5A IMPEDANCE BRIDGE
DESCRIPTION

CONTENTS

1. GENERAL

This section describes the 5A impedance bridge, an instrument for making measurements of return loss and impedance at frequencies between 1 and 150 kilocycles.

Return Loss - The bridge is intended principally for use in measuring return losses in the range from 20 to 40 db between impedances averaging around 135 or 600 ohms. Higher and lower return losses can be measured with some reduction in accuracy.

Impedance - The bridge measures impedance in terms of resistance and capacitance in parallel (rather than in series as in the case of some earlier types of bridges). Where necessary the parallel values of resistance and capacitance can be converted to the equivalent series values by means of conversion formulas given in Part 4.1. The bridge will measure impedance in terms of equivalent parallel resistance up to 1100 ohms directly, above this and up to 1 megohm with supplementary computation, and positive or negative equivalent parallel capacitance up to 0.11 microfarad.

The 5A impedance bridge is designed to be used in conjunction with the 2A amplifier detector, the 17B oscillator and the 30A transmission measuring set or their electrical equivalents.

2. EQUIPMENT AND CIRCUIT FEATURES

The impedance bridge is contained in an aluminum alloy box which is about 14-3/4" long, 12-5/8" wide and 9-1/4" deep overall. The weight of the set, including a cover for protecting the face equipment when not in use, is about 27 pounds.

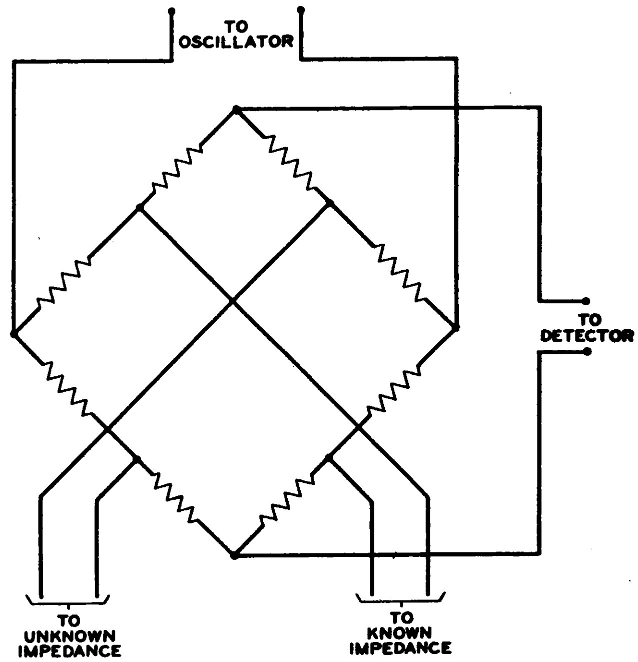


Fig. 1 - Simplified Schematic

The simplified schematic of the fundamental bridge circuit is shown in Fig. 1. This differs from the usual Wheatstone bridge in that the ratio arms are four pairs of equal resistances and the known and unknown are connected between midpoints of the opposite pairs. The inherent balance to ground of this arrangement is such that no transformers are needed in the bridge when measurements are made on lines normally encountered, reliance being placed on the output transformer of the 17B oscillator and the input transformer of the detector to provide satisfactory balance.

A view of the bridge is shown in photograph 1, Page 9. The equipment illustrated consists of three dials controlling two decade switches with mica condensers and one variable air condenser. By means of these the capacity may be varied continuously from 0 to 0.111 microfarad. Above the condenser dials are two resistance dials controlling one decade switch and one non-reactive slide wire. By these means the standard resistance can be varied continuously from 0 to 1100 ohms. There are also a number of binding posts, jacks and keys by which a variety of circuit arrangements may be set up. The uses of the various keys will be discussed in connection with the detailed schematic diagram which follows. Photograph 2, Page 10, is an interior view of the bridge showing the ratio arm assembly in the upper left.

Page 11 shows the detailed schematic of the bridge circuit. Besides binding posts and jacks for the oscillator and detector marked OSCILLATOR and DETECTOR, and binding posts for the known and unknown impedances, marked S_1-S_2, and X_1-X_2, respectively, there are posts R_1-R_2 and C_1-C_2 across which the variable resistance and capacitance standards are connected respectively. Several ground posts are also brought out to which the shields of the various leads as well as ground may be connected.

In the left of page 11 is shown the circuit arrangement for the keys appearing in photograph 1, page 9. The bottom two keys marked CAP STD operate together. The upper of the two connects the capacitance standard across either the unknown or the known terminals of the bridge. The lower of the two keys throws a small variable capacity across the side of the bridge opposite that of the standard. The purpose of this condenser is to balance out the residual capacitance of the capacitance standard so that the zero value does not have to be included as a part of the capacitance standard.

The key marked RES STD serves to connect the variable resistance standard also across either the known or unknown terminals.

The fourth key from the front serves to connect a 1000-ohm resistance across the X_1-X_2 posts. This is used when the parallel resistive component of the unknown is greater than 1100 ohms, in order to shunt down the unknown to within the range of the variable resistance standard.

The fifth key marked UNBAL-BAL is used to adapt the bridge to make measurements on either balanced or unbalanced-to-ground circuits.

The sixth and seventh keys marked CAL 25 DB and STD respectively, are for return loss measurements. Operating both keys to the right connects a 600-ohm resistance across the S_1-S_2 posts and a 671.4 ohm resistance across the X_1-X_2 posts. The return loss between these two resistances is 25 db. Similarly, throwing both keys to the left gives a return loss of 25 db between 135 and 151.1-ohm resistances.

The bridge is designed for a maximum safe input of 1 watt.

3. ACCURACY

The accuracy of measurement may be influenced by unbalances to ground in the unknown, as well as by the nature and size of the unknown impedance, and the leads used to connect the unknown impedance to the bridge. For the line impedances usually encountered, the bridge is well enough balanced that the accuracy is not impaired for practical purposes by such unbalances. For impedances considerably out of this range, unbalances may result in a broadening of the sharpness of balance as indicated by the detector and in a decreased accuracy of measurement.

Assuming that the above mentioned unbalances do not exist, the accuracy of measurement is as follows:

3.1 Return Loss Measurements - No Leads

$\pm$ 1 db within the range of 20 to 40 db provided measurements are made within the limits of 100 to 1000 ohms on balanced to ground circuits. Outside of this range the bridge will operate at somewhat reduced accuracy. The accuracy on unbalanced to ground circuits may be poorer than for balanced circuits.

3.2 Impedance Measurements - No Leads

As this bridge is designed for an overall impedance accuracy of $\pm$ 0.5% at the binding posts it may be stated that the individual accuracies of the components measured depend on the ratio of the reactance to effective resistance of the unknown and are:

$\pm\ (0.5\% + \frac{40}{L}\% + 5\mu\mu f)$ if the larger component is ($\pm$) capacitive;

$\pm$ (0.5% + 0.5 ohm) if the larger component is resistive,

where L is the resonating inductance in microhenries.

These accuracies apply to measurements on both balanced and unbalanced to ground circuits.

The accuracies of measurement for the smaller component are reduced from those stated roughly in proportion to the ratio of the reactance to effective resistance of the unknown.

3.3 Effect of Leads - Impedance

The accuracy of measurement is also materially affected by the leads used in connecting the impedance to be measured to the bridge. In measuring impedances it is often the practice to balance the capacity of the lead by a lumped capacitance placed across the other side of the bridge. This procedure may often cause considerable error depending on the length and characteristic impedance of the lead as a transmission line. It is recommended in the following that whenever a lead more than about one foot in length is needed to reach the impedance to be measured a similar compensating lead of the same electrical length be placed between the "known" side of the bridge (in this case S_1-S_2) and the resistance (R_1-R_2) and capacitance (C_1-C_2) standards. At balance the effects of the two leads exactly compensate one another and the lead error is zero, irrespective of lead length.

