# TYPE 1606.A R.F BRIDGE 

## Section 1 <br> INTRODUCTION

I.1 PURPOSE. The Type $1605 \cdot \mathrm{~A}$ R-F Bridge (Figure 1) is a null instrument espectally useful for accurate measurement of antcinas, $r$ - componcats, and other circuits having relanvely low impedances. The frequency range of the $b:$ idge is from 400 kc to 60 Mc . Measurements can be made; with reduced accuracy, at frequencies somiewhat above and below the nominal limits. The low-frequency limit is determinedmainly by senstivity considerations, and satisfactory measurements can usually be made at frequencies as low as 100 kc .

### 1.2 DESCRIPTION.

1.2.1 GENERAL. The bridge is mounted in an aluminum cabinet. Since capacitance between the bridge components and the inside walls of the cobinet comprises one arm of the bridge, the instrument camot be used outside of the cabinct. For rough usage in fitld applications, a separate luggage type carrying case is available as an accessory. The bridere can be operated either inside or outside of the luggage case.
1.2.2 CONTROLS. The following controls are on the panel of the instrument (see Figure 2):

| Control | Description | Function |
| :---: | :---: | :---: |
| REACTANCE | Vernier knob and four-inch dial | Indicates reactance. |
| RESIST ANCE | Vernier knob and six-inch dial | Indicates reslstance. |
| INITIAL BALANCE | Two rotary controls, with locking mechanisms | Used to obtain intial reactance and resistance balance |
| LOW, HIGH | Two-position toggle switch | Used to establish initial balance setting of the REACTANCE dial in the viclnity of 0 or 5000 ohms. |
| Capacitors (2) | Adjustments covered by snap buttons | Resistance calibration adjustment. |

1.2.3 CONNECTIONS. The following connections are on the panel of the instrument (see Figure 2):

| Connection | Descriptipn | Function |
| :---: | :---: | :---: |
| GEN. | Coaxial connector | Connects generator to bridge. |
| DET. | Coaxial connector | Connects detector to bridge. |
|  | Binding nost | Ground connection to unknown Impedance. |
|  | Tapped (6-32) terminal in circular window | Connection for unknown tmpedance. |



1. Generator connection
2. Ground binding post
3. Sonnection for untnown
4. Initial-balance range switch
5. Reslstąnce calibration adjustment (HIGH range)
6. Resistance calibration adjustment (LOW range)
7. Detector conhection
8. Reactance control
9. Resistance control
10. Reactance initial-balance control
11. Locking mechanism
12. Resistance initial-balance control
13. Locking mechanism

Figure 2. Panel Controls and Connections.
1.2.4 ACCESSORIES SUPPLIED. The following accessories are supplied with the Type 1606-A R-F Bridge:
a. Two clipleads for connecting the unknown impedance to the bridge, one about seven inches long, the other about 27 inches. Each lead has a threaded stud on one end and a clip on the other. Leads are stored in the accessory pouch when not in use.
b. A 3/4-in., 6-32 screw and a spacer $1 / 4$ inch in diameter and $1 / 2$ inch long. These are mounted on the unknown terminal to elevate the connection to the same level as the binding-post mountinghole, so that, if desired, a component can be connected
directlybetweenthe ground binding post and the unknown terminal without the use of leads.
${ }^{*} c$. Two Type 874-R22A Double-Shielded, threefoot Patch Cords for connections to generator and detector: These cords arefitted with Type 874 Coaxial Connectors.
d." One Type 874-PB58A Coaxial Panel Connector for mounting on the delector; if necessary, since for best results the detector should be fitted with a coaxial $r$-finput connector to completc the continuity of shielding. At higher frequencies the reactance of a binding post or of an inch of wire may cause noticcable error.

## Section 2 <br> PRINCIPLES OF OPERATION

2.1 GENERAL CIRCUIT DESCRIPTION AND BALANCE CONDITIONS. Tile basic circuit of the Type 161)6-AR-FBridec is shown infigure 3. An inatial balance is made with the unknowntermimals shortcircuited. The short-citcuit is then removed, and the bridge rebalanced with the unknown impedance connected to the terminals.

When the terminals are short-circuited, the balance conditions arc:

$$
R_{p}=R_{b} \cdot \frac{C_{a I}}{C_{n}}
$$

and

$$
\frac{1}{j \omega C_{p I}}=\frac{R_{b}}{R_{a}} \cdot \frac{1}{j \omega C_{n}}
$$

where $C_{a l}$ and $C_{p l}$ are the capacitances of the variable capacitors in the short-circuit balance position. When the short-circult is replaced by the unknown Impedance $Z_{X}=R_{X}+j X_{X}$, the new balance equations are:

$$
R_{p}+R_{x}=R_{b} \frac{C_{a 2}}{C_{n}}
$$

and

$$
j x_{x}+\frac{1}{j \omega C_{p 2}}=\frac{R_{h}}{R_{a}} \cdot \frac{I}{j \omega C_{n}}
$$

where $\mathrm{C}_{\mathrm{a} 2}$ and $\mathrm{C}_{\mathrm{p} 2}$ are the capacitances of the var: lable capacitors with the unknown impedsnce in the circuit.

The unknown resistance $\mathrm{R}_{\mathrm{x}}$ and the reactance $X_{X}$ are therefore related to the bridge constants by the expressions:

$$
R_{x}=\frac{R_{b}}{C_{n}} \cdot\left(C_{a 2}-C_{a 1}\right)
$$

and.

$$
x_{x}=\frac{1}{\omega}\left(\frac{1}{C_{p 2}}-\frac{1}{C_{p I}}\right)
$$

The resistance $R_{x}$ is proportional to the change in capacitance $\mathrm{C}_{\mathrm{a}}$, and the reactance $\mathrm{X}_{\mathrm{X}}$ depends upon a change in calpacitance $C_{p}$. The constant that relates resistance $R_{x}$ to ch3nge in capacitance $C_{a}$ is determined by the fixedresistance $R_{b}$ and fixed capacitance $C_{n}$. The reactance $X_{X}$ is actually meas:ured by the reactance substitution method, and is
equal and opposite in sign to the change in reactance of the capacitor $C_{p}$.


Figure 3. Basic Circuit of the Type 1606-A R-F Bridge.

### 2.2 DETA1LED CIRCUIT DESCRIPTION.

2.2.1 GENERAL. Simple relationships between the unknown resistance, reactance, and increments of capacitance are obtained by the series-substirution method of measurement. For simphcity of operation, auxiliary controls not shown in the basic diagram are added. Their functions are most easlly described by separatediscussions of the resistance and reactance balances.
2.2.2 RESISTANCE MEASUREMENT. The RESISTANCE dial, which controls varlable capacitor CI (see schematic diagram, Figure 10 ), can be calibrated in resistive ohms, with any capacitive setting as zero. For the maximum resistance range, this setting is chosen at minmum capacitance. A small variable trimmer capacitor, C 2 , is then connectedin paralled with Cl, so that the initial resistance balance, with the unknown terminals shortcircuited, can be msde at zero dial setting, irrespective of slight changes in the bridge parameters wlth time or frequency.
2.2.3 REACTANCE MEASUREMENT. The REACTANCE dial, which controls variable capacitor C3, can be calibrated in reactive ohms at any one frequency, again with any capacitance setting as zero.

For the maximum reactance range and the best ale distribution, this setting (dial zero) is chosen imaximum capacitance. A variade trimmer capacitor, C4, is then connected in serieswit C3, so that the initial reacinnce halance, with the unknown terminals short-circuited, canbe madic at zero dial setting or at other points on the dial, irrespective of changes in the hridge parameters with ume or frequency.

Another auxiliary control permits the measurement of both capacitive andinductive reactances equally well. With the zero position on the RI:ACT ANCE dial established at maximum capacitance, the dial scale reads inductive reactance directly; for measurements of capacitive reactance, the initial balance must be made at an ultcale reading so that the negative change in dial reading will remain on scalc. Since the range of adjustment of the INitlal BALANCE control does not permit initial balances to be established over the entire scale, a two-position (LOW, HIGI) switth is provided to shift the initial-balance adjustment range to eithe:
the top or hottom end of the dial by changing the value of the ratio-arm resistor (RI-R2). With this switch $\mathrm{i}:$. • LOW position, inltial balance can be obtainc: $\because$ the REACTANCE dial set from zeto to ahon! , for the measurement of inductive reactane elatively emall capacitivereactances. With tis ish at llict, an initial balance can be obtaine: the vicinity of the maximum setting of the REAA. . SNCE dial, for the nusasurment of large capacitu teactunces. The unknown reactance $c$ quals the ifference in the REACTANCE dial neading herwern the two balances divided by the frequency in megacycles, no matter where the dial is set for the inimal balance.
2.2.4 CTRCITT DIAGRAM. Figure 10 is a complete schematic diagram, showing the ratio-arm switch S1 and the two trimmer capacitors C2 and C4. In the instrument, the fixed capacitance C7 is composed chicfly of the capacitance to ground of the shiekitug system. Tike small adjusting capaclors, C5 and C , are used :o equalize the capactance from point A to ground in the two positions of SI.

