continuous rotary control with dial and vernier	For normal substitution measurement, sets final balance for R or B component.
7	*GENERATOR*	Pair of binding posts	Connection for external generator.
8	*DETECTOR*	Three binding posts	Connection for external null detector.
9	*UNKNOWN*	Pair of binding posts	Connection for component to be measured.

SECTION **2**

OPERATING PROCEDURE

2.1 GENERATOR CONNECTION.

Use an ac generator of known operating frequency between 20 cps and 20 kc. The General Radio Type 1210-C Unit RC Oscillator is a recommended source. To make the bridge direct reading, the generator frequency must be 100 cps, 1 kc, or 10 kc, and the f_0 switch set to the same value.

The maximum voltage that may be applied to the bridge is 130 volts rms with the f_0 switch at 10 kc or 1.0 kc. With the f_0 switch at 0.1 kc, the maximum voltage depends on the generator frequency, as shown in Figure 2-1. Since this switch can be set to 10 kc or 1.0 kc for the frequencies above 450 cps, 130 volts is the usual maximum voltage. A 60-cycle power line may be used for 60-cycle measurements, provided that a 1:1 isolation transformer is interposed between the line and the bridge. The setting of the f_0 switch is explained in paragraph 2.5.

Connect the generator to the *GENERATOR* terminals of the Type 1603-A, with the low side connected to the terminal that is grounded to the bridge panel.

2.2 DETECTOR CONNECTION.

Connect the black insulated *DETECTOR* terminal to the grounded terminal, using the connecting link, to measure the unknown as a grounded impedance or admittance (the usual type of measurement; for measurement of ungrounded components, refer to paragraph 5.5).

Connect a General Radio Type 1232-A Tuned Amplifier and Null Detector, Type 1212-A Unit Null Detector, or other suitable null-balance detector across the red and black *DETECTOR* terminals, with the high input of the detector connected to the red terminal. Unless the detector is logarithmic in response, it should contain some means for monitoring its sensitivity. In the measurement of nonlinear elements, such as iron-cored inductors, a tuned selective detector is preferable.

2.3 CONNECTION OF THE UNKNOWN.

Connect the unknown circuit element or network to the *UNKNOWN* terminals on the bridge panel. Connect the end of the unknown that is grounded, or that has the higher capacitance to ground, to the *LOW* unknown terminal. Leave the unknown thus connected while the desired measurements are made.

2.4 DECIDING WHETHER TO MEASURE Z OR Y.

2.4.1 GENERAL. The unknown can sometimes be measured as either an impedance, Z_x, or an admittance, Y_x, but in most instances, it can be measured only as one or the other.

If the approximate value of the component to be measured is known, use Figures 2-2 and 2-3 to determine which type of measurement should be made. Figure 2-2 shows the limits of impedance measurement and Figure

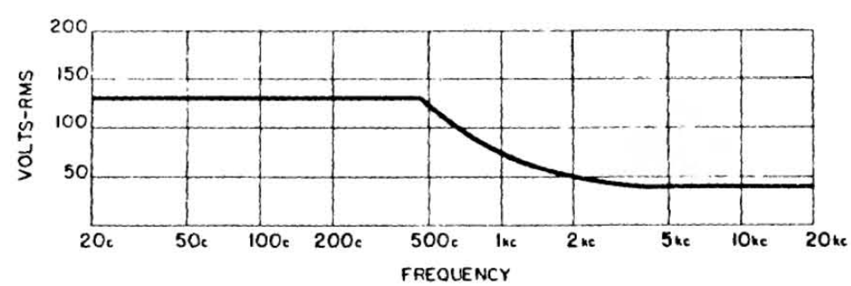


Figure 2-1. Maximum voltage that may be applied to the Z-Y Bridge with the f_0 switch set at 0.1 kc.

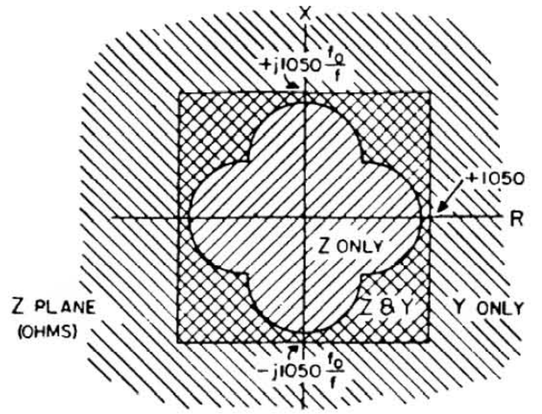


Figure 2-2. Impedance-measurement limits of the Type 1603-A Z-Y Bridge.

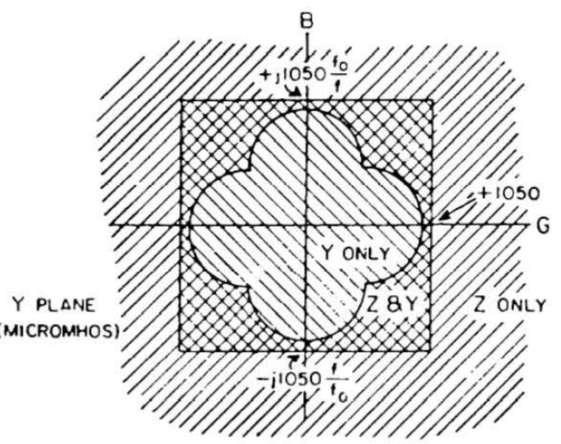


Figure 2-3. Admittance-measurement limits of the Type 1603-A Z-Y Bridge.

2-3 shows the limits of admittance measurements. Note that the imaginary scale for these plots is a function of either $\frac{f}{f_o}$ or $\frac{f_o}{f}$. The range for the imaginary part can therefore be extended by appropriate choice of f_o (refer to paragraph 2.5).

If the approximate value of the component to be measured is not known, make a trial balance as outlined in paragraph 2.4.2, 2.4.3, or 2.4.4 to determine whether the unknown should be measured as an impedance or an admittance.

The components of Y_x (in μmhos) can be computed from the components of Z_x (in ohms) and vice versa by means of the construction described in Appendix 1 or by the transfer equations in Appendix 2.

2.4.2 CAN THE UNKNOWN BE MEASURED AS AN IMPEDANCE? To find out, connect the generator, detector, and unknown to the bridge, set the f_o switch to the nearest frequency above the generator frequency, set the measurement switch to *NORMAL Z INITIAL BAL*, and adjust both Δ controls for balance. Then set the measurement switch to *Z MEASURE* and adjust the main controls for balance. If balance occurs within the ranges of both main dials, the unknown can be measured as an impedance. If the balance is offscale on either dial, the unknown must be measured as an admittance.

2.4.3 CAN THE UNKNOWN BE MEASURED AS AN ADMITTANCE? To find out, connect the generator, detector and unknown to the bridge, set the f_o switch to the nearest frequency below the generator frequency, set the measurement switch to *NORMAL Y INITIAL BAL*, and adjust both Δ controls for balance. Then set the the measurement switch to *Y MEASURE* and adjust the main controls for balance. If the final balance occurs within the ranges of both main dials, the unknown can be measured as an admittance. If the balance is offscale on either main dial, the unknown must be measured as an impedance.

2.4.4 MEASUREMENT AS EITHER IMPEDANCE OR ADMITTANCE. If, in the tests described in paragraphs 2.4.2 and 2.4.3, the main dials are on scale in both cases, the operator has a choice of measuring the given unknown as an impedance or as an admittance. See Figures 2-2 and 2-3.

> NOTE
>
> For any specific measurement, the measurement switch must be used either exclusively in its three left-hand positions (Z_x measurement) or exclusively in its three right-hand positions (Y_x measurement). For example, never follow an initial Z balance with a final Y balance.

2.5 SETTING THE f_o SWITCH.

When the operating frequency is 100 cps, 1 kc, or 10 kc, set the f_o switch to the same frequency for direct-reading measurements. For other operating frequencies, set the f_o switch to the nearest frequency above the generator frequency for impedance measurements and to the nearest frequency below the generator frequency for admittance measurements. The ratio of $\frac{f_o}{f}$ should be between 0.1 and 10.

For maximum precision, first make a trial balance with the f_o switch set as specified in the preceding paragraph. For an impedance measurement, if the final X_x balance is offscale on either end, set the f_o switch to the next higher frequency; or if the final X_x balance is onscale but less than 105 ohms, set the f_o switch to the next lower value. For an admittance measurement, if the final B_x balance is offscale on either end, set the f_o switch to the next lower value; or if the final B_x balance is onscale but less than 105 μmhos set the f_o switch to the next higher value.

If the generator frequency is not the same as the f_o switch setting, multiply the X_x indication in impedance measurements by $\frac{f_o}{f}$, and multiply the B_x indication in admittance measurements by $\frac{f}{f_o}$.

2.6 NORMAL MEASUREMENT PROCEDURE.

To measure an unknown under normal conditions, proceed as follows:

a. Connect the generator, detector, and unknown to the appropriate terminals on the bridge.

b. Decide whether to measure impedance or admittance (refer to paragraph 2.4).

c. Set the f_o switch to the measurement frequency (refer to paragraph 2.5).

d. Set the measurement switch to *NORMAL Z INITIAL BAL* for impedance measurement or to *NORMAL Y INITIAL BAL* for admittance measurement.

e. With the Δ controls, balance the bridge to obtain a null indication on the detector.

f. Set the measurement switch to *Z MEASURE* for impedance or to *Y MEASURE* for admittance.

g. Balance the bridge with the main controls.

h. If the f_o switch setting is the same as the generator frequency, the impedance or admittance value of the unknown is the value indicated on the main dials. If the generator frequency is not the same as the f_o switch setting, multiply the imaginary component (X or B) by $\frac{f_o}{f}$ for impedance or $\frac{f}{f_o}$ for admittance.

For example, if:

generator frequency = 2 kc
f_o switch setting = 10 kc
measurement - Z
final balance readings, R = 400
X = −200

then Z_x = 400 -j1000 ohms.

2.7 REVERSED OPERATION.

2.7.1 PRINCIPLES OF REVERSED OPERATION. The primary use of reversed operation is to take advantage of the expanded scales on the Δ controls by using the main controls for initial balance and the Δ controls for final balance. Actually, the four controls may be used in any desired combination to produce a balance. Computing the results would be quite cumbersome, however, if more than one of the *X OR G* controls, or more than one of the *R OR B* controls were used for the final balance.

Reversed operation yields more precise data than does normal operation when:

(1) In normal impedance measurement with the f_o switch set to 0.1 kc, the *X OR G* dial reads less than 120.

(2) In normal admittance measurement with the f_o switch set to 10 kc, the *R OR B* dial reads less than 140.

(3) In normal measurements, an initial balance cannot be obtained with the Δ controls.

(4) Increased accuracy is desired for measurements between 10 and 20 kc.

(5) Measurements are desired between 20 and 30 kc.

2.7.2 REVERSED OPERATION PROCEDURE. For reversed operation, connect the generator, detector, and unknown to the appropriate bridge terminals, decide whether to measure impedance or admittance (refer to paragraph 2.4), set the f_o switch to the measurement frequency (refer to paragraph 2.5), and then measure the unknown in accordance with Figure 2-4 and Table 2.

TABLE 2. PROCEDURE FOR REVERSED OPERATION

Use for (Fig. 2-4 Ref)	Prebalance and do not disturb	Preset	Set measurement switch to	Make initial balance with(*)	Record	Set measurement switch to	Make final balance with	Results(**)
inductive Z_x inductive Y_x Both components small. (1)		ΔX *OR* ΔG and ΔR *OR* ΔB near top scale	*Z (OR Y) MEASURE*	*X OR G* and *R OR B*	ΔX *OR* ΔG and ΔR *OR* ΔB	*Z (OR Y) INITIAL BAL REVERSED*	ΔX *OR* ΔG and ΔR *OR* ΔB	Difference between final and initial ΔX *OR* ΔG and ΔR *OR* ΔB readings, with signs reversed.
capacitive Z_x Both components small. (2)	*R OR B*	ΔX *OR* ΔG near top scale	*Z INITIAL BAL REVERSED*	*X OR G* and ΔR OR ΔB	ΔX *OR* ΔG and ΔR *OR* ΔB	*Z MEASURE*	ΔX *OR* ΔG and ΔR *OR* ΔB	Difference between final and initial ΔX *OR* ΔG and ΔR *OR* ΔB.
capacitive Y_x Both components small. (3)	*X OR G*	ΔR *OR* ΔB near top scale	*Y INITIAL BAL REVERSED*	ΔX *OR* ΔG and *R OR B*	ΔX *OR* ΔG and ΔR *OR* ΔB	*Y MEASURE*	ΔX *OR* ΔG and ΔR *OR* ΔB	Difference between final and initial ΔX *OR* ΔG and ΔR *OR* ΔB
Z_x with small *R* and large *X*. Y_x with small *B* and large *G*. (4)		*X OR G* at center scale (zero)	*Z (OR Y) INITIAL BAL REVERSED*	ΔX *OR* ΔG and *R OR B*	*X OR G* and ΔR *OR* ΔB	*Z (OR Y) MEASURE*	*X OR G* and ΔR *OR* ΔB	Difference between final and initial *X OR G* and ΔR *OR* ΔB
Z_x with small *X* and large *R*. Y_x with small *G* and large *B*. (5)		*R OR B* at center scale (zero)	*Z (OR Y) INITIAL BAL REVERSED*	*X OR G* and ΔR *OR* ΔB	ΔX *OR* ΔG and *R OR B*	*Z (OR Y) MEASURE*	ΔX *OR* ΔG and *R OR B*	Difference between final and initial ΔX *OR* ΔG and *R OR B*
High-frequency measurements (6)		*X OR G* and *R OR B* at center scale (zero)	*Z (OR Y) INITIAL BAL REVERSED*	ΔX *OR* ΔG and ΔR *OR* ΔB		*Z (OR Y) MEASURE*	*X OR G* and *R OR B*	Final *X OR G* and *R OR B*

(*) Make the initial balance primarily with the two controls listed in this column. The other two controls may be adjusted for balance unless otherwise noted by an entry in column 2.