An alternative method in eliminating lead effect which may be used in certain cases is to use a lead of approximately the same characteristic impedance at all frequencies as the unknown impedance to be measured. For example, in measuring impedance of open-wire lines a lead of the same gauge and same spacing as the pair to be measured may be constructed. The measurement is then made as described in Part 4.11, the lead being considered part of the unknown. An advantage of this method of measurement is that changes in the sign of the reactive component can be taken care of by moving the capacitance standard key.

3.4 Effect of Leads - Return Loss

In the case of return loss measurements the lead error in db depends, among other things, upon the value of the return loss, increasing to a constant value as the loss increases. The error depends on a number of factors such as the characteristic impedance and the length of the leads, and the impedance which is connected to it, as well as the frequency involved. It is important always to use as short leads as possible. The worst error occurs when measuring return losses of impedances around 600 ohms using shielded rubber covered wire of relatively low characteristic impedance. For a 60-ft. lead at 30 db return loss and a frequency of 140 kc. the error is about 0.7 db when a dummy compensating lead is used. If the dummy lead were omitted and only one lead were used, the error would be approximately 16 db. The lead error using this same type of lead will be considerably less than this when measuring return loss between impedances near 135 ohms since this is approximately the characteristic impedance of the shielded rubber covered leads.

Spaced leads having approximately the same characteristic impedance as the circuit whose return loss is being measured may be used with less error than when using a long, shielded, rubber-insulated wire lead. In measuring open-wire lines, care should be taken that the lead is of bare wire the same gauge and spacing as the open-wire pair. In cases where two leads are necessary to the same point, care must be taken to avoid excessive coupling between the two leads. This can be accomplished by separating the two leads as much as possible and maintaining the planes of the wires mutually perpendicular. With the two leads terminated in equal impedances of about the value of the impedance to be measured the return loss measured between them should be greater than 50 db.

For most practical purposes it is satisfactory to calibrate at the approximate mid-frequency of the frequency range being covered and use this calibration for all frequencies. In the case of sweep-frequency measurements there may also be errors in return loss due to the variation with frequency of the output of the 17B oscillator and the gain of the 2A amplifier detector unless the equipment is calibrated at each measuring frequency in accordance with Part 4.21, paragraph C. This may amount to a variation of ± .5 db in the case of the 17B oscillator and ± 0.5 db in the case of the 2A amplifier detector. If return loss measurements are being used to obtain impedance as described below, the setup should be calibrated at each frequency at which measurement is made to eliminate these gain variation errors.

4. OPERATION

This bridge is designed to be used in conjunction with the 17B oscillator, the 30A transmission measuring set and the 2A amplifier detector, or their electrical equivalents by connecting them as shown in Fig. 2. This arrangement is common to all the measurements described below. The 17B oscillator is satisfactory as a source of power, and the bridge is capable of utilizing its full output. The 135-ohm output must be used for all cases. The 30A set is satisfactory for the 135-ohm attenuator required for return loss measurements. The attenuator is necessary only when making return loss measurements, and in the following it will be assumed that no attenuator will be used in impedance measurements. This should be used in conjunction with the 2A amplifier detector. Detailed information regarding the 17B oscillator, the 2A amplifier detector and 30A set will be found in current descriptive literature.

The 2A amplifier detector is an untuned device whose maximum sensitivity is such that a signal frequency input of one milliwatt down 53 db will give approximately 0 db deflection on the output meter over the frequency range from voice frequency to 150 kc. The input impedance is 135 ohms. It is so designed that the output meter which it contains cannot be damaged by overloading the input when used in making the measurements below. When the 2A amplifier detector is used it is important to use the 17B oscillator because of the low harmonic output of that type of oscillator.

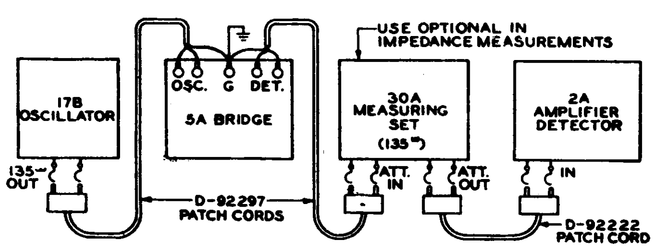


Fig. 2 - Typical Layout of Apparatus

4.1 Measurement of Impedance

Connect the 135-ohm output of the oscillator to the posts or jacks of the bridge marked OSCILLATOR and connect the posts or jacks of the bridge marked DETECTOR to IN of the 2A amplifier detector using shielded patch cord D-92227 or D-92222.

The bridge should generally be grounded as indicated in Fig. 2. The associated pieces of apparatus receive in turn their grounds from the bridge ground via the shields of the patch cords used in connecting together the apparatus.

In the following, a short lead refers to one that is one foot or less in length. A long lead is one that is greater than one foot in length.

4.11 Unknown Impedance Connected to Bridge with Short Lead

A. Set all keys of the impedance bridge in the middle position.

B. Operate the BAL-UNBAL key to the BAL position for measurements on balanced to ground circuits, and to the UNBAL position for grounded measurements. It should be noted that with the key in the UNBAL position, posts S_2 and X_2 and their corresponding jack connections are at ground potential. For measurements on unbalanced to ground circuits the grounded side of the unknown should therefore be connected to X_2.

C. Operate the CAP STD key to the S_1-S_2 position if the impedance to be measured is capacitive and to the X_1-X_2 position if the impedance to be measured is inductive.

D.(1) If the impedance to be measured has an equivalent resistance above 1100 ohms, operate the RES STD key to the S_1-S_2 position, and the 1000-ohm key to the X_1-X_2 position.

(2) If the unknown impedance is below 1100 ohms, leave these keys in the middle position.

E. With the oscillator set at the desired frequency and with an output approximately 25 db above a milliwatt, adjust the gain control of the amplifier detector until a convenient deflection is obtained on the output meter of the amplifier detector. Increasing the oscillator output above this level increases its harmonic content to a point where the accuracy of the measurements may be affected.

F.(1) If the unknown has an equivalent resistance greater than 1100 ohms, set the dials of the capacitance standard on zero and obtain an open circuit balance by varying the ZERO BAL adjustment and the dials of the resistance standard. As balance is approached the output deflection of the amplifier detector will decrease, the gain of the amplifier detector being increased then to maintain an on-scale deflection. Balance is reached at minimum deflection indicated by the fact that any change in either the resistance or capacitance standards increases the deflection.

Note: To obtain an open circuit zero balance if the bridge is used unbalanced, add a small padding condenser of the type commonly used in radio work and of about 100 micro-microfarads capacitance across the bridge terminals X_1-X_2 or S_1-S_2, depending on whether the capacitance standard is connected across S_1-S_2 or X_1-X_2, respectively.

(2) If the unknown is 1100 ohms or less, set the dials of the capacitance standard on zero and obtain an open circuit balance by varying the ZERO BAL adjustment. The resistance standard and the 1000-ohm resistance are out of the circuit.

In both F(1) and F(2), the balance is obtained as before, using the meter of the amplifier detector as an indicator, with the amplifier detector gain control set to give the required sensitivity.

G. If the resistance standard is not already in the circuit, operate the RES STD key to the S_1-S_2 position.

H. Connect the unknown to the X_1-X_2 terminals and rebalance by varying the capacitance and resistance standard until minimum deflection is reached on the amplifier detector as indicated by the fact that any change in the resistance and capacitance standards increases the deflection.

I. The reading of the capacitance standard indicates the equivalent parallel capacitance value of the unknown, the sign of the quadrature component being + or - depending on whether the capacitance standard is connected across S_1-S_2 or X_1-X_2, respectively. If closer accuracy than

3% is required for the reactance, the nominal capacitance values read should be corrected in accordance with the calibration table accompanying the bridge.

The expressions for the resistance of the unknown are

$R = R_1$ for measurements below 1000 ohms

$R = \frac{R_0 \times R_1}{R_0 - R_1}$ for measurements above 1000 ohms

where R_0 is the setting of the resistance standard at open circuit and R_1 is the setting of the resistance standard with the unknown connected across X_1-X_2.

