WAR DEPARTMENT TECHNICAL MANUAL

TM 11-2019

TEST SET I-49

WAR DEPARTMENT • 12 AUGUST 1944

RESTRICTED. *DISSEMINATION OF RESTRICTED MATTER.*—The information contained in restricted documents and the essential characteristics of restricted material may be given to any person known to be in the service of the United States and to persons of undoubted loyalty and discretion who are cooperating in Government work, but will not be communicated to the public or to the press except by authorized military public relations agencies. (See also par. 23*b*, AR 380-5, 15 Mar 1944.)

Washington : 1944

WAR DEPARTMENT,
WASHINGTON 25, D. C., 12 August 1944.

TM 11–2019, Test Set I–49, is published for the information and guidance of all concerned.

[A. G. 300.7 (5 Jul 44).]

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:
J. A. ULIO,
Major General,
The Adjutant General.

DISTRIBUTION:

As prescribed in paragraph 9a, FM 21–6: Armies (10); Corps (10); SvC (10); Dept (10); Def Comd (2); IC 4, 11 (5); [1] (2) Chief of Tech Sv (2); Arm & Sv Bd (2); Sig C Lab (15); PE (15); Sig C Dep (15); Sig C Repair Shops (10).

IC 4: T/O & E 4–240–1S.

IC 11: T/O & E 11–27, 11–237, 11–287, 11–577T, 11–587, 11–597, 11–7, 11–16, 11–57, 11–26, 11–47, 11–137, 11–317; T/O 11–107, 11–127.

[1] 11–500 Sig Serv Orgn:
40 Line Switchboard Team (GA); 1 Position Switchboard Team (GB); 2 Position Switchboard Team (GC); 200 Sta. Automatic Switchboard Team (GE); Switchboard Install Sec (GF); Cable Rep Sec (GL); Open Wire Rep Sec (GM); Telephone Carrier and Repeater Sec (GN); Spiral–Four Cable Sec (GP); Wire Rep Sec (GQ); Submarine Cable Sec (GR).

For explanation of symbols, see FM 21–6.

CONTENTS

SECTION I. DESCRIPTION.

II. INSTALLATION.

III. OPERATION.

IV. PREVENTIVE MAINTENANCE.

V. FUNCTIONING OF PARTS.

VI. CORRECTIVE MAINTENANCE.

VII. SUPPLEMENTARY DATA.

DESTRUCTION NOTICE

WHY —To prevent the enemy from using or salvaging this equipment for his benefit.

WHEN—When ordered by your commander.

HOW —SMASH—Use sledges, axes, handaxes, pickaxes, hammers, crowbars, heavy tools.
CUT—Use axes, handaxes, machetes.
BURN—Use gasoline, kerosene, oil, flame throwers, incendiary grenades.
EXPLOSIVES—Use firearms, grenades, TNT.
DISPOSAL—Bury in slit trenches, fox holes, other holes. Throw in streams. Scatter.

USE ANYTHING IMMEDIATELY AVAILABLE FOR THE DESTRUCTION OF THIS EQUIPMENT

WHAT—SMASH—Galvanometer, switches, resistors, panel, and all other parts.
BURN—Technical manuals.
BURY OR SCATTER—Any or all of the above pieces after destroying their usefulness.

DESTROY EVERYTHING

SECTION I

DESCRIPTION

---

1. General

Test Set I–49 is a compact, sturdy, portable Wheatstone bridge incorporating a number of features recommended by telephone engineers. It is rapid in operation, light in weight, and small in size. Designed for use in the field, all contacts are inclosed, the knobs are undercut, and the dial switches have positioning stops. The switches, keys, and binding posts are placed so that an operator wearing gloves can manipulate them easily. Connections for the various loop tests and for resistance measurements are made with a single cam type key switch.

2. Application

a. General. Test Set I–49 can be used—

(1) To determine the location of a fault on a circuit.
(2) To determine whether or not a circuit is in normal condition.
(3) To measure unknown resistance.
(4) As an auxiliary resistance box.

b. Types of Trouble. Faults which may be identified and located are opens, short circuits, crosses, and grounds. Faults which may be identified and measured are resistance unbalance and low insulation resistance.

3. Weight and Dimensions

Test Set I–49 is 8⅞ by 7⅞ by 5¾ inches, with the cover closed, and weighs approximately 8 pounds.

4. Power Requirements

Power for the test set can be obtained from either of two sources: a self-contained 4.5-volt source, consisting of three standard flashlight cells (Battery BA–30); or an external source. When an external source of power is used, the switch BA (fig. 2 (7)) must be turned so that the arrow on the knob points toward EXT and the external source of power is connected to the binding posts BA + and — (fig. 2 (18)). External voltages up to 200 volts direct current can be used. When an external voltage exceeding 45 volts is used, an external resistance of 10 ohms for each volt in excess of 45 volts must be placed in series with the test set and the voltage source.

Example: If an external source of 90 volts is to be used, a resistance of 10 x 45, or 450 ohms, would have to be placed in series with the test set and the voltage source.

Figure 1. Test Set I–49, cover raised.

SECTION II

INSTALLATION

---

5. Permanent Installation

a. GENERAL. The Wheatstone bridge is used in central office trouble-locating desks to determine the location of faults in wire lines. Bridges used in installations of this type may differ in design and operating sequence, but all of them utilize the same basic principle when balanced. When a fault is localized, a trouble-locating team, equipped with a portable Wheatstone bridge and other measuring devices, is sent to a test point nearer the trouble for a final measurement and check.

b. PERMANENT INSTALLATION. In a central office testing station, the Wheatstone bridge is permanently installed with auxiliary equipment such as keys and cords connected to the bridge. This additional equipment makes all circuits easily accessible for tests, and provides speed and ease in setting up the necessary circuits for the various tests.

c. TEST SET I–49 USED IN A PERMANENT INSTALLATION. Test Set I–49 is designed to be used as a portable bridge, but can be used for permanent or semipermanent installations by using a cord and plug for testing from the switchboard, or by using a test shoe and cord for testing from the distributing frame. Connections to the test set will depend upon the type of test equipment used. If used with a wire chief's test cabinet, refer to TM 11–345.

6. Portable Use

a. When used in the field, the Wheatstone bridge must be a light, portable bridge such as Test Set I–49. Connections to the bridge are made with temporary leads or are made directly to the wires under test. More accurate determination of the location of faults can be made in the field, because the test set can be brought closer to the trouble and fewer factors which cause errors will be present.

b. For use in the field, place Test Set I–49 as near as practicable to the test point. Connect the wires of the circuit to be tested to binding posts X_1 and X_2 (fig. 2 (14)) of the test set with the shortest possible leads. Make sure the leads are solidly connected to the test set and the circuit under test. When testing for a grounded circuit, a low-resistance ground (cable sheath or suitable ground rod) should be connected to binding post *GR* on the test set. There are a number of methods of securing good ground connections:

(1) Connect the ground wire from binding post *GR* to a water pipe or other buried metallic body, with a large area of contact with the earth.

(2) Connect the ground wire from binding post *GR* to multiple ground rods driven to a depth of 4 to 5 feet and spaced far enough

apart to prevent overlapping of the high-resistance zone surrounding each ground rod.

(3) Treat the soil surrounding multiple ground-rod installations with chemicals to reduce the resistivity of the soil. Such materials are sodium chloride (common salt), calcium chloride, copper sulphate, etc. For further details on securing good ground connections, refer to TB SIG 37.

7. Power Connections

a. SELF-CONTAINED BATTERIES. The self-contained power source consists of three Batteries BA–30, connected in series to supply a voltage of 4.5 volts. To renew the batteries, remove the two screws holding the metal plate on the end of the carrying case (fig. 18 (19)); remove the plate and tilt the case, permitting the batteries to slide out. When replacing the batteries be sure to insert the bottom (negative terminal) of the battery first, following this procedure with the other two batteries. The center terminal (positive) of the last battery inserted will make contact with the metal plate (19) when it is replaced.

Caution: If the test set is not in continuous service, remove the batteries when the test is completed and before the test set is stored.

b. EXTERNAL POWER CONNECTIONS. When a d-c voltage greater than that of the self-contained battery is required for Test Set I–49, this voltage can be connected to the test set as described in paragraph 4.

Caution: Do not apply more than 200 volts direct current to Test Set I–49. When voltage in excess of 45 volts is applied, follow the instructions given in paragraph 4.

SECTION III

OPERATION

8. Simplified Operation of Test Set I–49

a. General. A simplified operating procedure is presented for use in the most common tests. It is intended for use by personnel not familiar with Test Set I–49, and who do not have the time to study in detail the operation of the bridge. Step-by-step instructions for the operation of the various switches are given. The method of obtaining the result of the measurement is shown without the use of formulas. Tests covered in this manner are the measurement of an unknown resistance, the measurement of loop resistance, the simple Varley test, and the regular Varley test. The theory of the Wheatstone bridge circuit and the coverage of additional methods of testing are explained in paragraphs 14 to 19, inclusive.

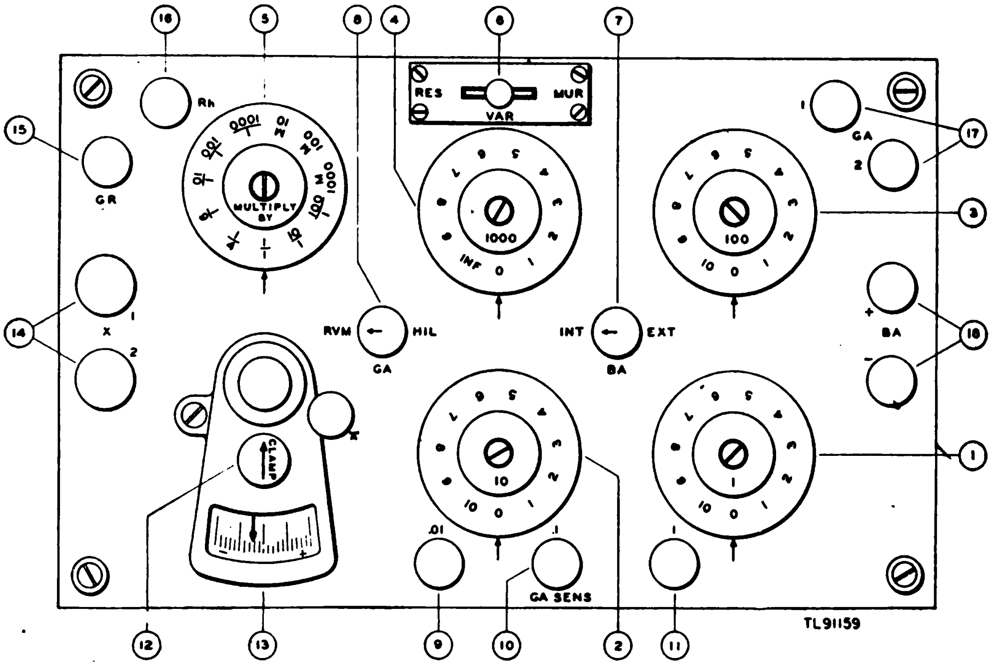


Figure 2. Test Set I–49—panel view.

b. Operation of Test Set I–49. (1) To place Test Set I–49 in operation after the test set has been placed in a level position and the cover has been raised, check the power connections to the panel of the test set. To do this, release the galvanometer pointer by sliding the clamp (12)* in the direction opposite to that indicated by the arrow on the clamp. If the pointer of the galvanometer does not rest at the center of the graduated scale, center it by turning the bakelite knob on the galvanometer case just above the clamp (12).

