

**KS-14959 TEST SET
 (PORTABLE WHEATSTONE BRIDGE)**

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1. GENERAL

1.01 This section describes the KS-14959 test set (portable Wheatstone bridge) used in making resistance measurements and locating faults in conductors by means of bridge measurements.

1.02 Either the 5430A test set manufactured by the Leeds and Northrup Company or the RN3 test set manufactured by the Industrial Instruments Company may be supplied under the KS-14959 test set designation.

1.03 While the information in this section applies specifically to the KS-14959 test set, it is applicable to other type bridges. If another type bridge is used, it will be necessary to determine the functions of its dials and keys. This information is generally given in the instructions in the cover of the bridge.

2. DESCRIPTION

A. Leeds and Northrup 5430 and 5430A Test Sets

2.01 Fig. 1 shows the Leeds and Northrup 5430A test set. The superseded Leeds and Northrup 5430 test set is similar to the 5430A except for the following differences in the face-plates: The galvanometer key is marked IN and OUT instead of R.V.M. and HIL and the battery key is marked IN and OUT instead of INT and EXT. Each set weighs about 9-1/2 pounds and is contained in a wooden case 9 inches long, 7-1/2 inches wide, and 6-1/2 inches high. Three KS-14711 dry batteries are required; these must be ordered separately.

2.02 Fig. 2 shows the circuit diagrams of the Leeds and Northrup 5430 and 5430A test sets.

2.03 The designations of the various dials, keys and binding posts on the 5430A and 5430 test sets and the function and operation of each are given below:

R Arm: The R arm or balancing rheostat has four dials marked 1000, 100, 10, and 1 and is variable from 0 to 10,110 ohms in steps of one ohm. In operating the bridge, the 1000 dial is adjusted first, starting at zero

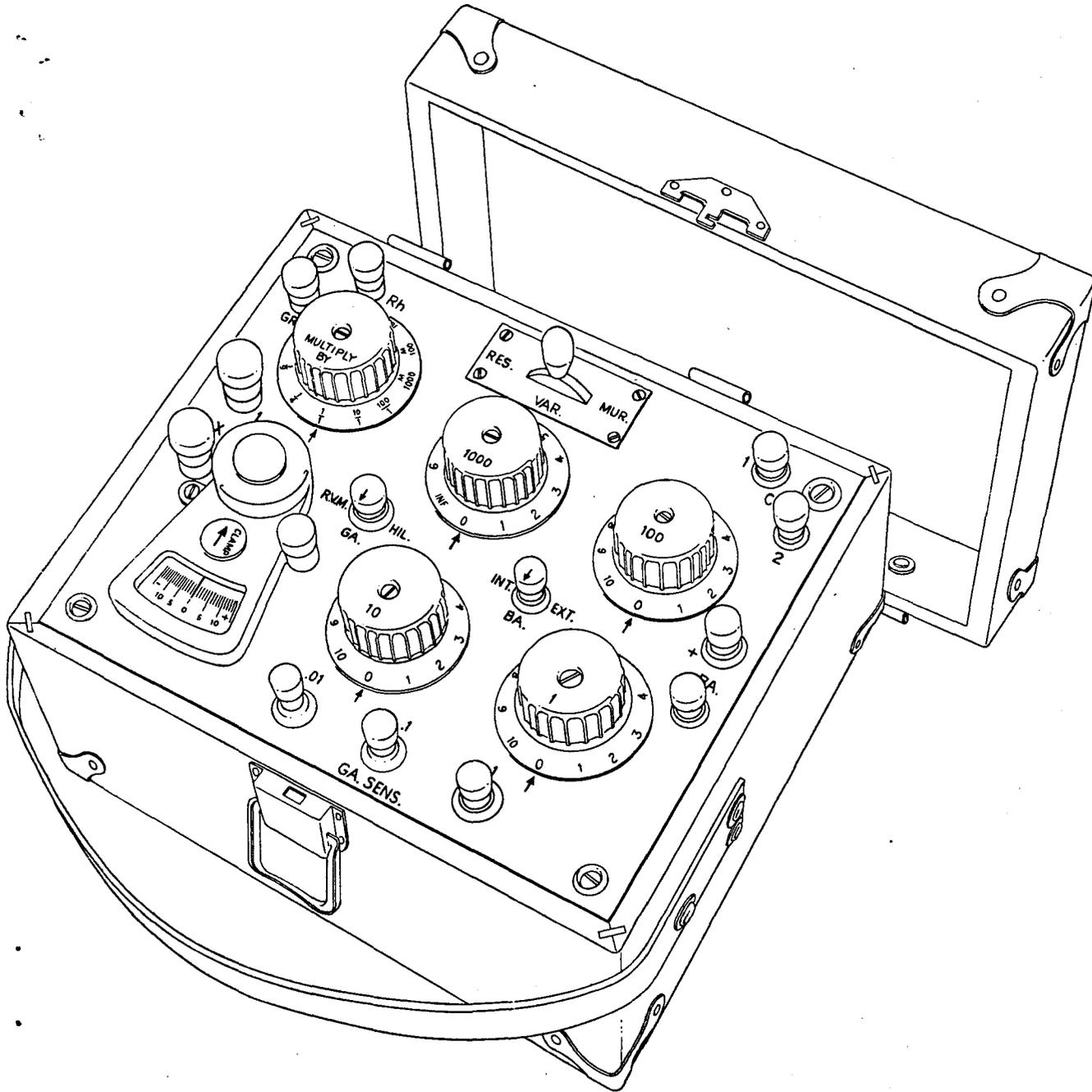


Fig. 1 - Leeds and Northrup 5430A Test Set

and working to the value directly below the one which causes a reversal in the movement of the galvanometer needle. The 100, 10 and 1 ohm unit dials are similarly adjusted in the order named until no deflection is apparent or until a change of one position on the 1 ohm unit dial reverses the deflection.

Ratio $\frac{A}{B}$: The markings on the MULTIPLY BY dial indicate the relative values of the two resistors known as the A and B arms of the bridge. These arms together with the R arm constitute the three variable resistors generally used in making Resistance and Varley measurements. The markings M1000, M100, and M10 indicate the dial positions in which the A arm has the designated resistance and the B arm is eliminated. The M settings are used in making Murray Loop measurements.

The ratios used in Varley and Resistance measurements are 1/1000, 1/100, 1/10, 1/9, 1/4, 1/1, 10/1, and 100/1. These ratios provide for measurements up to one megohm and Varley and Murray measurements of any length of conductor likely to be encountered. The 1/9 and 1/4 ratios are especially useful in the Three-Varley method of locating grounds, crosses, and shorts.

Galvanometer: The moving system (needle, zero adjustment, locking device and scale) of the galvanometer is a removable unit mounted on the faceplate. The sensitivity of the galvanometer is such that one volt impressed through a resistance of one megohm will produce a deflection of at least one scale division.

The set should be as level as practicable and the pointer should be set at zero by means of the zero adjustment knob before measurements are made. When the set is not in use, the needle should be held in place by means of the locking clamp.

Shunt Keys (GA SENS): These keys and their associated shunts are in the galvanometer circuit and control the amount of current that will flow through the galvanometer. With the GA1.0 key depressed, maximum current flows through the galvanometer; one-tenth of this current flows

through the galvanometer when the GA.1 key is depressed and one-hundredth when the GA.01 key is depressed.

In balancing the bridge, the GA.01 key is depressed first. When the needle deflection has been reduced to one or two scale divisions, the GA.1 key may be depressed. When balancing has again reduced the needle deflection to one or two scale divisions, the GA1.0 key may be used to complete the balancing. The shunt keys also serve to connect battery to the bridge and, therefore, it is necessary to press only one key in balancing the bridge.