The equivalent series resistance (R_s) and reactance (X_s) can be computed from the measured parallel values of the resistance and capacitance of the unknown by means of the expressions:

$$R_s = \frac{R}{1 + R^2 \omega^2 C^2}$$

$$X_s = \frac{R^2 \omega C}{1 + R^2 \omega^2 C^2}$$

where C = calibrated parallel capacitance in farads of the unknown
$\omega = 2\pi f$ (f = frequency in cycles)
R = resistance in ohms (on parallel basis) of the unknown.

4.12 Impedance Measurement Using Long Leads. Reactance is Negative

A. Set all keys to the middle position except the BAL-UNBAL key, which should be operated to the BAL or UNBAL position depending on whether measurements are to be made on balanced or unbalanced circuits. The oscillator may be set at any convenient frequency.

B. Cut two approximately equal lengths of shielded lead (preferably shielded rubber covered office wiring - #720 cable). These should be of such length as to reach the impedance to be measured. Connect one to the X_1-X_2 posts and the other to the S_1-S_2 posts connecting the shields of the leads in each case to the associated ground post. Adjust the lengths of the two leads by cutting one of them to such a length that a bridge balance is reached.

C. The free end of the lead which is attached to the S_1-S_2 posts should be connected to the capacitance standard posts C_1-C_2, thereby connecting S_1 and S_2 to C_1 and C_2 respectively. Set the capacitance standard on zero. Place a trimmer air condenser (not provided) at the free end of the lead which is connected to posts X_1-X_2 and adjust the trimmer for zero balance. This is to balance out the residual capacitance of the capacitance standard as explained in Part 2. The trimmer condenser should have a maximum capacity of approximately 250 f and may be of the type commonly employed in radio work.

D. Operate the RES STD key to C_1-C_2. Connect the unknown impedance to the lead connecting to the posts X_1-X_2. If the unknown is a grounded circuit, the grounded side should be connected to X_2. Balance the bridge. If the series components of the unknown impedance are desired they may be computed as per Part 4.11, Paragraph I.

Fig. 3 shows the bridge arranged to make a measurement of impedance of a balanced to ground circuit having negative reactance, the resistive component being less than 1100 ohms. Leads are shown connecting the unknown to the bridge.

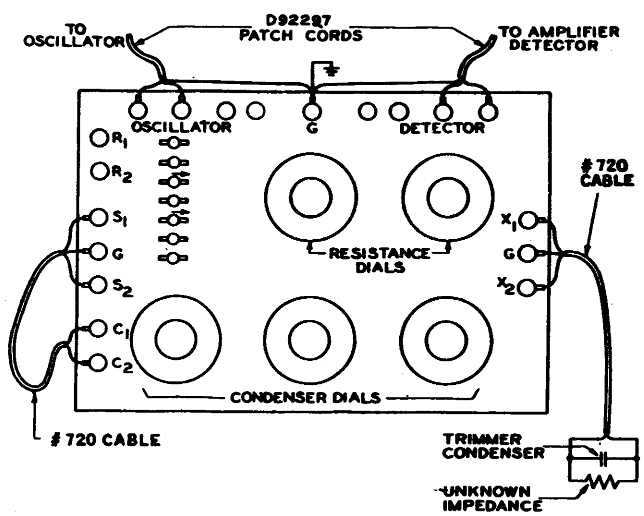


Fig. 3 - Connections for Measuring Impedance with Negative Reactance. Long Leads Used

4.13 Impedance Measurement where Long Lead is Necessary to Connect Unknown to the Bridge. Reactance is Positive

In this measurement a fixed condenser must be placed directly across the unknown impedance and must be of such a magnitude as to more than annul the positive reactance of the unknown. The procedure is as follows:

A. Cut and balance the leads as in paragraphs A, B and C of Part 4.12.

B. Operate the RES STD key to C_1-C_2 and connect the unknown impedance to the lead attached to X_1-X_2. Place a condenser of approximately 0.1 microfarad or less across the unknown impedance. This condenser may be a commercial molded mica condenser such as is used in radio work. This is in addition to the trimmer condenser. Balance the bridge if possible. If the bridge cannot be balanced increase the capacitance across the unknown by adding other condensers until a balance can be obtained.

C. Subtract the capacitance reading of the bridge at balance from the total capacitance shunted across the unknown. This difference in capacitance as expressed in farads is used directly in the formulas in paragraph I, Part 4.11 to give the series impedance of the unknown. The sign of the reactance is positive.

D. The total value of the shunt capacitance used can be measured, if not already known, as per Part 4.1.

4.2 Return Loss Measurements

In many instances in the field it is desired to adjust impedances to meet certain return loss requirements. Although such can be done by means of impedance measurements, the computations involved in the derivation of return loss make direct measurements desirable in many instances. The bridge is arranged for making such return loss measurements: (1) between any two impedances, and (2) between any impedance and the resistance and capacitance standards of the bridge itself.

4.21 General Procedure

The general procedure in making a return loss measurement is the same in all cases.

A. Connect as in Fig. 2 the oscillator, attenuator and amplifier detector to the bridge as in making an impedance measurement. The same equipment is satisfactory for both types of measurements. Set oscillator to the desired frequency and adjust the output to approximately +25 db with respect to one milliwatt. The 135-ohm output of the oscillator must be used. Set all keys of the bridge to the middle or normal position.

B. Operate the BAL-UNBAL key to the BAL position for measurements on balanced to ground circuits, and to the UNBAL position for grounded measurements. It should be noted that with the key in the UNBAL position, posts S_2 and X_2 and their corresponding jack connections are at ground potential. For measurements on unbalanced to ground circuits the grounded side of the unknown should therefore be connected to X_2.

C. Calibrate the bridge by operating keys STD and CAL 25 DB to 600ω or to 135ω depending on which is nearer the value of the impedances between which the return loss is to be measured. Set the attenuator of the 30A set to 25 db and adjust the gain control of the 2A amplifier detector until the meter of the 2A amplifier detector reads 0 db. If this is not practicable reduce the loss in the attenuator until the 0 reading is obtained. Designate the attenuator reading as A_1.

D. Restore STD and CAL 25 DB keys to middle position.

E. Connect the impedances to the bridge in the manner detailed below for the various conditions.

F. Readjust the attenuator until the output meter reads as nearly the previous level as possible, leaving unchanged the gain control of the amplifier detector and the output of the oscillator. Designate the attenuator and meter readings as A_2 and M_2, respectively. Due regard must be given to the sign of M_2. The return loss is $(25+A_1)-(A_2+M_2)$ db.

The general procedure outlined in this section depends on whether or not leads are needed to connect the unknown impedance or impedances to the bridge. Therefore each case is discussed individually below. In each case the equipment is connected and calibrated and the results are computed as in paragraphs A, B, C, D and F of Part 4.21.

4.22 Short Leads Required

4.221 Measurements Between Two Impedances of Unknown Value

A. Connect the oscillator and other equipment to the bridge and calibrate for 25 db as explained in the foregoing paragraphs A, B, C and D of Part 4.21 using either 135 or 600 ohms, depending on which is thought to be nearer the impedance of the two unknowns.

B. Connect one of the impedances to posts X_1-X_2 and the other to S_1-S_2.

C. Make the measurement and compute as in paragraph F, Part 4.21.

Figure 4 shows the bridge connected for such a measurement.

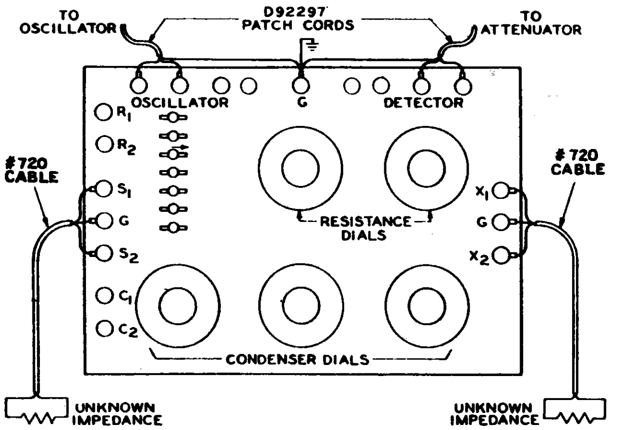


Fig. 4 - Return Loss Measurement Between Two Impedances of Unknown Value. Short Leads Required.