---

*All points referred to in paragraph 8 are shown in figure 2.

(2) If the self-contained voltage source is to be used, turn switch BA(7) to INT. If an external source of voltage is to be used, connect the external source to the binding posts BA + and —, and turn switch BA(7) to EXT. Observe the precautions specified in paragraph 4.

(3) Turn switch GA(8) to RVM. Throw key switch RES-VAR-MUR(6) to RES. Turn dial switch MULTIPLY BY 5 to $\frac{1}{1}$. Turn dial switches (2), (3), and (4) to 0. Turn dial switch (1) to 5.

(4) Short-circuit binding posts X (1 and 2) (14). Press GA SENS switch (9) and release. If the galvanometer pointer deflects, set the bridge controls as specified for various tests and proceed with the test.

(5) Dial switches (1), (2), (3), and (4) control the value of the R arm of the test set. Dial switches (1) adds or substracts resistance from the total value of the R arm in steps of 1 ohm; dial switch (2) in steps of 10 ohms; dial switch (3) in steps of 100 ohms; and dial switch (4) in steps of 1,000 ohms. Dial switch (5) controls the ratio of the A and B arms of the bridge. The panel of the test set has a reference mark adjacent to each dial switch to show which value on the respective dial switches is to be used.

(6) The galvanometer is connected in the bridge circuit by three push-contact switches. The meter movement is protected against injury by shunts. Switch .01 (9) gives one-hundredth of the maximum sensitivity of the galvanometer; switch 1 (10) gives one-tenth of the maximum sensitivity; and switch 1 (11) gives maximum sensitivity. To protect the galvanometer, switch (9) should be used for the first reading of the galvanometer. If the deflection appears extreme, do not press switch (10) until the bridge has been readjusted. If the swing of the pointer of the galvanometer is toward the end of the scale marked +, the R arm has too little resistance. If the swing of the pointer is toward the end of the scale marked —, the R arm has too much resistance.

Caution: This holds true only when the self-contained batteries are inserted correctly or when the external voltage is connected to the binding posts BA with the correct polarity.

(7) When the deflection of the pointer has been reduced to a small amount, press switch (10). If the deflection is still small, press switch (11) and adjust the bridge for zero deflection of the galvanometer.

(8) When the galvanometer ceases to deflect, indicating that the bridge is balanced, read the setting of the four dial switches comprising the R arm of the bridge. Dial switch (1) reads in units, dial switch (2) reads in units of tens, dial switch (3) reads in units of hundreds, and dial switch (4) reads in units of thousands. When the bridge is balanced, the value marked on the dial which is opposite the reference mark on the panel of the test set is the value to be used. Assume that dial switch (1) is set at 5, dial switch (2) is set at 3, dial switch (3) is set at 6, and dial switch (4) is set at 2. The numerical value of the reading of the R arm would then be 2,635.

c. USE OF TEST SET I–49 AS AUXILIARY RESISTANCE BOX. To use Test Set I–49 as an auxiliary resistance box, connect leads to binding posts X_2 and Rh (14) (16). This connection forms a circuit comprised of the four variable resistances controlled by dial switches (1), (2), (3), (4). The resulting circuit is independent of the remainder of the test set controls (fig. 19). This makes resistance from 0 to 10,110 ohms available in steps of 1 ohm, controlled only by the setting of the above dial switches.

Caution: To prevent damaging the resistance coils of the test set, the current should not exceed the specified values when using the following values of the resistance:

Maximum value of resistance (ohms)	*Maximum value of current (amperes)*
10,000	0. 005
5,000	0. 007
1,000	0. 017
100	0. 055
10	0. 17

9. Identifying a Faulty Conductor

To test for a grounded conductor in a cable (fig. 3) with Test Set I–49 the galvanometer and the internal battery are connected together in series, forming a test instrument which is independent of the bridge.

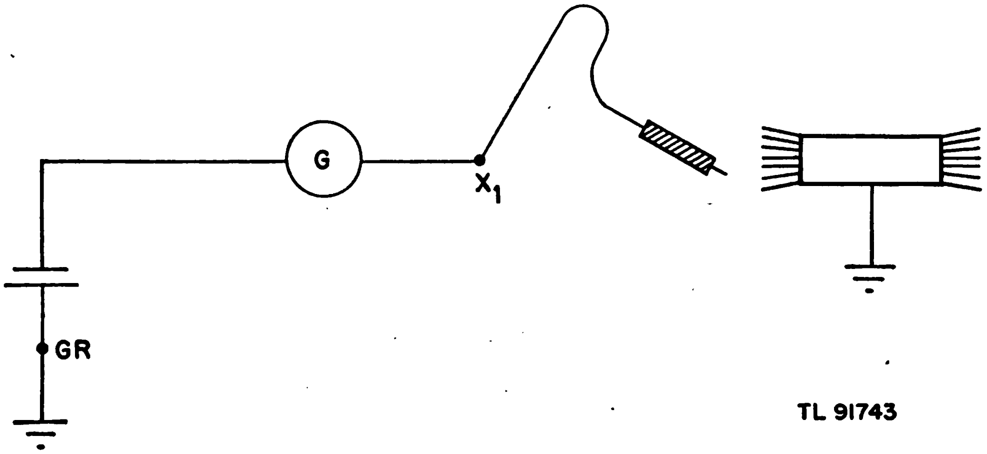


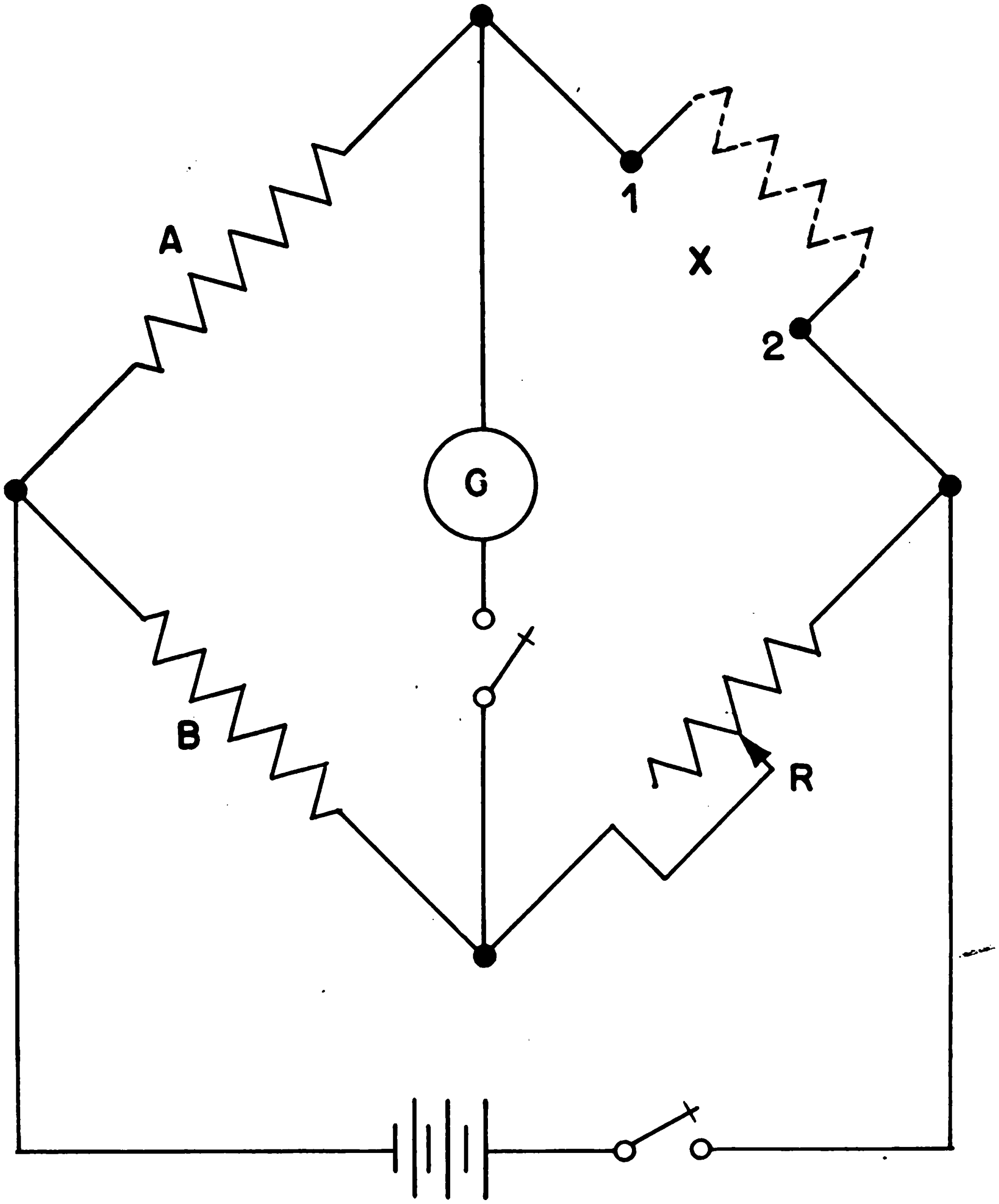
Figure 3. Identifying a faulty conductor.

a. Set the ratio dial MULTIPLY BY at $\frac{M}{1000}$. Turn the switch GA to the RVM position. Throw the key switch RES-VAR-MUR to VAR. Turn switch BA to INT.

b. To test for a grounded conductor, connect the binding post GR to ground or the cable sheath. Touch the wires in the cable one after another to binding post X_1 with switch GA SENS 1 held down. When the grounded wire is touched, the galvanometer will deflect strongly. With the sensitive galvanometer used in the test set, high-resistance grounds can be detected with the internal 4.5-volt battery.

c. To test for a cross or a short circuit, the procedure is the same as for a ground, except that binding post GR is connected to one of the suspected wires instead of to the ground.

d. To test for an open circuited wire, the binding post GR is connected to cable sheath or, in the case of nonmetallic sheathing, to the ground. The far end of the cable or wires are grounded to the cable sheath, or connected to a good ground. As the near end of the wires



TL 91744

Figure 4. Measuring an unknown resistance.

are touched one by one to binding post X_1, the galvanometer will deflect if the wire is good, but not if it is open.