Loop Key: The three-position lever-type key on the bridge provides means for setting up the desired circuit in making Resistance, Varley, or Murray Loop measurements. The corresponding key positions are marked RES, VAR, and MUR.

Galvanometer Key (GA): In the 5430A set, the key has two positions marked R.V.M. and HIL. The key should be set at R.V.M. in making Resistance, Varley, and Murray measurements. The HIL (Hilborn) setting is no longer used. If an external galvanometer or telephone receiver is used in making a measurement, the internal galvanometer should be disconnected from the circuit by removing the knurled head galvanometer supporting screw.

In the 5430 set, the key has two positions marked IN and OUT. With the key set at IN, the internal galvanometer is operative. If an external galvanometer or a telephone receiver is used with the bridge, the key should be turned to the OUT position. The external galvanometer or receiver should be connected to the GA1 and GA2 posts.

Battery Key (BA): This is a two-position key marked INT-EXT in the 5430A set and IN-OUT in the 5430 set. With the key in the INT or IN position, the internal battery is operative. In the EXT or OUT position, an external battery can be connected to the BA+ and BA- posts. The internal battery consists of three KS-14711 dry batteries which can be replaced when necessary without removing the faceplate. With this voltage the bridge is sufficiently sensitive to permit balancing the

R arm to an accuracy of .1 per cent when measuring the loop resistance of cable conductors or locating grounds, crosses, and shorts of low resistance.

In the case of faults having a resistance of several thousand ohms or more, higher voltage may be employed. In general, a higher voltage is preferable to a more sensitive galvanometer in locating faults of fairly high resistance. With a sensitive galvanometer fluctuations of the galvanometer needle due to interfering potentials are so magnified that the advantage gained from the greater galvanometer deflection is partially offset. A 1000-ohm current limiting resistor is connected in series with one of the BA binding posts. The resistor affords sufficient protection to the bridge for external battery potentials of approximately 45 volts. If a higher voltage battery is used, sufficient external resistance should be connected in series with the battery to make a total current limiting resistance equal to about 20 ohms per volt. An external resistor need not be used when a Megger is employed as the source of potential, as the internal resistance of this set will limit the current sufficiently.

Binding Posts:

BA+ and BA-: For connecting external sources of potential to the bridge.

GA1 and GA2: For connecting an external galvanometer or receiver to the bridge.

X₁, X₂, and GR: The good and bad wires and ground are connected to these posts in various ways, depending on the nature of the trouble, in making bridge measurements.

RH: The balancing rheostat of the bridge (R arm) is accessible for use as a variable resistance through binding posts RH and X₂. The RH post is not used in cable fault locating work.

B. Industrial Instruments Company RN3 Test Set

2.04 Fig. 3 shows the Industrial Instruments Company RN3 test set. The set weighs about 9-1/2 pounds and is contained in a wooden

case 9-1/4 inches long, 7-1/2 inches wide and 6-1/2 inches high. Three KS-14711 dry batteries are required; these must be ordered separately.

2.05 Fig. 4 shows the circuit diagram of the Industrial Instruments Company RN3 test set.

2.06 The designations of the various dials, keys, and binding posts and the function and operation of each are given below.

R Arm: The R arm or balancing rheostat has four dials marked 1000, 100, 10, and 1 and is variable from 0 to 10,110 ohms in steps of one ohm. In operating the bridge, the 1000 dial is adjusted, starting at zero and working to the value directly below the one which causes a reversal in the deflection of the galvanometer needle. The 100, 10, and 1 ohm unit dials are similarly adjusted in the order named until no deflection is apparent or until a change of one position on the 1 ohm unit dial reverses the deflection.

Ratio: The markings on the Ratio $\left(\frac{A}{B}\right)$ dial indicate the relative values of the two resistors known as the A and B arms of the bridge. These arms together with the R arm constitute the three variable resistors generally used in making Resistance and Varley measurements. The markings M1000, M100, and M10 indicate the dial positions in which the A arm has the designated resistance and the B arm is eliminated. The M settings are used in making Murray Loop measurements.

The ratios used in Varley and Resistance measurements are 1/1000, 1/100, 1/10, 1/9, 1/4, 1/1, 10/1, 100/1, and 1000/1. These ratios provide for measurements up to one megohm and Varley and Murray measurements of any length of conductor likely to be encountered. The 1/9 and 1/4 ratios are especially useful in the Three-Varley method of locating grounds, crosses, and shorts.

Galvanometer: The galvanometer is similar to the galvanometer in the 5430A, Leeds and Northrup test set.

Shunt Keys (GA SENS): These keys are similar to those in the Leeds and Northrup 5430A test set and operated in the same manner.