## Section 3

## INSTALLATION

3.1 GENERAL. The complete measurement sctup usually consists of the Type 1606-A R-F Bridge, a well-shielded radio-frequency oscillator, and a well-shielded radio receiver, which serves as a detector.
3.2 OSCILLATOR. The r-foscillator must be capable of covering the frequency band of 400 kc to 60 Mc (or any desired portion thercof) with a maximum output voltage of between 0.1 and 10 volts, (For measurements on bradeast antennas, the maximum possible oscillator voltage should be used to override interfercnce. ${ }^{1}$ The oscillator should have a coaxlal output connector. (The Type 1211-C Unit Oscillator, with a range of 0.5 to 50 Mc , 1s especially recommended.) Atso, the following Instruments may be used as slgnalgenerators for the frequencies indicared:

| Instrument | Range |
| :--- | :--- |
|  | $20 \mathrm{cps}-0.5 \mathrm{Mc}$ |
| - ype 1215-B Unit Oscillator | $50-250 \mathrm{Mc}$ |
| Type 1330-An-Bridge Oscillator | $5 \mathrm{kc}-50 \mathrm{Mc}$ |
| See Appendix I |  |


| Instrument | Range |
| :--- | :--- |
| Type $805-D$ Standard-Signal <br> Generator <br> Type $1001-A ~ S t a n d a r d-S i g n a l ~$ <br> Generator | $16 \mathrm{kc}-50 \mathrm{Mc}$ |

3.3 DETECTOR. The receiver should have a sensitivity control, a beat frequency oscillator, a switch to cut out the AVC circuit, and coverage of the fre quency band of 400 ke to 60 Mc , or any desired portion thereof. Conventional communication-type receivers are usually satisfactory. For best results, the recelver should be equipped with a coaxial input connector. The Type 874-PB58A Coaxial Panel Connector is supplied as an accessory for installation on receivers not so equipped.
3.4 GROUNDING. When the instrument Is used for antenna impeclance measurements, it should be grounded at a single poitt, through a connection of as low reactance as possible. When the instrument is used to measure impedance of components. grounding is usually not required. To facllitate
making the ground connection, a ground clamp is provided on the instrument case. The ground lead should be a short length of copper strip, about an inch wide. In a maintenance shop sotup, a satisfactory ground can be made by copper foil cover ing the top of the bench, even though the bench is physically far removed from ground. If the foil area is large enough, it will usually be found that a connectionfrom it to ground (e.g. Lhrougha steam radiator system) will make no apprectable difference in results. The foil area shoukt he at last great enough so that the generator, britige, and detector can all be placed upon it. Large metal structures, such as relay racks, are also found to be adequate grounds. If the grounding is inadequate, It will usually be found that the instrument panel is at a differemi potential from the hand of the operator, and that the balance can be changed if the panel is touched.
3.5 STR AY PICKUP. If the bridge panclis at ground potentialand the generator and detector panels are not, it is usually an indication of excesslve reactance in the connections from the outer conductors of the coaxial leads to the generator and detector panels. Use of the double-shiclded, single-conduc tor coaxial cables supplied, with coaxial connect ${ }^{-}$ ors on both generator and detector panels, will generally eliminate the se diffe: יmces in potential.

As a check for stray plckup, balance the bridge with the unknown terminals short-circuited and remove the detector cable from the panel jack of the bridge. The detector plckup should be negligible If the generator is adequately shielded. If the outer shell of the cable jack can be touched to the ground shell of the detector connector without significantly increasing the recelver output, no excessive reactance exlsts. If the detector, when disconnected from the bridge, shows considerable pickup, it is usually an indication of poor shielding in the generator and detector or ofergy transfer from the generator to the detector through the power linc. The leakage can also be produced by a faulty cable. It is sometlmes found, where grounding conditions cannot be carefull y controlled, that individial ground connectlons from the generator, brtdge, and detector panelsto a common ground point give less pickup and better results than a single common ground to the brldge alone. The use of coaxial cables and connectors at both generator and detector is par-

Key to Flgure 4.
A - Short cllp lead
B - Unknown component
C - Ground blnalig post
D - Unknown terminal
E - Bridge panel
F - Coarial line
G - Clamp
H $-10-32$ screw substituted
for panel screw

A - Short cllp lead
B - Unknown component
C - Ground bincilig post
nown terminal
bridge panel
P-Coaxial line
G-Clamp
for panel screw

I- Bus whre
J - Strap (recommended at hlgh frequencies)
K - Network under test
L- Ground terminat
M - Spacer
N - Banana ptn or Type 874-61-4 Inner Conductor

d: Short No. 20 bus wire used to measure input impedanee to coaxial line. For injtiat batance, shert moner and outer cosmal conductors by a strap, or connect bus wire tu grounderl shell it coaxial the. Most accurate method, espccially at hugter frequencses

e. Component connected directly to bridge terminals. Recommended for accurate measurements on small components, es pecially al:ove 20 Mc.

Figure 4. Methods of Connection.
ficularly recommended to avoid as much as nosible the necessity for such multiple ground conections. In some cases, the effects of stay pickup are reduced if the generator and detector connections are rcversed.

For a further check for stray plckup, repeat the procedure described earlier in this paragraph, with the generator cable in place of the detector cable. For antena measurements, cheek for coupling between the anterna and the generator or detector by repeating the above checks with the antenna connected to the unknown terminals and the bri.lge balanced.
3.6 PRELIMINARY ADJUSTMENTS. The following adjustmentsmust be made to prepare the instrumen: for use:
a. Connect the generator and detector to the bridge, using the cahles and connectors provided.
b. Ground the equipment if necessary. (Refer to paragraph 3.4.)
c. Set the generator and detector to the proper frequencies. The input signai shouki be cw (unmodulated) to prevent possible dlfficulties arlsing from side bands.
da, Connect leads according to paragraph 3.7.
3.7 LEAD APPIICATIONS. The following types of leads shontd be used for the applications indicated (sec Figure 4):
a. Long clip lead (supplled) - Use only when short lead canot be used, and then only at friquencies below 5 Mc.
b. Short clip lead (supplied) - Useful over the frequency range of the bridge. For greatest accuracy, especialiy at frequencies above 20 Mc , use a two-inch or shorter bus whe or the terminals themselves.
c. Bus wire leads - A two-inch or shorter lead is recommended, particularly at frequencies above 20 Mc . If longer leads arc used at lower frequencies, their capacitances to giound nust be measured or estimated (refer to paragraph 4.4).
d. Bridge rerminals - Most accurate measurements result when the unknown impechance can be mounted directly across the bridge terminals.

Use of the terminals alone and terminals with a short bus wire lcad also have the advantage of confining the important electrostatic flelds to a relatively small area and thus minimizing hand capacibance effects, which may be noticeable when small capacitors are measured.

## Section

## OPERATING PROCEDURE

## 4.i INTTIAL BALANCE.

### 4.1.1 PROCEDURE.

a. set controls for initial balance as follows: (i) If unit to be measured has an inductive reactance, set switch to LOW, and REACTANCE and RESISTANCE dials to zero and short circuit the unknown terminals.
(2) If circuit is known to have a capacitive reactance, set switch to HIGH, REACTANCE dial to 5000, and RESISTANCE dial to zero.
(3). If the sign of the reactance is unknown, set switch to HIGH, REACTANCE dial to about 3400, and RESISTANCE dial to zero The mid-dial setting makes it possible to obtain a balance or at least an indication of the sign of the reactive halance with efther inductivé or capacitive unknowns. :
b. Balance the bridge to a null by varying the 'NTTYAL BALANCE controls.
..1.2 LIMITS. At lower frequencjes, with the switch at LOW, initial balance can be obtained at REACT-

ANCE settings from zero to about 1200; with the switch at HiGH, from about 3100 to 5000 . As the frequency is raised, these reactance limits tend to move up the dial because of the inductive reactance of the connecting lead. Depending upon the length of the connecting lead, a frequency will be found above which intitial balance cannot be obtalned with the REACTANCE dial at zero and the switch at LOW. A high frequency will be found at which the initial balance can no longer be obtained with the REACTANCE dial at 5000 and the switch at HIGH. The shift in balance causes no corresponding error in measurement since, in the series-substitution process, the constant Inductive reactance of the connecting lead cancels out. It does, however, reduce rhe reactance range of the bridge, since the full coverage of the RE ACTANCE dial cannot be obtained. The cffect can be corrected, when necessary, by the insertion of a small fixed capacitor (about $200 \mu \mathrm{f}$ ) in series with the connecting lead to neutralize the inductive reactance.