(**) Multiply the imaginary component, *X OR B*, by $\frac{f_o}{f}$ for impedance measurements, or by $\frac{f}{f_o}$ for admittance measurements.

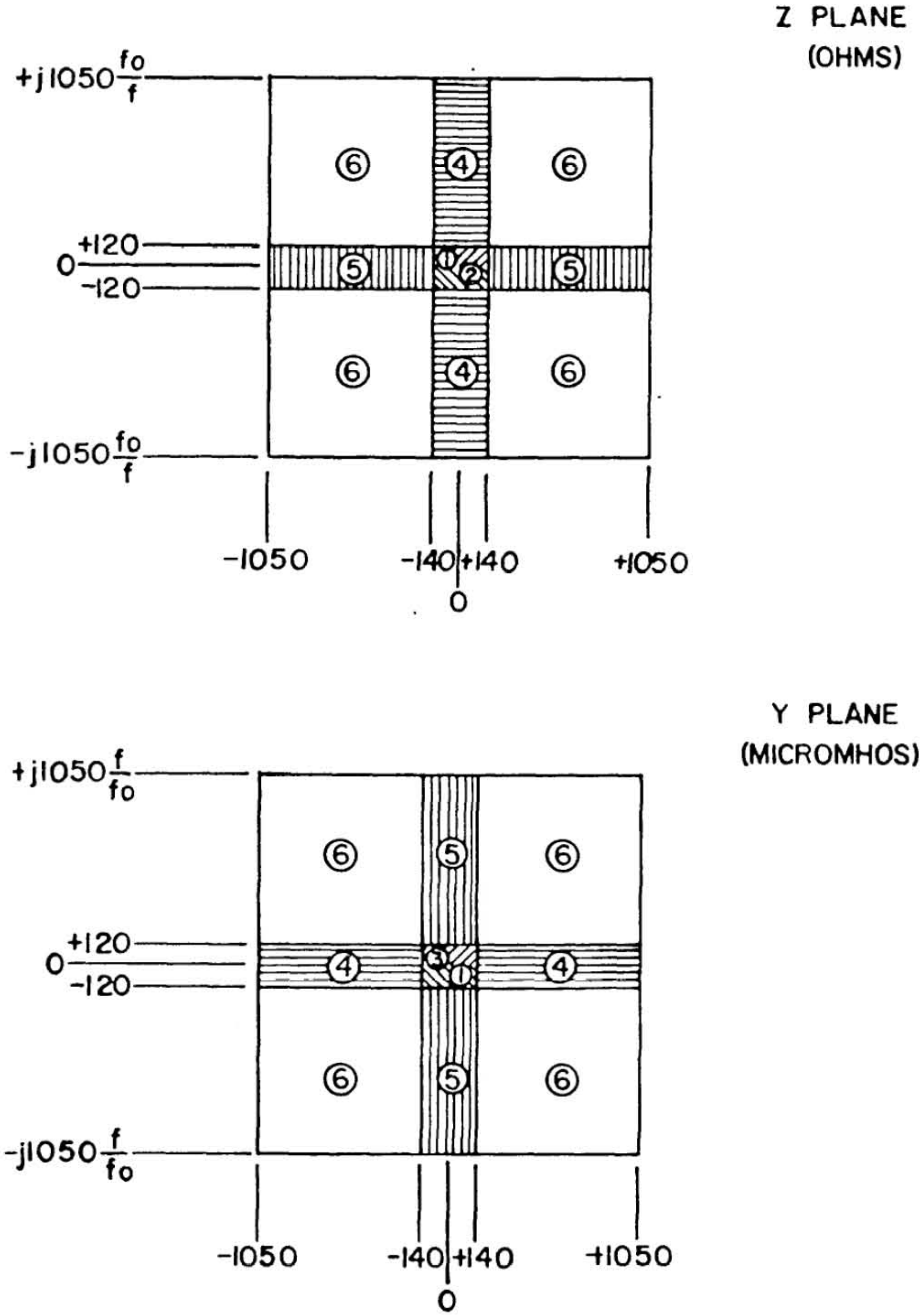


Figure 2-4. Ranges for reversed-operation measurement of impedance (above) and admittance (below). Measurement procedures are given in Table 2.

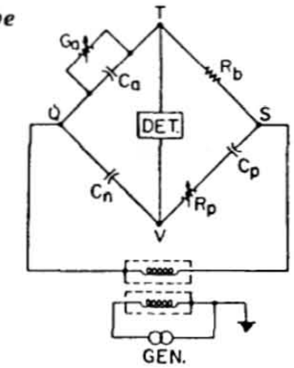
SECTION **3**

PRINCIPLES OF OPERATION

3.1 GENERAL.

The basic circuit of the Type 1603-A Z-Y Bridge is shown in Figure 3-1. The B arm is a fixed resistor R_b and the N arm is a fixed capacitor C_n. As with any impedance bridge, two separate controls must be adjusted for a complete null balance. These are (1) a rheostat, in parallel with fixed capacitor C_a, that varies the conductance G_a of the A arm, and (2) a rheostat, in series with fixed capacitor C_p, that varies the resistance R_p of the P arm.

Figure 3-1. Basic circuit of the Type 1603-A Z-Y Bridge.



An external sinusoidal ac generator is connected to the bridge across Q-S through an internal double-shielded isolation transformer having a 4-to-1 step-down turns ratio. An external null-balance detector is connected to the bridge across T-V.

The Z-Y Bridge employs a substitution technique: an initial balance, without the unknown element, is followed by a final balance with the unknown in the circuit. The difference in the points of balance indicates the complex components of the unknown. This procedure avoids some of the residual-impedance errors ordinarily encountered in bridge circuits as well as certain calibration errors of the bridge components.

For impedance measurement, the unknown is inserted, by switching, in series into the P arm of the bridge (between R_p and V). For admittance measurement, the unknown is connected in parallel across the A arm (between Q and T).

On the left-hand side of the panel, the *X OR G* control and the *ΔX OR ΔG* control are in parallel and vary the conductance G_a of the A arm. On the right-hand side of the panel, the *R OR B* control and the *ΔR OR ΔB* control are in series and vary the resistance R_p of the P arm. The dials on these controls in no way indicate the actual values of G_a and R_p, but indicate the change in μmhos, δG_a, and the change in ohms, δR_p, between the initial and final balances.

The two main dials have identical zero-centered and linear scales extending to 1050 units in each direction. The *ΔX OR ΔG* and *ΔR OR ΔB* dials have full-scale ranges of 120 and 140 units respectively and are purposely made nonlinear. Each Δ dial is calibrated in the same units, and functions in the same rotational sense as its companion main dial.

A six-position switch in the upper right-hand part of the panel disconnects the high unknown terminal for all initial balances and inserts the unknown into the A or the P arm of the bridge for the final balance, depending on whether impedance or admittance is to be measured. The low terminal of the unknown remains directly connected at all times, either to the bridge vertex T for the three admittance positions or to the vertex V for the three impedance positions. For both admittance and impedance measurements there are two alternative initial-balance positions (designated as *NORMAL* and *REVERSED*; refer to paragraphs 2.6 and 2.7), and a single position (designated as *MEASURE*) for the final balance.

NOTE

For any specific measurement, this switch must be used either exclusively in its three left-hand positions (impedance measurement) or exclusively in its three right-hand positions (admittance measurement). For example, never follow an initial impedance balance with a final admittance balance.

3.2 COMPONENTS MEASURED.

The customary types of impedance bridges (Maxwell, Hay, Schering, etc) usually have limited maximum and minimum ranges and evaluate, more or less directly, the inductance or capacitance of the unknown circuit element together with its resistance, its Q, or its dissipation factor D. Determination of the reactance or susceptance values of the unknown requires computation in terms of the angular frequency ω.

For many applications, the parameters of prime importance are the Cartesian coordinates of the complex impedance, series resistance and reactance, or the Cartesian coordinates of the complex admittance, conductance and susceptance. The Z-Y Bridge measures these Cartesian coordinates over an extended audio-frequency range, nominally from 20 cps to 20 kc. The unknown may lie in any of the four quadrants of the complex plane, since this bridge can measure both positive and negative values of R_x and G_x as well as X_x and B_x, which individually can have any magnitude from zero to infinity. In this sense, it is a truly universal bridge.

The basic equations for the resistance R_x and the conductance G_x of the unknown are:

$$R_x \text{ (in ohms)} = \delta R_p \text{ (in ohms)} \qquad (1)$$

$$G_x \text{ (in } \mu\text{mhos)} = \delta G_a \text{ (in } \mu\text{mhos)} \qquad (2)$$

These equations hold for any value of the operating frequency f. Positive values of R_x and G_x are indicated by a counterclockwise displacement of the corresponding control dial for the final balance (decrease of R_p or G_a). Clockwise displacement indicates negative R_x or G_x.

When the unknown is measured as an impedance, the basic equation for its reactance, in terms of the selected f_o is:

$$X_x \text{ (in ohms)} = \left(\frac{f_o}{f}\right) \delta G_a \text{ (in } \mu\text{mhos)} \qquad (3)$$

A positive (inductive) reactance is indicated by a counterclockwise rotation of the corresponding control dial for the final balance (decrease of G_a). A negative (capacitive) reactance is indicated by a clockwise rotation of the corresponding control dial for the final balance (increase of G_a).

When the unknown is measured as an admittance, the basic equation for its susceptance, in terms of the selected f_o, is:

$$B_x \text{ (in } \mu\text{mhos)} = \left(\frac{f}{f_o}\right) \delta R_p \text{ (in ohms)} \qquad (4)$$

A positive (capacitive) susceptance is indicated by a clockwise rotation of the corresponding control for the final balance (increase of R_p). A negative (inductive) susceptance is indicated by a counterclockwise rotation of the corresponding control for the final balance (decrease of R_p).

Equations 3 and 4 can be transposed to read:

$$\delta G_a = \left(\frac{f}{f_o}\right) X_x = \frac{2\pi f^2 L_x}{f_o} = \frac{1}{2\pi f_o C_x} \qquad (3A)$$

$$\delta R_p = \left(\frac{f_o}{f}\right) B_x = \frac{f_o}{2\pi f^2 L_{xp}} = 2\pi f_o C_{xp} \qquad (4A)$$

These equations show that when an inductive unknown is measured as an impedance (equation 3A) or as an admittance (equation 4A), the value of δG_a or δR_p (and the corresponding final-balance scale reading) will be directly or inversely proportional to f^2. Accordingly, with an inductive unknown, the generator frequency must be known accurately if correct values of X_x or B_x are to be obtained.

Conversely, when a capacitive unknown is measured, the value of G_a or R_p is independent of f, provided that C_x and C_{xp} are independent of f, and we need not know the generator frequency exactly to obtain an accurate X_x or B_x measurement.

Equations 3A and 4A can be used to obtain the series parameters L_x and C_x or the parallel parameters L_{xp} and C_{xp} of the unknown.

3.3 BRIDGE CIRCUITS.

The bridge networks for normal operation are shown in Figures 3-2, 3-3, and 3-4, in which the resistive elements are designated by the symbols used in the schematic diagram:

R1 is the *ΔR OR ΔB* control.

R2 is the *R OR B* control.

R4 is the *ΔX OR ΔG* control and is in series with the fixed resistor R7.

R5 is the *X OR G* control and is in series with the fixed resistor R8.

The value of R_p (Figure 3-1) is thus the sum of R1 and either R2 or R3, while the value of G_a is the over-all conductance of the four-resistor network (R4, R6, R7, R8) in the A arm.

For impedance measurements, the vertex V is grounded, and for admittance measurements the vertex T is grounded.

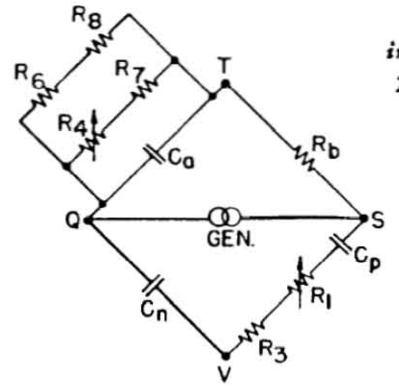


Figure 3-2. Normal initial balance for either Z_x or Y_x measurement.

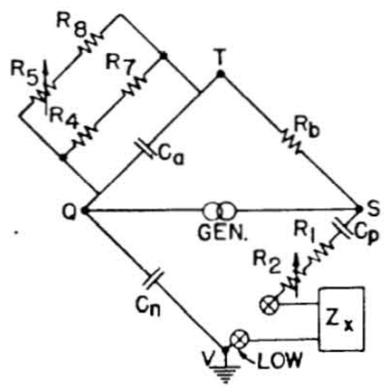


Figure 3-3. Normal final balance for Z_x measurement.

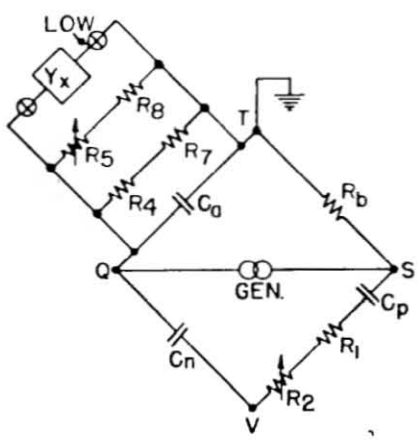


Figure 3-4. Normal final balance for Y_x measurement.