4.222 Return Loss Measurements Between 135 or 600 Ohms and an Unknown Impedance

A. Set up and calibrate the equipment as described in Part 4.21.

B. Connect the unknown to X_1-X_2 and operate the STD key to either the 600 or the 135-ohm side depending on which the unknown is to be measured against.

C. Measure and compute as in paragraph F, Part 4.21.

4.223 Return Loss Measurements Against Any Resistance Standard

A. Set up and calibrate the equipment as in Part 4.21.

B. Connect the unknown to X_1-X_2 and operate key RES STD to S_1-S_2. Adjust the standard resistance dials of the bridge to the value of resistance against which return loss is to be measured. Measure and compute as in paragraph F, Part 4.21.

4.23 Long Leads Required Between Unknown and Bridge

4.231 Return Loss Measurements Between Two Impedances of Unknown Value

A. Connect oscillator, attenuator and amplifier detector to the bridge and calibrate as in Part 4.21.

B. Cut two approximately equal lengths of shielded lead (preferably shielded rubber covered office wiring #720 cable). They should be no longer than is necessary to reach the unknown. Connect one lead to the X_1-X_2 posts and the other to the S_1-S_2 posts, connecting the shields of the leads in each case to the associated ground posts. With the UNBAL-BAL key set to BAL and all other keys on the bridge in the middle position, adjust the lengths of the two leads by cutting them until a bridge balance is reached, as indicated by the output meter. The procedure is the same as described previously in Part 4.12 in making impedance measurements. Spaced leads may also be used as described in Part 3.4.

C. Connect the two unknown impedances to the free ends of the two leads, respectively, and proceed to measure the loss as in paragraph F, Part 4.21.

4.232 Return Loss Measurements Between an Unknown Impedance and Any Fixed Resistance

Repeat 4.231 except connect terminals S_1 and S_2 to terminals R_1 and R_2, respectively and ground the shield of the #720 cable to the G post associated with S_1 and S_2. Adjust the standard resistance dials to the value against which return loss is being measured. Operate the UNBAL-BAL key to the appropriate position; all other keys should be in the middle position. Measure the loss as in paragraph F, part 4.21. Fig. 5 shows the bridge connected for such a return loss measurement on a balanced to ground circuit.

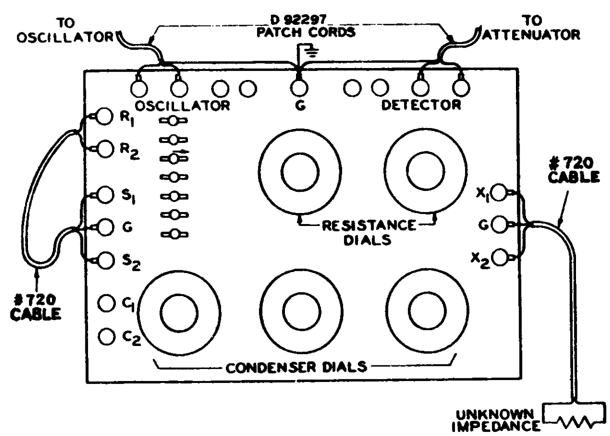


Fig. 5 - Return Loss Measurement Between Unknown Impedance and any Fixed Resistance. Long Leads Required

In order to facilitate converting return loss values to their equivalent reflection coefficients the relation between the two as shown graphically on page 104 is provided.

4.3 Impedance from Return Loss Measurements

4.31 General Discussion

As pointed out previously the 5A bridge is satisfactory for the direct measurement of impedance in terms of parallel resistance and capacitance. Where it is desirable to know the impedance in terms of series resistance and capacitance, the parallel resistance and capacitance can be converted by means of the formula in 4.11. It is possible, however, to obtain the series impedance of an unknown impedance graphically from two return loss measurements made between the unknown and each of two resistances differing by a few ohms. No computations are necessary and no balancing of resistance or condenser standards need be done. However, there is a sacrifice in accuracy under certain conditions.

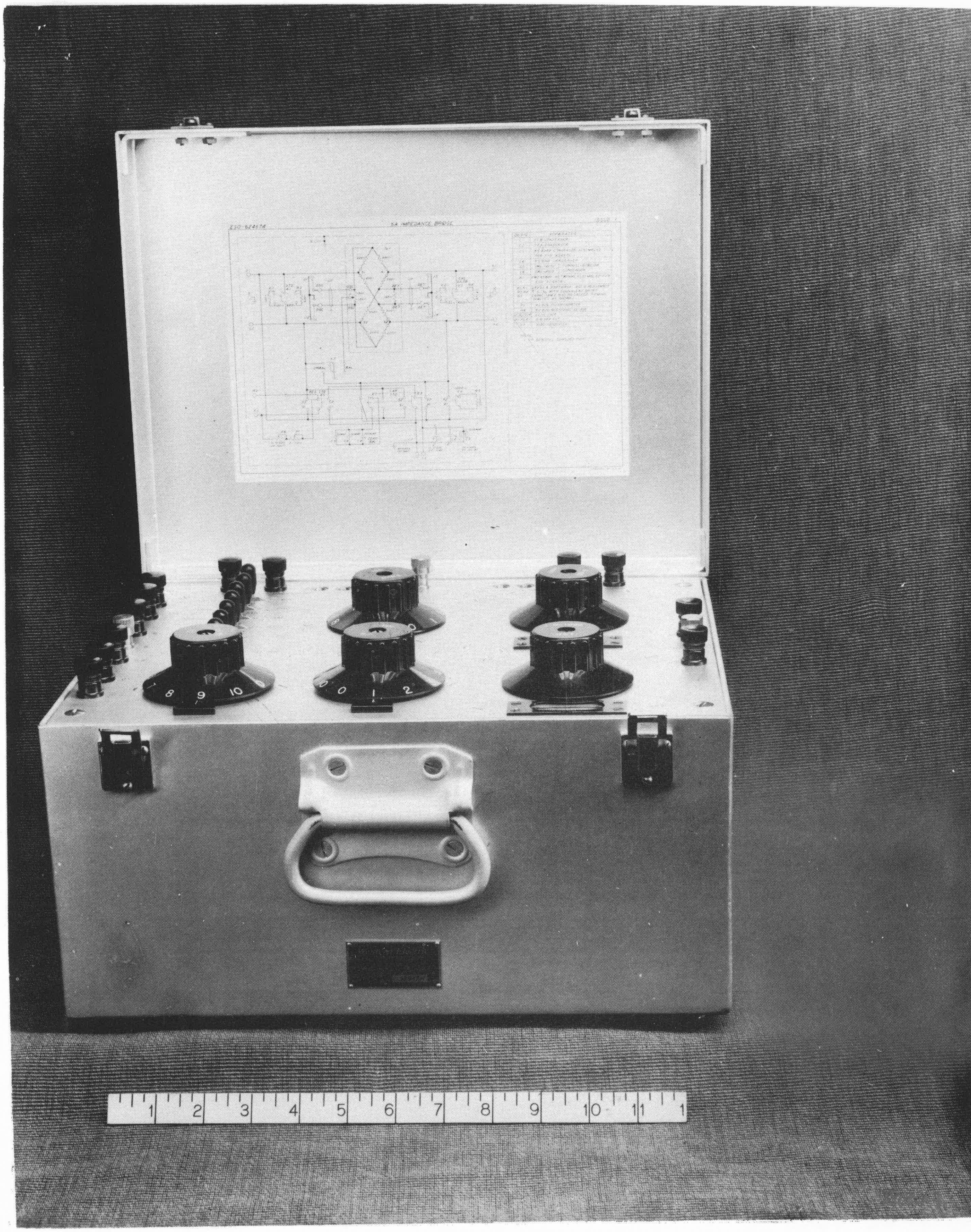
It is well known that all the possible impedances which give a fixed return loss against a fixed resistance, lie on a circle whose radius and center depend on the return loss. Therefore, a measurement of return loss of an unknown impedance against 600 ohms gives the radius and center of a circle somewhere on which the unknown impedance must lie. Similarly, a second return loss measurement against a different resistance gives a circle of different size and center. The intersections of these two circles give the resistance and reactance of the unknown but not the sign of the reactance. Charts appropriate to the bridge are attached for thus obtaining impedance from two return loss measurements. Each of these charts comprises two sets of circles, each set corresponding to a series of fixed return losses against a fixed resistance.