Figure 5. Range of Initial Reactance Dial Setting as a Function of Frequency.

Typical curves of the shifts in initial balánce are shown in Figure 5. With the short cllp lead, as sliown, the shift is relatively small over the entire frequency range of the instrument, and it is usually not necessary to use a series capacitor at any frequency. With the long lead, the shift is appreciahle, and at frequencies above 15 or 20 Mc a series capacitor may be necessary. However, the use of the long lead at these frequencies is not recommended as the errors are liable to be fairly large.

When a short bus wire is used for the connecting lead, or when the unknown is connected directly across the bridge terminals, the initial-balance range shifts with frequency in the opposite direction from the shift when a clip lead is used (see. Figure 5). This reverse sinift is caused by compensating reactances, included in the bridge to minimize the initial-balance shift when clip leads are used. At the highest frequencies, the bridge cannot be balanced in the vicinity of 5000 or at zero, but it can be'balanced over most of the intermediate range.
 null; adjust the bridge controls until the signal in-
dicated by the detector disappears. Either an aural or a visual indication of signal amplitade may be usect. If an aural indication is used, the receiver beat-frequency oscillator should be switched on and tuned to produce an audible beat in the headset. The $r-f$ gain control on the receiver should be set at a level at which the receiver is not saturated. Then, with the receiver AVC off, a rough null should be found. The $r$-f gain should then be increased, and a more accurate null found. This process should be repeated until the null is located with adequate accuracy. If a visual indication is desired, the $S$ meter on the reciver can be used. (For this purpose, the AVC shoutd be on.) The null can then be determined from a minimum meter reading. The $r$-f gain control should be set at the maximum level required to obtain a balance with the desired precision of measurement. Usually, the most satisfactory method is a combination of the visual and aural methods, in which the rough balance is made with the headset, with the AVC on. The precise balance should be made with the generator signal unmodulated. The AVC tends to broaden the null, and sometimes makes locating the null thore dif: ficult. Therefore, operation of the AVC should be left to the discretion of the operator. If the receiv-
or does not have an adequate r-f sensitlvity control, educing the generator output or detunlng the receiver may produce the same general results. For precise balance, the generator output should be set at maximum, so that the ratio of uscful output to leakage is as great as possible.

### 4.2 MEASUREMENT OF UNKNOWN IMPEDANCE WITHEN DIRECT-READING RANGES OF BRIDGE.

a. Connect the ground terminal of the unknown impedance to the brldge panel. Use as short a lead as possible. See Figure 4 for suggested methods of connecting various types of unknowis. (For an inherently grounded impedance, such as a low-frequency antenna, this ground connection can be omitted, since the bridge is already grounded through a low-reactance connection. Refer to paragraph 3.4.) The unknown should be located so that it can be reached with one of the two connecting leads supplied, or with a short bus whre (about No. 20), or connected by its own leads across the unknown terminals.
b. Clip the connecting lead to the ground termi nal of the unknown impedance (or short-circutt the terminals of the unknown witt a low-indtetance strap) and establlsh an initial balance (refer to paragraph 4.1). If the component is to be connected by means of its own leads between the ground bindig post and the unknown terminal, substitute a short bus wire or strapping for the component.
c. Remove the connecting lead from the grounded terminal of the unknown impedance, connect to the ungrounded terminal (or remove the short-circuit from the unknovn), and rebalance with the RESISTANCE and REAC' ANCE controls. The location of the connecting lead should be alteredas little as possible when the clip is shifted from the grounded to the ungrounded terminal, in order to minimize the changes in the lead inductance. If the unknown is to be connected by its own leads, substitute the unknown for the bus wire or strapping thsed for initial balance (refer to step b).
d. Read the unknown resistance directly on the RESISTANCE dial. The unknown reactance equals the change in reading of the REACTANCE dial, for aqy initlal setting, divided by the frequency in megacycles. - If the unknown reactance is inductive, the maximum dial-reading accuracy and range is ohtained when the initial setting is made at zero. ${ }^{1}$
${ }^{1}$ When a short bus wire lead or no lead is uised, it may not be possible to obtain an Inltial balance at zero at frequencies above 50 Mc . If initiai halance is not obtainalle with the swltech at LOW, switch to HIGH and obtain an initial balance at the lowest possibie RE ACTANCE dial setting. The measured inJuctive reactance is then the difference between. final and initial REACTANCE dial readingsdivided by the frequency in Mc.

Under these conditions, the change in reateng of the REACTANCE dial cquals the final din! reading. If the unknown reactance is capacitive and lares m nagnitude, the intial sctimg shoul: the mote at 5000 ohms. ${ }^{2}$ The chanee in reading of tiereacer ANCL dial then equals 5000 obmis mims the that dial reading.
e. Due to the compression of the RDACTANCE scale at the high end, the precision of measurement with the REACTANCE dial initially sct at sfan may not be the highestatainable when a cipacitive reactance that produces a dial rcadime difference of less than 5000 ohms is measured. In such instances, accuracy can be imporoved by a second measurement of the circuit, with the intial RIISCTANCE setting slightly highor dian the defference in readings obtained in the first measurement. If the desired initial reactance setting lies in the range (sce Figure 5) over whichinitial balance is posslble with the switch at LOW, set the switch at LOW for the initial balance. If the desired initia! REACTMNCE setting is in the range (sce rigure 5) in which no initial batance is possible, set the REACTANEE dial near the lowest point at which an initial balance is possible with the switcl at llliitl.
f. The following is atother methrst of achleving the same result for capacitive reactence:s producing less than 1000 ohms differcnces in the REACTANCE readings:
(1) Set the RE.SIST ANCE dial to the resistance previously measured (as in d, above) and the REACTANCE dial to zero.
(2) Clip the commecting lead to the ungrounded terminal of the unknown imperance.
(3) Ohtain an initial balance with the switch at LOW.
(4) Clip the connecting lead to the grounded terminal and rebalance with the RESIST ANCE and REACTANCE dials. The REACTANCE dial then reats upscale for capacitive reactance, and the precision of reading is the same as for inductive reactance. This method has the disadvantage of requiring two sets of balances, one to determlne the fesistive component and the other to determinc the reactive component.
g. If it is not known whether the reactive component of the impedance to be measured is inductive or capacitive, the following procedure is helpful: For initial balance, set the switch to H1GH and the REACTANCE dial to the lowest setting at which initial balance is possible (normally not above 3400 ohms). This setting permits a change in scale reading of 1600 ohms inductive or 3400 ohms capacitive.
${ }^{2}$ When a short bus wirc lead or no lead is used, it may not he possible to obtàin an initial balance at 5000 at frequencies above 10 Mc . Under these conditions, set the REACTANCE dial at the highest setting at which an initial balance is obtainable.

If the receiver sensitivity is turned down, this available reactance range is sufficient to Indicate the approximate magnitude and sign of the unknown reactance, on if the reactance is greater than the above limits, the direction in which the dial must be turned for a reactance balance is indicated, and a new intial balance canbe established accordingly.

### 4.3 MEASUREMENT OF UNKNOWN MPEDANCE

 OUTSDE DIRECT-READING RANGES OFBRIDGE. If the resistive or reactive component of tite unknown impedance falls outside of the direct-readlng range of the bridge, indirect measurements can be made through the use of an auxiliary parallel capacitor. When a pure reactance, $j X_{a}$, is connected in parallel with the unknown impedance, $Z_{x}=R_{x}+$ $j X_{x}$, and as $X_{a}$ approaches zero, the effective input impedance, $z_{m}=R_{m}+j X_{m}$, becomes$$
\begin{aligned}
& R_{m} \cong R_{x} \frac{x_{a}^{2}}{R_{x^{2}}+x_{x^{2}}^{2}} \\
& x_{m} \cong x_{a}
\end{aligned}
$$

"Shunting down" a high impedance with a parallel capacitor will accordingly bring elther or both the resistive and reactive components within the measurement range of the bridge. To measure a high impedance by this method, proceed as follows:
a. Connect one lead of the auxiliary capacitor to the ground terminal of the unknown impedance, and place the other lead near the ungrounded terminal of the unknown.
b. Establish arfinitial balance and measure the capacitive reactance ( $\mathrm{X}_{\mathrm{a}}$ ) of the auxiliary capacitor as described in paragraph 4.2.
c. Connect the ungrounded lead of the auxiliary capacitor to the ungrounded terminal of the unknown, keeping the capacitor-lead length as near as possible to that used in the measurement with the actual unknown connected.
d. Measure the effective impedance appearing across the bridge terminals, $Z_{m}=R_{m}+j X_{m}$. Then calculate the unknown impedance from the relations

$$
\begin{align*}
& R_{x}=\frac{R_{m}}{A}  \tag{1}\\
& X_{x}=\frac{X_{m}-\frac{R_{m}{ }^{2}}{X_{a}}-\frac{X_{m}{ }^{2}}{X_{a}}}{A} \tag{2}
\end{align*}
$$

where

$$
A=\left(1-\frac{X_{m}}{X_{a}}\right)^{2}+\left(\frac{R_{m}}{X_{a}}\right)^{2}
$$

Since the auxiliary reactance ( $X_{a}$ ) is capacillve, the number to be inserted for $X_{3}$ on cquations (1) and (2) will be negative. The sign of the effecti:c reactance $\left(X_{m}\right)$ will be positive or negative depat. irg on whether the measured value is inductive $u$ capacitive.