Theoretically, the initial balance values of G_a and R_p should be independent of the operating frequency and the position of the f_o switch. Nevertheless, the initial balance will shift and a new setting is required whenever a change is made in any of the following:

(1) the operating frequency, f

(2) the position of the f_o switch

(3) a shift from impedance to admittance measurement, or vice versa

(4) a change from normal to reversed operation, or vice versa.

This initial-balance shift, which has no appreciable effect upon the final data, is caused by the action of some frequency-sensitive residual impedance and by the fact that the fixed bridge parameters cannot economically be made to have their exact theoretical values. A change made solely in the parameters of the unknown does not require a new initial balance.

Initial balance is made with the two Δ controls and final balance is made with the two main controls. Hence, in accordance with the legend given on the main dials, their scales read directly (without subtraction) the values of δG_a and δR_p to be substituted into equations (1) through (4).

For normal initial balance (Figure 3-2), the measurement switch removes the two main-control rheostats (R2 and R5) from the bridge circuit and replaces them with two fixed resistors (R3 and R6), which have the center-scale resistance values of R2 and R5, respectively. Hence, the main dials may remain in any arbitrary position for the initial balance. This feature is a decided convenience, especially when the unknown is measured at different frequencies to determine its frequency characteristic.

Figures 3-3 and 3-4 are the circuits for the impedance and admittance final balances in normal operation. All four controls are now in circuit, but the final balance is made solely with the two main controls (R2 and R5).

Normal operation is the quickest and most foolproof method of determining whether, at the given operating frequency, the unknown is inductive or capacitive and whether its R_x and G_x are positive or negative.

3.4 REVERSED OPERATION.

The conditions under which reversed operation will yield more reliable and precise data than normal operation are:

(1) When the adjustment ranges of the Δ controls will not permit an initial balance in normal operation.

(2) When R_x is less than 140 ohms or G_x is less than 120 μmhos.

(3) When, in a normal impedance measurement with the f_o switch set to 0.1 kc, the *X OR G* dial reading is less than 120 units.

(4) When, in a normal admittance measurement with the f_o switch set to 10 kc, the *R OR B* dial reading is less than 140 units.

(5) For measurements between 10 and 20 kc, somewhat more accurate data can be obtained with re-

versed operation due to the action of certain bridge residuals (refer to Section 4).

(6) Reversed operation permits this bridge to be used, with decreasing accuracy, up to 30 kc. Use above 30 kc is not recommended.

In the reversed initial balance for either impedance or admittance measurement, all four controls are in circuit and may be used in any desired combination to produce balance (see Figure 3-5).

In the reversed final balance for either impedance or admittance measurement, all four controls are still in circuit. Theoretically, any desired combination of these controls might be used to establish final balance. Hence, the values of G_a and R_p for equations (1) through (4) might be computed from the combined displacements of these dials between their initial and final setting. Such a procedure is cumbersome, however, and is not recommended.

The practical method is to use only one of the *X OR G* controls and only one of the *R OR B* controls for the final balance. The δG_a and δR_p values are then the differences between the initial and final scale readings of these two dials. No cognizance is taken of the scale reading of the two controls which are not manipulated in making the final balance.

Reversed final balance can be made with:

a. Both main controls.

b. One main control and the Δ control on the opposite side of the bridge panel.

c. Both Δ controls.

Procedure for reversed operation is outlined in paragraph 2.7. Refer to Section 4 for residual corrections to δG_a, which may be significant in certain cases.

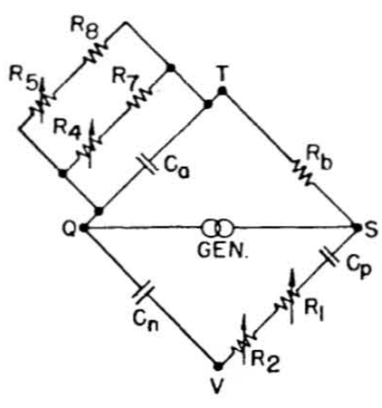


Figure 3-5. Reversed initial balance for either Z_x or Y_x measurement.

3.5 BALANCE EQUATIONS.

With reference to Figure 3-1, this section develops the working equations (1) through (4) under the assumption that no residual impedances exist in the bridge network.

Let G_{a1} and R_{p1} be the initial-balance values of these parameters. Then the complex equation for the initial balance is:

$$R_{p1} - \frac{j}{\omega C_p} = -\frac{jR_b}{\omega C_n}(G_{a1} + j\omega C_a) \qquad (5)$$

From equation (5) we obtain the two (scalar) initial-balance equations:

$$R_{p1}C_n = R_bC_a \qquad (6)$$

$$C_n = R_bC_pG_{a1} \qquad (7)$$

Note that both equations (6) and (7) are independent of frequency and that the initial balance will have no sliding zero since neither control parameter occurs in both equations.

Let G_{a2} and R_{p2} be the final-balance values of these parameters. Then the complex equation for final balance in impedance measurements is:

$$R_{p2} + R_x + j\left(X_x - \frac{1}{\omega C_p}\right) = \frac{-jR_b}{\omega C_n}(G_{a2} + j\omega C_a) \qquad (8)$$

Equation (8) yields the two (scalar) impedance-measurement final-balance equations:

$$C_n(R_{p2} + R_x) = R_bC_a \qquad (9)$$

$$C_n(1 - \omega C_pX_x) = R_bC_pG_{a2} \qquad (10)$$

which again show no sliding zero. Note, however, that equation (10) is a function of ω^2 if X_x is inductive, but is independent of ω if X_x is capacitive (refer to paragraph 3.2).

Let G_{a3} and R_{p3} be the final-balance values of these parameters for admittance measurement. Then the complex equation for final balance is:

$$R_{p3} - \frac{j}{\omega C_p} = \frac{-jR_b}{\omega C_n}(G_{a3} + G_x + j\omega C_a + jB_x) \qquad (11)$$

Equation (11) yields the two (scalar) admittance-measurement final-balance equations:

$$R_{p3}C_n = R_b\left(C_a + \frac{B_x}{\omega}\right) \quad (12)$$

$$C_n = R_bC_p\,(G_{a3} + G_x) \quad (13)$$

which again show no sliding zero. Note, however, that equation (12) is a function of ω^2 if B_x is inductive, but is independent of ω if B_x is capacitive (refer to paragraph 3.2).

Since a substitution technique is employed with the Type 1603-A Z-Y Bridge, we can combine equations (6) and (9) to obtain our original equation (1) to determine the components of Z_x:

$$R_x = R_{p1} - R_{p2} = \delta R_p$$

which yields a positive R_x if R_{p1} exceeds R_{p2}. Likewise, combining equations (7) and (10), we have:

$$X_x = \frac{R_b}{\omega C_n}\,(G_{a1} - G_{a2}) = K\,(G_{a1} - G_{a2}) \quad (14)$$

where the bridge constant, K, is the product of the scalar impedance values of the B and N bridge arms:

$$K = \frac{R_b}{\omega C_n} \quad (15)$$

Note that X_x will be positive (inductive) if G_{a1} exceeds G_{a2}.

In a like manner, we can combine equations (7) and (13) to obtain our original equation (2) to determine the components of Y_x:

$$G_x = G_{a1} - G_{a3} = \delta G_a$$

in which G_x will be positive if G_{a1} exceeds G_{a3}. Combining equations (6) and (12) gives:

$$B_x = (R_{p3} - R_{p1})\left(\frac{\omega C_n}{R_b}\right) = \frac{R_{p3} - R_{p1}}{K} \quad (16)$$

Note that B_x will be negative (inductive) if R_{p1} exceeds R_{p3}.

3.6 CHOICE OF BRIDGE PARAMETERS.

Note that, in the two types of measurement, the functions of the two balance controls are transposed. In the measurement of impedance, the change in R_p gives directly the real component R_x and the change in G_a determines the imaginary component X_x; while in the measurement of admittance, the change in R_p determines the imaginary component B_x and the change in G_a gives directly the real component G_x.

A given scale on the R_p control can be made direct-reading in both R_x and B_x by the proper choice of the bridge constant, K ($\frac{R_b}{\omega C_n}$). Similarly, the G_a control can be made direct-reading in both G_x and X_x. If these common dial scales are to be calibrated in ohms and micromhos, the required value of K is 10^6. If complete coverage of all possible values of the unknown either as an impedance or as an admittance is desired, the unknown resistance range must be the reciprocal of the unknown conductance range. In the Type 1603-A Z-Y Bridge, when K equals 10^6, identical ranges of 1000 ohms and 1000 μmhos have been chosen for the complex parameters of the unknown, with an overlap of 50 units on each end. Initial balance must then occur at midrange of both main-control scales to permit measurement of positive and negative values of R_x, G_x, X_x, and B_x.

For linear main-dial scale in resistance and susceptance, R_p should be a linear rheostat. To obtain a linear main-dial scale in conductance and reactance, the value G_a is actually the conductance of a fixed resistor in series with a rheostat (the G_a control), which is wound on an appropriately tapered form.

From equation (15) it is seen that the bridge constant, K, is a function of frequency. The f_o switch selects the fixed parameters of the bridge network to keep each of the products R_bC_a and R_bC_p constant and, simultaneously, to give K a value of 10^6 for any one of three convenient reference frequencies: f_o = 100 cps, 1 kc, or 10 kc. When the bridge is operated at the selected reference frequency, we have:

$$X_x \text{ (in ohms)} = 10^6\,\delta G_a \text{ (in } \mu\text{mhos)} \quad (17)$$

$$10^6 B_x \text{ (in } \mu\text{mhos)} = -\delta R_p \text{ (in ohms)} \quad (18)$$

thus giving direct-reading scales in X_x and B_x. When the operating frequency, f, differs from the selected reference frequency, f_o, we can substitute the value:

$$K = 10^6 \frac{f_o}{f} \tag{19}$$

into equations (14) and (16) and obtain the original working equations:

$$X_x \text{(in ohms)} = \frac{f_o}{f} (\delta G_a \text{ in } \mu\text{mhos})$$

$$B_x \text{(in } \mu\text{mhos)} = \frac{-f}{f_o} (\delta R_p \text{ in ohms})$$

The basic component values chosen for this bridge are as follows: Starting with $C_n = 0.1\ \mu f$ and choosing the initial-balance values to be $R_p = 1100\ \Omega$ and $G_a = 2200\ \mu$mhos, then $R_b = 628.3\ f_o$, $C_a = \frac{0.1752}{f_o}$ and $C_p = \frac{0.07238}{f_o}$.

3.7 CONDITIONS FOR BOTH Z_X AND Y_X MEASUREMENT.

For a specific operating frequency and f_o setting, there is a choice between impedance and admittance measurement only over a small range (see Figures 2-2 and 2-3). However, for a specific operating frequency, f, it may be possible to have X_x (f/f_o) less than 1000, permitting a final balance with the *X OR G* control, while for a different f_o setting, it may also be possible to have B_x (f_o/f) less than 1000, permitting a final balance with the *R OR B* control. To have this choice, however, R_x must be less than 1000 ohms and G_x must be less than 1000 μmhos. This condition demands that R_x lies within the limits:

$$\frac{1000}{1 + Q_x^2} < R_x \text{ (in ohms)} < 1000 \tag{20}$$

or, what is the same thing, that G_x lies within the limits:

$$\frac{1000}{1 + Q_x^2} < G_x \text{ (in } \mu\text{mhos)} < 1000 \tag{21}$$

The larger the value of Q_x, the broader will be the range of R_x and G_x values which satisfy equations (20) and (21). It should be understood that, while equations (20) and (21) must be satisfied to have a choice of measurement, they do not, per se, stipulate that a choice is possible.

3.8 UNIVERSALITY OF THE BRIDGE.

In terms of the working equations (1) through (4), we can now demonstrate the universality of the Type 1603-A Z-Y Bridge, having scale range of ±1000 ohms or μmhos, for any given f and any chosen f_o.

A final balance of this bridge can be obtained in terms of impedance if R_x and X_x (f/f_o) are both below 1000 ohms. If either of these quantities exceeds 1000 ohms, an impedance balance is possible. However, if the unknown is connected in parallel in the A arm, a final admittance balance can be obtained, as the following consideration will show. If either component of the complex impedance, $R_x + jX_x(f/f_o)$, exceeds 1000 ohms, the scalar value of this impedance must exceed 1000 ohms. This means that the scalar value of the corresponding complex admittance, as well as each of its components, must be less than 1000 μmhos.

Conversely, and by the same reasoning, if either of the quadrature components G_x or $B_x(f_o/f)$ exceeds 1000 μmhos an admittance balance is impossible whereas an impedance balance can always be made.

Thus, either a final Z_x or a final Y_x balance is always possible, and we have a truly "universal" bridge with an infinite range.

As shown in paragraph 2.5, it may be possible to enhance the precision of an X_x measurement by reducing the original f_o value, or to enhance the precision of a B_x measurement by increasing the original f_o value.

SECTION **4**

EFFECT OF RESIDUAL IMPEDANCES

4.1 GENERAL.

In any impedance bridge, the basic balance equations are modified by the existence of various residual impedances. The final effect of certain residuals that exist unchanged in both initial and final balances, is automatically canceled in the substitution technique used in this Z-Y Bridge. Other residuals may produce a certain amount of sliding zero when unknowns with low-Q values are measured. In general, the degree to which bridge residuals modify the basic equations increases with the operating frequency. The most important residuals in this bridge are discussed in the following paragraphs.