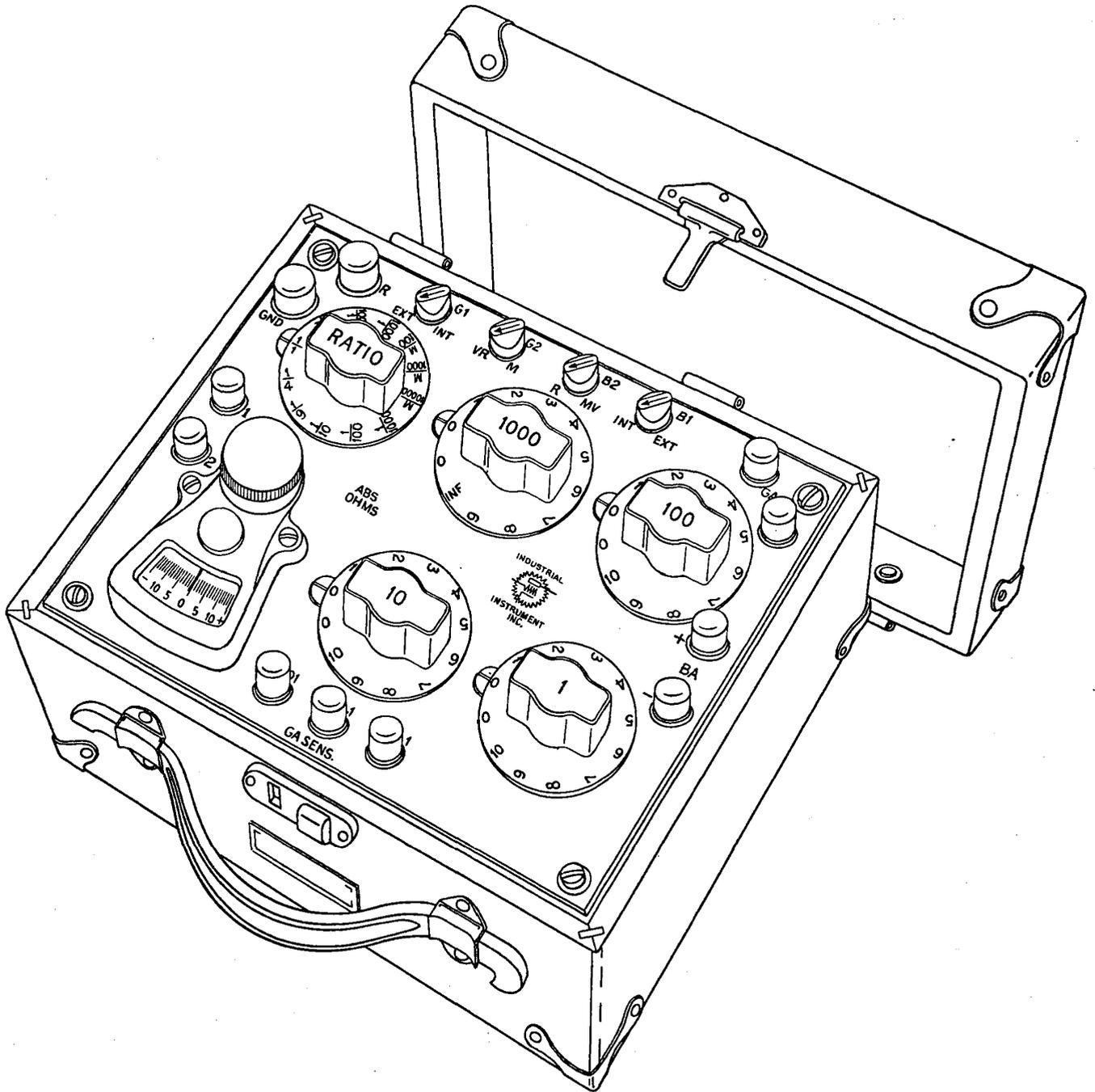


Fig. 3 – Industrial Instruments Company RN3 Test Set

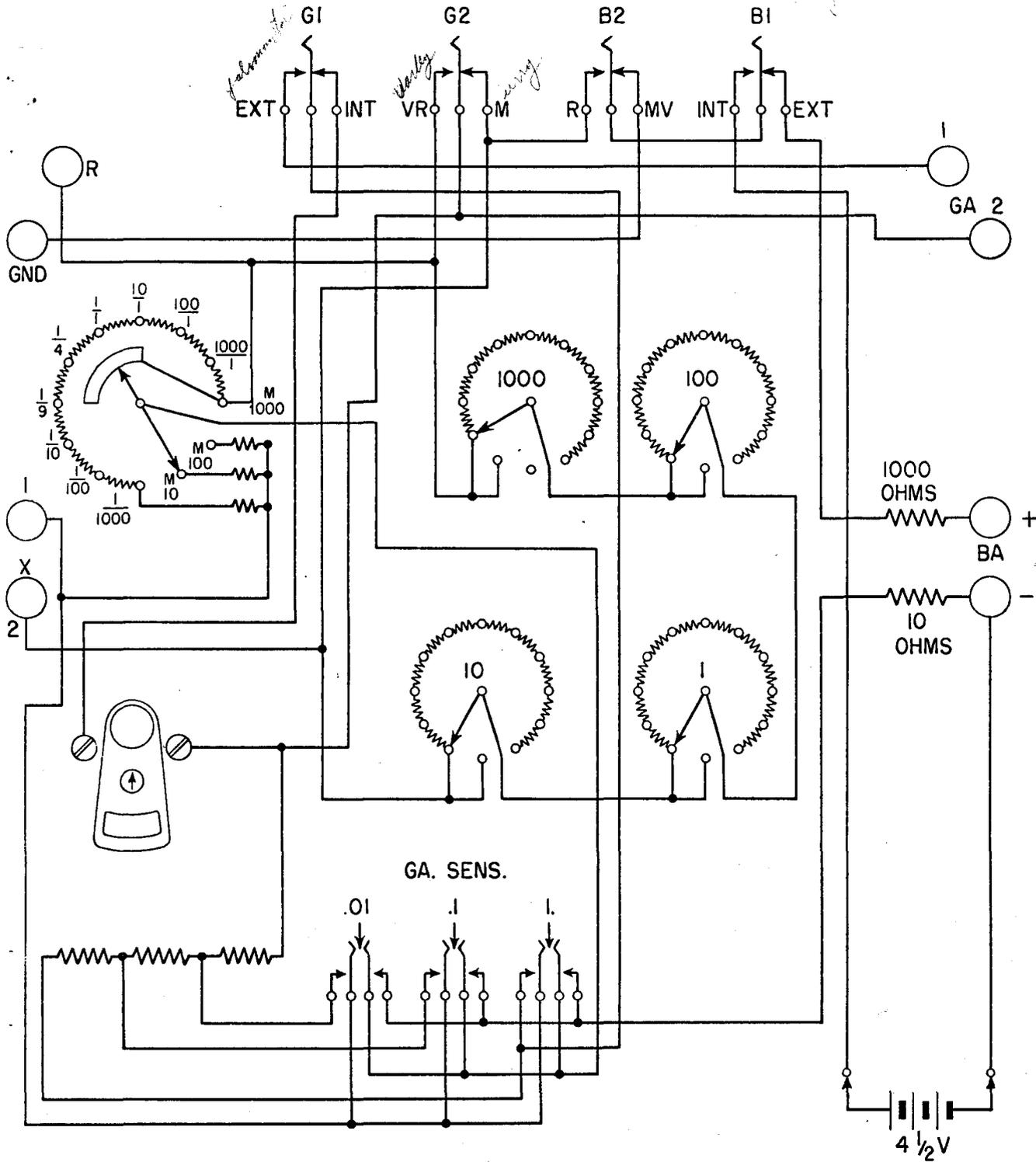


Fig. 4 - Circuit Diagram of Industrial Instruments Company RN3 Test Set

Loop Keys (G2 and B2): These are two turn keys which provide means for setting up the desired circuit to make Resistance, Varley, or Murray Loop measurements. For a resistance measurement set the keys at VR and R, for a Varley at VR and MV, and for a Murray at M and MV.

Galvanometer Key (G1): This is a two-position key marked EXT and INT. With the key set at INT, the internal galvanometer is operative. If an external galvanometer or a telephone receiver is used with the bridge, the key should be turned to the EXT position. The external galvanometer should be connected to the GA binding posts.

Battery Key (B1): This is a two-position key marked INT-EXT. With the key in the INT position, the internal battery is operative. In the EXT position, an external battery can be connected to the BA+ and BA- posts. The internal battery consists of three KS-14711 dry batteries which can be replaced when necessary without removing the faceplate.

With this voltage the bridge is sufficiently sensitive to permit balancing the R arm to an accuracy of .1 per cent when measuring the loop resistance of cable conductors or locating grounds, crosses, or shorts of low resistance.

In the case of faults having a resistance of several thousand ohms or more, higher voltages may be employed. In general, a higher voltage is preferable to a more sensitive galvanometer in locating faults of fairly high resistance. With a sensitive galvanometer fluctuations of the galvanometer needle due to interfering potentials are so magnified that the advantage gained from the greater galvanometer deflection is partially offset. A 1000-ohm current limiting resistor is connected in series with one of the BA binding posts. This resistor affords sufficient protection to the bridge for external battery potentials of approximately 45 volts. If a higher voltage battery is used, sufficient external resistance should be connected in series with the battery to make a total current limiting resistance equal to about 20 ohms per volt. An external resistor need not be used with a Megger.

Binding Posts:

BA+ and BA-: For connecting external sources of potential to the bridge.

GA: For connecting an external galvanometer to the bridge.

X₁, X₂, and GR: The good and bad wires and ground are connected to these posts in various ways, depending on the nature of the trouble, in making bridge measurements.

R: The balancing rheostat of the bridge (R arm) is accessible for use as a variable resistor through the binding posts R and X₂. The R post is not used in cable fault locating work.

3. PRECAUTIONS

3.01 The GA SENS (galvanometer sensitivity) keys should always be operated in the proper sequence to minimize off-scale readings; otherwise the accuracy of the galvanometer will be impaired.

3.02 The galvanometer needle should always be clamped when the set is not in use.

3.03 The GA SENS keys should not be operated when changing the setting of the R arm.

3.04 The set is an accurate and sensitive instrument and care, therefore, should be exercised in handling and transporting it in order not to damage the working parts.