4.32 Procedure for Obtaining Impedance

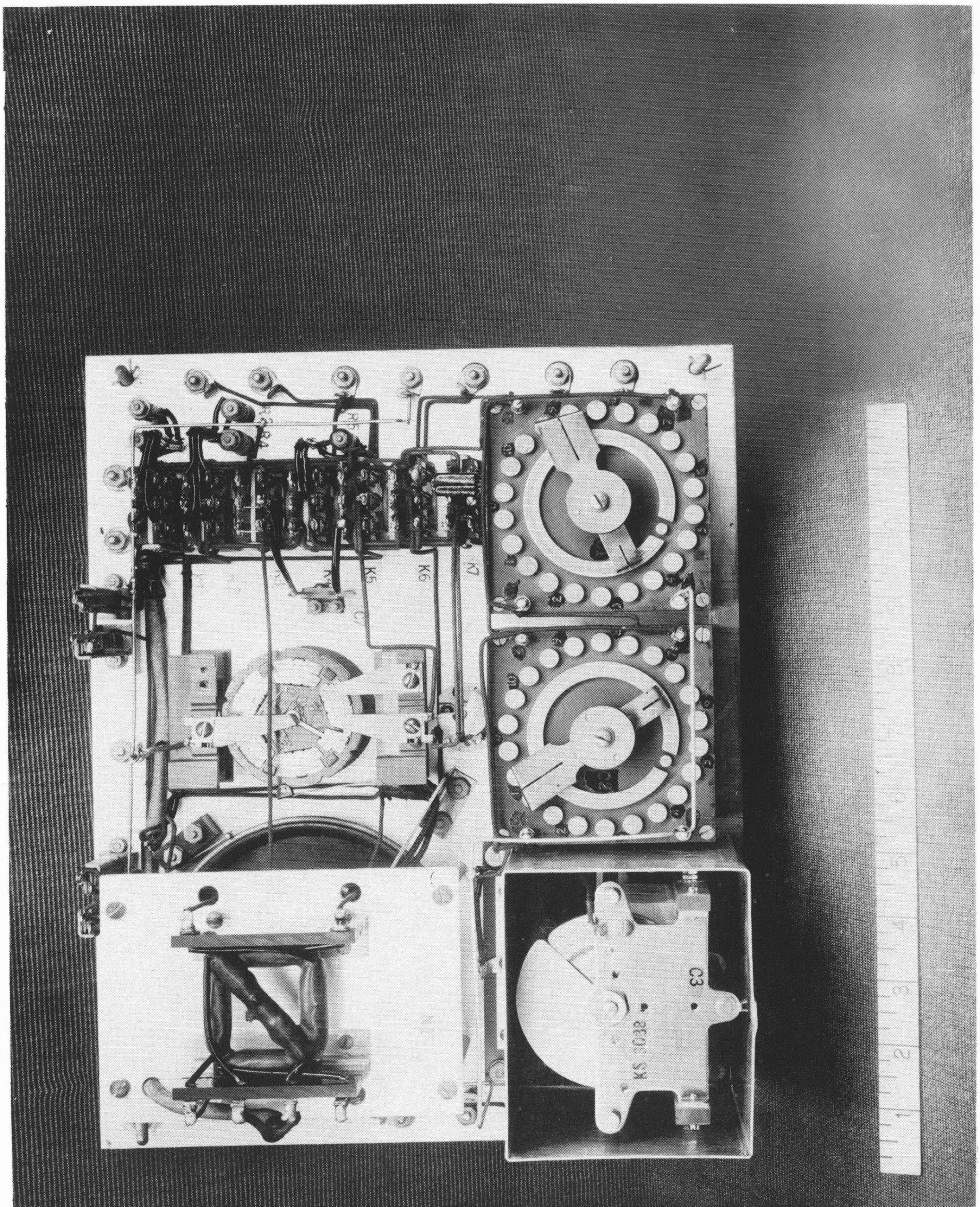
Attached are four charts, pages 13 to 16, inclusive, which have been prepared showing return loss circles against resistance values of 125, 135 and 145 ohms; and also 500, 550 and 600 ohms.

A. In making such a measurement, first estimate the approximate value of the unknown impedance which in most carrier work will be in the range of resistance listed above and make two return loss measurements as per Part 4.232. The two measurements should be made against two standard resistances in the above list which are on either side of the estimated impedance of the unknown. Enter the chart which is appropriate to the two standards used and estimate by interpolation the two circles corresponding to the two return losses measured. The intersection of the two circles gives the impedance, but not the sign of the reactance. This may be determined simply at the conclusion of one or the other return loss measurement. When long leads are used between the X_1-X_2 terminals and the unknown impedance, and between the S_1-S_2 terminals and the R_1-R_2 terminals of the resistance standard as set forth on 4.232, the sign of the reactance may be determined by throwing the key RES STD to C_1-C_2 and turning the condenser standard from its zero setting so as to put capacitance in parallel with the resistance standard. When short leads are used as set forth in 4.223 the capacitance standard should be added to the resistance standard by throwing the CAP STD key to the S_1-S_2 position. If, as the capacitance is increased from zero, the return loss decreases (meter reading increases) the reactance of the unknown is inductive in sign. If the return loss increases, the sign is negative.

As an illustration of the procedure to be followed, assume that the impedance of an 8 inch spaced 128-mil open-wire line is to be measured. It is probable that its impedance lies somewhere between 550 and 600 ohms. Therefore, measure its return loss against a 600-ohm standard and then against a 550-ohm standard, as described in Part 4.232. Assume that the measured return losses are 32 and 33 db, respectively. After measuring the return loss against 550 ohms, and with all adjustments unchanged throw key RES STD to C_1-C_2 and increase slowly the setting of the capacitance standard starting from zero. Assume the output meter reading decreases as the capacity is increased. The reactance of the open-wire line must be negative, as explained above. After determining the sign of the reactance, enter the 550-600-ohm chart and locate the 32 db circle centering around 600 ohms and then estimate the location of the 33 db circle centered around 550 ohms. The two circles intersect at 573 ± j 12 ohms. Since it has been determined that the reactance is negative the unknown impedance is, therefore, 573-j 12 ohms.



Photograph 1 — View of Bridge



Photograph 2 — Interior View of Bridge

BELL TELEPHONE LABORATORIES, INC.