4.2 RESIDUAL CAPACITANCE AT BRIDGE VERTICES.

The residual capacitance to ground at each vertex of the bridge network exists in all impedance bridges. If one vertex of the Type 1603-A Z-Y Bridge, such as vertex V, is actually grounded, the residual capacitance of the opposite vertex, T, has no effect on the bridge balance. The residual capacitance of vertex Q exists in parallel with the large capacitor C_n (0.1 μf) and has a negligible effect. The ground capacitance of vertex S is thrown across the P arm of the bridge and may have an appreciable effect at high frequencies. These conditions exist, in both initial and final balances for impedance measurements of grounded unknowns (Figure 5-10) or in measuring a direct Y_d value (Figure 5-11).

For admittance measurements of a grounded unknown (or in measuring a direct impedance value, Z_d) the vertex T is directly grounded. The ground capacitance of vertex Q is now in parallel with C_a (minimum value 0.018 μf) and is usually negligible. The residual capacitance of vertex S is now thrown across the B arm of the bridge and will have an appreciable effect at high frequencies, especially when f_o is set to 10 kc giving the maximum R_b = 6.3 kΩ.

In substitution measurements, these vertex residuals exist in both initial and final balances so that, to a first order, their effects cancel in an evaluation of G_a and R_p. However, shifting the S-vertex residual from the P arm to the B arm requires too large a displacement of the Δ controls between initial balances for impedance and admittance measurements. Three steps are therefore taken to minimize the effective residual capacitance at the S vertex:

(1) C5, C6, and C7 are given a minimum capacitance to ground.

(2) The shielded transformer (Figure 3-1) is connected so that it contributes a minimum amount to this residual.

(3) A small voltage, of appropriate phase and magnitude, is introduced at S to cancel partially the effect of this residual capacitance. For this purpose, a small capacitor, C12, joins S and the ungrounded terminal of the generator. This canceling action, being a function of the frequency characteristic of the transformer, cannot be perfect, so that a new initial balance is required when shifting from impedance to admittance measurements.

4.3 RESIDUAL INDUCTANCE IN MAIN CONTROLS.

The second residual of importance in this Z-Y Bridge is the residual inductance of the winding of the two main rheostat controls, R2 and R5, which are assumed to be pure resistances in the basic equations. The effect of this residual has been largely canceled at midscale and at extreme-scale positions by the connection of an appropriate capacitor, C8, C9, C10, and C11, across each half of each of these rheostat windings. When f_o is set to 10 kc, C9 is augmented by C13. A residual inductance reaches a maximum at the 500-scale points.

The fact that this center-point cancellation is not perfect is the principle reason why some difference exists between normal initial balances and reversed balances for either impedance or admittance measurements.

Due to this residual inductance, reversed operation using the two main controls in both the initial and final balances (paragraph 2.7) should yield more accurate data.

An appropriate capacitor, C16, is likewise connected across the Δ control, R1.

4.4 CORRECTION FOR RESIDUAL INDUCTANCE IN MAIN *R OR B* CONTROL.

To obtain the most accurate value of reactance or conductance, it may be desirable, in certain cases, to compute and apply a correction to the observed value of δG_a in order to compensate for the residual inductance that remains in the main *R OR B* control rheostat. Conversely, it has been found that no correction is necessary in R_p due to residual inductance remaining in the main *X OR G* control.

This correction to δG_a is practical only when reversed operation is used. It is a function of the final balance setting of the main *R OR B* control and is proportional to the ratio f^2/f_o, so that it is most important with higher operating frequencies and when f_o is set to 0.1 kc. The procedure is as follows:

a. Observe the scale reading of the main *R OR B* control at final balance and from the curve in Figure 4-1, determine the positive numerical value of M. This curve was computed on the basis that f and f_o are each 1 kc.

b. If the final-balance position of the main *R OR B* control reads positive resistance (or inductive susceptance), the correction term in µmhos is:

$$\text{Correction to } \delta G_a = k_1 M\left(\frac{f^2}{f_o}\right) \qquad (22)$$

c. If the final-balance position of the main *R OR B* control reads capacitive susceptance, the correction term in µmhos is:

$$\text{Correction to } \delta G_a = k_2 M\left(\frac{f^2}{f_o}\right) \qquad (23)$$

d. The individual values for the constants, k_1 and k_2, for this particular bridge are:

Type 1603-A Z-Y Bridge Serial No.__________

k_1 = __________ k_2 = __________

when f_o = 10 kc, k_2' = __________

e. When measuring an inductive impedance or any admittance with a positive G, decrease the observed absolute value of δG_a by the correction term.

f. When measuring a capacitive impedance or any admittance with a negative G, increase the observed absolute value of δG_a by the correction term.

g. Use these corrected values of δG_a in the basic equations (2) and (3).

Residual inductance in the main *R OR B* control causes excessive counterclockwise or deficient clockwise rotation of either the *X OR G* or *ΔX OR ΔG* control for final balance. Two different k values result from the five-percent tolerance in the compensating capacitors, C8 and C9.

Parenthetically, it may be noted that the correction to X_x in ohms is the product k_1Mf and is the corresponding residual inductive reactance in ohms in the main *R OR B* control and is thus proportional to f and independent of f_o. When f = 10 kc, the maximum correction to X_x usually lies within the limits of 2 to 4 ohms. The curve in Figure 4-1 was drawn on the assumption that a 500-ohm carbon resistor showed a fictitious reactance of 0.2 ohm at 1.0 kc, so that, at the ±500-scale position, the main *R OR B* control had a maximum noncompensated inductance of 32 µh.

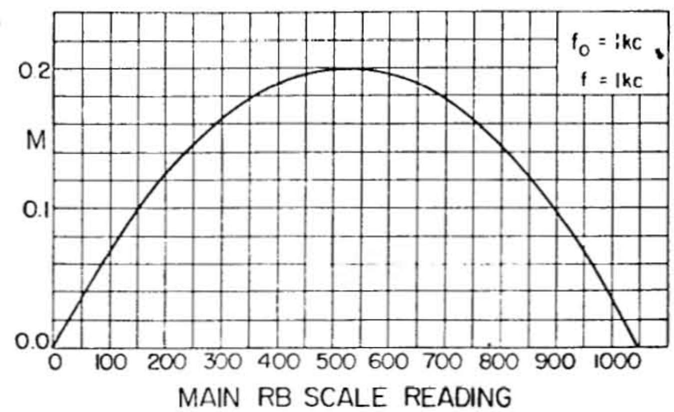


Figure 4-1.
Correction factor M (for Equations 22 and 23).

4.5 RESIDUAL CORRECTIONS OF DIRECT ADMITTANCE MEASUREMENTS.

In the final balance for direct admittance measurements (refer to paragraph 5.5.2) the bridge capacitor C_n is augmented by the ground capacitance of the unknown terminal that is connected to the high bridge terminal. If the smaller ground capacitance, C_{g2}, exceeds 1000 pf, a correction for this residual is desirable. Proceed as follows:

a. With C_{g2} against the high bridge terminal, measure the direct components of admittance:

$$G_d = (\delta G_a)_1 + 22{,}000\, C_{g2} \qquad (24)$$

$$B_d = \frac{f}{f_o}\left[(\delta R_p)_1 + 10\, C_{g2}\left[1100 + (\delta R_p)_1\right]\right] \qquad (25)$$

b. Reverse the connections to the unknown so that C_{g1} is against the high bridge terminal and measure the same direct components:

$$G_d = (\delta G_a)_2 + 22{,}000\, C_{g1} \qquad (26)$$

$$B_d = \frac{f}{f_o}\left[(\delta R_p)_2 + 10\, C_{g1}\left[1100 + (\delta R_p)_2\right]\right] \qquad (27)$$

c. Connect together the two direct terminals of the unknown to short out the direct admittance and leave C_{g1} and C_{g2} in parallel. Shift the detector terminals and measure the combined ground susceptance, B_g, of the resulting grounded two-terminal unknown:

$$B_g = \omega(C_{g1} + C_{g2}) = \left(\frac{f}{f_o}\right)(\delta R_p)_3 \qquad (28)$$

d. Solution of these simultaneous equations yields the values of the two ground capacitances:

$$C_{g1} = \frac{B_g}{2\omega} + \left[\frac{(\delta G_a)_1 - (\delta G_a)_2}{44{,}000}\right] \qquad (29)$$

$$C_{g2} = \frac{B_g}{2\omega} - \left[\frac{(\delta G_a)_1 - (\delta G_a)_2}{44{,}000}\right] \qquad (30)$$

These computed C_g values are then substituted above to give the corrected components of the direct admittance. In the foregoing equations, capacitance values are in microfarads and ω is in radians per second. If any final balance indicates an inductive susceptance, the corresponding (δR_p) is negative.

In the measurement of a three-terminal admittance that is balanced to ground so that each ground capacitance is given directly by the ratio B_g/ω, the measurement in step b is not necessary.

SECTION **5**

APPLICATIONS

5.1 TYPICAL LABORATORY MEASUREMENTS.

The following random tests made with the Type 1603-A Z-Y Bridge demonstrate the universality of this instrument.

1. The curve shown in Figure 5-1 is the input impedance of an electronic network with feedback. The Type 1603-A Z-Y Bridge was used to measure positive and negative values of both real and imaginary components.

2. If the resonant frequency of an inductor is below 20 kc, the susceptance can be determined as shown in Figure 5-2. To locate the fundamental resonant frequency, adjust the generator frequency until R_p (observed on the ΔR OR ΔB dial with reversed operation) vanishes. Alternatively, a few measurements of B_x can be made in the vicinity of f_1, and the frequency for B_x = 0 is then determined by graphical interpolation.

3. Figure 5-3 shows a typical "black-box" problem, in which the frequency characteristics of im-

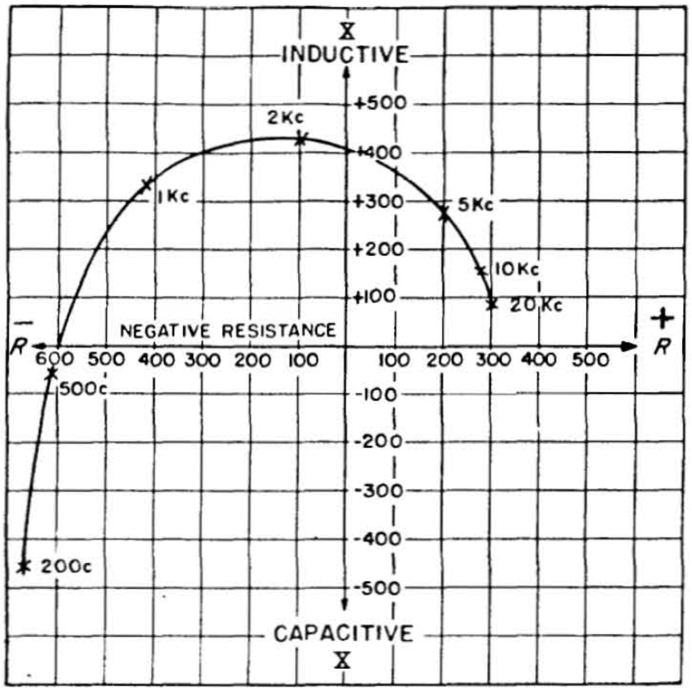


Figure 5-1. Input impedance of a feedback circuit showing negative resistance characteristic.

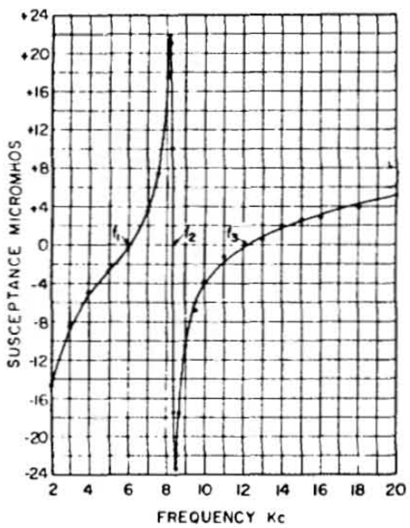


Figure 5-2. Susceptance variation of a 5-henry inductor at frequencies where distributed capacitance produces resonance effects.

pedance components are given for the illustrated LCR network, which was resonant just below 1 kc.

4. The electroacoustic behavior of transducers is shown by their circle diagrams. Figure 5-4 shows the unclamped circle for a small, two-ohm, two-inch loud-

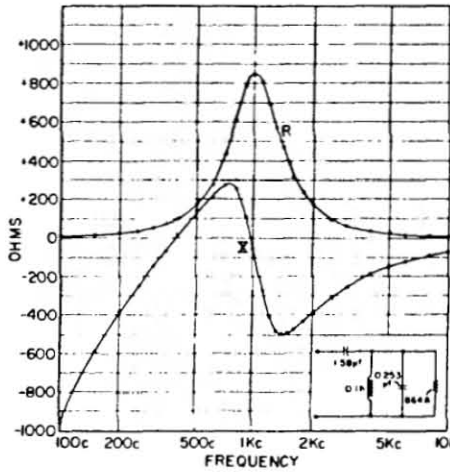


Figure 5-3. Impedance components of "black box" as a function of frequency.