10. Simple Resistance Measurement

a. PROCEDURE. (1) Place the test set in a level position. Raise the cover.

(2) Release the galvanometer pointer by sliding the locking clamp in the opposite direction to that indicated by the arrow on the clamp

knob. Center the galvanometer pointer by turning the bakelite knob on the galvanometer case just above the locking clamp.

(3) Turn switch GA to the RVM position.

(4) Turn switch BA to the INT position.

(5) Throw key switch RES-VAR-MUR to the RES position.

(6) Connect the unknown resistance to be measured to the binding posts X_1 and X_2 of the test set. Make sure that the connections from the resistance to the binding posts are of low resistance, are clean and free from oxidation, and are firmly secured.

(7) Set the dial switch MULTIPLY BY at $\frac{1}{1}$. The settings of the four dial switches comprising the *R* arm of the bridge will depend upon the value of the unknown resistance. Assume that the unknown resistance has a value of about 5,000 ohms. Set the 1,000 dial switch at 5, and the 100, 10, and 1 dial switches at 0.

(8) Press the .01 GA SENS switch. The galvanometer pointer swings to the right. It is then known that the *R* arm does not have enough resistance. The 100 dial switch is set at 1. The .01 GA SENS switch is again pressed. The pointer again swings to the right, but the swing is much less than before. The 10 dial switch is set at 5. The .01 GA SENS switch is pressed. The galvanometer pointer barely moves to the right. The .1 GA SENS switch is pressed and the pointer swings to the right with more force. The 1 dial switch is set at 4. The .1 GA SENS switch is pressed. No movement of the pointer is noted. The 1 GA SENS switch is pressed and the pointer swings to the right a very little. The 1 dial switch is set at 5 and the 1 GA SENS switch pressed again. Still there is a slight swing to the right. The 1 dial switch is set at 6 and the 1 GA SENS switch pressed. The pointer does not move, indicating that the bridge is balanced.

b. RESULTS. With the bridge balanced, the reading of the *R* arm of the bridge is noted. The 1,000 dial switch is set at 5, the 100 dial switch is set at 1, and 10 dial switch is set at 5, and the 1 dial switch is set at 6. This gives a reading of 5,156 for the *R* arm. Multiply this value by the setting of the MULTIPLY BY dial switch, and the value of the unknown resistance will be given in ohms. This time the setting of the ratio dial switch is $\frac{1}{1}$ which multiplied by 5,156 gives a value of 5,156 ohms for the value of the unknown resistance.

11. Simple Loop Test

a. PROCEDURE. The procedure in measuring the loop resistance of a circuit does not vary greatly from that just outlined in the measurement of unknown resistance.

(1) Place the test set in a level position and raise the cover.

(2) Unlock the galvanometer pointer and set the pointer at the center of the graduated scale by means of the bakelite knob.

(3) Turn switch GA to the RVM position.

(4) Turn switch BA to the INT position.

(5) Throw key switch RES-VAR-MUR to the RES position.

(6) Have any equipment on the circuit removed, and a jumper (short circuit) placed across the far end of the circuit under test.

(7) Connect the test set to the circuit at the test point (fig. 5). Connect the wires to binding posts X_1 and X_2. If leads are used to connect the test set to the circuit, they must be of low resistance, or considerable error will be introduced.

(8) Set the dial switch MULTIPLY BY at $\frac{1}{1}$ and balance the bridge as outlined in paragraph 10*a*. If the bridge cannot be balanced, the setting of the dial switch MULTIPLY BY may require changing. Reset and balance the bridge.

b. RESULTS. When the bridge has been balanced so that no deflection of the galvanometer pointer can be noted, read the settings of the four dial switches comprising the *R* arm. Multiply this reading by the setting of the dial switch MULTIPLY BY and the result will be the resistance of the loop circuit in ohms.

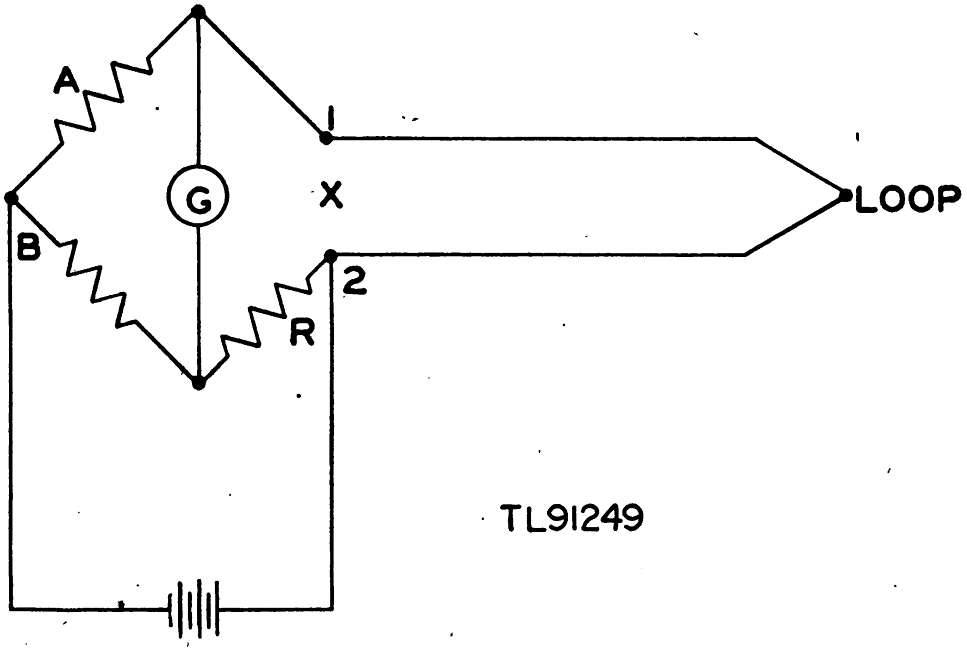


Figure 5. Simple loop test.

Example: A loop circuit is set up and the test set is connected as described above. When the bridge is balanced, the dial switch MULTIPLY BY is set at $\frac{1}{10}$. The 1 dial switch is set at 3, the 10 dial switch is set at 2, the 100 dial switch is set at 7, and the 1,000 dial switch is set at 1. The reading of the *R* arm is then 1,723. Multiplying this value by the setting of the ratio arm (MULTIPLY BY dial switch): 1,723 x $\frac{1}{10}$, the resistance of the loop circuit is found to be 172.3 ohms.

c. LOCATING SHORTS AND CROSSES. The locating of crosses or shorts by loop resistance tests requires that check tests be made from the far end of the circuit in addition to the test made at the original test point.

(1) The check tests can be made from the far end of the circuit; however, in practice it is often not convenient to transfer the test set

to the far end of the circuit in order to make measurements from that end. A substitute for this method is to connect the distant end of the faulty pair to a good cable pair. This permits testing to the fault from both ends of the circuit from one test point.

(2) The reason for making check tests is evident if it is realized that *few* crosses or shorts have *zero* resistance at the point of contact. If the resistance of the cross or short due to contact resistance should be several hundred ohms, any calculations to determine the location of the fault would be in error if a check test were not made.

Example: A cable pair, upon being tested, indicates a short circuit. The cable is composed of No. 19 B&S gauge wire. The loop resistance per mile of this size wire is 85.01 ohms. The test man has the equipment removed from the faulty circuit and also from a good circuit. After having a jumper placed across the good pair at the far end, he measures the resistance of the good circuit and finds it to be 425.05 ohms. Then the good pair is connected to the faulty pair at the far end of the circuit. Connecting the test set to the faulty pair at the test point, the resistance to the fault is measured and found to be 297.5 ohms. This would indicate that the distance to the fault from the test point would be equal to 297.5 divided by 85.01 or 3.5 miles from the test point. He connects the test set to the good pair and measures the resistance from the test point through the good pair to the far end and back to the fault. This value is 637.6 ohms; 637.6—425.05 (loop resistance of good pair)=212.55 ohms. Divided by 85.01, this indicates that the fault is 2.5 miles from the far end. This cannot be true as the circuit is only 5 miles long and the calculations indicate a length of 6 miles. Then the actual short is at a point halfway between 3.5 miles from the test point and 2.5 miles from the far end. $3.5-2.5=1.$ $\frac{3.5+1}{2}=2.25$ miles, or the distance from the test point to the fault. The error in the original calculation is equal to $3.5-2.25$, or 1.25 miles. $1.25\times 85.01=106.3$ ohms or the resistance at the short.

12. Simplified Varley Loop Test

a. PROCEDURE. This test is used where the faulty and the good wires are alike in resistance.

(1) Set the test set in a level position, raise the cover, unlock the galvanometer pointer, and center the pointer on the graduated scale by means of the bakelite knob located on the galvanometer case.

(2) Remove all equipment from the circuit and place a short circuit across the far end of the circuit.

(3) Turn switch GA to the RVM position.

(4) Turn switch BA to the INT position.

(5) Throw key switch RES-VAR-MUR to the VAR position.

(6) Connect the grounded wire to binding post X_2 and the good wire to binding post X_1.

(7) Connect a wire from binding post GR to a good ground connection (fig. 6 (1)).

(8) Set the dial switch MULTIPLY BY at $\frac{1}{1}$.

(9) Adjust the settings of the four dial switches comprising the *R* arm of the bridge until no deflection is noted on the galvanometer when the 1 GA SENS key is pressed.

b. RESULTS. When the bridge is balanced, the reading of the *R* arm of the bridge, divided by the *loop resistance* for the correct size wire obtained from the wire tables in paragraph 26 will give the distance from the ground to the far end of the circuit.