4. MAINTENANCE

4.01 In general, the set should require little maintenance aside from battery renewals. If the set is not working properly, it should be returned for repair in accordance with local routine.

4.02 The battery compartment, on the left-hand side of the case, is covered by a metal panel. To install batteries, remove the panel and worn batteries, then insert the new cells and replace the cover.

4.03 Replacement parts.

Battery, Dry, KS-14711

5. LOCATING FAULTS

A. GENERAL

5.01 If a working pair is needed to make a bridge measurement, it should be disconnected from central office equipment and subscriber apparatus while the test is being made.

B. MEASUREMENT OF RESISTANCE

5.02 Resistance is measured as follows:

- (1) Connect the unknown resistance to the X₁ and X₂ binding posts.
- (2) Rotate the GA key to R.V.M. and BA key to the IN or OUT position, depending on whether internal or external battery is used.
- (3) Set the loop key to the RES position.
- (4) Estimate the resistance of the unknown and set the MULTIPLY BY dial accordingly. The best setting for various resistances is:

Unknown Resistances	MULTIPLY BY Setting
Less than 10 ohms	$\frac{1}{1000}$
10 to 100 ohms	$\frac{1}{100}$
100 to 1000 ohms	$\frac{1}{10}$
1000 to 10,000 ohms	$\frac{1}{1}$
10,000 to 100,000 ohms	$\frac{10}{1}$
100,000 to 1,011,000 ohms	$\frac{100}{1}$

- (5) Balance the bridge by adjusting the R arm.
- (6) With the bridge balanced, the value of the unknown resistance can be determined from the following equation:

$$X = \frac{A}{B} R$$

Where X = the unknown resistance in ohms

R = the value of the R arm

$\frac{A}{B}$ = the setting of the MULTIPLY BY dial

Example: If the MULTIPLY BY dial is set at $\frac{1}{1000}$ and the bridge is balanced with the R arm set at 8,300 ohms, the resistance is:

$$X = \frac{1}{1000} \times 8,300 = 8.3 \text{ ohms}$$

5.03 *Loop Resistance of a Cable Pair:* The method of connecting the cable pair to the bridge is shown in Fig. 5. The strap across the conductors should be tight and of negligible resistance. The measurement should be made as outlined in Paragraph 5.02.

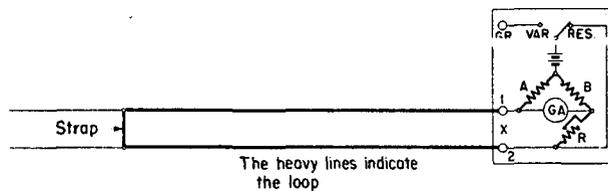


Fig. 5

5.04 When leads are used to connect the unknown resistance to the test set, the resistance of the leads must be determined and then subtracted from the total resistance to obtain the exact value of the resistance being measured.

C. MEASUREMENT OF FAULTS — THREE-VARLEY METHOD

5.05 The Three-Varley method of locating grounds, crosses, and shorts requires three measurements from which the resistance to the fault from both ends of the cable or section under test as well as the total resistance of the wire can be determined. To make the measurements, two good conductors are also required; these conductors must be relatively free from leakage. The measurements are known as the Varley I, Varley II and Varley III measurements. The method has the advantages that the gauge of the two good wires need not be the same as that of the bad wire and it is not necessary to measure the resistance of the leads. The strap at the far end should be tight and of negligible resistance. The same setting of the MULTIPLY BY dial should be used in making the three measurements.

5.06 The method of connecting the good and bad wires to the set in making the Varley I measurement for a ground, cross or short is the same. The connections for the Varley II and Varley III depend on whether the fault is a ground, cross or short. The connections for each measurement are illustrated.

Varley I for Grounded, Crossed, or Short-Circuited Conductor

5.07 The measurement is made as follows:

- (1) Connect one side of a good pair (use spare if possible) to the X₁ post, the bad wire to the X₂ post, and the other side of the good pair to the GR post, as shown in Fig. 6.

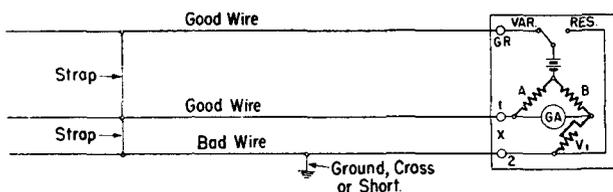


Fig. 6

- (2) At the far end strap the three wires together.
- (3) Set the GA key to the R.V.M. and the BA key to the IN or OUT position, depending on whether internal or external battery is used.
- (4) Set the loop key at VAR.
- (5) Select a MULTIPLY BY setting; generally $\frac{1}{9}$ will be satisfactory.
- (6) Balance the bridge by adjusting the R arm and designate the reading V₁.

Note: If the defective pair is short-circuited and difficulty is experienced in determining which side of the pair to strap to the good wires, make two Varley I measurements with each wire of the short-circuited pair strapped in turn to the good pair. The connection which gives the larger reading should be used in making the Varley II and Varley III measurements.

Varley II for Grounded Conductor

5.08 The measurement is made as follows:

- (1) Disconnect the good wire from the GR terminal and then connect the GR terminal to a grounded cable sheath or ground. The connections are shown in Fig. 7.

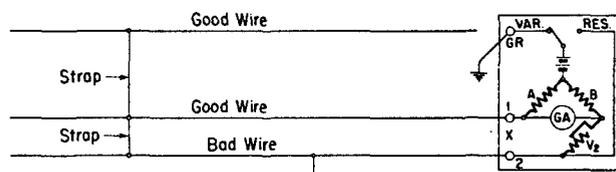


Fig. 7

- (2) Balance the bridge by adjusting the R arm and designate the reading V₂.

Varley III for Grounded Conductor

5.09 The measurement is made as follows:

- (1) Disconnect the GR lead from the grounded cable sheath or ground and place a strap between the GR and X₂ terminals, as shown in Fig. 8.

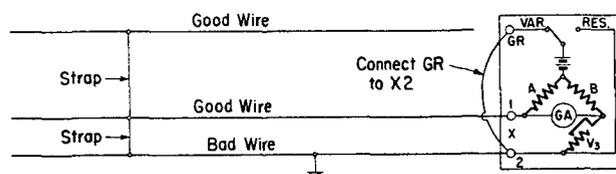


Fig. 8

- (2) Balance the bridge by adjusting the R arm and designate the reading V₃.

Varley II for Cross or Short Circuit

5.10 The measurement is made as follows:

- (1) After the Varley I, disconnect the good wire from the GR terminal. Then connect the other wire of the bad pair, if the fault is a short-circuited pair, or the other wire involved if the fault is due to crossed conductors to the GR terminal as shown in Fig. 9.

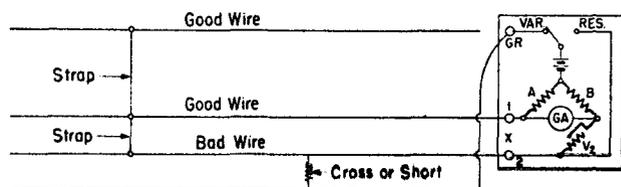


Fig. 9

- (2) Balance the bridge by adjusting the R arm and designate the reading V_2 .

Varley III for Cross or Short Circuit

5.11 The measurement is made as follows:

- (1) Disconnect the strap from the mate or other wire involved in the fault and then connect the strap to the X_2 binding post, as shown in Fig. 10.