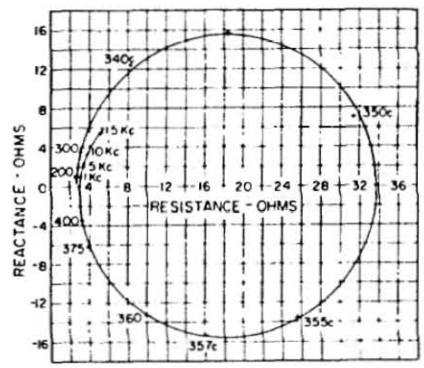


Figure 5-4. Reactance vs resistance for a typical loudspeaker.

speaker without a transformer, and shows acoustic resonance at 352 cps.

5. Figure 5-5 shows how the series capacitance of an electrolytic capacitor measured over the audio range falls progressively with increasing frequency, and how the series resistance rises rapidly with decreasing frequency below 400 cps.

6. Figure 5-6 shows the impedance components of a magnetic tape-recorder head. Since the slopes of the R and X curves remain positive, no unwanted resonance occurs within the audio range.

7. The bridge is particularly useful in measurements of the ac conductivity of electrolytic solutions. Irrespective of dielectric constant, the reactive component of the test-cell impedance can be balanced.

Figure 5-7 is data taken on tap water in a Balsbaugh cell.

8. Some of the many other applications for which the Type 1603-A Z-Y Bridge is suited are:

a. determination of leakage reactance of transformers,

b. impedance measurements of open- and closed-circuit transmission lines at audio frequencies, and

c. measurements for circular arc plots of solids with lossy polarizations in the audio-frequency range. Such data have hitherto been difficult to procure in this range.

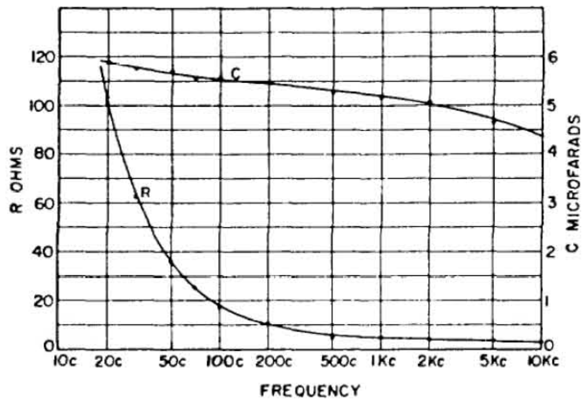


Figure 5-5. Impedance parameters of an electrolytic capacitor.

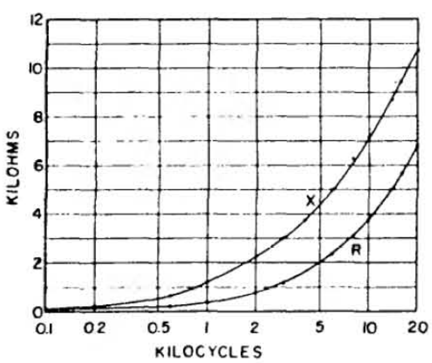


Figure 5-6. Impedance components of tape recorder head as a function of frequency.

5.2 MEASUREMENT OF DC ACTIVE UNKNOWNS.

Within certain voltage limitations, the Type 1603-A Z-Y Bridge can be used to measure the internal

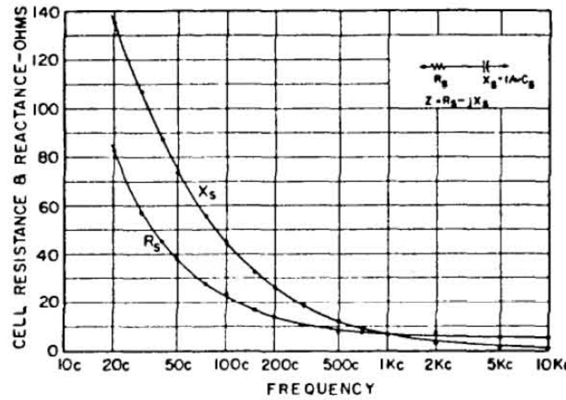


Figure 5-7.
Impedance components of a Balsbaugh cell (110 pf empty) filled with tap water. Since the electrodes of this particular cell were not designed for use with water, the data are not indicative of the actual constants of the water, but are presented here only as an example of this type of measurement.

impedance of dc active unknowns, such as batteries and dc power supplies. In order to prevent a momentary short-circuiting of the unknown and detrimental switch arcing, as the measurement switch is operated, it is essential that the voltage of the unknown be applied to the bridge only with the measurement switch set at either *Z MEASURE* or *Y MEASURE*. Therefore, this switch cannot be used for introducing the unknown for the final balance, as is conveniently done for all passive unknowns.

To measure internal impedance of dc active unknowns:

a. Connect the *LOW* terminal of the unknown to the bridge.

b. Make the desired initial balance.

c. Set the measurement switch to *Z MEASURE* (or *Y MEASURE*).

d. Attach the high terminal of the unknown to the bridge and make the final balance.

e. Disconnect the high side of the unknown before switching the measurement switch.

f. For impedance measurement, short-circuit the unknown terminals to discharge the bridge capacitors before switching the measurement switch.

If the dc emf does not exceed 15 volts, the active unknown can be measured as either impedance or admittance, depending upon its internal parameters. For admittance measurements, the unknown will be subjected to approximately a 75-ohm resistive bridge load with f_o set to 0.1 kc; approximately 210 ohms with f_o set to 1.0 kc; and approximately 290 ohms with f_o set to 10 kc. For impedance measurements, the load will be infinite.

> **CAUTION**
>
> If the dc emf is between 15 and 150 volts, the active unknown can be measured only as an impedance, which means that its internal resistance must be less than 1050 ohms. In this case, do not set the measurement switch to any of the three admittance positions.

5.3 MEASUREMENT OF INCREMENTAL INDUCTANCE.

Although this bridge was not designed specifically for the purpose, it is possible to measure the incremental inductance of a relatively low-impedance test inductor, provided that its resistance is less than 1000 ohms so that it can be measured as an impedance.

Connect a suitable dc biasing emf in series with an ammeter and rheostat of value r across the inductor as it is measured. If L and R are the series parameters of such a test inductor (scalar impedance = Z), the measured components of its parallel combination with r are:

$$X_x = \frac{\omega L}{1 + \frac{2R}{r} + \frac{Z^2}{r^2}} = \frac{\omega L}{1 + 2\frac{R}{r}} \qquad (31)$$

$$R_x = \frac{R\left(1 + \frac{Z^2}{Rr}\right)}{1 + \frac{2R}{r} + \frac{Z^2}{r^2}} = \frac{R\left(1 + \frac{Z^2}{Rr}\right)}{1 + 2\frac{R}{r}} \qquad (32)$$

The third members of these equations are valid approximations if r is kept large enough so that Z^2 is negligible compared with r^2. To evaluate the small correction term in the denominator of equation (31), we will assume the less extreme inequality that the square of Z is negligible compared to the product Rr in equation (32) and obtain:

$$R = \frac{R_x}{1 - \frac{2R_x}{r}} \qquad (33)$$

Finally, substitute equation (33) into equation (31) to give the desired incremental inductance:

$$L = \frac{X_x}{\omega\left(1 - \frac{2R_x}{r}\right)} \qquad (34)$$

in the presence of the biasing current. The incremental storage factor of the test indicator will be approximately X_x/R_x.

It is assumed above that the biasing branch has an impedance, $r + j0$. Since a dc active network is being measured, use the procedure outlined in paragraph 5.2. The dc voltage drop across the test inductor must not exceed 150 volts, and the measurement switch must be restricted to the three impedance positions.

5.4 MEASUREMENT OF POLARIZED CAPACITORS.

By an analogous procedure, electrolytic capacitors carrying a dc polarizing voltage up to 150 volts can be measured as impedances. A suitable polarizing emf with the correct polarity is applied through a resistor of value r across the test capacitor. The voltage source should be on the low side to minimize the effect of its ground capacitance so that the impedance of the polarizing branch is essentially $r + j0$. If there is any appreciable dc leakage current in the capacitor, the applied emf must be reduced by the Ir drop in r (measured by an ammeter in the polarizing path) to give the actual potential on the capacitor.

If C and R are the series parameters of the test capacitor, (scalar impedance = Z), the measured components of its parallel combination with r are:

$$X_x = \frac{-1}{\omega C\left(1 + \frac{2R}{r} + \frac{Z^2}{r^2}\right)} = \frac{-1}{\omega C\left(1 + \frac{2R}{r}\right)} \qquad (35)$$

$$R_x = \frac{R\left(1 + \frac{Z^2}{Rr}\right)}{1 + \frac{2R}{r} + \frac{Z^2}{r^2}} = \frac{R\left(1 + \frac{Z^2}{Rr}\right)}{1 + \frac{2R}{r}} \qquad (36)$$

The third members of these equations are valid approximations if we make r large enough so that Z^2 is negligible compared with r^2. To evaluate the small correction term in the denominator of equation (35) we will assume the less extreme inequality that the square of Z is negligible compared with the product Rr in equation (36) and obtain equation (33) as in paragraph 5.3. Finally, substitute equation (33) into equation (35) to give the polarized value of capacitance:

$$C = \frac{1 - \frac{2R_x}{r}}{\omega X_x} \qquad (37)$$

The dissipation factor of this polarized capacitor will be approximately R_x/X_x.

Since a dc active network is being measured, use the procedure outlined in paragraph 5.2 and use only the three impedance positions of the measurement switch.

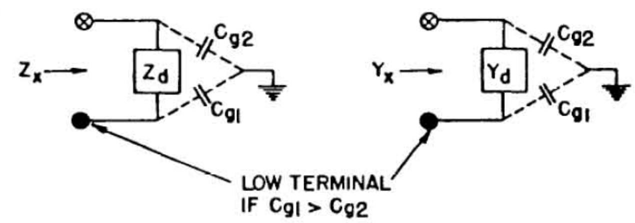


Figure 5-8. Delta network of nongrounded two-terminal element.

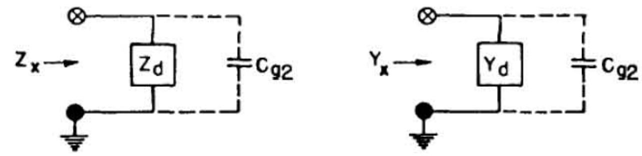


Figure 5-9. Grounded two-terminal element.

5.5 MEASUREMENT OF UNGROUNDED UNKNOWNS.

5.5.1 GENERAL. A two-terminal impedance with neither terminal grounded constitutes a delta network composed of the direct impedance Z_d (or a direct admittance, Y_d) between its terminals plus the ground capacitances C_{g1} and C_{g2} between its terminals and ground (see Figure 5-8). If these two ground capacitances are equal in value, this delta network is described as a balanced impedance or admittance. If C_{g1} is not equal to C_{g2}, the network is unbalanced to a degree determined by the ratio of the two ground capacitances and the terminal having the larger ground capacitance is designated as the low terminal, while the other terminal is the high terminal.

When one terminal of the impedance is directly grounded (usually the low terminal), the delta network no longer exists, since C_{g1} is short-circuited, and we have the direct Z_d or Y_d in parallel with the ground capacitance, C_{g2}, of the high terminal (see Figure 5-9). The unknown can then be measured as a grounded element as outlined in Section 2.

By suitable arrangement of the *DETECTOR* terminals on the bridge panel, it is also possible to measure the impedance or admittance of either the direct element with both ground capacitances effectively removed, or the unknown as a delta network, balanced or unbalanced, which consists of its direct value, Z_d or Y_d, paralleled by the series combination of its two ground capacitances (see Figure 5-8). This triple choice is a valuable feature which is not available in many impedance bridges.

5.5.2 MEASUREMENT OF THE DIRECT VALUE OF THE UNKNOWN. If C_{g1} differs appreciably from C_{g2}, connect the low terminal of the unknown to the *LOW* bridge terminal, and the ground terminal, if existent, to the bridge chassis. Strap the red *DETECTOR* terminal to the adjacent ground post (see Figure 5-10). Connect the null detector to the two insulated terminals with its high input to the black terminal. Neither terminal of the unknown is now directly grounded, and:

a. The larger of the two ground capacitances, C_{g1}, is now across the detector where it has no effect upon the balance of the bridge.

b. In an admittance measurement, the smaller capacitance, C_{g2}, augments the fixed bridge capacitor (C_n = 0.1 μf) by a small amount which, in most cases, is quite negligible. (Refer to paragraph 4.5 for corrections, if necessary.)

c. In an impedance measurement, the smaller capacitance, C_{g2}, constitutes an additional arm of the bridge from the high side of the unknown to vertex T. For small values of C_{g2}, the error introduced is usually negligible.

Note that only the direct value, Z_d, is in the P arm of the bridge for impedance measurements and only the direct value of Y_d is in the A arm for admittance measurements.

5.5.3 MEASUREMENT OF THE BALANCED OR UNBALANCED DELTA VALUE OF THE UNKNOWN. For this measurement, neither of the insulated *DETECTOR* terminals of the bridge is strapped to the ground terminal; in fact, the entire bridge network is floating above

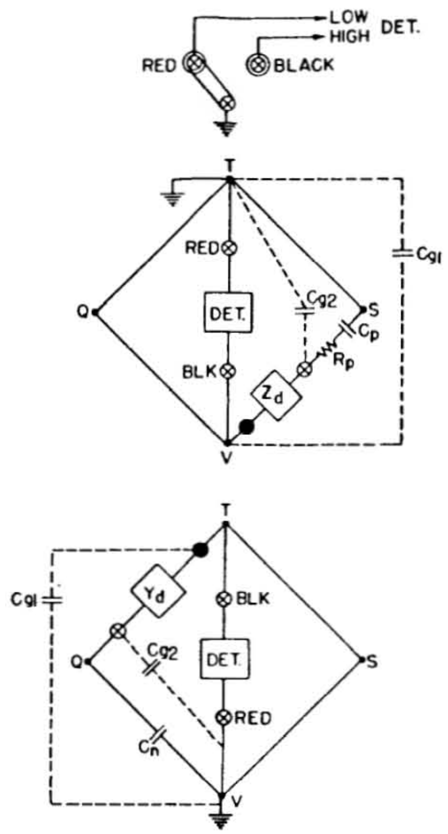


Figure 5-10. Measurement of the direct values, Z_d and Y_d.