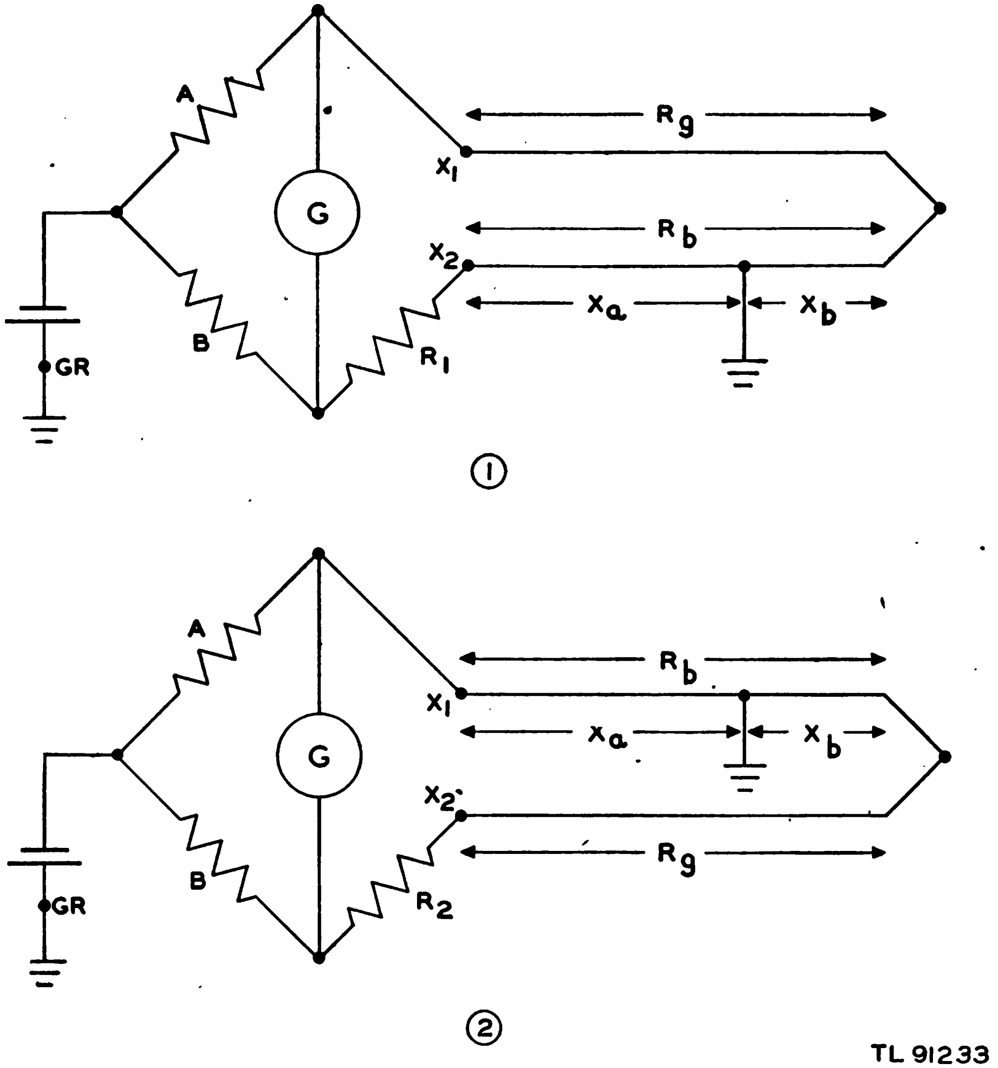


Figure 6. Regular Varley loop test and check.

13. Regular Varley Loop Test and Check

a. The Varley loop test is best adapted to fault location in high-resistance loops. A line fault location by the Varley loop method requires the use of one good wire in addition to the faulty wire. It consists essentially of determining the loop resistance of the conductors between the fault and the far end of the circuit.

b. A grounded Varley measurement is one in which the return path from the fault to the battery is through the ground (fig. 6).

It should be noted that the magnitude of the resistance in the return path does not affect either the bridge balance or the calculations for determining the Varley loop resistance. The resistance in the return path does affect the sensitivity of the bridge and, therefore, the accuracy of the bridge.

c. Remove all equipment from the circuit to be tested. Place a short circuit across the good and bad wires at the far end.

(1) Place the test set in a level position, raise the cover, and release the galvanometer pointer. Center the pointer on the graduated scale.

(2) Connect the test set to the circuit at the test point. The faulty wire should be connected to binding post X_2 and the good wire connected to binding post X_1.

(3) Turn switch GA to the RVM position.

(4) Turn switch BA to the INT position.

(5) Throw key switch RES-VAR-MUR to the RES position.

(6) Balance the bridge. Note on paper the value of the resistance of the loop, as this value will be substituted in the equation for computing the resistance from the test set to the fault.

(7) Connect a wire from binding post GR to a good ground connection.

(8) Throw key switch RES-VAR-MUR to the VAR position.

(9) Set the dial switch MULTIPLY BY at $\frac{1}{9}$ or $\frac{1}{4}$. These ratios are provided for Varley measurements and should be used whenever possible, as they simplify the calculations.

(10) Balance the bridge. Note the reading of the *R* arm and the ratio arm.

(11) The resistance from the test set to the fault is found by using the equation:

$$X_a = \frac{rB - AR}{A + B},$$

where X_a is the resistance from the test set to the fault, r is the resistance of the loop obtained in the first balancing of the bridge, R is the reading of the R arm of the bridge after the second balance, and A and B, respectively, are the numerator and denominator of the fraction obtained from the setting of the dial switch MULTIPLY BY. When using the values obtained from the setting of the ratio dial switch, always consider them as fractional values and not decimal values. The calculation of the resistance in a test of this type is not difficult as the following example will illustrate.

(12) To make a check test, interchange the good and bad conductors (fig. 6 (2)) and balance the bridge. The resistance from the test set to the fault is found by using the equation.

$$X_a = \frac{A(R_2 + r)}{A - B},$$

where X_a is the resistance from the test set to the fault, r is the resistance of the loop obtained in the first balancing of the bridge $(R_g + R_b)$, R_2 is the reading of the R arm of the bridge for the check test, and A and B, respectively, are the numerator and denominator of the fraction obtained from the setting of the dial switch MULTIPLY BY.

Example: A circuit in a lead-covered aerial cable 65 miles long grounds on the one side of the circuit. The equipment is removed from both ends of the circuit and a jumper is placed across the circuit at the far end. Test Set I–49 is connected to the circuit at the test point and the resistance of the loop is measured as outlined above. The resistance of the loop is found to be 5,525 ohms. This value is written down. The connection is made to binding post GR and the cable sheath. The key switch is thrown to VAR. The ratio dial switch MULTIPLY BY is set at $\frac{1}{4}$. The reading of the R arm when the bridge is balanced is 9,560. Then $R=9{,}560$, $r=5{,}525$ ohms (the resistance of the loop), $A=1$, and $B=4$. Substituting these values in the equation,

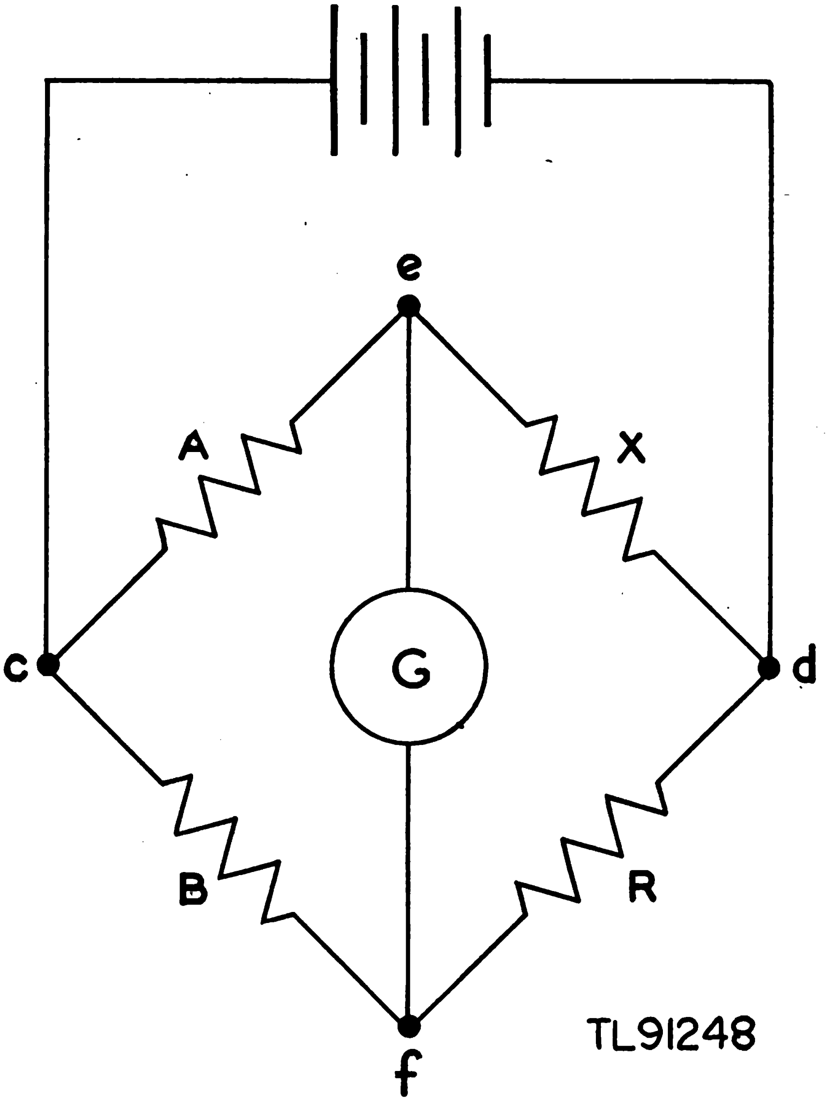


Figure 7. Wheatstone bridge, basic circuit.

$$X_a=\frac{rB-AR}{A+B},\ X_a=\frac{(5{,}525)4-1(9{,}560)}{1+4}=\frac{22{,}100-9{,}560}{5}$$

is equal to 2,508 ohms or the resistance from the test set to the fault. A check test is made, interchanging the good and bad conductors on binding posts X_1 and X_2. The ratio dial switch MULTIPLY BY remains set at $\frac{1}{4}$. The bridge is balanced and the reading of the R arm or R_2 is 7,015. Substituting these values in the equation

$$X_a=\frac{A(R_2+r)}{A+B}=\frac{1(7{,}015+5{,}525)}{1+4}=\frac{12{,}540}{5}$$

is equal to 2,508 ohms. This value of resistance is the same as that found in the original test; then, dividing the value of resistance by the resistance per unit length at the existing temperature of the size wire used in the cable will give the distance from the test set to the fault.