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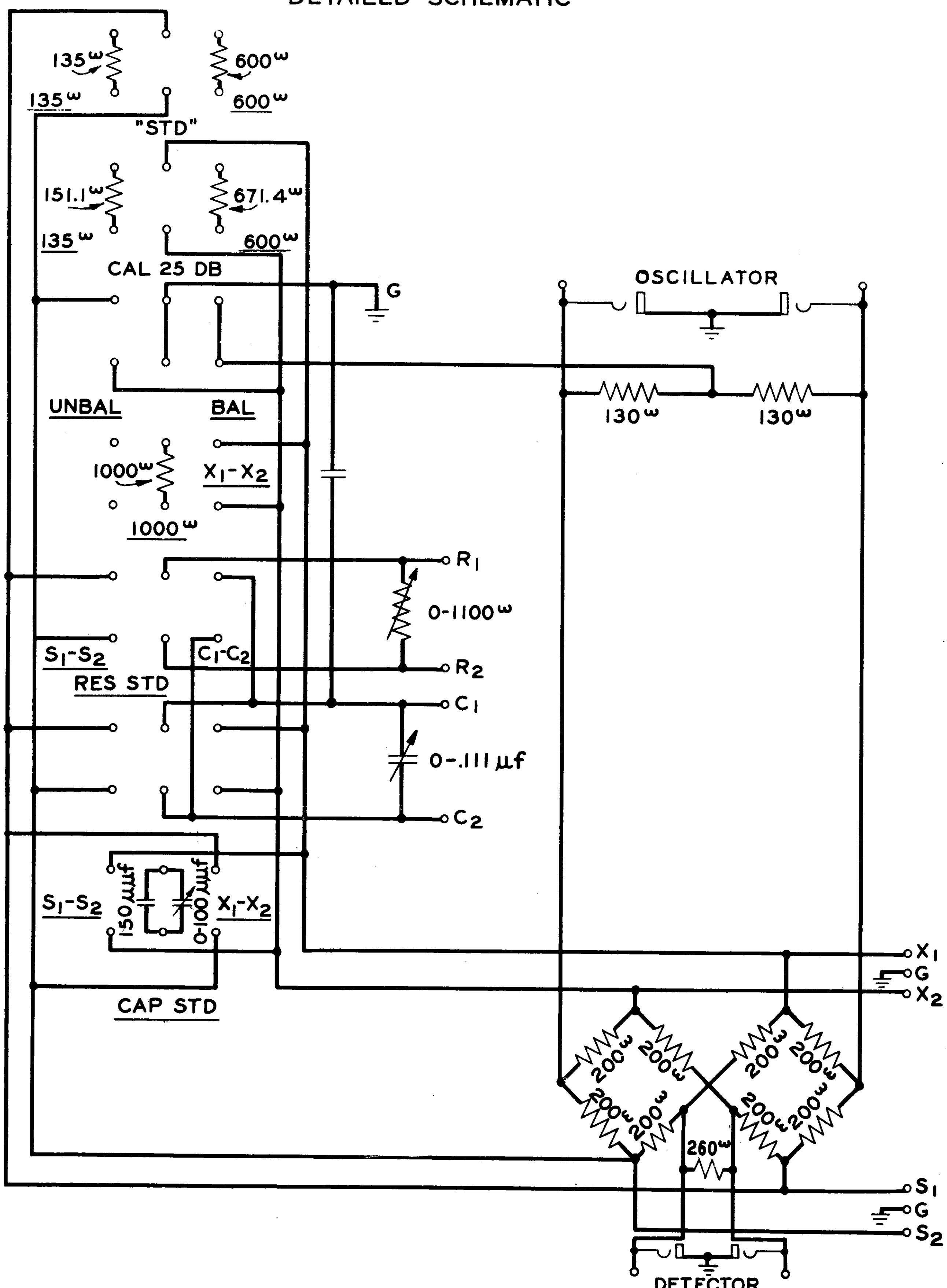
H.E.C. 4-26-38