The value of the auxiliary capacitor to be 4 i is easily determined by experiment. It shouki ic kept reasonably sinall, so that impedances to the measured are not reduced so far that precision of dial reading is lost. A value between 35 and 2001415 is usually satisfactory. The resistance ( $R_{3}$ ) of the auyiliary capacitor is generally negligible, but can be corrected for as follows: Subtract from the effective resistance ( $\mathrm{R}_{\mathrm{m}}$ ) of the parallel combination (eapacitor and unknown) a resistance

$$
\Delta R=R_{a} \frac{X_{m}^{2}+R_{\dot{m}^{2}}^{2}}{X_{a}^{2}}
$$

The corrected value of $n_{m}$ can then be substituted in cquations (1) and (2). For example, if, at a frequency of 2 Mc , an auxiliary mica capacltor of approximately $100 \mu \mu$ is used with the short cliplead, its reactance should be about 800 ohms, corresponding to a difference of 1600 in inithal and final REACTANCE dial readings. Since an initial balance cannot be obtained with the REACTANCE dial set at 1600 , the dial should initially be set at the lowest practical setting above 1600 at which initial balance is possibie. Say this turns out to be 3400, with the switeh set at HIGH. The short clip lead is comnected to ground and the inftial balance is made. Then the clip is connected to the auxillary capacitor and the bridige is rebalanced with the RESISTANCE and REACTANCE dials. The final readings are 0.5 and 1840, respectively. Therefore:

$$
\begin{aligned}
& R_{a}=0.5 \mathrm{ohm} \\
& X_{a}=\frac{(1840-3400)}{2}=-780 \mathrm{ohms}
\end{aligned}
$$

- The circuit to be measured is then connected to the cllp lead with the auxiliary capacitor, and to the ground binding post, and the bridge is rebalanced. The final RESISTANCE reading is $i 15$ ohms and the final REACTANCE reading is 2020. Tharefore:

$$
R_{m}=115 \text { ohms }
$$

and

$$
x_{m}=\frac{(2020-3400)}{2}=-690 \mathrm{ohms}
$$

(At the hlgher frequencies, $R_{m}$ and $R_{a}$ must be corrected for the effects of inductance In the RESISTANCE capacltor. Refer to paragraph 4.5.)

The correction for the resistance of the auxiliary Dacitor is

$$
\Delta \mathrm{R}=0.5\left(\frac{690^{2}+115^{2}}{780^{2}}\right)=0.5 \mathrm{olm}
$$

The corrected effective resistance, $\mathrm{R}_{\mathrm{m}}{ }^{\prime}$, is then

$$
\mathbf{R}_{\mathbf{m}}^{\prime}=115-0.5=114.5 \mathrm{ohms}
$$

The unknown resistance and reactance are calculated from equations (1) and (2) as follows:

$$
\begin{aligned}
& R_{m}^{\prime}=114.5 \text { ohms } \\
& X_{m}=-690 \text { ohms } \\
& X_{a}=-780 \text { ohms } \\
& A=\left(1-\frac{-690}{-780}\right)^{2}+\left(\frac{114.5}{-780}\right)^{2}=0.0349 \\
& R_{x}=\frac{114.5}{0.0349}=3281 \text { ohms }
\end{aligned}
$$

$$
x=\frac{-690-\frac{114.5^{2}}{-780}-\frac{(-690)^{2}}{-780}}{0.0349}=-1801 \text { ohins }
$$

For this unknown, somewhat greater accuracy would have been obtained if a $35-\mu \mathrm{ff}$ auxiliary ca-pacltor had been used.
4.4 LEAD CORRECTIONS. In common with other types of impedance-measuring equipment, the brldge can measure impedance only at its own terminals. The resldual impedances of the connecting leads often cause this impedance to differ from the impedance appearing at the terminals of the device under test. Under some circumstances, the difference can be ignored and the measured impedance taken as the impedance of the device under test, including the leads. In most Instances, however, the device will not be used with the same leads used to connect it to the measuring equipment, and it is necessary to compensate for the effect of the leads to obtain the desired impedance. An exact correction requires an analysis as a transmission line, and the procedure is laborious and cumbersome. Approximate corrections will normally yield satisfactory accuracy.

In paragraph 3.7 it is noted that the length and loeation of connecting leads to the unknown impedance should be altered as little as possible when he clip is shifted for initial and final halances: This precaution insures that the inductive react-
ance of the leads is very nearly equal under the two conditions, and therefore that it cancels out in the series-sulistitution g lucess.

It will be remembered that a short bus wire connection is used tor initial balance where the unknownis to be connected directly between the bridge terminals. (See Figure 4.) The inductive reactance of this bus wire connection does effect the measurement, since it is removed when the unknown is mensured. The reactance of the bus wire should be added (t reactance) to the measurcd reactance of the unknown. for No. 20 hus wire, the reactance at 1 Mc is 0.08 ohm, and is directly proportional to frequency. This correction is negligible, except at higher frequencles, and can be reducerl to a negligible value at all frequercles by the use of a wiste strap rather than a No. 20 bus wire.

The capacitance toground of a connecting lead will cause errors in measurement that increase as the frequency is raised. Since the capactance of a connecting lead to ground has the same effect as a capacitancedeliberately placed in parallel with the unknown impeclance, the correction fot its effect can be determined directly from equations (1) and (2), where $Z_{m}=R_{m}+i X_{m}$ is the observed inpedance, and $X_{a}$ the reactance of the lead impedance. If the connecting leads are kept at a reasonable distance from metal objects, say an inch or more at the closest polnt, their capacitances to ground are approximately as follows:

| er | 2.0 H ${ }^{\text {f }}$ |
| :---: | :---: |
| Terminals, $1 / 2-i n$. spacer, and 2-in. \#20 bus wire | $2.5 \mu \mu \mathrm{f}$ |
| Short connecting lead | 3.8 \% ${ }^{\text {r }}$ f |
| Long connecting lead | $8.3 \mu \mathrm{ff}$ |

The reactances corresponding to these capacitances are plotted in Figure 6. For example, if a circuit is measured at a frequency of 5 Mc with the short connecting lead ( $X_{a}=8500$ ohms ), and the effective resistance and reactance are 522 ohms and -55.6 ohms, respectively, the true resistance and reactariee of the unknown circuit, corrected for the effect of the lead capacitance, are (from equations 1 and 2):
$A=\left(1-\frac{-55.6}{-8500}\right)^{2}+\left(\frac{522}{-8500}\right)^{2}=0.991$
$\mathrm{R}_{\mathrm{X}}=\frac{522}{-0.99 \mathrm{I}}=527 \mathrm{ohms}_{\mathrm{S}}$
$x_{x}=\frac{-55.6-\frac{529^{2}}{-8500}-\frac{(-55.6)^{2}}{-8500}}{0.991}=.-23.4$ ohms

Figure 6. Capacitive Reactance to Ground of Connecting Leads as a Function of Frequency.


When impedance components are measured outside the direct-reading range of the bridge, no lead corrections are necessary. Precautions in keeping the length and position of the connecting lead as nearly the same as possible Insures constant inductance, which cancels out in the seriessubstitution method; the reactance of the connect-ing-lead capacitance to ground is included in the measured reactance ( $X_{a}$ ) of the parallel capacitoi:.