14. Basic Wheatstone Bridge Circuit

In a simple Wheatstone bridge circuit (fig. 7)*, four resistances are connected together in the shape of a diamond. This forms a series-parallel circuit and is commonly called a *bridge circuit*. Resistors A, B, and R are resistances of known value. Resistor X is the unknown resistance. A galvanometer is connected across points e and f. A source of voltage is connected across points c and d. If the bridge is balanced, the galvanometer will show that no current is flowing from e to f. When this condition exists, points e and f are at the same potential. When points e and f are at the same potential, voltage drop c to e equals voltage drop c to f, and voltage drop e to d equals voltage drop f to d. The current flowing through resistor A is the same as that flowing through resistor X. Also, the current flowing through resistor B is the same as that flowing through resistor R. With the above relationships established, a proportion can be set up. $\frac{A}{B}=\frac{X}{R}$ or $XB=AR$. Then in terms of the unknown, $X=\frac{A}{B}R$.

a. From this explanation, it is evident that it is easy to measure resistance if the value of three of the four resistances is known.

b. Resistors A and B are referred to as the ratio arms. Only their *ratio*, not their individual values, need be known. Resistor R generally is composed of four variable resistors, individually controlled, which change the value of the R arm of the bridge in steps of 1 ohm, 10 ohms, 100 ohms, and 1,000 ohms. A bridge of this type is commonly called a decade bridge.

15. Three-Varley Method

To locate a ground by the Three-Varley method, three different bridge arrangements (fig. 8) are balanced and the readings of the R arm are designated R_1, R_2, and R_3.

a. Connect the faulty conductor to binding post X_2.

b. Connect the faulty wire at the far end to two good conductors. Connect one good wire to binding post X_1 and one good wire to binding post GR (fig. 8(1)).

c. Turn switch GA to RVM.

***All points referred to in paragraph 14 are shown in figure 7.**

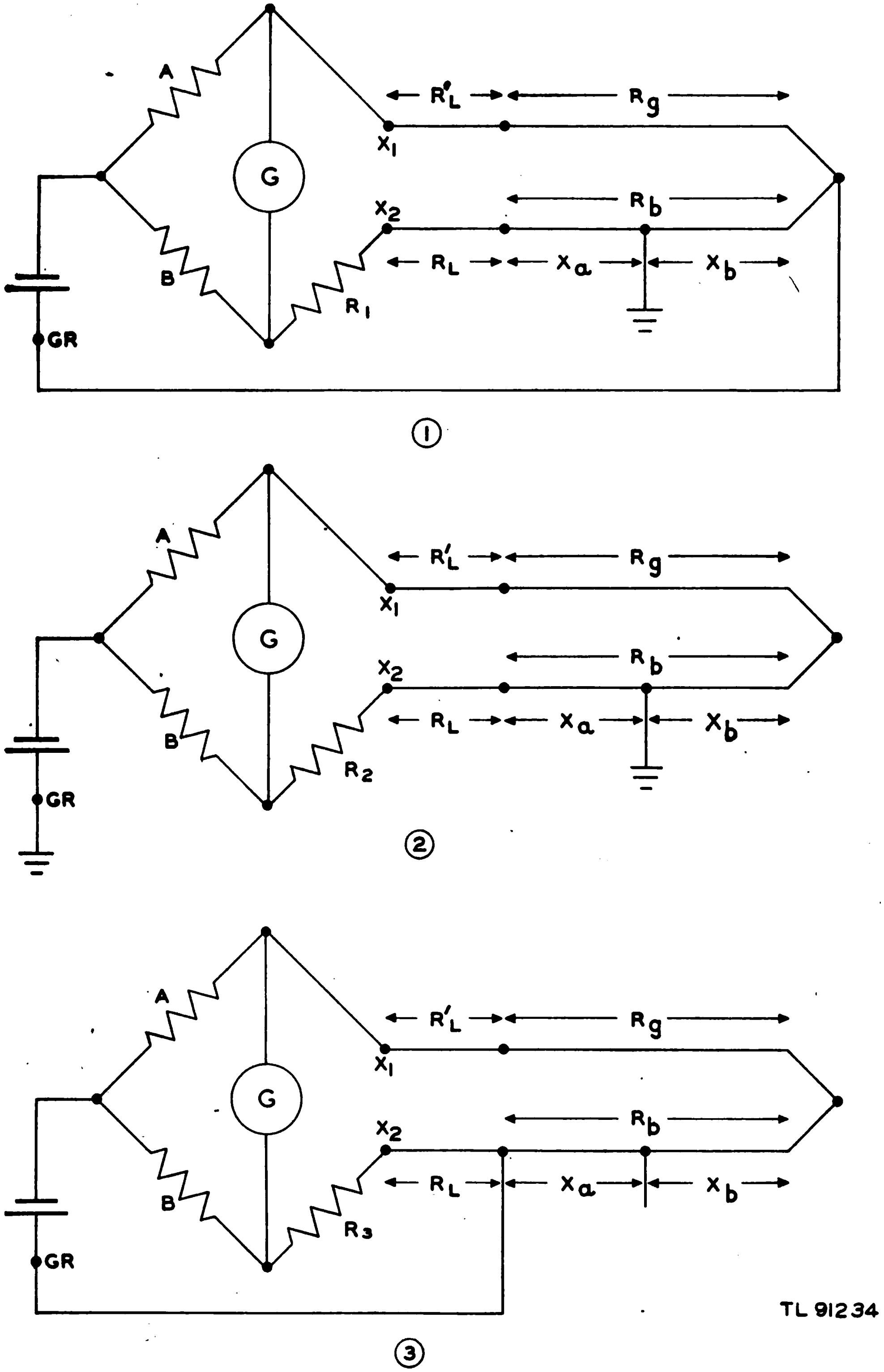


Figure 8. Three-Varley method.

d. Throw the key switch RES-VAR-MUR to the VAR position.

e. Turn ratio dial switch MULTIPLY BY to $\frac{1}{4}$ or $\frac{1}{9}$ for convenience in calculations. This setting must not be changed during the three measurements.

(1) Balance the bridge.

(2) Note the reading of the R arm and designate it as R_1.

f. To read R_2, remove the good wire from the binding post GR and connect the binding post GR to ground (fig. 8(2)).

(1) Balance the bridge.

(2) Note the reading of the R arm and designate it as R_2.

g. To read R_3, remove the ground wire from the binding post GR and connect the binding post GR to binding post X_2 (fig. 8(3)).

(1) Balance the bridge.

(2) Note the reading of the R arm and designate it as R_3.

h. Then the resistance from the far end of the circuit to the fault X_b, the resistance from the test set to the fault X_a, and the resistance of the faulty conductor R_b can be found by using the working equations—

$$X_b=\frac{A}{A+B}(R_2-R_1),\ X_a=\frac{A}{A+B}(R_3-R_2),\ \text{and}$$

$$R_b=X_a+X_b=\frac{A}{A+B}(R_3-R_1).$$

i. This method is useful because it uses two good wires of *any resistance* and a ground connection. Simultaneously, it measures the resistance of the faulty conductor and the resistance from the fault to each end of the faulty wire. This method eliminates the effects of lead resistance and is very useful when the test set has to be placed some distance from the test point.

j. When the total resistance of the loop is more than about 1,100 ohms, it may be impossible to balance the bridge when using ratios of $\frac{1}{9}$ or $\frac{1}{4}$. It may be necessary to use $\frac{1}{1}$. Then, if the good wire is of lower resistance than the faulty wire, the bridge cannot be balanced in the Varley 1 test (fig. 8(1)). Connect a small resistor between the test set and the good conductor. It is used during all three tests. Any reasonable value of resistance which is large enough to make the resistance of the good conductor higher than that of the faulty conductor can be used. Its value need not be known since it is automatically eliminated by the method of the test.

Example: A conductor in a 10-pair, rubber-covered cable, approximately 12 miles long, develops a fault. The cable is tested and shows a ground on the faulty conductor. The other circuits in the cable are urgently needed and cannot be used for test purposes. A field-wire circuit, terminating at the same points as the cable, is not in use and is used for the test. The ratio dial of the test set is set at $\frac{1}{4}$ and the test set connected for the test (fig. 8(1)). The bridge is balanced and the reading of the R arm is 1,732. This value is marked down as R_1 and the test set is connected for the second test (fig. 8(2)). The bridge is balanced and the reading of the R arm is 2,482. This value is marked down as R_2. The test set is connected for the third test (fig. 8(3)) and the bridge is balanced. The reading of the R arm is 4,302 and is marked down as R_3.

When

$$X_b=\frac{A}{A+B}(R_2-R_1),$$

substituting the values and solving shows:

$$X_b=\frac{1}{1+4}(2{,}482-1{,}732)=150 \text{ ohms}.$$

Likewise,

$$X_a=\frac{A}{A+B}(R_3-R_2) \text{ or } X_a=\frac{1}{1+4}(4{,}302-2{,}482)=364 \text{ ohms};$$

$$R_b=\frac{A}{A+B}(R_3-R_1) \text{ or } R_b=\frac{1}{1+4}(4{,}302-1{,}732)=514 \text{ ohms},$$

or the resistance of the faulty conductor. The resistance of the conductors in this cable is 42.9 ohms per conductor per mile. Dividing the resistance of the faulty conductor from the test set to the fault by the resistance per conductor per mile, the distance from the test set to the fault is equal to $\frac{364}{42.9}$, or approximately 8.5 miles.