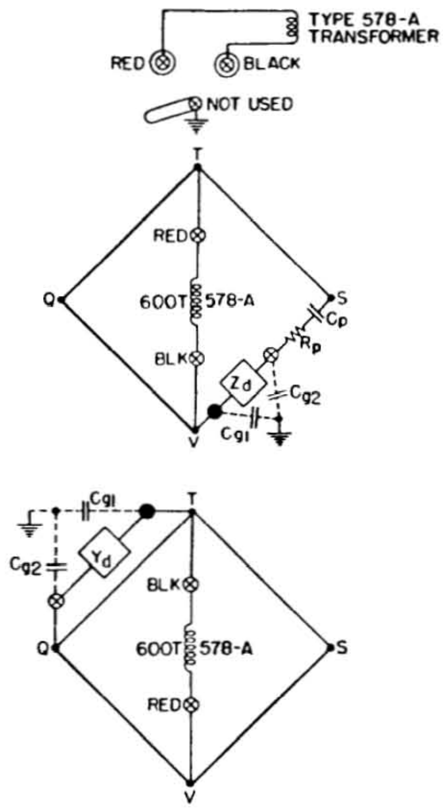


Figure 5-11. Measurement of the delta values of Z_x and Y_x balanced or unbalanced.

ground (see Figure 5-11). The detector must be connected to the bridge through an external shielded transformer (General Radio Type 578 or equivalent) as shown in Figure 5-12. The low side of the detector itself can be grounded. Note that the complete delta network of the unknown now exists in the P arm for impedance measurements and in the A arm for admittance measurements.

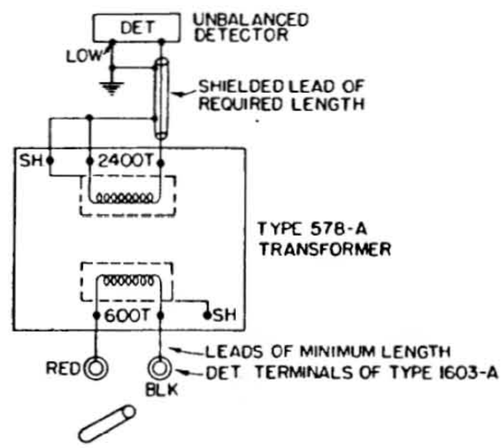


Figure 5-12. Use of double-shielded detector transformer in measuring delta network of nongrounded element.

SECTION **6**

SERVICE AND MAINTENANCE

6.1 WARRANTY.

We warrant that each new instrument sold by us is free from defects in material and workmanship and that properly used it will perform in full accordance with applicable specifications for a period of two years after original shipment. Any instrument or component that is found within the two-year period not to meet these standards after examination by our factory, district office, or authorized repair agency personnel will be repaired or, at our option, replaced without charge, except for tubes or batteries that have given normal service.

6.2 SERVICE

The two-year warranty stated above attests the quality of materials and workmanship in our products. When difficulties do occur, our service engineers will assist in any way possible. If the difficulty cannot be eliminated by use of the following service instructions, please write or phone our Service Department (see rear cover), giving full information of the trouble and of steps taken to remedy it. Be sure to mention the serial and type numbers of the instrument.

Before returning an instrument to General Radio for service, please write to our Service Department or nearest district office, requesting a Returned Material Tag. Use of this tag will ensure proper handling and identification. For instruments not covered by the warranty, a purchase order should be forwarded to avoid unnecessary delay.

6.3 CLEANING OF CONTROL RHEOSTATS.

If the Type 1603-A Z-Y Bridge is idle for an extended period, a small amount of sludge may form on the contact surface of the resistance windings of the four control rheostats. This will produce an electrical noise when the controls are manipulated, which is indicated by a scratchy noise when an earphone detector is used, or by erratic behavior of a visual null detector. This condition makes precise balancing annoyingly difficult although it usually does not invalidate dial readings once balance is established.

To remedy this situation, rotate the controls back and forth several times over their full ranges. Avoid slamming dials against their mechanical stops. If the condition persists, remove the bridge from the cabinet and clean the bearing surfaces of the rheostat cards with a clean lint-free cloth, preferably moistened with alcohol or a half-alcohol, half-ether mixture. DO NOT use water, gasoline, or saliva. DO NOT use any abrasive and DO NOT apply any lubricant.

The two main controls are readily accessible for cleaning. When cleaning, use extreme care not to disturb the tension of the rheostat arm or its setting on the rheostat shaft.

To clean either of the Δ controls, it is necessary to disassemble the rheostat and to recalibrate a specific reference point on the scale. Proceed as follows:

a. Notice the amount of clearance existing between the front surface of the dial and the under surface of the transparent indicator. It will not be necessary to disturb the indicator to remove the dial. When reassembling, make sure that the dial is replaced with the same clearance.

b. Loosen the two setscrews that fasten the dial to the shaft. Do not disturb the collar on the rear end of the shaft.

c. A red flexible wire leads from the terminal on the rear of the rheostat. Unsolder this wire at the end away from the rheostat.

d. Remove the single screw opposite the contact terminal on the rear of the rheostat.

e. Withdraw the cap portion of the rheostat and remove the dial and friction washers from the shaft. Clean the bearing surface of the winding as directed above.

f. Rotate the shaft to align the contact brush on the radius with the hole. Replace the rheostat cap and simultaneously introduce the front end of the shaft into the friction washers and dial bushing.

g. Rotate the cap so that its rotary contact terminal bisects the small angle between the two terminals on the base of the rheostat. Replace and tighten the single screw.

h. Connect one unknown terminal of a Wheatstone Bridge to the red wire and the other unknown terminal to the wire that runs directly to the base terminal of the rheostat (nearer to the top of the bridge). Rotate the shaft by means of the external rear collar, and, independently, rotate the dial on the shaft until, with a dial reading of 120, the measured resistance is:

for the ΔX *OR* ΔG control: 18,400 ohms ±20 ohms (one wire turn)

for the ΔR *OR* ΔB control: 23.0 ohms ±0.2 ohms (one wire turn)

i. Tighten the two dial set screws to restore the clearance noted in step a between the dial and its indicator.

j. Recheck the resistance value for a scale reading of 120, and, if satisfactory, resolder the red wire.

6.4 PRELIMINARY TROUBLE-SHOOTING

The apparent failure of the bridge to function properly may be due to sources outside the bridge. If initial balance cannot be obtained:

a. Check that the generator is actually applying an ac voltage to the *GENERATOR* terminals.

b. Check that the null detector responds with sufficient sensitivity and is not overloaded.

c. Determine whether the unknown is open- or short-circuited, as follows:

(1) Measure the unknown with reversed operation using the Δ controls (refer to paragraph 2.7).

(2) If identical initial and final Z_x balances are obtained, the unknown is essentially a short circuit, and $Z_x = 0 + j0$.

(3) If identical initial and final Y_x balances are obtained, the unknown is essentially an open circuit, and $Y_x = 0 + j0$.

6.5 ISOLATION OF DEFECTIVE COMPONENT

Suspicion of defective components in the bridge network or faulty switching can often be verified from the following 1-kc measurements with a vacuum-tube voltmeter. Table 3 gives the ratio of the 1-kc voltage across each bridge arm to the voltage across the generator diagonal QS when the controls are adjusted to give either a normal or a reversed initial balance. The last two columns indicate how these voltages vary as the main control dials are given a right-hand rotation (reversed initial balance). The last line gives the ratio of the diagonal voltage QS to the generator voltage.

TABLE 3

Bridge Arms*	0.1 kc	1 kc	10 kc	*X OR G*	*R OR B*
ST/QS	0.54	0.63	0.94	Increase	Decrease
SV/QS	0.54	0.63	0.94	Decrease	Increase
QV/QS	0.75	0.40	0.068	Decrease	Decrease
QT/QS	0.75	0.40	0.068	Decrease	Decrease
QS/E_{gen}	0.18	0.24	0.25	Decrease	Decrease

*The four vertices of the bridge can be identified as follows:

a. Vertex Q is the common connection of the four capacitors C1, C2, C3, and C4.

b. Vertex T is the lead connecting the front terminals of R11 and C2.

c. Vertex S is a common connection of the three resistors R9, R10, and R11.

d. Vertex V is anchor terminal 6.

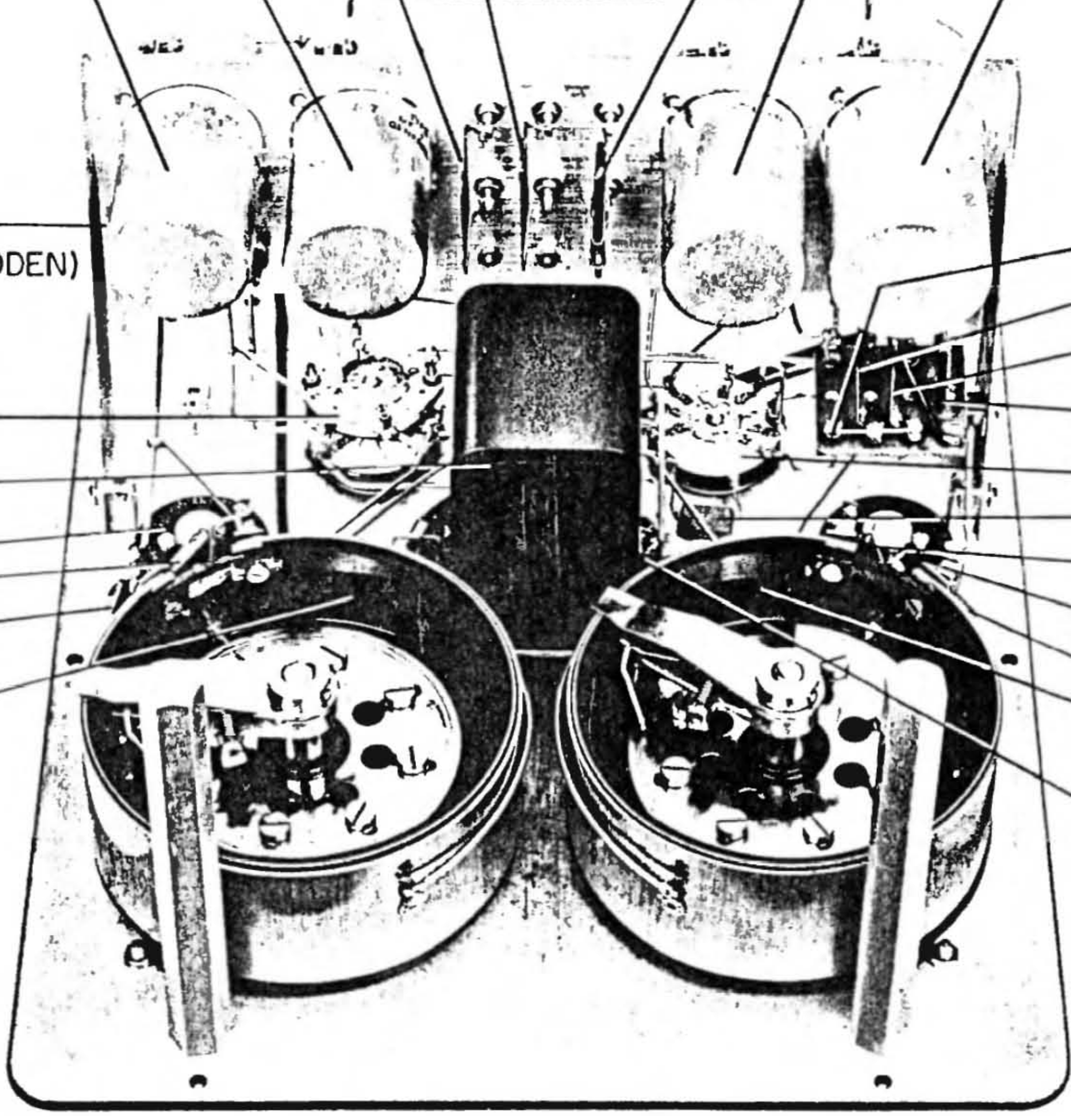


Figure 6-1. Rear interior view of the Type 1603-A Z-Y Bridge.