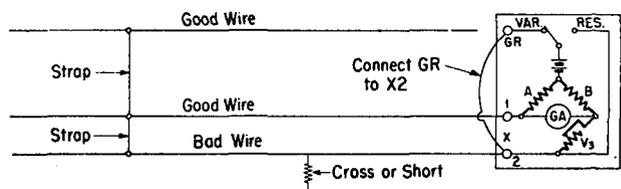
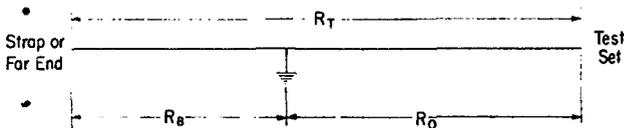


Fig. 10

- (2) Balance the bridge by adjusting the R arm and designate the reading V_3 .

5.12 The resistance of the faulty wire from the strap to the fault (R_B), from the test set to the fault (R_O) and the total resistance of the wire from the set to the strap (R_T) can be determined by the following equations:



$$R_B \text{ (resistance back)} = \frac{A}{A + B} (V_2 - V_1)$$

$$R_O \text{ (resistance out)} = \frac{A}{A + B} (V_3 - V_2)$$

$$R_T \text{ (total resistance)} = \frac{A}{A + B} (V_3 - V_1)$$

5.13 The fraction $\frac{A}{A + B}$ appears in each of the above equations and must be the same for a particular set of measurements. To simplify computation the setting $\frac{1}{9}$ should be used whenever possible. With this ratio the fraction becomes $\frac{1}{1 + 9}$ or $\frac{1}{10}$ and it is only necessary to point off one decimal place to determine the result. If the Varley I, II and III measurements can not be made with $\frac{1}{9}$ setting, try the $\frac{1}{4}$ setting in which case the fraction becomes $\frac{1}{1 + 4}$ or $\frac{1}{5}$. In some cases it may be necessary to use the $\frac{1}{1}$ setting in which case the fraction becomes $\frac{1}{1 + 1}$ or $\frac{1}{2}$. In making measurements between manholes to determine the point where the cable should be exposed by excavating, a $\frac{1}{100}$ setting of the MULTIPLY BY dial should be used to obtain the best results.

5.14 The methods of applying the V_1 , V_2 and V_3 resistance values and the equations given above will depend on (a) whether the bad wire is made up of one gauge or a combination of gauges, and (b) whether the conductor is loaded. The interpretation of the measurements is outlined in Part D.

D. INTERPRETATION OF THREE-VARLEY MEASUREMENTS

5.15 *Information Required:* In locating faults by bridge measurements it is generally necessary to obtain from plant records the following information:

- (a) Gauge or gauges of the conductor being measured.
- (b) The length of wire of each gauge.
- (c) The location of the branch cables and terminals in which the conductor under test appears.

(d) Number, resistance and location of loading coils and code designation of the cases.

5.16 Reference to plant records is likewise helpful in determining the geographical location of the fault from the computed location.

5.17 In making bridge measurements between splices a short distance apart for the purpose of digging to repair the cable, the length used in the computation should be obtained by measuring with a steel or linen tape. If there is any doubt as to the location of the cable, trace its path as covered in the sections on locating the path of a cable.

5.18 **Faulty Conductor of One Gauge Non-loaded:** The resistance of a wire of uniform diameter is directly proportional to its length. Therefore, where a faulty conductor is nonloaded and is of one gauge throughout the length under test, the location of the fault can be determined by substituting the resistance values obtained in the following equations:

The distance to the fault from the testing end

$$D_o = \frac{V_2 - V_1}{V_2 - V_1} D_T$$

The distance to the fault from the far end

$$D_B = \frac{V_2 - V_1}{V_2 - V_1} D_T$$

where

V_1 , V_2 and V_3 are the Varley measurements obtained as outlined in Part 5C. Note that the $\frac{A}{B}$ ratio cancels out in these formulas.

D_o = Distance to the fault from the testing end.

D_B = Distance to the fault from the far end.

D_T = Total length of the bad wire.

5.19 **Example:** If the Varley measurements are $V_1 = 137$ ohms, $V_2 = 236$ ohms and $V_3 = 308$ ohms, and the length of the faulty conductor (D_T) is 1070 feet:

The distance from the testing end to the fault

$$D_o = \frac{308 - 236}{308 - 137} (1070) = 450 \text{ feet}$$

The distance from the far end to the fault

$$D_B = \frac{236 - 137}{308 - 137} (1070) = 620 \text{ feet}$$

5.20 If the bridge measurements were made correctly and the computations are accurate, then D_o plus D_B should equal D_T , the total length of the bad wire.

5.21 **Two or More Gauges — Nonloaded Conductor:** The method of determining the location under this condition is illustrated by the following example: Assume that the bad wire consists of 800 feet of 19-gauge wire, 350 feet of 22-gauge wire and 400 feet of 24-gauge wire, and that $R_o = 9.9$ ohms and $R_T = 23.7$ ohms.

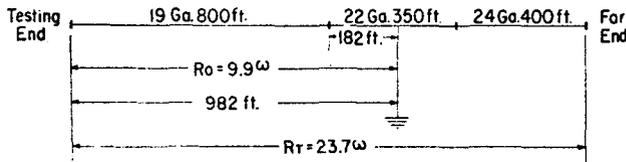
Calculate the resistance (at 68° F.) to each gauge junction and to the far end of the conductor obtaining the resistance of each gauge per 1000 feet from the table of conductor resistances given in another section. The computations are shown in the following sketch. The calculated and measured (R_T) resistances from the test set to the far end generally will not be the same due to the temperature of the wire. If there is a difference, the ratio of the two should be used to obtain the corrected resistance to each junction point, thus

Testing End	19 Ga. 800 ft. (.8x8.049=6.44 ω)	22 Ga. 350 ft. (.35x16.19=5.67 ω)	24 Ga. 400 ft. (.4x25.94=10.37 ω)	For End
Calculated Resistance	6.44 ω	5.67 ω 6.44 ω	12.11 ω 10.37 ω	22.48 ω
Measured Resistance				23.7 ω
Corrected Resistance	(Multiply by $\frac{23.7}{22.48}$)	6.79 ω	12.76 ω	23.7 ω

As the measured resistance (R_o) from the set to the fault is 9.9 ohms, it will be seen that the fault is somewhere in the 22-gauge section. The fault is 9.9 ohms - 6.79 ohms or 3.11 ohms from the junction of the 19 and 22 gauges.

The distance from this junction point is $\frac{3.11 \times 350}{5.97^*} = 182$ feet. The distance from the testing end is 800 + 182 = 982 feet.

*The corrected resistance of the 350-foot section of 22-gauge wire is 12.76 - 6.79 or 5.97 ohms.



5.22 Loaded Conductor: The method of determining the location of a fault in a loaded conductor is illustrated by the following example. Assume that the conductor is 19 gauge, that it is loaded with five No. 622 coils, that $R_o = 175.2$ ohms and $R_T = 315.1$ ohms.

Calculate the resistance of each load section. (The method of calculating the resistance of a wire is covered in Paragraph 5.21.) Then, beginning at the testing end, add the calculated resistance of each load section and the loading coils consecutively to the load points where R_o is both smaller and larger than the calculated resistance to that point. Also, calculate the resistance of the wire to the far end. The calculated and measured (R_T) resistances generally will differ due to the temperature of the wire. If there is a difference, the ratio should be used to correct the calculated resistances to each side of the fault, as shown in Fig. 11.