5A IMPEDANCE BRIDGE
DETAILED SCHEMATIC



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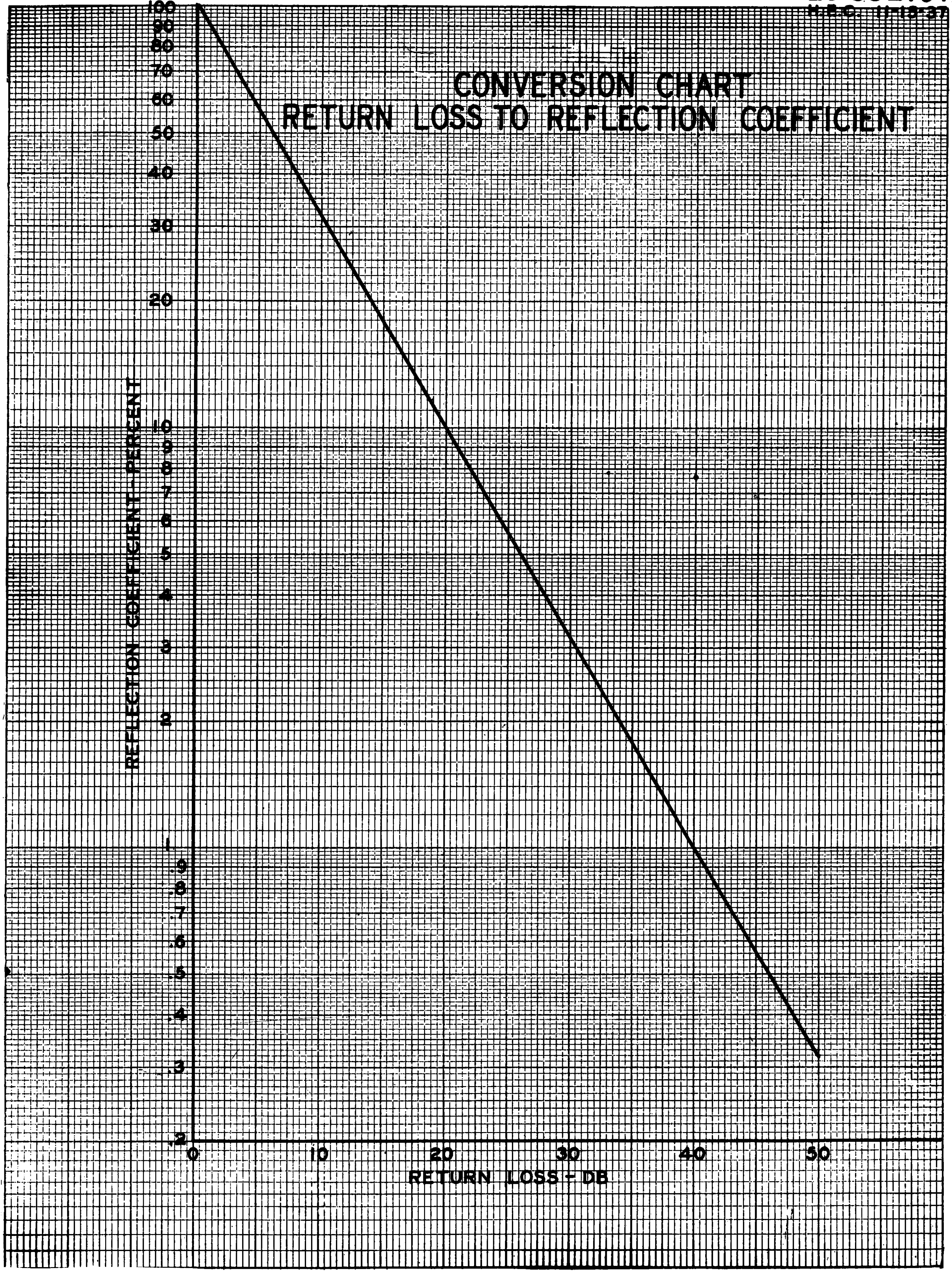
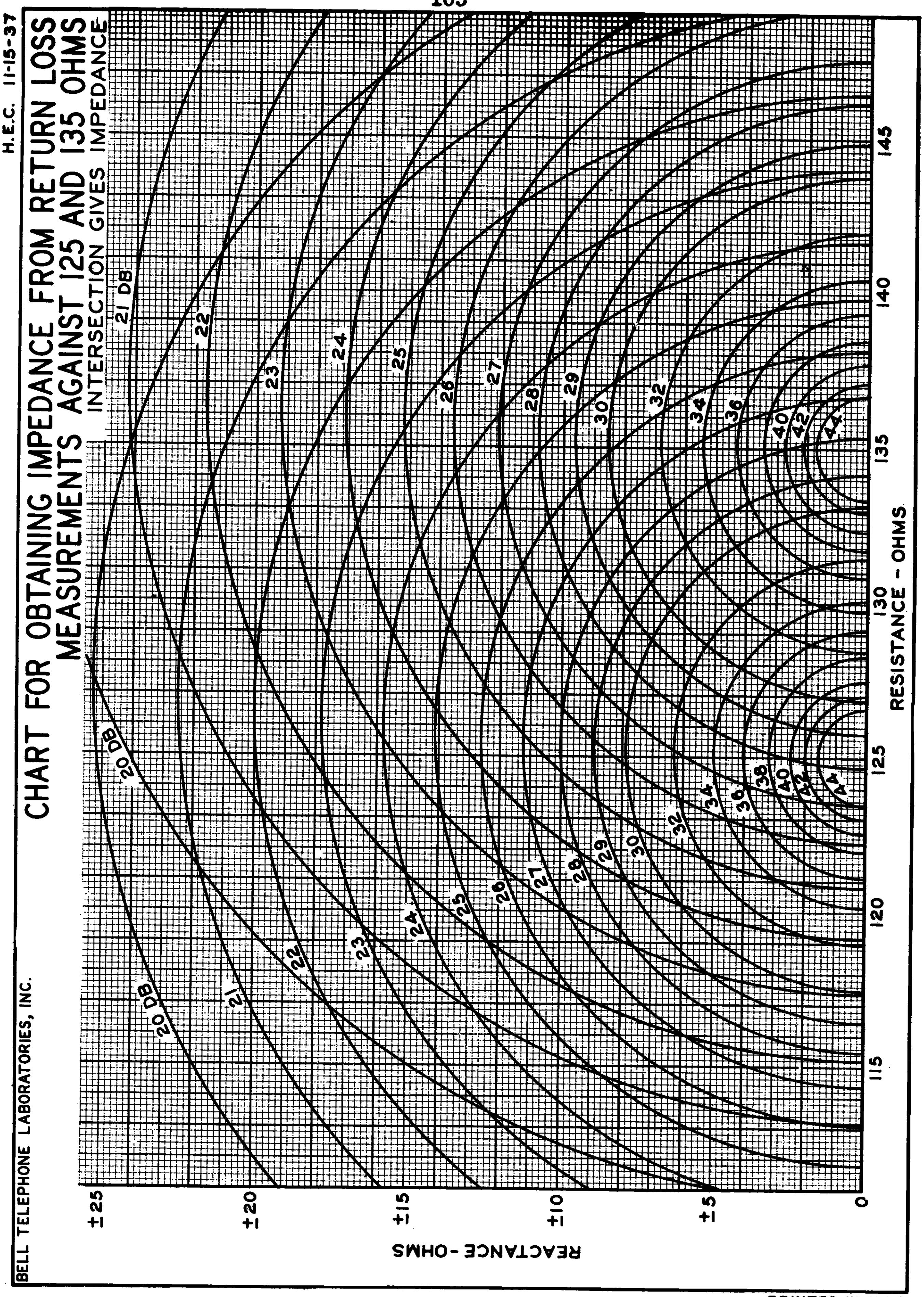
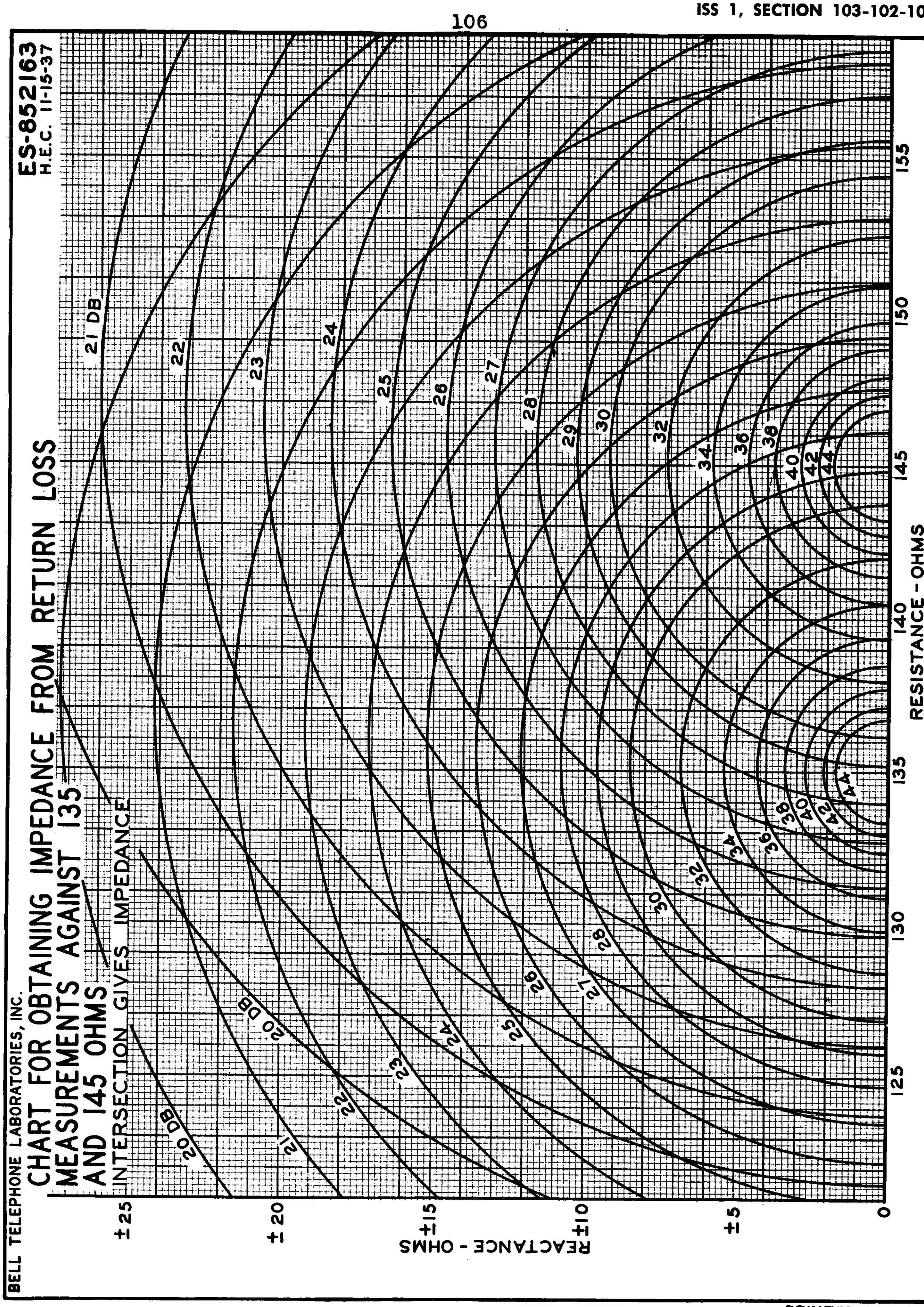
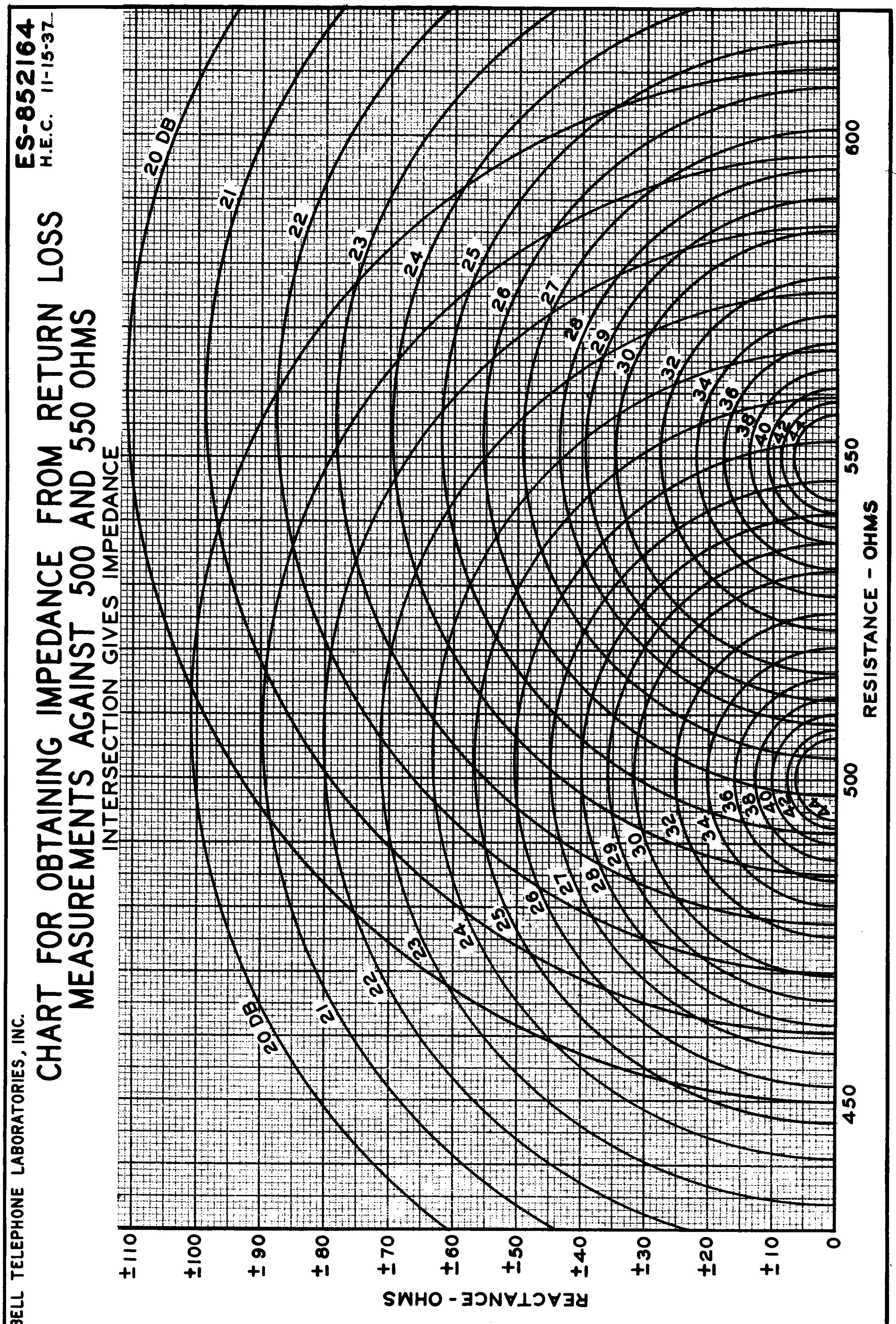
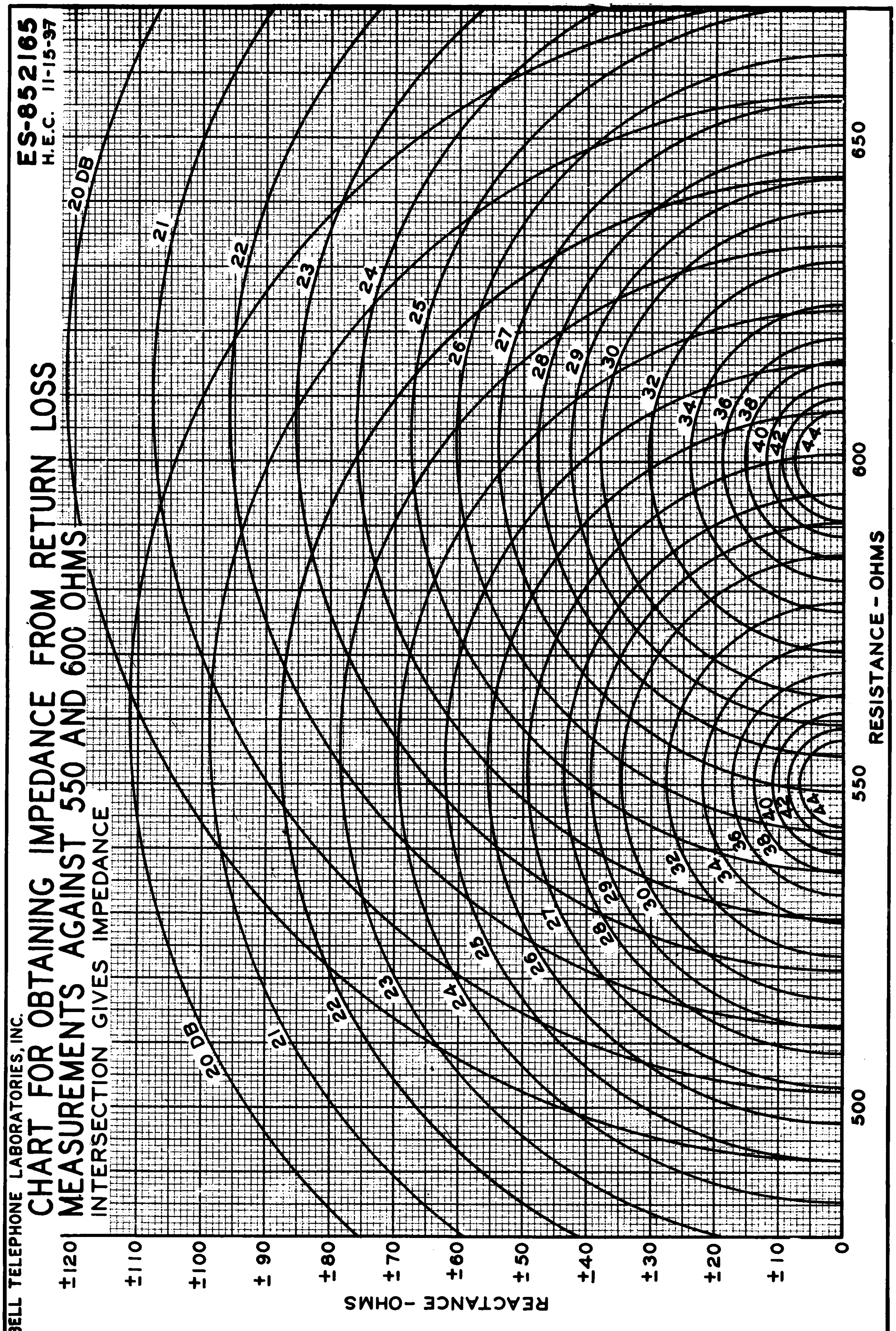