16. Murray Loop Test and Check

a. The Murray loop test is very useful when locating faults in relatively low-resistance loops, such as short sections of communication and power cables. In this test, the loop formed by the two conductors is divided at the fault into two parts, which form the two arms of a Wheatstone bridge (fig. 9). The fault shown here is a ground. If the fault should be a cross, the battery (binding post GR) is connected to the second faulty wire. The other two bridge arms consist of known resistors A and R, the latter being adjustable in small steps over a wide range of values. At the bridge, in the case of a ground, the battery is connected to the cable sheath or to a good ground connection.

b. Let r be the resistance of the loop formed by the two conductors, and X_a the resistance of the faulty conductor from the bridge to the fault. When the bridge is balanced by adjusting the R arm to the value R_1, which reduces the current through the galvanometer to zero,

$$\frac{A_1}{R_1}=\frac{r-X_a}{X_a},$$

from which

$$X_a=\frac{R_1r}{A_1+R_1}.$$

To check the test, interchange the good and bad conductors (fig. 9(2)). The reading of the R arm on the check test is R_2. Then

$$\frac{A_2}{R_2}=\frac{X_a}{r-X_a}$$

from which

$$X_a=\frac{A_2 r}{A_2+R_2}$$

c. In making Murray loop tests on communication cables, using a dial type bridge, it is desirable to make A_1 and A_2 equal to 1,000 ohms. If the good and bad wires are of the same resistance, R_1 will always be less than A_1 and R_2 will always be more than A_2. When the fault is near the test end, it will sometimes be impossible to make A_2 equal to 1,000. In such cases, it is advisable to make A_2 equal to 100. When the fault is at the far end, $R_2=R_1=A_1=A_2$. When the fault is at the near end, R_2 will be infinity, and R_1 will be zero. Thus,

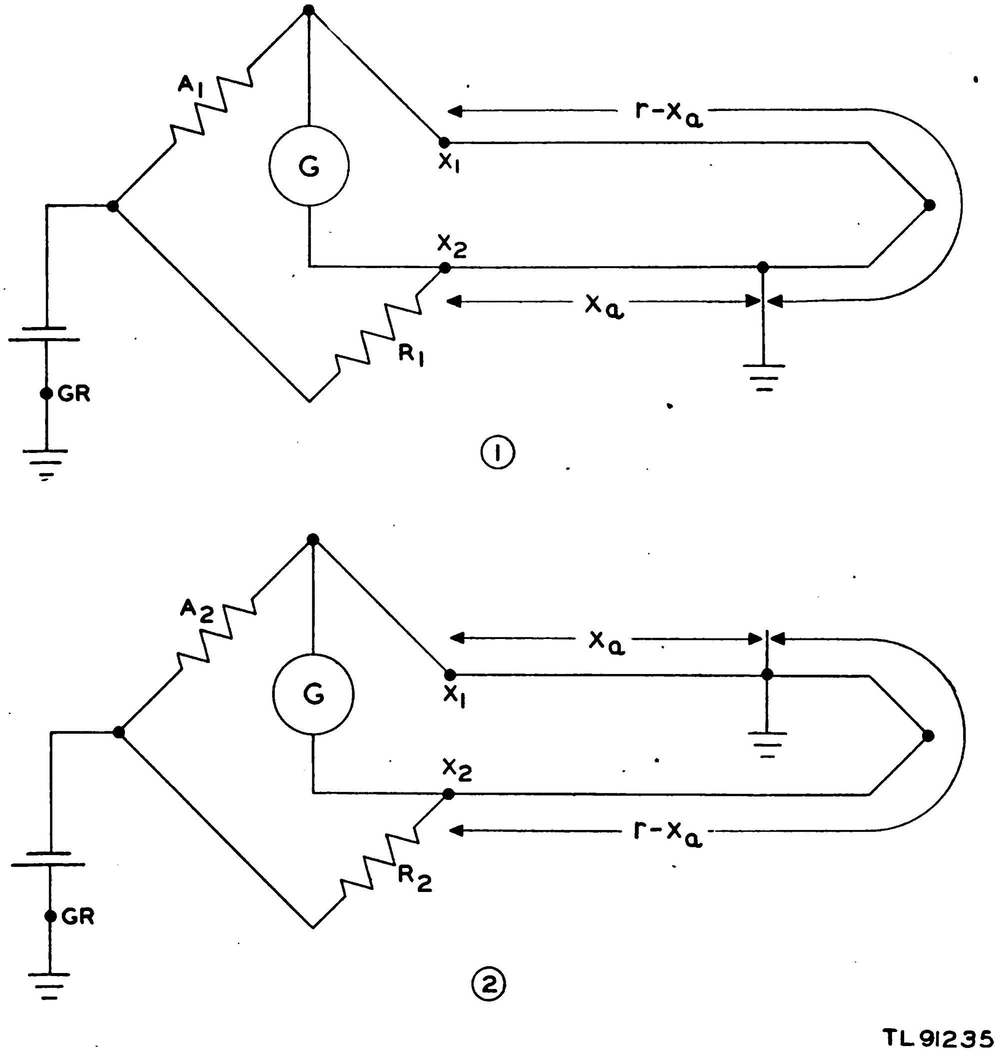


Figure 9. Murray loop test and check.

it is possible to obtain some idea of the location of the fault simply by inspection of the values of R_1 and R_2.

d. Using Test Set I–49, proceed with the Murray loop test as follows:

e. Remove all equipment from the circuit and place a short circuit across the far end of the circuit (fig. 9 (1)).

f. Connect the faulty wire of the circuit to binding post X_2, and the good wire of the circuit to binding post X_1 of the test set.

g. Connect a wire from the binding post GR to the cable sheath or to a good ground connection.

h. Turn switch GA to RVM. Turn switch BA to INT or EXT, depending on the source of voltage to be used.

i. Set the ratio dial MULTIPLY BY to $\frac{\text{M}}{1000}$. If the bridge can not be balanced, change the ratio dial settings to $\frac{\text{M}}{100}$.

j. Throw key switch RES-VAR-MUR to MUR.

k. Balance the bridge.

l. When the bridge is balanced, the reading of the R arm is designated R_1, the value of the ratio dial setting is designated A_1, the values substituted in the equation

$$X_a = \frac{R_1 r}{A_1 + R_1},$$

and the value of X_a can be computed.

m. To make a check test, interchange the good and bad conductors (fig. 9 (2)) and balance the bridge. The reading of the R arm is then designated as R_2 and the setting of the ratio dial as A_2. Then

$$X_a = \frac{A_2 r}{A_2 + R_2}.$$

Example: A circuit in a section of spiral-four cable 4 miles long develops a fault. When tested it shows a ground on the faulty conductor. Test Set I–49 is connected to the circuit at the test point. The equipment is removed from the circuit and a short circuit is placed across the far end of the circuit. Binding post GR is connected to a good ground connection (fig. 9 (1)). The key switch RES-VAR-MUR is thrown to the MUR position. The ratio dial switch is set at $\frac{\text{M}}{1000}$. When an attempt is made to balance the bridge the galvanometer deflection is too weak to read. To increase the sensitivity of the bridge (2), Batteries BA–2 (22.5 volts each) are connected in series and connected to the binding posts *BA*, + and –, observing the correct polarity. Switch *BA* is turned to the EXT position. The galvanometer now shows a strong deflection and the bridge is balanced. The reading of the R arm when the bridge is balanced is 522. The loop resistance per mile of spiral-four cable is 78 ohms per mile, including the loading coils placed in each ¼-mile length. The resistance of the loop or r then is 312 ohms. Since the

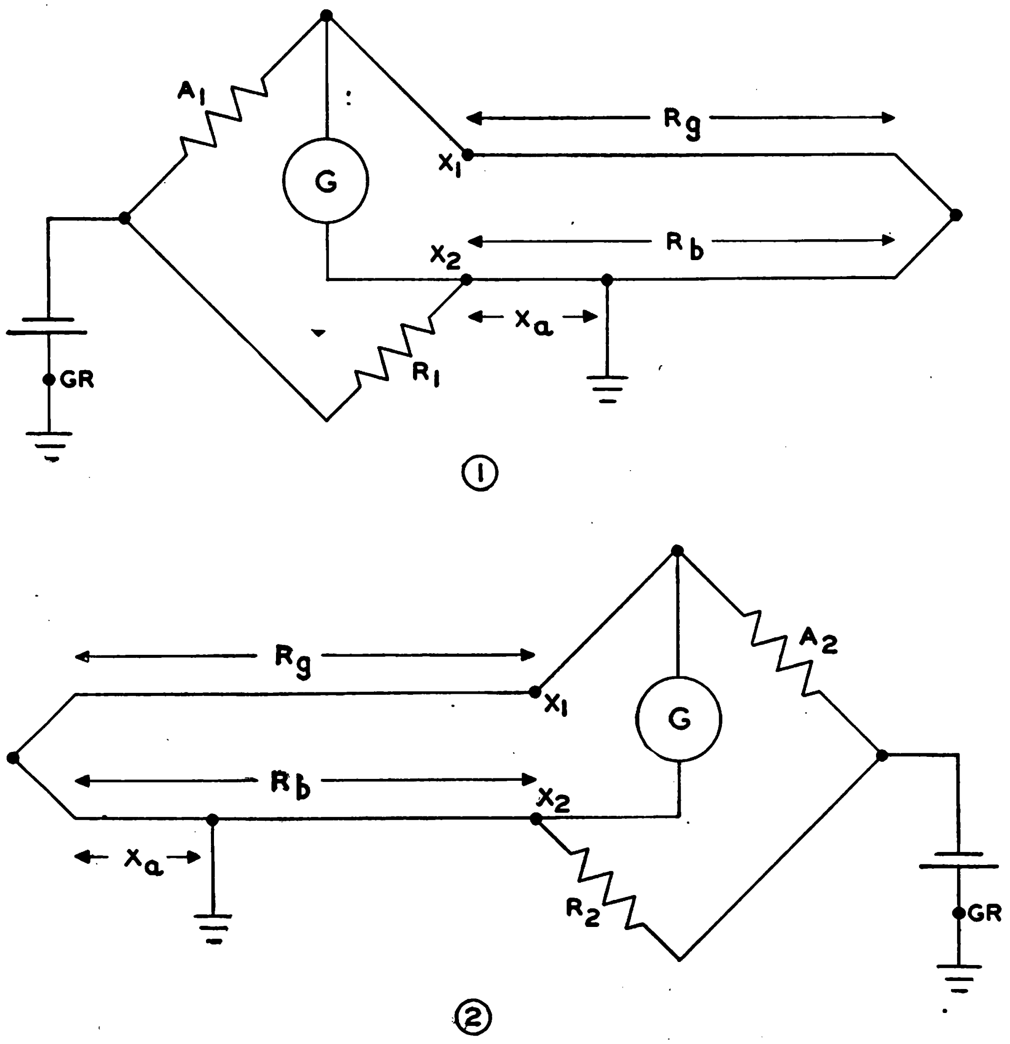


Figure 10. Modified Murray loop test and check.

setting of the ratio dial was $\frac{M}{1000}$, $A_1=1{,}000$. Substituting these values in the equation,

$$X_a=\frac{R_1 r}{A_1+R_1}=\frac{522(312)}{1{,}000+522}=107 \text{ ohms.}$$

For a check test, the good and bad conductors are interchanged (fig. 9(2)). The ratio dial remains set at $\frac{M}{1000}$. The bridge is again balanced. The reading of the *R* arm is 1,916. Calling this value R_2 and substituting in the equation,

$$X_a=\frac{A_2 r}{A_2+R_2}=\frac{1{,}000(312)}{1{,}000+1{,}916}=107 \text{ ohms.}$$

Converting resistance to distance, the location of the fault is determined.

n. If the trouble was caused by a cross instead of a ground, the location is determined by forming a loop by connecting one crossed wire to binding post X_2 and joining it at the far end to a good wire which is connected to X_1. The other crossed wire is connected to binding post GR, which is not grounded. In other respects the procedure is the same as for a ground.