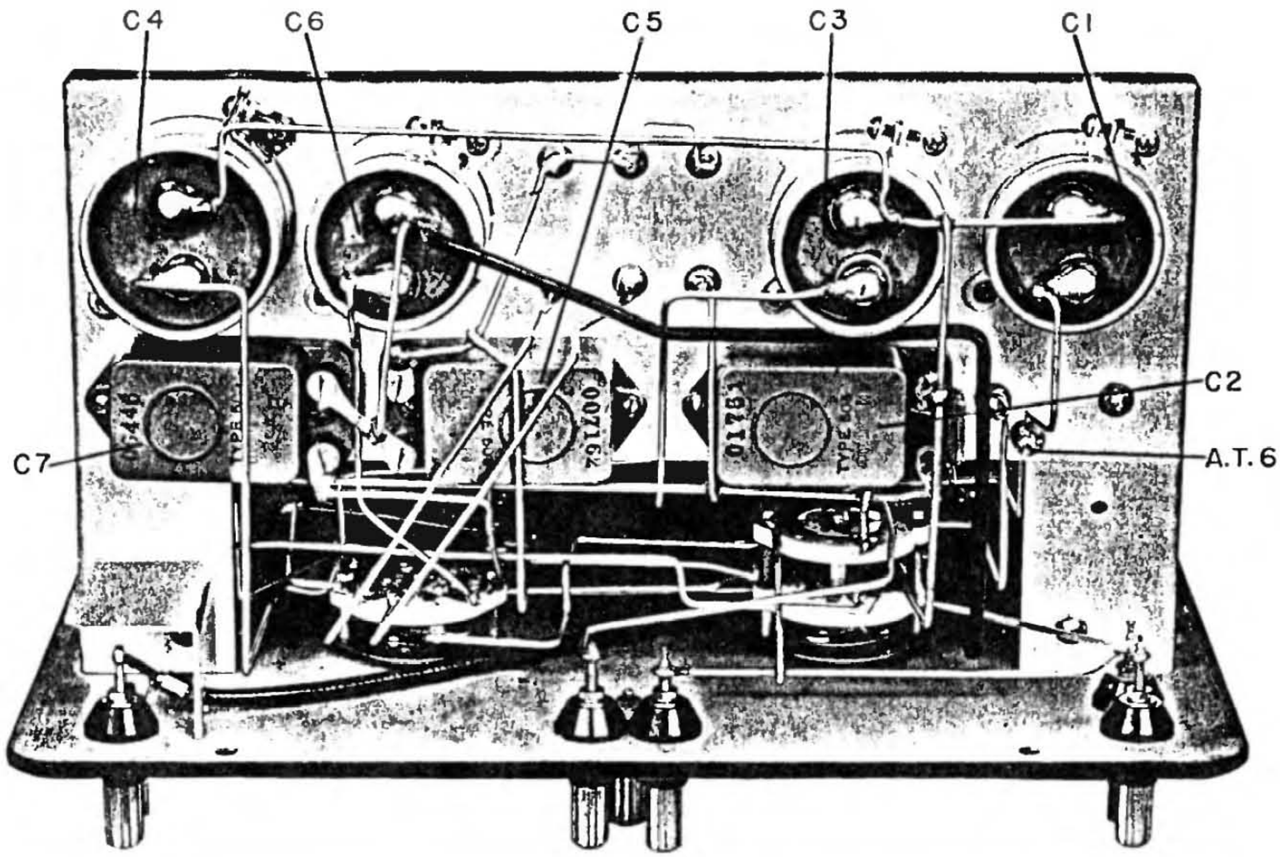


Figure 6-2. Top interior view of the Type 1603-A Z-Y Bridge.

PARTS LIST

	DESCRIPTION	PART NO.	FMC	MFG. PART NO.	FSN
CAPACITORS					
C1	Plastic, 0.100μF ±.25%, 100V	4860-5200	24655	4860-5200	
C2	Plastic, 0.100μF ±.25%, 100V	0505-4760	24655	0505-4760	
C3	Plastic, 0.1576μF ±1%, 100V	4860-5300	24655	4860-5300	
C4	Plastic, 1-733μF ±1%, 50V	4860-4900	24655	4860-4900	
C5	Plastic, 1-733μF ±1%, 50V	0505-4780	24655	0505-4780	
C6	Plastic, 0.7090μF ±1%, 100V	4860-5000	24655	4860-5000	
C7	Plastic, 0.7090μF ±1%, 100V	0505-4770	24655	0505-4770	
C8	Mica, 200pF ±5%	4860-1900	81349	CM20D201J	
C9	Mica, 240pF ±5%	4860-2000	81349	CM20D241J	5910-101-4714
C10	Mica, 750pF ±5%	4680-2900	81349	CM20D751J	
C11	Mica, 1300pF ±5%	4740-0100			
C12	Mica, 15pF ±10%	4660-0500	76433	CM20B150K	5910-227-0814
C13	Mica, 130pF ±5%	4680-1600	81349	CM20D131J	
C14	Trimmer, 1.5-7pF	4910-0300	72982	TS2ANPO, 1.5pF	5910-950-1224
C15	Trimmer, 7-45pF	4910-0100	72982	TS2AN?00, 7-45pF	5910-799-9275
C16	Mica, 1000pF ±5%	4680-3200	81349	CM20D102J	
C17	Mica, 240pF ±5%	4680-2000	81349	CM20D241J	5910-101-4714
C18	Trimmer, 5-20pF	4910-0400			
C19	Mica, 620pF ±5%	4680-2700	81349	CM20D621J	
RESISTORS					
R1	Potentiometer, 150Ω µ5%	0973-4020	24655	0973-4020	
R2	Potentiometer, 2.11 to 2.14KΩ	0433-4040	24655	0433-4040	
R3	Resistance strip, 1.055KΩ ±0.1%	0510-3750	24655	0510-3750	
R4	Potentiometer, 20KΩ ±5%	0973-4070	24655	0973-4070	
R5	Potentiometer, 20KΩ ±5%	0433-4050	24655	0433-4050	
R6	Potentiometer, 160.1Ω ±0.05%	1603-0260	24655	1603-0260	
R7	Resistance strip, 6KΩ ±0.1%	0510-3770	24655	0510-3770	
R8	Resistance strip, 317.5Ω ±0.05%	0510-3780	24655	0510-3780	
R9	Resistance strip, 63.46Ω ±0.1%	0510-3790	24655	0510-3790	
R10	Resistance strip, 698.1Ω ±0.1%	0510-3800	24655	0510-3800	
R11	Resistance strip, 6.283KΩ ±0.1%	0510-3810	24655	0510-3810	
TRANSFORMERS					
T1		0578-9701	24655	0578-9701	
SWITCHES					
S1	Rotary wafer	7890-0972	24655	7890-0972	
S2	Rotary wafer	7890-0960	24655	7890-0960	
BINDING POSTS					
J1	BNC Type	4060-0100	24655	4060-0100	5940-626-9922
J2	BNC Type	4060-0100	24655	4060-0100	
J3	BNC Type	4060-0100	24655	4060-0100	
J4	BNC Type	4060-1800	24655	4060-1800	5940-272-1464
J5	BNC Type	4060-0100	24655	4060-0100	5940-626-9922
J6	BNC Type	4060-0100	24655	4060-0100	5940-626-9922
J7	BNC Type	4060-1800	24655	4060-0100	5940-272-1464

PARTS LIST (cont)

DESCRIPTION	PART NO.	FMC	MFG. PART NO.	FSN
Patch Cord	0274-9880	24655	0274-9880	
Patch Cord	0874-94			
Patch Cord	0274-9880	24655	0274-9880	
Patch Cord	0874-9692	24655	0874-9692	
Foot	5250-0200	24655	5250-0200	
Dial Asm. Inductive Reactance	1603-0340	24655	1603-0340	
Knob - Inner control	5520-3500	24655	5520-3500	
Knob - Outer control	5520-2100	24655	5520-2100	5355-954-7040
Dial Asm - Resistance	1603-0350	24655	1603-0350	
Knob - Inner control	5520-3500	24655	5520-3500	
Knob - Outer control	5520-2100	24655	5520-2100	5355-954-7040
Dial + Knob Asm-Initial Balance ΔX to ΔG	1603-0360	24655	1603-0360	
Dial + Knob Asm - Initial Balance ΔR to ΔB	1603-0370	24655	1603-0370	
Feet - Quantity of 8	5260-1100	24655	5260-1100	
Handle	5360-0500	24655	5360-0500	
Indicators - 4	5470-0900	24655	5470-0900	6625-351-1405
Knob - Frequency for Direct Reading	5500-1100	24655	5500-1100	5355-912-0009
Knob - Initial Balance	5500-1100	24655	5500-1100	5355-912-0009

From Federal Supply Code for Manufacturers Cataloging Handbooks H4-1 (Name to Code) and H4-2 (Code to Name) as supplemented through June, 1967.

Code	Manufacturers Name and Address
00192	Jones Mfg. Co., Chicago, Illinois
00194	Walsco Electronics Corp., Los Angeles, Calif.
00656	Aerovox Corp., New Bedford, Mass.
01009	Alden Products Co., Brockton, Mass.
01121	Allen-Bradley, Co., Milwaukee, Wisc.
01295	Texas Instruments, Inc., Dallas, Texas
02114	Ferroxcube Corp. of America, Saugerties, N. Y. 12477
02606	Fenwal Lab. Inc., Morton Grove, Ill.
02660	Amphenol Electronics Corp., Broadview, Ill.
02768	Fastex Division of Ill. Tool Works, Des Plaines, Ill. 60016
03508	G. E. Semiconductor Products Dept., Syracuse, N. Y. 13201
03636	Grayburne, Yonkers, N. Y. 10701
03888	Pyrofilm Resistor Co., Cedar Knolls, N. J.
03911	Clairex Corp., New York, N. Y. 10001
04009	Arrow, Hart and Hegeman Electric Co., Hartford, Conn. 06106
04713	Motorola Semi-Conduct Product, Phoenix, Ariz. 85008
05170	Engineered Electronics Co., Inc., Santa Ana, Calif. 92702
05624	Barber-Colman Co., Rockford, Ill. 61101
05820	Wakefield Eng., Inc., Wakefield, Mass. 01880
07127	Eagle Signal Div. of E. W. Bliss Co., Baraboo, Wisc.
07261	Avnet Corp., Culver City, Calif. 90230
07263	Fairchild Camera and Instrument Corp., Mountain View, Calif.
07387	Birtcher Corp., No. Los Angeles, Calif.
07595	American Semiconductor Corp., Arlington Heights, Ill. 60004
07828	Bodine Corp., Bridgeport, Conn. 06605
07829	Bodine Electric Co., Chicago, Ill. 60618
07910	Continental Device Corp., Hawthorne, Calif.
07983	State Labs Inc., N. Y., N. Y. 10003
07999	Amphenol Corp., Borg Inst. Div., Delavan, Wisc. 53115
08730	Vemaline Prod. Co., Franklin Lakes, N. J.
09213	General Electric Semiconductor, Buffalo, N. Y.
09408	Star-Tronics Inc., Georgetown, Mass. 01830
09823	Burgess Battery Co., Freeport, Ill.
09922	Burndy Corp., Norwalk, Conn. 06852
11236	C.P.S. of Berne, Inc., Berne, Ind. 46711
11599	Chandler Evans Corp., W. Hartford, Conn.
12498	Teledyn Inc., Crystalonics Div., Cambridge, Mass. 02140
12672	RCA Commercial Receiving Tube and Semi-conductor Div., Woodridge, N.J.
12697	Clarostat Mfg. Co. Inc., Dover, N. H. 03820
12954	Dickson Electronics Corp., Scottsdale, Ariz.
13327	Solitron Devices, Tappan, N. Y. 10983
14433	ITT Semiconductors, W. Palm Beach, Florida
14655	Cornell Dubilier Electric Co., Newark N. J.
14674	Corning Glass Works, Corning, N. Y.
14936	General Instrument Corp., Hicksville, N. Y.
15238	ITT, Semiconductor Div. of Int. T. and T. Lawrence, Mass.
15605	Cutler-Hammer Inc., Milwaukee, Wisc. 53233
16037	Spruce Pine Mica Co., Spruce Pine, N. C.
19644	LRC Electronics, Horseheads, New York
19701	Electra Mfg. Co., Independence, Kansas 67301
21335	Fafnir Bearing Co., New Briton, Conn.
24446	G. E. Schenectady, N. Y. 12305
24454	G. E., Electronic Comp., Syracuse, N. Y.
24455	G. E. (Lamp Div), Nela Park, Cleveland, Ohio
24655	General Radio Co., W. Concord, Mass 01781
26806	American Zettler Inc., Costa Mesa, Calif.
28520	Hayman Mfg. Co., Kenilworth, N. J.
28959	Hoffman Electronics Corp., El Monte, Calif.
30874	International Business Machines, Armonk, N.Y.
32001	Jensen Mfg. Co., Chicago, Ill. 60638
35929	Constanta Co. of Canada Limited, Montreal 19, Quebec
37942	P. R. Mallory and Co. Inc., Indianapolis, Ind.
38443	Marlin-Rockwell Corp., Jamestown, N. Y.
40931	Honeywell Inc., Minneapolis, Minn. 55408
42190	Muter Co., Chicago, Ill. 60638
42498	National Co. Inc., Melrose, Mass. 02176
43991	Norma-Hoffman Bearings Corp., Stanford, Conn. 06904
49671	RCA, New York, N. Y.
49956	Raytheon Mfg. Co., Waltham, Mass. 02154
53021	Sangamo Electric Co., Springfield, Ill. 62705
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70563	Amperite Co., Union City, N. J. 07087
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89665	United Transformer Co., Chicago, Ill.
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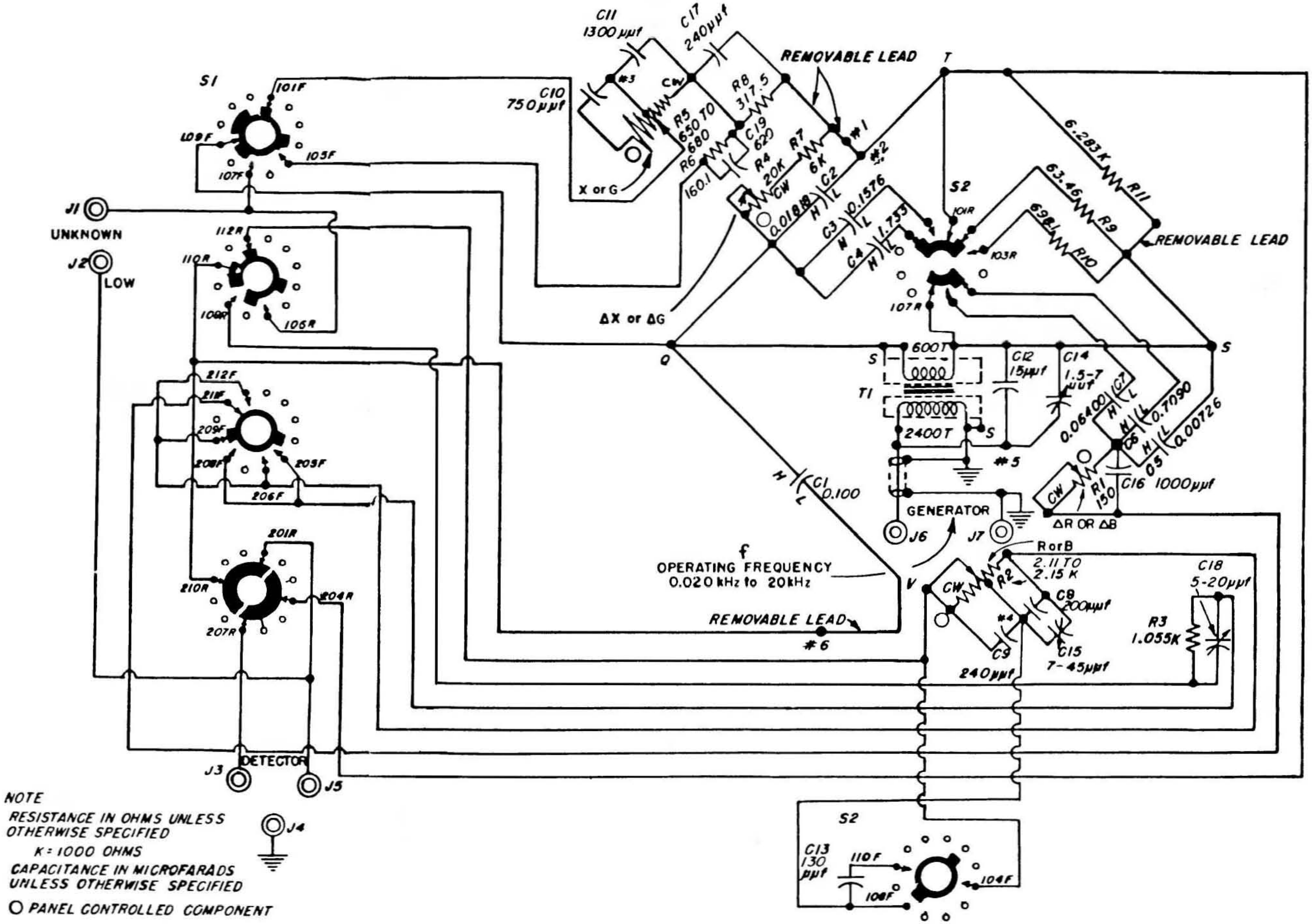