It should be noted that the foregoing treatment of lead corrections is approximate. For instance, if the inductive reactance of the connecting lead is comparable to the unknown impedance, the voltage to ground will vary along the lead. Also, the effective capacitance will nol be the same as it is when the inductive reactance of the lead is small compared with the unknownimpedance. In fact, when the unknown impedance is zero, the effective sapacitance to ground of a connecting lead will be only one third of the static value. In compensation, it should be noted, that the lower the unknown impedance, the less the effect of lead capacitance. Obviously, the shorter the connecting lead, the smal-- ?r will be the lead corrections. Use the shortest .ossible connecting lead, thercfore, especially at ercquencies above 5 Mc . To aid in estimating the
inductive reactance of the leads relative to the unknown impedance, approximate inductance values are as follows:

| Short lead | $0.14 \mu \mathrm{~h}$ |
| :--- | :--- |
| Long lead | $0.71 \mu \mathrm{~h}$ |
| $2-\mathrm{in} . \# 20$ bus wire | $0.025 \mu \mathrm{~h}$ |
| l-in. $\$ 20$ bus wire | $0.013 \mu \mathrm{~h}$ |

### 4.5 CORRECTIONS FOR RESIDUAL PARAMETERS.

 Frequency limits for accurate $r$ - $\ell$ impedance measurements are nearly always determined by residual parameters in the wiring and in the impedance elements. While these are extremely small in the Type 1606-AR-F Bridge, they are sill large enough to affect performance at the highest frequencies and to set the linit of operation at about 60 Mc .The low - frequency limit is determined by factors that cause the bridge sensitivity to decrease at the lower frequencies and by compression of the REACTANCE dial calibration. For most applications, satisfactory operation is possible at frequencies as low as 100 kc .

The high-frequency limit is determined by the inductance in the resistance capacitor, C1. This


Figure 7. Muitiplying Factor for RFSISTANCE Dial as a Function of Frequency and Dial Seting (for use with 7 -in. connecting lead).


Figure 8. Multiplying Factor for RESISTANCE Dial as a Function of Frequency and Dial Sciting (for use with terminals alone or with lead less than 2 inches long).

Inductance causes the effective capacitance to increase as the frequency is raised, and therefore causes the dial reading for a given resistance value to decreas. Correction curves are given in Figures 7 and 8. The correction curve in Figure 8 is the actual correction for inductance in the resistance capacitor, and is valid when the unknown is connected directly across the bridge terminals or by means of a connecting lead less than two inches in iength. When the short clip lead is used at
high frequencies, the absorption of the lead induct ance in the initial batance causes an error, whach is conbined with the resistance capaciter indtact ance error in Figure 8. (Refer to paras raph o.2e.) For greatest acouracy at the extrome froburney limits, use a short length of bus wite in place of the 7-in. iead supplicd, or connect the unknown directly across the bridge terminals. (Refer to paragraph 4.2.)

## Section 5

## TYPICAL MEASUREMENT PROCEDURES

5.1 GENERAL. The following procedures are given as a guide to the practical application of the bridge.
5.2 MEASUREMENT OF A $\mathbf{i 0 0 - \mu \mu f ~ C A P A C I T O R ~}$ AT 500 KC . The unknown impedance in this exam ple is a small mica capacitor of good power factor.
a. Connect the generator and detector. Assume that the short clip lead has been chosen for this measurement. Screw the lead into the unknown terminal, and check for leakage as outlined in paragraph 3.5.
b. Fasten one end of the capacitor to the binding post, and adjust its location so that the clip of , the connecting leacican be transfered from the ungrounded capacltor lead to the grounded capacitor lead with a minlmum change in the position of the connecting lead. (See Figure 4a.)
c. Since a capacitive reactance is to be measured, the REACTANCE dial will read downscale; hence it must initially be set at a point higher than the expected change in dial reading. Since here the approximate magnitude of the unknown resistance can be estimated from its nominal capacitance, a satisfactory initial REACTANCE dial setting can be easily determined. The unknown reactance in this case is about 3200 ohms, which corresponds to a 1600 -ohm change in dial readings. Therefore, from Figure 5, it can be seen that the switch must be at HIGH and the dial at about the lowest setting at which balance is possible, about 3400 ohims. With the clip lead connected to the ground binding post, and the RESISTANCE dial at zero, set up the initial balance using the INITIAL BALANCE controls. The signal should completely disappear at the balanec: point. If if does not, the reason may be that the REACTANCE dial setting is too low for a balance. If this is the case, move to a slightly higher setting.
d. Transfer the clip of the connecting lead to the ungrounded lead of the capacitor and rehalance with the RESISTANCE and REACTANCE dials. Suppose the readings are 3.2 ohms'and 1870 ohms, respectively. Before corrections, the indlated resistance $\mathrm{R}_{\mathrm{m}}$ and reactance $\mathrm{X}_{\mathrm{m}}$ are:

$$
\begin{aligned}
& \mathrm{R}_{\mathrm{m}}=3.2 \mathrm{ohms} \\
& \mathrm{X}_{\mathrm{nl}}=\frac{1870-3400}{0.5}=-3060 \mathrm{ohms}
\end{aligned}
$$

e. Since the frequency is very low, the correction for inductance in the RESISTANCE capacitor is negligible.
f. To correct for the connecting-lead capacitance to ground, determine from Figure 6 the react ance $X_{a}$ of the short connecting lead at 500 kc . It Is $-84,000$ ohms. Applying equations (1) and (2):

$$
\begin{aligned}
A & =\left(1-\frac{-3060}{-84,000}\right)^{2}+\left(\frac{3.2}{-84,000}\right)^{2}=0.927 \\
R_{x} & =\frac{3.2}{0.927}=3.45 \mathrm{ohms} \\
X_{x} & =\frac{-3060-\frac{3.2^{2}}{-84,000}-\frac{(-3060)^{2}}{-84,000}}{0.927}=\frac{-2948}{0.927} \\
& =-3180 \mathrm{ohms}
\end{aligned}
$$

g. From these measurements the capacitance and dissipation factor $D_{X}$ can be found:

$$
\begin{aligned}
& C_{x}=\frac{1}{\omega X_{x}}=\frac{10^{2}}{2 \pi \cdot 0.5 \cdot 10^{6} \cdot 3180}=100 \mu \mu \\
& D_{x}=\frac{R_{x}}{X_{x}}=\frac{3.45}{3180}=0.00109
\end{aligned}
$$

### 5.3 MEASUREMENT OF ANTENNA IMPEDANCE AT 1170 KC.

a. Usually an antenna terminal is solocated that the bridge cannot be brought close enough to the antenna terminal to permituse of the short connecting lead. Therefore, screw thelong comecting lead into the ungrounded bridge terminal.
b. Using the shortest practicable length of copper strap, rround the bridge case to the metal rack in which the antennaterminal is housed. If the connection to the ground clamp on the case cannot conveniently be made, foosen the manel and slide a picce of copper foil into the crack between the pancl and the instrument case. Do not ground to panel screws; as they may not be making conact with the panei because of paint. (if desired, an unpainted $10-$ 32 screw can be substituted for one of the panel rews for a ground connection.)
c. Arrange the connecting lead so that it can be clipped to the antenna terminal or the nearest ground point on the rack with as little change in physical location as possible. The lead should be kept away from metal objects throughout its length.
d. Connect the generator and detector, and check for leakage as outined in paragraph 3.5. For best results, generator and delector should be filted with completely shielded coaxial connectors.
e. Since the sign and magnitude of the reactance component are unknown, ground the connecting lead to the rack, set the switch to HIGH, the REACTANCE dial to about 3400 ohms, and establish an initial balance using the INTTIAL BALANCE controls.
f. Transfer the connecting-iead clip to the antenna terminal and rehalance with the RESISTANCE and REACTANCE dials. Suppose the readings are 193 ohms and 3250 ohms, respectively. On the first neasurement it is usually desirable to check for leakage with the antenna connected. Disconnect tre generator coaxial connector and observe the signal magnitude with only the outer sheils of the connectors making contact. Any signal that appears is a leakage signal. Repeat this procedure with the detector connector. The effect of leakage detected canbe estimated by observation of the amitude of the leakage signal. After reconnecting .te generator or detector, determine the shift from balance of elther the RESISTANCE or REACTANCE
dial required to produce an unbalance signal equal in anplitude tr the leakage signal. The shift in dial reading oh ohs is appoximately the maximum magnitude of the error. This method does not indicate the disribution of the error hetween the resistance and reaciance meatsurements.
g. In this measuremont the resistance reading is adequately mecise, but the reactance readiag is not as precise as might be desited because of crowding on the REACTANCE dial scale, For a more precise reactance measurement, initally set the RFACTANCE dial nearer to zero, or set the REACTANCi: dial to zero and balance the bridge with the antemna connected, using the INTIALBALANCE controls. If the former method is used, set the REACTANCE dial at a point slighty higher than the difference in REACTANCE readings previously obtained. Since the afference was 150 ohms, set the switch to LOW, REACTANCE to 170, RESISTANCE to zero, clip the connecting lead to ground, and set up au initial balance. Then shift the clip to the antenna terminal and rebalance, using the RE SISTANCE and Ri:ACTANCE diais. Suppose the readings obtained are 193 ohms and 10 oinns, respectively. Before corrections, the indicated resistance $R_{m}$ and reactance $X_{m}$ are:

$$
\begin{aligned}
& \mathrm{R}_{\mathrm{m}}=193 \text { ohms } \\
& \mathrm{x}_{\mathrm{m}}=\frac{10-170}{1.17}=-137 \mathrm{ohms}
\end{aligned}
$$