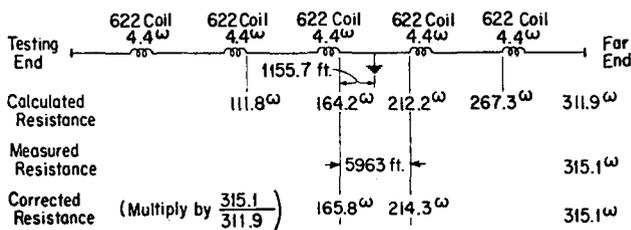


Fig. 11

It will be seen that the fault is somewhere in the fourth loading section from the testing end. The fault is 9.4 ohms ($175.2 - 165.8$) from the third loading coil. The distance in feet from the third loading coil is

$$\frac{9.4 \times 5963}{48.5^*} = 1155.7 \text{ feet.}$$

*The corrected resistance of the 5963-foot load section is $214.3 - 165.8$ or 48.5 ohms.

5.23 Faults Which Appear to be at Branch Splices: If in the case illustrated in Fig. 12 the strap is at A and the location of a

fault appears to be at a bridging point p, the fault may be either at that point or somewhere in the branch cable B, such as point o. Since p is the bridging point, remove the strap at A and place it on the conductor in the lateral at B and make a second measurement. In this instance the second measurement will indicate that the fault is located at o. If the fault had been at p in the branch splice, both the first and second measurements would have indicated the fault to be at p.

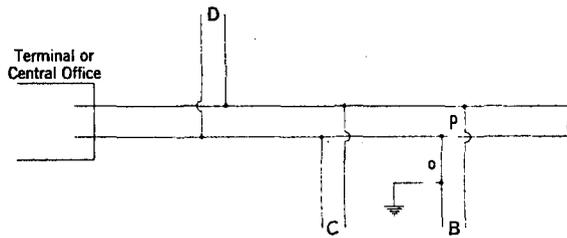


Fig. 12

E. MURRAY LOOP MEASUREMENTS

5.24 Grounds, shorts and crosses can also be located by means of Murray measurements. The diagram in Fig. 13 illustrates the method of connecting the bridge to the cable conductors when the fault is a ground. The good and bad wires should be connected directly to the X₁ and X₂ binding posts, if possible, or leads of negligible resistance should be used. If the fault is a short or a cross, the X₂ binding post is connected to one of the faulty wires and the GR binding post is connected to the other faulty wire instead of to ground. The loop key should be set at MUR and the MULTIPLY BY dial at

$$\frac{M}{1000}$$

apply only when the good and bad conductors are of the same gauge and length.

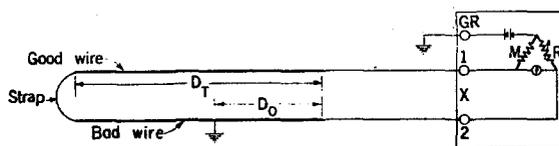


Fig. 13

5.25 Balance the Bridge and Designate the Reading R: The length of the bad conductor from the testing end to the fault can be determined from the following equation:

$$D_o = \frac{2RD_T}{M + R}$$

Where D_o = Length of conductor from testing end to the fault

R = Reading of the R arm

D_T = The total length of the conductor

M = Setting of MULTIPLY BY dial

5.26 Example: Assume that the length of the cable is 2400 feet and

$$R = 600$$

$$M = 1000$$

$$\begin{aligned} \text{then } D_o &= \frac{2RD_T}{M + R} \\ &= \frac{2 \times 600 \times 2400}{1000 + 600} = \frac{2,880,000}{1600} = 1800 \text{ feet} \\ &\qquad\qquad\qquad \text{from testing} \\ &\qquad\qquad\qquad \text{end to fault} \end{aligned}$$

F. COMPLETE CABLE FAILURE — USE OF EXTERNAL GOOD WIRES

5.27 Three-Varley Method: When all the conductors in the cable are bad, good conductors in another cable which follows the same route may be used for testing purposes. The $\frac{1}{9}$ setting of the MULTIPLY BY dial will usually be satisfactory, although when the good wires are considerably longer than the bad the $\frac{1}{4}$ or $\frac{1}{1}$ setting may be necessary in order to obtain a balance. When the $\frac{1}{1}$ setting is resorted to, it may occasionally be found impossible to balance the bridge; this occurs when the resistance of the good conductor connected to the X₁ binding post is about equal to or less than the resistance of the bad conductor connected to the X₂ binding post. To obtain a balance under these conditions a resistor should be inserted between the good conductor and the X₁ binding post. The fixed resistor should be left in the circuit while all three Varley measurements are made.

5.28 If the test is being made between near-by manholes a length of drop wire may be used as the good wires. The good wires need not be of the same gauge as the bad wire. The $\frac{1}{100}$ setting of the MULTIPLY BY dial should be used to obtain best results.

5.29 Reversed Varley: Where the bridge can not be balanced in the Varley I measurement and a resistance for use between the good wire and the bridge is not available, the good and bad wires with their leads should be interchanged while making the Varley I measurement. The $\frac{1}{1}$ setting of the MULTIPLY BY dial must be used in this case and the three *Varley equations* in Paragraph 5.12 become:

$$R_B = \frac{V_2 + V_1}{2}$$

$$R_o = \frac{V_3 - V_2}{2}$$

$$R_T = \frac{V_3 + V_1}{2}$$

G. COMPLETE CABLE FAILURE — NO GOOD WIRES AVAILABLE

5.30 Where it is impracticable to establish an auxiliary good wire, one of the following methods may be used to locate the fault, using two bad wires. It should be understood that these methods will give reliable results only when:

- (a) The faults on the two wires are at the same point.
- (b) The fault resistances are approximately constant during the test.
- (c) The conductor resistances of the wires are approximately equal.

5.31 The measurements should be made using external battery with a potential of about 50 volts.

5.32 Corrected Varley Loop: Where two wires are available for measurement, which have relatively low fault resistances to ground (1000 to about 5000 ohms) differing by at least 25 per cent, as determined by voltmeter, or loop measurement with a bridge, the corrected Varley method may be used to locate the fault.

5.33 Three Varley measurements are required on the two wires selected for test.

(1) The wire having the lower insulation resistance should be connected to the X₂ binding post. Call the end to which the test set is connected for the first test, the testing end; and the other end, the far end. Make a Varley measurement with the far end of the two wires strapped and the GR binding post connected to a grounded cable sheath or ground.

The MULTIPLY BY dial should be set at $\frac{1}{1}$.

Balance the bridge and designate this reading V₁. See Fig. 14.

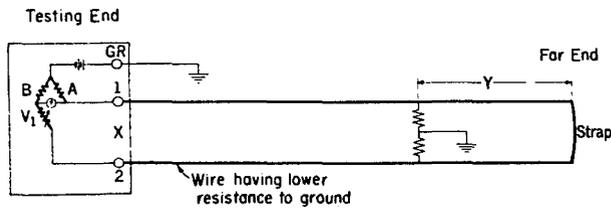


Fig. 14

(2) A second Varley measurement should be made at the far end with the wires open at the testing end. The MULTIPLY BY setting should not be changed. Balance the bridge and designate the reading V₂. See Fig. 15.

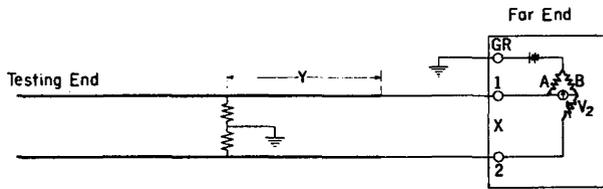


Fig. 15

(3) A third measurement should be made at the far end with the conductors connected to the bridge, as shown below, using the same MULTIPLY BY dial setting. Balance the bridge and designate the reading V₃. If a balance can not be obtained with the $\frac{1}{1}$ setting, use the $\frac{1}{10}$ setting (for V₃ only) and balance the bridge. See Fig. 16.