Figure 6-3. Schematic diagram.

number refers to the section. The section nearest the panel is 1, the next section back is 2, etc. The next two digits refer to the contact. Contact 01 is the first position clockwise from a strut screw (usually, the screw above the locating key), and the other contacts are numbered sequentially (02, 03, 04, etc), proceeding clockwise around the section. A suffix F or R indicates that the contact is on the front or rear of the section, respectively.

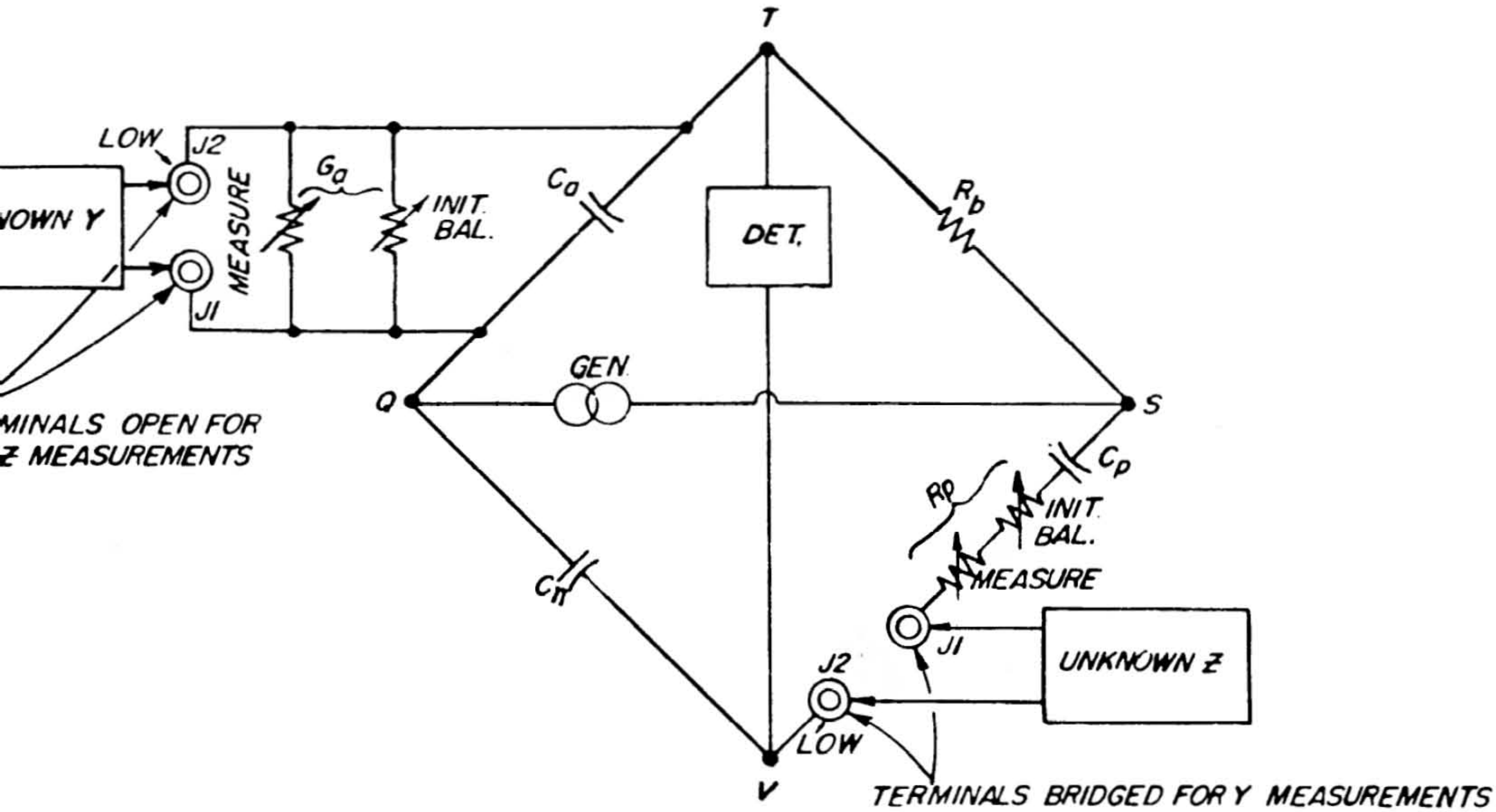

Figure 6-4. Elementary schematic diagram of the Type 1603-A Z-Y Bridge.

BRIDGE INPUT IMPEDANCE AT INITIAL BALANCE. The variation of the input impedance which exists at initial balance across the vertices Q and S of the bridge, as f_o and f are varied, is shown in the following table.

f_o	f	Z_{QS}
0.1 kc	0.1 kc	417 - j189
0.1 kc	1 kc	75 - j84
0.1 kc	10 kc	60 - j8.7
1 kc	0.1 kc	1080 - j53
1 kc	1 kc	820 - j330
1 kc	10 kc	410 - j85
10 kc	0.1 kc	6730 - j194
10 kc	1 kc	6150 - j1750
10 kc	10 kc	1410 - j1590

APPENDIX 1

Construction Method to Convert Y_x to Z_x (or Z_x to Y_x)

Admittance values can readily be converted to impedance values (and vice versa) by a simple construction method[1]. This procedure is especially helpful when the final measurement results are to be plotted rather than tabularized.

To convert admittance to impedance:

1. Compute $10^6/G_x$ and $-10^6/B_x$ (G_x and B_x in μmhos), and mark these points on the Z plane (see Figure A-1).

2. Draw the line between these two points.

3. With a square (or a construction) find the perpendicular from this line through the origin.

4. The intersection of the perpendicular and the line is Z_x.

To convert Z_x to Y_x compute $10^6/R_x$ and $-10^6/X_x$, plot these points on the Y plane, and proceed with the construction described above.

[1] E.W. Boehne, "The Graphical Solution of Linear Networks", AIEE paper, General Meeting, Fall, 1962.

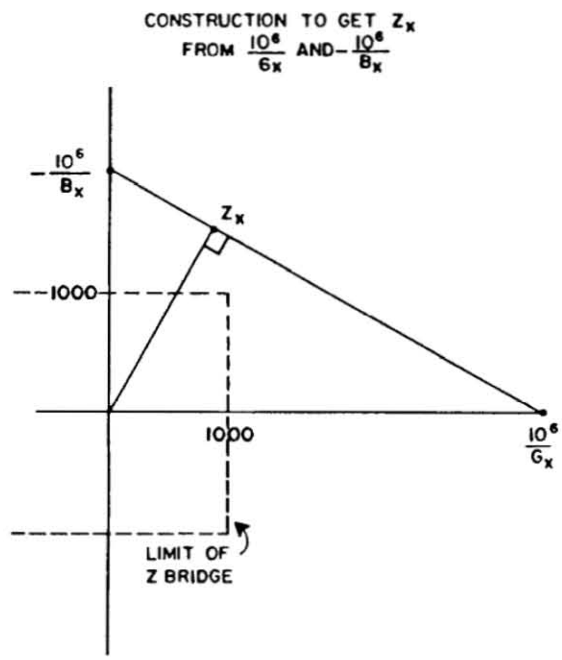

Figure A-1.
Construction for converting admittance components to impedance components.

APPENDIX 2

Transfer Equations

The following equations can be used to convert impedance components to admittance components and vice versa:

Z_x (in ohms) to Y_x (in μmhos)

$$G_x = \frac{10^6 R_x}{R_x^2 + X_x^2} = \frac{10^6 R_x}{Z_x^2} \tag{38}$$

$$B_x = \frac{-10^6 X_x}{R_x^2 + X_x^2} = \frac{-10^6 X_x}{Z_x^2} \tag{39}$$

Y_x (in μmhos) to Z_x (in ohms)

$$R_x = \frac{10^6 G_x}{G_x^2 + B_x^2} = \frac{10^6 G_x}{Y_x^2} \tag{40}$$

$$X_x = \frac{-10^6 B_x}{G_x^2 + B_x^2} = \frac{-10^6 B_x}{Y_x^2} \tag{41}$$

The storage factor, Q_x, the tangent of the phase angle θ_x by which the applied voltage leads the input current, can be computed by:

$$Q_x = \left| \tan \theta_x \right| = \frac{X_x}{R_x} = \frac{B_x}{G_x} \tag{42}$$

The dissipation factor, the cotangent of the same angle, can be computed by:

$$D_x = \left| \cot \theta_x \right| = \frac{R_x}{X_x} = \frac{G_x}{B_x} \tag{43}$$

The power factor, the cosine of the same angle, can be computed by:

$$PF_x = \cos \theta_x = \frac{R_x}{Z_x} = \frac{G_x}{Y_x} \tag{44}$$

The parallel resistance and reactance, R_{xp} and X_{xp}, can be computed by:

$$R_{xp} = \frac{10^6}{G_x} = \frac{Z_x^2}{R_x} = R_x(1 + Q_x^2) \tag{45}$$

$$X_{xp} = \frac{-10^6}{B_x} = \frac{Z_x^2}{X_x} = X_x(1 + D_x^2) \tag{46}$$

APPENDIX 3

VOLTAGES ACROSS THE UNKNOWN AT FINAL BALANCE.

An approximation to the voltages existing across the unknown after the final balance has been made may be computed from the following equations, in which E (generator) must be limited to a maximum value stipulated in paragraph 2.1.

a. When the unknown is measured as an impedance, Z_x:

$$\frac{E\ (\text{Unknown})}{E\ (\text{Generator})} = \frac{Z_x}{4\sqrt{1.21 \times 10^6 + (X_x - \frac{1}{\omega C})^2}} \qquad (47)$$

b. When the unknown is measured as an admittance, Y_x:

$$\frac{E\ (\text{Unknown})}{E\ (\text{Generator})} = \frac{G_b}{4\sqrt{m + (\omega C_a + B_x \times 10^{-6})^2}} \qquad (48)$$

In these equations ω is in radians per second and the numerics C, m, G_b, and C_a, in terms of the setting of the selector switch, have the following values:

Selector Switch Setting	C	m	G_b	C_a
x 0.1	87.7×10^{-9}	329×10^{-6}	159.2×10^{-4}	1741×10^{-9}
x 1.0	41.7×10^{-9}	14.55×10^{-6}	15.92×10^{-4}	175.8×10^{-9}
x 10	6.68×10^{-9}	5.67×10^{-6}	1.592×10^{-4}	18.18×10^{-9}

These equations assume that the voltage across the bridge vertices Q and S is one fourth of the generator voltage. Actually, E_{QS} may be somewhat less than $\frac{E_{GEN}}{4}$ due to transformer losses. If the exact value of the voltage on the unknown is required, it should be measured with a high-impedance electronic voltmeter.

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