If the latter methodis used, ieave the RESISTANCE dial set at 193 ohms, and set the REACTANCE dial to zero, with the switch at LOW. Leave the antenna connected and set up an initial balance using the INITIAL BALANCE controis. Transfer the connecting lead clip to ground ant rebalance the bridge with the RESISTANCE and REACTANCE dtals. The RESISTANCE diai should read zero at balance. Suppose the RE ACTANCE dial reads 160 ohms. Before corrections, the indicated resistance $R_{m}$ and reactance $\mathrm{X}_{\mathrm{n}}$ are:

$$
\begin{aligned}
& \mathrm{R}_{\mathrm{m}}=193 \text { ohms } \\
& \mathrm{X}_{\mathrm{m}}=\frac{0=160}{1.17}=-137 \mathrm{ohms}
\end{aligned}
$$

h. For most accurate results, corrections must be made for effects of the connecting-lead capacitance to ground. From Figure 6, the corresponding reactance ( $\mathrm{X}_{\mathrm{a}}$ ) of the long connecting lead is - 16,400 t 1.17 Mc . The corrected impedance can then be brained from equations (1) and (2).

$$
A=\left(1-\frac{-1.37}{-16.400}\right)^{2}+\left(\frac{193 .}{-16.400}\right)^{2}=0.984
$$

$$
\begin{aligned}
& R=\frac{-193}{0.984}=196 \text { ohms } \\
& x_{x}=\frac{-137-\frac{193^{2}}{-10,400}-(-137)^{2}}{0.984}-18.410=-136 \mathrm{ohms}
\end{aligned}
$$

5.4 MEASUREMENT OF A 50-OIIM LINE TERMINATED IN ITS CHARACTERISTIC IMPEDANCE AT 50 MC . At very high frequenclec. lead corrections are very importiat. If is also desirahle, if possible, to bring up the outer conductor of the coaxial line over the pancl and make contact either with the panel directly or with a chmp placed under one of the pand screys. (One of the black pane: screws supplied must he replacodwith an unpainted 10-32 screw for this application.) (Sce Figure 9.)
a. Connect the penerator and detector, and check for leakage as ouflined in paragraph 3.5. At high frequencies, reliable micasurcmeats cannot be made untess both the sencrator and detector are fitted with coaxial comnctors.
b. As indicated in paragraph 3.7, cither the short clip lead or a short lengtit of No. 20 bus wire can be used for conncetion to the unknown. Assume that the short clip lead is used for this measurement.
ew the lead into the ungrounded tridge terminal ...d clip it to ground directly at the end of the coaxial line under test. (Sec Figure 4b.) The reactance of any ground connection used is therefore'included in the initial baiance and is not measured as part of the unknown.
c. Since the line is terminated in its characteristic impedance, the measured reactance will be low. Therefore, the REACTANCE dial should initially be set in the lower part of its range, say at 500 ohms, with the switch at LOW. Restabiish initial balance using the INITIAL BALANCE controls.
d. Transfer the connecting-leadclip to the center conductor of the coaxial line and reibaiance with the RESISTANCE and REACTANCE controls. Sufpose the readings are 40.5 ohms and 350 ohms, respectively. Before corrections; the indicated resistance $R_{m}$ and reactance $X_{m}$ are:

$$
\begin{aligned}
& \mathrm{R}_{\mathrm{m}}=40.5 \mathrm{oh} \mathrm{~ms} \\
& \mathrm{X}_{\mathrm{m}}=\frac{350-500}{50}=-3.0 \mathrm{oh} \mathrm{hs}
\end{aligned}
$$

For a slightiy more precise reactance reading, repeat the measurement, with the REACTANCE dial 'ially set closer to z.cro.
e. To correct for inductance in the resistance capacitor, determine from Figuie 7 the cortccion
for a dlal reading of 40.5 ohms at 50 Mc . It is 1.23 . The corrocted value of resistance then becomes

$$
\mathrm{R}_{\mathrm{m}}^{\prime}=40.5 \cdot 1.23=49.8 \text { olims }
$$

f. To correat for the capacitance to ground of the connectiog lead, determine from Pigure o the corresponting reactance ( $X_{i t}$ ) of the shortclip lead at 50 Mc . It is -8.38 ohms. Applying equations (1) and (2) to determine the actual line inputimpednace, ${ }_{7}$.

$$
\begin{aligned}
& A=\left(1-\frac{-3}{-838}\right)^{2}+\left(\frac{49.8}{-8} \frac{8}{38}\right)^{2}=0.996 \\
& \mathrm{R}_{\mathrm{x}}=\frac{49.8}{0.996}=50.0 \text { ohms } \\
& X_{x}=\frac{-3.0-\frac{49.8^{2}}{-838}-\frac{(-3)^{2}}{-838}}{0.996}=0 \text { ohms }
\end{aligned}
$$

g. This example is cited as an extreme case, in which failure to correct for the inductance of the resistance capacitor leads to an crror in resist ance measurement in the order of 20 percent.
5.5 MEASUREMENT OF BALANCED CIRCUITS. The Type 1606 - A R-F Bridge will not measurc balancedeircuits directly. However, the measurement can be made by an indirect method. In the balanced circuit shown in Figure 8a, the following three impedance measurements a re required:

$$
\begin{aligned}
\mathrm{Z}_{1}= & \text { impedance between } \mathrm{A} \text { and ground, } \mathrm{B} \\
& \text { grounded, } \\
\mathrm{Z}_{2}= & \text { impedance between } \mathrm{B} \text { and ground, } \mathrm{A} \\
& \text { grounded, } \\
\mathrm{Z}_{3}= & \text { impedance between } \mathrm{A} \text { and } \mathrm{B} \text { connected } \\
& \text { together and ground. }
\end{aligned}
$$

The effective components of the balancednetwork can be calculated from the following equations:

$$
\begin{aligned}
& Z_{A B}=\frac{2 Z_{1}}{1+\frac{Z_{1}}{Z_{2}}-\frac{Z_{1}}{Z_{3}}} \\
& Z_{B C}=\frac{2 Z_{2}}{1+\frac{Z_{2}}{Z_{3}}-\frac{Z_{2}}{Z_{1}}} \\
& Z_{A C}=\frac{2 Z_{3}}{1+\frac{Z_{3}}{Z_{1}}-\frac{Z_{3}}{Z_{2}}}
\end{aligned}
$$



Figure 8 a.

$$
\begin{aligned}
& \text { If the line is exactly balanced, } Z_{A C}=Z_{B C} \text { and } \\
& Z, \quad Z_{2} .
\end{aligned}
$$

An auxiliary nerwork to permit direct measurements can be consuricice. Detalls are given in the Gonral Radio Expermenter of Scptember, $19+2$.

Section o

## CHECKS AND ADJUSTMENTS

6.1 RESISTANCE CALIBRATION. If the RESISTANCE dial calibration changes slightly with time or rough usage, trimmer capacitors CS and C6, mounted under snap buttons on the pancl, can be used to restore callbration. Capacitor C5, under the lower snap button, adjusts the RESISTANCE dial span with the switch at LOW. Capacitor Co, under the upper snap button, adjusts the RESISTANCE dal sponwith the switch at ligh. To checlicolination, measure the resistance of a goodr-fresistor, prefcrably the carbon-film type, at i Mc. with the switch first set at LOW and then at HIGH. The measured reslstances at both switch settings should match the $d-c$ value within one percent. If they do not, adjust $C 5$ and C6. Turning these capacitor's clockwise decreases the dial reading for a given resistar. and vice versa. Be sure to readjust the iniIt salance after cach adjustment, as the capacitors affect the initial halance as weli as the RESISTANCE dial.
6.2 CORRECTION FOR INDUCT ANCE IN RESISTANCE CAPACITOR. The change in effective capacitance of the resistance capacitor (rcfer to paradraph 4.5) is subject to some variation between instruments. Therefore, direct use of the average correction curves of Figures 7 and 8 may lead to error in the resistance measurement. This error is a constant fraction of the correction percentage, and amounts to maximum of $\pm 0.2$. That is, if the average correction factor is, say 1.15 (correction percentage $=15 \%$ ) as determined from Figure 7 or 8, the correction for any individual instrument may be from 1.12 to 1.18 . For smali corrections, such departures from the average are usualiy negligihle. At the highest frequencics, however, they may be farge enough to warrant an individual check on the correction curves.
a. To check the curves of Figure 8, measure a good hish-frequency resistor, such as a carboncomposition or carhon-film resistor, whose resistance is known'to be 50 ohms. a Type 874 -ibM 50-ohm Termination, o: a Type 874-W100 100-ohm Cnnxial Standard, at a frequency of 50 Mc with the s hat LOW. Connect theresistor directlyacross the bridge terminals or use a very short No. 20
bus wire lead. Suppose the measured resistance and reactance of a 50 -olm resistor are:

$$
\begin{aligned}
& \mathrm{R}_{\mathrm{m}}=37.7 \text { ohms } \\
& \mathrm{x}_{\mathrm{m}}=\frac{-600}{50}=-12.0 \text { ohns }
\end{aligned}
$$

b. The actual resistance "seen" by the bridge is the effective series resistance of the parallel combination of the standard resistor and the con-necting-leat capacitance. The effective resistance $R_{e}$ is:

$$
R_{e} \cong \frac{R_{x}}{1+\left(\frac{R_{x}}{x_{a}}\right)^{2}}=\frac{50}{1+\left(\frac{50}{838}\right)^{2}}=49.8 \mathrm{ohms}
$$

(This is an approximation because the effective reactance of the resistor is assumed to have a negligible effect. For accurate results, the resistance value should not exced 2500 f ohms, where $f$ is the frequency in megacycles.)