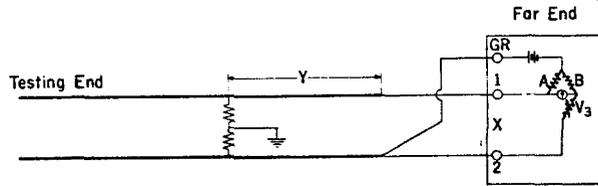


Fig. 16

5.34 The resistance from the far end to the fault can be determined from the following equation:

$$\text{With } \frac{1}{1} \text{ setting in all measurements } Y = \frac{V_1 V_3}{2 V_2}$$

$$\text{With } \frac{1}{10} \text{ setting in the } V_3 \text{ measurement } Y = \frac{V_1 V_3}{20 V_2}$$

Several separate sets of measurements should be made and the resistance from the far end to the fault should be based on those sets of measurements which appear to be consistent. To determine the distance from the far end to the fault, multiply the resistance Y by the feet per ohm of the bad conductor.

5.35 *Corrected Murray Loop*: If there is considerable difference in the resistance of the conductors to ground, the following method can be used to locate the fault. With the loop key set at MUR, the two wires selected should be connected to the X₁ and X₂ binding posts, as indicated in Fig. 17.

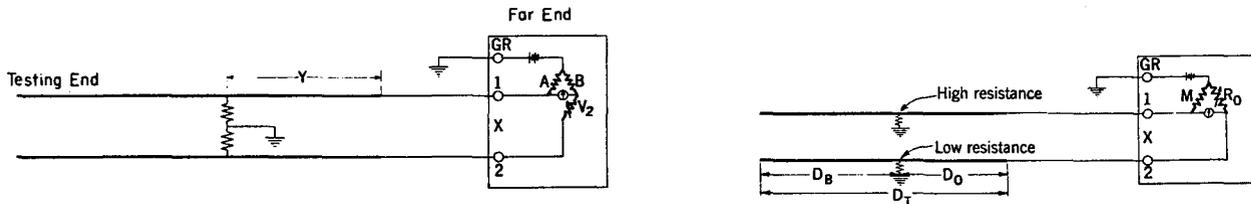


Fig. 17

Make a Murray measurement with the MULTIPLY BY dial set at $\frac{M}{1000}$ and the far end of the loop open. Balance the bridge and designate the reading R₀. If the R₀ reading is larger than 1000, reverse the leads connected to the X₁ and X₂ binding posts and rebalance the bridge. The best results are obtained when the resistance in the R arm is in the order of 300 ohms or less.

5.36 Then strap the two wires together at the far end and make another Murray measurement, as described in Paragraph 5.24. Designate the reading R_s .

5.37 The distance to the fault from the far end can be determined from the formula:

$$D_B = \left(\frac{M - R_s}{M + R_s} \right) \left(\frac{M + R_o}{M - R_o} \right) D_T$$

Where D_T = Length of conductor under test

R_o = Reading of R arm with the far end open

R_s = Reading of R arm with the far end short-circuited

M = Setting of MULTIPLY BY dial

D_B = Distance to the fault from the far end

D_o = Distance to the fault from the testing end

5.38 *Example:* Under conditions in which the following values have been obtained: $R_o = 230$, $R_s = 380$, $D_T = 1050$ feet and $M = 1000$, the distance from the far end to the fault

$$D_B = \left(\frac{1000 - 380}{1000 + 380} \right) \left(\frac{1000 + 230}{1000 - 230} \right) 1050$$

$$D_B = 754 \text{ feet}$$

$$D_o = D_T - D_B$$

$$D_o = 1050 - 754$$

$$D_o = 296 \text{ feet}$$

5.39 *Straight Resistance Method:* Where all wires are about equally affected and the resistance of the fault is comparable in magnitude to the resistance of the wires, the resistance from each end of the cable to the fault can be determined as follows: In making the measurements, the fault resistance must remain constant and the conductors selected should preferably be wires of the same pair. The diagram of connections is illustrated in Fig. 18. These measurements should be made using the 4-1/2 volt bridge battery; higher potentials should not be used as they may change the resistance of the fault considerably. The loop key should be set at RES.

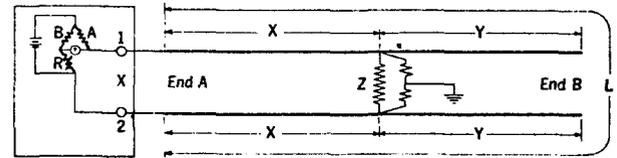


Fig. 18

5.40 With the wires open at end B, make a loop resistance measurement from end A and designate the reading R_1 ; this is the series resistance $2X + Z$. Then measure the loop resistance from end B with the wires open at end A and designate the reading R_2 . The latter is the series resistance $2Y + Z$. The resistance X from end A to the fault and the resistance Y from end B to the fault can be determined from the following equations:

$$X = \frac{L + (R_1 - R_2)}{4}$$

$$Y = \frac{L - (R_1 - R_2)}{4}$$

L is the normal loop resistance of the two conductors as determined from the table of conductor resistances contained in another section.

5.41 Several sets of measurements should be made of R_1 and R_2 . The computations for X and Y should be based on those sets of measurements which appear to be consistent and the average of these values should be computed. To obtain the distance of the fault from the ends of the cable, multiply the average values of X and Y by the appropriate feet per ohm of the conductor.

H. LOCATING OPENS BY MURRAY MEASUREMENTS

5.42 The location of an open in a conductor can be determined by Murray measurements. The location is obtained by direct comparison of the open wire and a good wire. The method assumes that the two wires have uniform capacitance to ground throughout their length and are similar in other respects. It is necessary, therefore, that the good wire be of the same gauge and length as the open wire, including branches. The mate of the open wire should be used as the good wire whenever practicable. The length of the branches should be

known. No attempt is made to correct for changes in gauge, or for loading.

5.43 Fairly accurate results can be obtained if the total length of the conductors (D_T) is not over one or two thousand feet and the wires are of the same gauge and nonloaded. In long or loaded cables, only an approximate location can be obtained by this method.

5.44 The type of tone used can affect the ease and possibly the accuracy of the balance. A relatively pure tone, such as from a vacuum tube oscillator (500 to 1000 cycles) is preferable to that from a buzzer tone. Tone from a 27A or 76-type set should be satisfactory.

5.45 To locate an open, connect the faulty wire and preferably its mate to the test set as shown in Fig. 19. Tone, such as from a 76-type set, should be connected between a grounded cable sheath or ground and the BA—binding post. A receiver should be connected between the X, and X₂ binding posts.

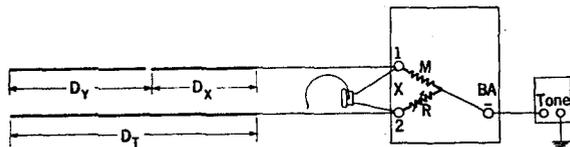


Fig. 19

5.46 Set the loop key in the MUR position and the MULTIPLY BY dial in the $\frac{M}{1000}$ position. With the tone operating, adjust the R arm dials until a balance is obtained as indicated by the absence of tone in the receiver or until a minimum tone is heard, as explained below. Designate the reading R_1 . Then make a similar measurement from the other end of the cable or section and designate this reading R_2 .