17. Modified Murray Loop Test and Check

a. When only one good conductor is available but is not of the same length or size as the faulty conductor, the fault can be located by making a Murray loop test at each end of the cable (fig 10(1) and (2)).

b. Follow the procedure outlined in paragraph 16 for Murray loop tests.

c. Keep in mind that if the faulty conductor is connected to binding post X_2 for the first test, it must be connected to the same binding post when the check test is made at the other end of the circuit.

d. Let R_b be the resistance of the faulty conductor, R_g the resistance of the good conductor, and X_a the resistance from the first test point to the fault. If R_1 is the reading of the R arm of the bridge when connected for the first test (fig. 10(1)), and A_1 is the setting of the ratio dial switch MULTIPLY BY, then

$$\frac{A_1}{R_1}=\frac{R_g+R_b-X_a}{X_a}.$$

Repeat the test at the other end of the circuit, connecting the faulty conductor to the same binding post, and using the same ratio dial setting (fig. 10(2)). When the bridge is balanced for the check test, the reading of the R arm of the bridge will be R_2, and the setting of the ratio dial will be A_2. Then

$$\frac{A_2}{R_2}=\frac{R_g+X_a}{R_b-X_a}.$$

Since the resistance of the good conductor R_g is the same in both tests, it can be eliminated and the two equations can be combined, resulting in

$$X_a=\frac{R_1\ (A_2+R_2)\ R_b}{R_2\ (A_1+R_1)+R_1\ (A_2+R_2)}.$$

18. Fisher Loop Test and Check

a. The Fisher loop test is useful when all of the conductors in a cable are bad, making it necessary to use auxiliary conductors, external to the cable, for the test. The test requires two additional conductors, which may be of any size or length. The only requirement is that they terminate at the same point as the circuit to be tested.

b. Two tests are made. The first is identical with the Murray loop test, and connections are made, using the first auxiliary conductor as R_g (fig. 11①). In the second test (fig. 11②), the ground connection is removed from the binding post *GR* and the second auxiliary conductor is connected to binding post *GR*.

c. Let R_b be the resistance of the faulty conductor, X_a the resistance from the test point to the fault, and R_g the resistance of the auxiliary conductor. The resistance of the faulty conductor must be known. The resistance of the auxiliary conductors need not be known. When

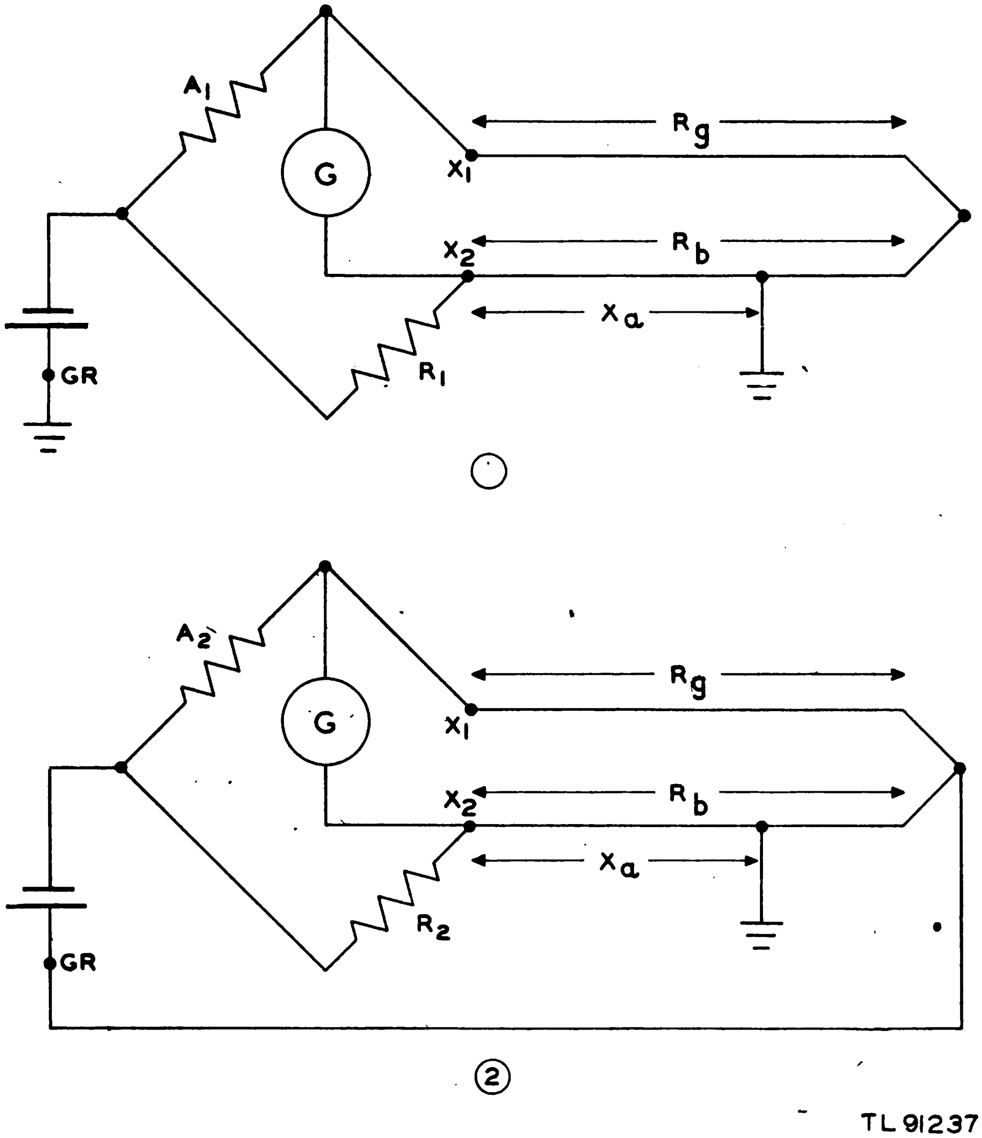


Figure 11. Fisher loop test and check.

A_1 is the setting of the ratio dial switch MULTIPLY BY, and R_1 is the reading of the *R* arm of the bridge, then

$$\frac{A_1}{R_1}=\frac{R_g+R_b-X_a}{X_a}.$$

From the second test (fig. 11②), when A_2 is the setting of the ratio dial and R_2 is the reading of the *R* arm, then

$$\frac{A_2}{R_2}=\frac{R_g}{R_b}.$$

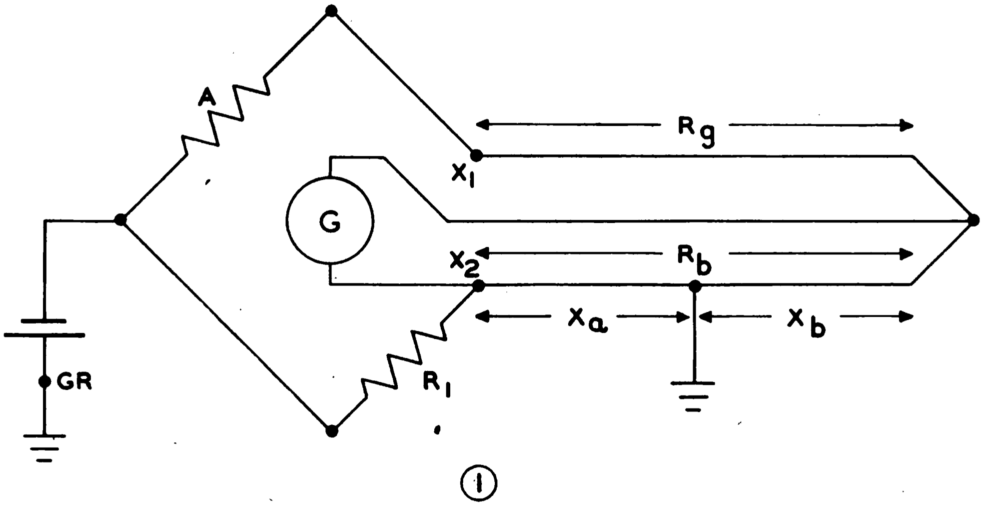
Eliminating R_g from both equations, then

$$X_a = \frac{(A_2 + R_2)R_1}{(A_1 + R_1)R_2} R_b.$$

d. If the resistance of the faulty conductor is not known, the Three-Varley method, described in paragraph 15, may be used on a circuit test under the above conditions.