The correction factor is equal to the ratio:

$$
\begin{equation*}
K=\frac{R_{e}}{R_{m}}=\frac{49.8}{37.7}=1.32 \tag{3}
\end{equation*}
$$

c. The correction factor for this particular instrument canbe obtaine 1 for any'resistance setting from this one measurement through the reiation:

$$
\frac{R_{m}^{\prime}}{R_{m}}=K=1+A\left(R_{m}+560\right) f^{2}
$$

where $f$ is the frequency in megacycies, $R_{m}$ ' is the effective resi stance of the unk nown across the b,idge terminals (that is, the effective series resistance of the parallet combination of the unknown impedance and the capacitance of the bridge ieads and terminal, and $\mathrm{R}_{\mathrm{m}}$ is the resistance read from the RESISTANCE dial. Therefore:

$$
A=\frac{k-1}{\left(R_{m}+560\right) f^{2}}
$$

For the example given:

$$
\begin{aligned}
A & =2.13 \cdot 10^{-7} \\
\text { and } \quad K & =1+2.13\left(R_{m}+560\right) \mathrm{f}^{2} \cdot 10^{-7}
\end{aligned}
$$

A complete set of curves can now be drawn for the particular instrument, either by computation of points from equation (3), or by finding the frequency at which the average correction of Figure 8 agrees with the obscrvectcorrcction and muttiplyingall frequencies by the ratio of this frequency to the measurement freruency.

Assume that, for a 100 -ohm resistor at 50 $\mathrm{Mc}, \mathrm{K}$ is found to be 1.31. Figure 8 shows a correction factor of 1.31 at about 48 Mc , for a 77 -ohnn indicated resistance. If all frequencies are multiplied by the ratio 48/50 or 0.96 . the curve of Figure 3 may be used dircetly, or a new set of curves may be drawn with a correct frequency scale.
d. To check the curves of Figure 7, which are - 'd when the short clip lead is used, the same '. cedure can be used, except that the clip lead must be used for the connection to the unknown.

$$
\frac{R_{m}}{R_{m}}=K=1+B\left(R_{m}+390\right) f^{2}
$$

anct $\quad B=\frac{K-1}{\left(R_{m 1}+390\right) f^{2}}$
This expression and the $K$ factor differ from those required for the bus wire connection in that they include an effect of the lead inductance not considered in the lead corrections. With the terminals alone or a very short lead, this effect is negligible but it is significant when the shortclip lead is used.
6.3 REACTANCE CALIBRATION. The calibration of the REACTANCE dial is difficult to check ac-
curatcly, duc to the unavailabitity of capacitance standards that are reliable when mounted on the bridge temmats. However, rough checks can be mate as follows:
a. Set the swith to LOW, the REACTANCE diat to its low end, and balatice at 1 Mc with the ciplead groumbed.
b. Move the Rl:ACTANCF dialurscale and try to obtain another null. If the dialis propery oriented with the variable capacitor, no other null will be found.
c. Set the switcli to 1 HGH , the REACTANCE dila to its maximum counterclockwise position (highend of dial), and batance the bridge.
d. Again look for another null. - No mull should be found, since, if orientation is correct, the variable capacitor will travel slightly less than from its maximum to its minimun capselance when the iial is rotated from one stop to the oher. If two nulls are found, the dial has probably stipucd and shoutd be readjusted, To readjust the dial, remove the dial cover, loosen the two sel screws locking, the dial hub to the shaft, rotate the dial with respect to the shaft, and tighten the set serews.
c. Repeat the search for two nulls and readjust the unit until only onc null is found in each case.

For a more accurate check, measure the reactance of seweral silver-mica capacitors at 1 Mc , and compare the capacitance calculated from the measured ceactance ( $C=\frac{1}{2 \pi i X}$ ) with the nominal capacitance of the capacitor measured. Be sure to take into account the bridge lead capacitor when making the emparison.

Another method is to measure a capacitor (about $150 \mu \mathrm{ff}$ ) whose capacitance is not accurately known, with the REACTANCF dial set at 3400 , and again with the dial at $50 \% 0$. If the calibration is corred and the dial is properly oriented with respect to the capacitor. the measuredreactance will bethe same for all threc measurements. The most likely cause of a change in the REACTANCE dial calibration is slippage of the hub onthe dial or one of the gears calused by luose set serews. After locating and thentemer the toose set screws, check and adjust the dial as descrived above.

## Section 7

## SERVICE Ai) MAINTENANCE

7.1 GENERAL. The two-year warranty given with every General Radio instrument attests the qualioy of materials and workmanship in our proflucts. When difficulties do occur, our service enginer ts will assist in any way possible.

In case of difficulties that cannot he eliminated by the use of these scrvice instructions, pleast write or phone our Service Department, giving full Information of the trouble and of steps takento remedy it. Be sure to mention the serial and type numbers of the instrument.

Before returning an Instrument to General R:dio for service, please write to our Service Department or nearest district office (see back cover), requesting a Returned Material Tag. Lise of this tag will insure proper handling and identification. For instruments not covered by the warranty, a purchase order should be forwarded to avoid un-
essary delay.

### 7.2 SERVICE.

7.2.1 TROUBLE SHOOTTNG. The Type 1606 - A is a relatively simple tnstrument, and visual inspection will locate most troubles that may be encountered. The trouble-shooting chart (page 19) lists some troubles that may occur, and corrective measures.

### 7.2.2 DISASSEMBLY OF RESISTANCE DIAL.

## NOTE

Do not remove the RESTSTANCE dial itself unless absolutely necessary, for once it is removed it is difficult to replace it without loss of calibration.
a. Remove cover from panel by removing two screws and lockwashers, below and to the right and left of the shaft opening. This may be done without danger to calibration, as may steps $b$ and $c$.
b. Remove the knob and plate from the cover by removing two screws and lockwashers from the plate.
c. To separate knob and plate, remove two set rews from the knob.
d. To remove internal ring gear and dial, remove three screws from stop ilate.
e. The thub is connected to the capacitor shaft by means of set screws, through an intermediate insulating foushing. The bub is electrically grounded to the panel by three flat spritgs between the back of the frit and the panel.

### 7.2.3 RECALIBR ATION AND RE ASSEMBLY OF RE-

 SISTANCE DIAL. If the dial has been moved or the calibration lost, reculibrate by measuring the resistance (at any frequency below one megacyele) of various composition resistors whose d-c resistances are accurately known. The measured resistance of each reslator equals its d-c resistance. When replacing the dial, adjust the stops on the gear drive heforc recalibration, so that they operate slightly before the capacitor reaches the built-In stop at minimum capacitance or the zero end of the dial. To make this adjustment, reorlent the gear chive, or, if necessary, loosen the set screws holding the hul to the shaft and rotate the shaft. The sot screivs are behind the pancl at the base of the lub.To reassemble, simply rever: the disassembly procedure (paragraph 7.2.2). The cover, plate, and knob can be assembled and then mounted as a unit on the dial.

### 7.2.4 REACTANCE DIAL.

NOTE
Do not remove the REACTANCE dial unless it ts ahsolutely necessary, for once it is removedit is difficult to replace it without loss of calibration.

The REACTANCE dial has a gear drive slmilar to that used on the RESISTANCE dial. However, the dial itself cannot be removed without removal of the hub, which is secured to the shaft by set screws. No grounding spring is required.

If the dial is damaged, copy the calibration on a new dial and set the new dial on the shaft as described in paragraph 6.3.- The same procedure can be followed if the dial has been removed or if the set screws have slipped. If the calibration is completely lost, roughly calibrate the new dial by measuring the reactance of several silver-mica capacitors ( 30 to $3000 \mu \mathrm{ff}$ ) at 1 Mc . Their approx-
imate reactances can be computed fron: their nominal capacitances: $x=\frac{1}{2 \pi f C}$. Insiall and adjust the
dial as outlined in paragraph 6.3. and arbitramy set the zero point near the left-hand cud of the range. To determine the point corresponding to the reactance of each capacitor medsured. initially set the REACTANCE dial to zero, make the initial halance with the clip lead counceted to the canacitra, and make the final balance with the clip lead connected to ground. The final setling in cach case equals the reactance of the capacitor and lead meas ured. Several points can be determinedand markea on the dial. The dial is approximately linear in measured capacitance, and a curve can be dowa by means of the measured points and the intermediate points determince.