ES-852162
H.E.C. 11-15-37
CHART FOR OBTAINING IMPEDANCE FROM RETURN LOSS
MEASUREMENTS AGAINST 125 AND 135 OHMS
INTERSECTION GIVES IMPEDANCE
BELL TELEPHONE LABORATORIES, INC.
REACTANCE - OHMS
±25
±20
±15
±10
±5
0
RESISTANCE - OHMS
115
120
125
130
135
140
145
20 DB
21 DB
21
22
23
24
25
26
27
28
29
30
32
34
36
38
40
42
44


106
BELL TELEPHONE LABORATORIES, INC.
CHART FOR OBTAINING IMPEDANCE FROM RETURN LOSS
MEASUREMENTS AGAINST 135
AND 145 OHMS
INTERSECTION GIVES IMPEDANCE
ES-852163
H.E.C. 11-15-37
RESISTANCE - OHMS
REACTANCE - OHMS


BELL TELEPHONE LABORATORIES, INC.
CHART FOR OBTAINING IMPEDANCE FROM RETURN LOSS MEASUREMENTS AGAINST 500 AND 550 OHMS
INTERSECTION GIVES IMPEDANCE
ES-852164
H.E.C. 11-15-37
REACTANCE - OHMS
±110
±100
±90
±80
±70
±60
±50
±40
±30
±20
±10
0
RESISTANCE - OHMS
450
500
550
600
20 DB
21
22
23
24
25
26
27
28
29
30
32
34
36
38
40
42
44



BELL TELEPHONE LABORATORIES, INC.
CHART FOR OBTAINING IMPEDANCE FROM RETURN LOSS
MEASUREMENTS AGAINST 550 AND 600 OHMS
INTERSECTION GIVES IMPEDANCE
ES-852165
H.E.C. 11-15-37
RESISTANCE - OHMS
REACTANCE - OHMS
500
550
600
650
±120
±110
±100
± 90
± 80
± 70
± 60
± 50
± 40
± 30
± 20
± 10
0
20 DB
21
22
23
24
25
26
27
28
29
30
32
34
36
38
40
42
44