(a) **Balancing Bridge:** Under some conditions difficulty may be experienced in balancing the bridge as the balance point is approached. In such cases proceed as follows: Determine as nearly as possible the point of least tone. If a movement of the unit dial does not make a noticeable change in the volume of the tone, set the unit dial at 5 and move the 10 dial

first up one point and then down one point from the original value. A lower tone when the 10 dial is decreased one point indicates that the setting of the unit dial is too high. Set the unit dial to 4 and again swing the 10 dial. Continue the operations until a value is reached in the unit dial that gives equal tone volume when the 10 dial is moved up and down one point. Similarly a balance can be made with the 100 dial if the effect of the changes in the 10 dial can not be distinguished.

5.47 The location of the open can be determined from the following equation:

$$D_x = \left(\frac{R_1}{R_1 + R_2} \right) D_T \text{ or}$$

$$D_y = \left(\frac{R_2}{R_1 + R_2} \right) D_T$$

Where D_x = Length of faulty wire from testing end to the open (including the lengths of the branches).

R_1 = First bridge reading.

R_2 = Second bridge reading.

D_T = Length of mate (including branches).

D_y = Length of faulty wire including branches from the far end to the open.

Example:

$$D_T = 1500 \text{ feet}$$

$$R_1 = 81 \text{ ohms}$$

$$R_2 = 890 \text{ ohms}$$

$$D_x = \left(\frac{81}{81 + 890} \right) \times 1500 = 125 \text{ feet}$$

I. LOCATION OF SPLIT PAIRS AND QUADS BY MURRAY MEASUREMENTS

5.48 **Split Pairs:** In either quadded or non-quadded cable, the splice in which two pairs are split can generally be determined by means of Murray measurements. If the length of the section under test is not over five miles, the error in the location should not exceed the distance between two splices. The conductors involved in the test must be free from crosses, shorts, grounds, and opens. Two measurements are required.

5.49 The method of connecting the conductors to the bridge for the first measurement is indicated in Fig. 20. The loop key should be set at the MUR position. The MULTIPLY BY dial should preferably be set at $\frac{M}{1000}$. With tone such as from a 76-type set operating, adjust the R arm until minimum tone is obtained. Then connect the lead from the X_2 binding post to the mate of the conductor formerly connected to the X_2 post and again balance the bridge. The larger of the two readings should be designated R_1 , and the connections that gave this reading should be retained for the second test.

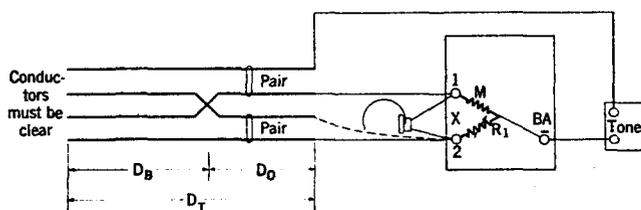


Fig. 20

5.50 The second measurement should be made with the conductors connected to the bridge as shown in Fig. 21. Balance the bridge for minimum tone and designate the reading R_2 .

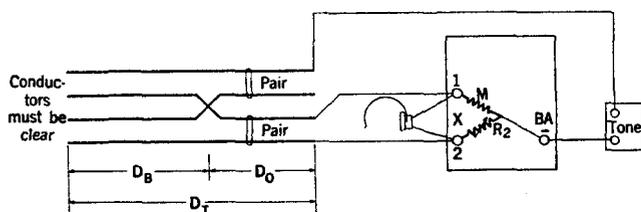


Fig. 21

5.51 The length D_0 from the testing end to the split can be determined from the following equation:

$$D_0 = \frac{(R_1 - M) D_T}{(R_1 + R_2) - 2M}$$

Where D_0 = Length of conductor from fault to testing end.

R_1 = First reading.

R_2 = Second reading.

M = Setting of MULTIPLY BY dial.

D_T = Total length of the conductor.

The length D_B from the far end to the split can be determined from the following equation:

$$D_B = \frac{(R_2 - M) D_T}{(R_1 + R_2) - 2M}$$

5.52 *Split Quad*: The procedure for locating a split between two quads is the same as that followed in locating a split between two pairs except that each pair of the two quads concerned is shorted at the testing end. The method of connecting the shorted pairs to the bridge for the tests is illustrated in Fig. 22. R_1 and R_2 should be determined as before and substituted in the equation given in Paragraph 5.51.

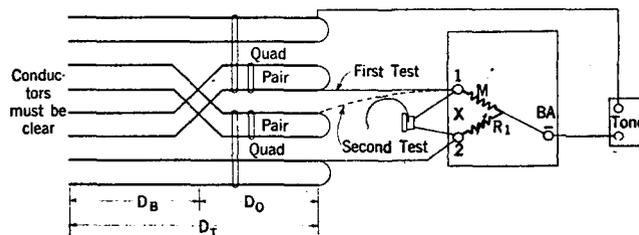


Fig. 22

J. LOCATION OF SERIES RESISTANCE UNBALANCES

5.53 Series resistance unbalances in nonloaded cables ranging from a few ohms to several hundred ohms in conductors not over two or three miles in length can generally be located by the method outlined below. The method will give accurate results under conditions where:

- The resistance unbalance exists on only one wire of the pair.
- The unbalance remains reasonably constant while the measurements are being made.
- The conductor resistance of the wires of the pair containing the unbalance is equal, except for the series resistance.
- The capacitance unbalance between the two pairs used in the test is negligible.

5.54 The apparatus required and the diagram of connections are shown in Fig. 23.

The potentiometer is required to permit reducing the tone output to the minimum required for balancing the bridge.

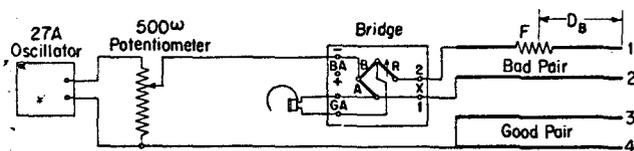


Fig. 23

5.55 Set the MULTIPLY BY dial at $\frac{1}{1}$ and the loop key at the VAR position. Balance the bridge with the far ends of the pairs open. Call the reading R_0 . Then make a second test with wires 1, 2, 3 and 4 shorted at the far end. Call this reading R_s . The distance (D_B) from the far end to the unbalance can be determined from the following equation:

$$D_B = D_T \sqrt{\frac{R_0}{R_s}}$$

Where

R_0 = Reading of the R arm with far ends of the wires open.

R_s = Reading of the R arm with far ends of the wires connected together.

D_T = Total length of the faulty wire.

It will be found that there is generally considerable tone in the receiver even when the bridge is balanced, particularly if the cable is long or if the series resistance is high. The balance point is broader and more difficult to determine with the far end short-circuited than with the far end open. However, after some experience it should be possible to obtain a reasonably accurate balance by means of the following balancing procedure.

5.56 Assume a condition where the bridge is balanced when the resistance in the R arm is 127 ohms. It will ordinarily be apparent that the balance point lies between 120 and 130 ohms. Then with the unit dial in the first position, move the 10 dial back and forth between the 10-ohm and 30-ohm positions, thus placing unbalances of 10 ohms in either direction. When the unit dial is set at 7 ohms, the tone heard in the receiver for settings of 117 and 137 should be equal.

5.57 Usually best results are obtained when the tests are made at the end of the cable nearer the fault. The tone output should be as small as practicable in order to minimize changes in fault resistance. A sufficient number of separate measurements should be made to ensure that consistent results are being obtained.