### 7.2.5 REMOVAL OF SHIELDS FROM C3 AND C4.

 There are three nesting shiclds around capacitors C 3 and C 4 . They are fastened to $\mathbf{i / 4 - i n c h}$ aluminum base plates by $6-32$ screws at the ends nearest the panel. To remove the outer shich, unsolker the lead to R3 and disconnect the straps hetween Sl and the shield and between Cl and the shicld. Do not anply any more heat than necessary to R3.When replacing the shields, pass the lead to R3 through the grommet hole in the shield by soldering a six-inch length of small-diameter bus wire to the end of the lead, threading the small wire thoough the grommet, and drawing the lead through as the shicld is shpped in place.
7.2.6 REMOVAL OF THE TRANSFORMER. Thi transformer and the panel connector are perman ently fastened together, and the panel connector must be removed beforc the transformer. The outer shicld around the reactance capacitor must be partially removed in order to disconnect the transformer sccondary lead. Unsolder the center conductor of the secondary line aukt remove the nut securing the coaxial fitting to the $1 / 4$-inch aluminum base plate. The transformer itself is mounted to the panel by four screws whoseheads appear on the front of the panel.
7.2.7 SPLiT GEARS. If the splitgears are removcd, they should be reassemhled with the upper and lower sections offset when gears are mestied, to provide the spring pressure to eliminate backlash. The springs should be extended two to threc full tecth on the large gears, and compressed $1-1 / 2$ to two tecth on the small gears.

## TROUBLE-SHOOTING CHART

Trouble



Balance erratic or nolsy
Intial-bảlance adjustment range stiffed

Backlash In dials or controts
Bridge halance changes as bifidge or vartous parts of circuit are touchest.

## Action or Probable Cause

a. Check gewerator and recciver connections.
b. Check generator and recciver goeration by looscly coupling generator to detector or hy comecting a voltineter to hridge end of cable from generator.
c. Check frequency band and setting of generator and detector.
a. Cineck cables for short or open clrcult.
b. Check generator ourput.
c. Check receiver sensitivity and tuning.
d. Cheek hridsee circuit tor shorts.
e. Clieck transformer by connecting a voltmeter across unknown terminals. Difference between generator voliape and Indicated voltage will vary with frequency. Ac I Mc, inclicated voltage should be at teasl one third of generator voltage.
a. Clip lead not connecred 10 ground.
b. Reacrance diat set at point where balance cannot be obtalned. (See Figure 5.)
c. HIGI-IOW switch at wrong position.
d. Unknown impedance heyond direct-reading range of instrument.
e. Resistance dial not at zero for tnimal batance.
f. Leart hetwecn P, 4 and ungrounded terminat on panel broken or disconnected.
g. One of reststors in bridge burned out.
h. Short circutt in a capacitor.

Capacitor C7 open or disconnected.

Loose connection or faulty resistor in bridge.
Resistors shifted in value. Check d-c resistances.

Check all set screws on shafts.
Leakage is prescnt. Refer to paragraph 3.5.

## Section 8

PARTS LIST

| $\begin{gathered} \text { REF. } \\ \text { DESIG. } \end{gathered}$ | Name and description | LOCATING FUNCTION |
| :---: | :---: | :---: |
| C1 | CAPACITOR, VARIABLE, AIR DIFLECTR!C, DJte-meshing type, $30 \mu$ min, $220 \mu \mathrm{ff}$ max, special cajucity runing chatacturistic, 1000 va a peak voltage, shaft adjustment, 170 deg cw rotation of ptates. Fumished only as complete assembly. Gencral Radio Co. Part No. 916-30. | OIMS RESISTANCE control |
| C2 | CAPACITOR, VARIABLE, AIR DIELFCTRIC, plate-meshing type, $55 \mu \mathrm{f}$ max, straight line capacity tuting characteristlc, 1000 va-c peak voltage, shaft adjustment, 360 deg continuous rotation, Gentral Radio Co. Part No. 1420406. | INTIAI, BALANCE controi |
| c3 | CAPACITOR, VARIABLE, AIR DIELECTRIC, plate-meshing tyle, 25 , 4 m min, $220 \mu$ f max, straisht lime capacity turny; characteristic, 1000 va-c peak voltage, extension shaft inljustment, 180 deg cew rotation, General Radio Co. Part No. 1420-405. | OIMS REACTANCE: <br> control |
| C4 | CAPACITOR, VARIABLI:, AIR DEELECTRIC. plate-meshing type, $25 \mu \mathrm{~m}$ min, 220 puf max, stra!ght linc capacity thand characteristic, abo va-c peak voltage, extension shaft aljustment, 360 de: continnous rotation, General Radio Co. Part No. 14:0-404. | INITIAL BALANCE control |
| C5 | CAPACITOR, VARIABIE, AIR DEELICTRIC, concemtic type, $3 \mu \mu \mathrm{~min}, 12 \mathrm{fif}$ max. stralght line capacity thing ctaracteristic. 3 50 y ac breadown test voltage, screw-driver adj.stmont. General Radio Co. Part No. COA-II. | Capacitance to ground equalizer |
| C6 | Same 25 C 5. | Caparitance to ground equalizer |
| C7 | CAPACITOR, FIXED, MICA DIELECTRIC, $15 \mu \mu \pm 10 \%$ tolerance, 500 dcwv, General Radio Co. Part No. COU-24. |  |
| 11. | CONNECTOR, RECF,PTACLE, banana and binding-post typue, not polartzed, General Radio Co. Part No. BP-10 (i1716). | Ground binding post |
| J2 | CONNECTOR, COAXIAL, General Radio Co. Part No. 874-307. | GEN. connector |
| 33 | Same as J2. | DET. connector |
| R1 | RESISTOR, FIXED, FLM, 220 ohms $\pm 1 \%$ tolerance, not tapped, i/2 watt power dissipation, JAN RN20X2200F, General Radio Co, Pat No. REF-65. | Ratio-arm resistor |
| R2 | RESISTOR, FIXED, FILM, 90 ohms $\pm 1 \%$ tole rance, not tapped, 1/2 watt power dissipation, JAN RN20X90ROF, General Radio Co. Part No. REF:6j. | Ratio-arm reststor |
| R3 | RESISTOR, FIXED, WIRE WOUND, 330 ohms, $\pm 1 \%$ tolerance, $1 / 4$ watt power dissipation, not tapjed, General Radio Co. Part No, 1600-304. | Fixed hridge resistor |
| R4 | RESISTOR, FIXED, COMPOSITION, 390 ohnis, $\pm 5 \%$ tolerance, not tapped, 1,2 watt power dissipation, JAN RC20BF391], Alten-Bradley Co. Part No. 3915. | Fixed bridge resistor in scries with unknown component |
| S1 | SWITCH, KNIFE, General Radio Part No. P1606-37 (cannot be histalled as a unit, but is made up of scparate elements). | HIGI-LOW switeh |
| TI | TRANSFORMER, RADIO-FREQUENCY, 2 windings singte-tayer wound: inductance, primary and secondary; 25 hh at $100 \mathrm{ke} ;$ turis and wire size, primary and secondary: ? rurns No. 28 . WW enamel copper wire; d-c resistance: primary 0.108 ohm, secordary 0.053 ohm, not tapped, no adiustable tuning, General Radto Co. Part Nu. 1606-32. | Input transformer |



Figure 9. Interior View of Type 1606-A R-F Bridge.


Figure 10. Schematic Diagram of Type 1606-AR-F Bridge.

## APPENDIX 1

## GENERATOR VOLTAGE LIMITS

The maximum generator voltage that can be safely applied to the bridge varies with frequency and with the setting of the HIGH-LOW switch. Figure 11 shows the limits under various conditions. In antenna measurements, the noise and spurious signals picked up by the antenna under test can cause a significant broadening of the mull. In instances where the noise pickup is objectionable, an improvement can often be obtained if the generator and detector connections to the bridge are inter-
changed (generator plugged into DETECTOR connector and detector plugged into GENERATOR connector). If the results are still unsatisfactory, a more selective dercctor, such is a communications receiver with a crystal fitier, stoull be used or the generator voltage should be increased. As seen in Figure 11, considerably higher voltages can be applied to the bridge whon the generator and detector connections are interchanged.


Figure 11. Generator Voltage Limits with Normal and Interchanged Connections.