19. Hilborn Loop Test and Check

a. This method is useful for locating faults in section lengths of cable. Two good conductors, the resistance of one of which must be known, are required for this test, The connections differ from the Murray loop test in that the known resistance of the good conductor is in the A arm of the bridge. Test Set I–49 is arranged so that the



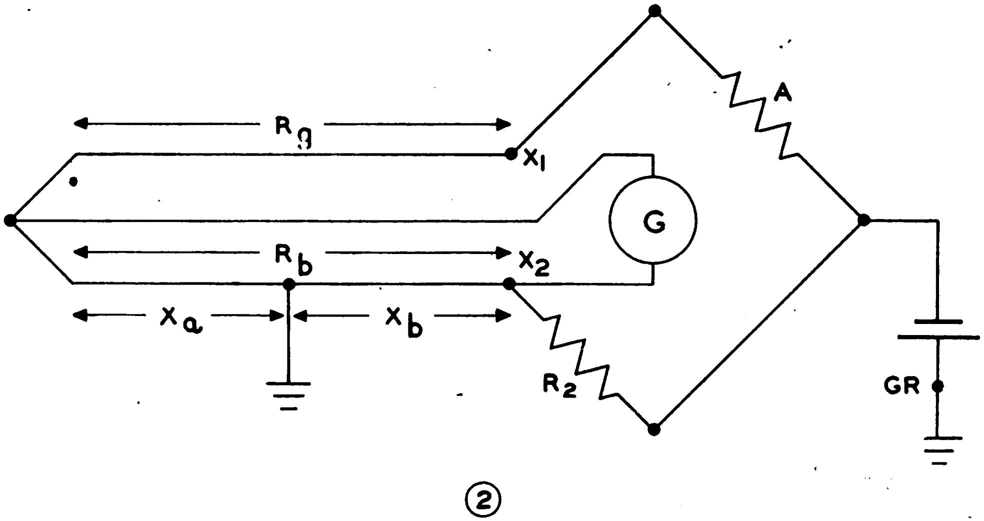


Figure 12. Hilborn loop test and check.

internal galvanometer can be used for this test by turning the switch GA to the HIL position, and connecting the second auxiliary conductor to the binding post GA_1.

b. To test by this method, remove all equipment from the line. Place a short circuit at the far end of the circuit across the faulty conductor and the two good conductors to be used for the test (fig. 12(1)).

c. At the test point, connect the good conductor of known resistance to binding post of X_1 the test set.

d. Connect the faulty conductor to binding post X_2.

e. Connect the second good conductor to binding post GA_1.

f. Connect binding post GR to ground or cable sheath.

g. Throw key switch RES-VAR-MUR to MUR.

h. Turn switch GA to HIL.

i. Turn ratio dial MULTIPLY BY to $\frac{M}{1000}$ or $\frac{M}{100}$.

j. Balance the bridge.

k. When the bridge is balanced, the value of the R arm of the bridge R_1, the setting of the ratio dial A, and the known resistance of the good conductor R_g and faulty conductor R_b are substituted in the equation $\frac{A+R_g}{R_1}=\frac{X_b}{R_b-X_b}$, from which $X_b=\frac{A+R_g}{A+R_g+R_1}R_b$, or the resistance from the fault to the far end.

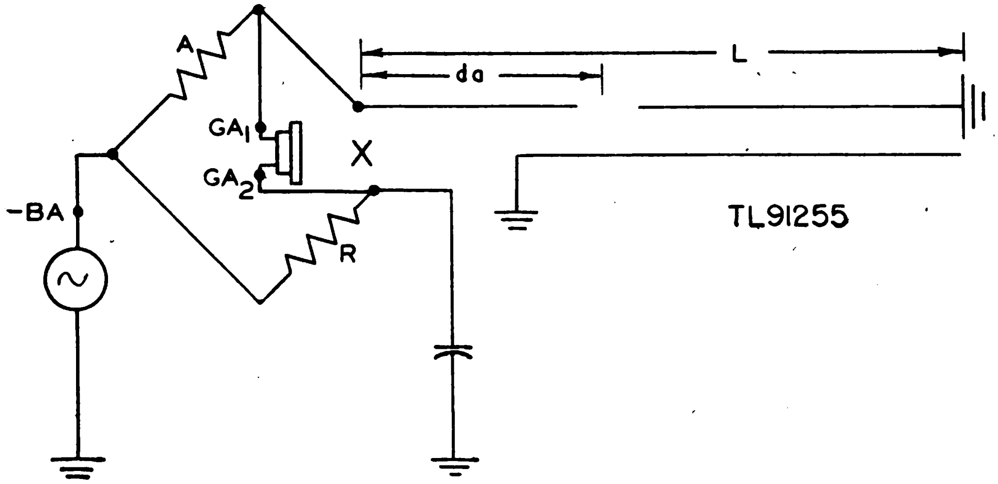


Figure 13. Locating an open.

l. To check the value arrived at, repeat the test at the far end of the circuit (fig. 12(2)). Ne sure that the same conductors are used and the same connections are made as in the first test. When the bridge is balanced for the second test, the resistance from the first test point to the fault is given by the equation, $X_a=\frac{(A+R_g)\,R_b}{A+R_g+R_2}$.

20. Capacitance Test for the Location of Opens

a. When a conductor is completely broken (open) and there is no return circuit from the break to the test point, a new set of conditions must be considered. In locating the break, use is made of the fact that every conductor possesses capacitance with any neighboring conductors, and forms with them a capacitor. The conductor itself forms one plate; the neighboring conductors, the cable sheath, or the earth, forms the other plate; the cable insulation, air, or other insulating material, forms the dielectric of the capacitor.

b. By balancing the capacitance of the faulty conductor against that of a good conductor in the *same cable*, fairly accurate locations can be determined. If the good and the bad wires are about the same length and gauge but not in the same cable, approximate locations can be determined.

c. The connections used are essentially the same as the basic Wheatstone bridge circuit (fig. 7) with resistor R replacing resistor B in the ratio arm, a capacitor of known value replacing resistor R, and the unknown capacitance connected in place of the unknown resistance. The galvanometer is replaced by headphones and the battery is replaced by an a-c source. If the ratio of resistors A and R are varied, some point will be found where there is a minimum of sound in the headphones. The bridge is then balanced. A proportion can be set up, differing from the proportion for the resistance bridge. The larger the value of capacitance, the lower the reactance of the capacitor at a given frequency. Then, with the two resistance arms replaced by capacitors, the proportion becomes an inverse relationship, or $\frac{A}{R}=\frac{C}{C_1}$, where C is the capacitor of known value replacing the R arm, and C_1 is the unknown capacitor replacing the X arm of the basic bridge.

d. The location of an open using Test Set I–49 requires the use of additional equipment: a 1- or 2-mf capacitor, a telephone receiver or headset, and a source of alternating current such as produced by a subcycle or Telering converter, or other similar source of a-c ringing current.

e. Remove all equipment from the faulty circuit.

f. Ground the open wire at the distant end. Connect the open wire at the test point to binding post X_1 (fig. 13). Ground the good wire at the test point and leave the distant end free.

g. Connect one lead of the 1- or 2-mf capacitor to binding post X_2. Connect the other side of the capacitor to ground.

h. Connect the telephone receiver or headset to GA binding posts 1 and 2. Turn switch GA to RVM. Remove screw A from the galvanometer (fig. 2 (13)).

i. Connect one side of the a-c source to the binding post —BA. Connect the other side of the power source to ground (fig. 13). Turn switch BA to EXT.

j. Turn ratio dial switch MULTIPLY BY to $\frac{\mathrm{M}}{1000}$, $\frac{\mathrm{M}}{100}$, or $\frac{\mathrm{M}}{10}$. Throw key switch RES-VAR-MUR to MUR.

k. Balance the bridge. Balancing the bridge in this case will be indicated by the absence of sound, or by a minimum of sound in the receiver or headset.

l. Note the value of the setting of the R arm. Call this value R_1.

m. Disconnect the open wire from binding post X_1 and ground it. Remove the good wire from the ground connection and connect it to binding post X_1.

n. Balance the bridge. Call the value of the R arm R_2.

o. Substitute the values of R_1 and R_2 in the equation $d_a = \frac{R_1}{R_2} L$ where d_a is the distance to the open in feet, and L is the length of the conductors in feet.

p. Repeat the tests from the other end of the circuit, and compare the results of the two tests for a more accurate location of the break.

21. Branched Circuits

a. Branched circuits require careful consideration when locating faults on them. The usual procedure of testing from one end of the circuit can be very inaccurate unless certain precautions ase observed.

b. A ground develops on a branch circuit *L* (fig. 14). A preliminary test is made from the end of circuit *T*. The ends of all the circuits involved are cleared of equipment and the circuit is short-circuited at point *D*, forming the loop *TBD*. The first test indicates that the fault is located at junction *B*. After removing the short circuit from the circuit at point *D*, and after short-circuiting the branch circuit at point *L*, thus forming the loop *TBL*, a second test will determine the location of the fault in this loop.

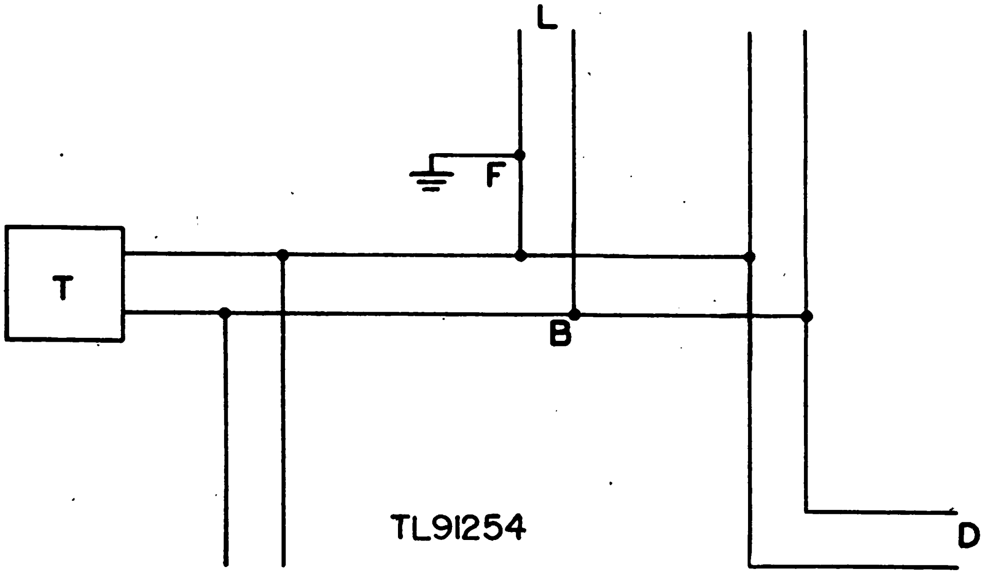


Figure 14. Branched circuits.

c. After the distance to a fault has been determined, a physical inspection of the circuit should be made near the point thus located. If no signs of the trouble are observed, the nearest splice may be opened. However, if the location has been determined from a test made at a central test point as in the case of cable systems, it is preferable to open the next splice beyond the indicated location, as this will facilitate the connections in case a second test is necessary.

22. Interpretation of Results

a. GENERAL. All the methods covered thus far have solved for the resistance of the faulty conductor either from the test point to the fault, or from the fault to the far end of the circuit being tested. To determine the distance to the fault, it is necessary to divide one of these resistance values by the resistance per unit length of the faulty conductor at the existing temperature. The location of the fault is then given in units of length. However, disadvantages are found in this method. Errors of serious magnitude which are caused by differences in temperature, nonuniform wire gauges, or circuits composed of wire with different diameters, will result. Another method, referred to as the percent method, will give more accurate results in most cases.

b. DISTANCE TO A FAULT BY THE PERCENT METHOD. If a conductor or loop is composed throughout of the same size of wire, its length is directly proportional to its resistance. If its length is known, it is often unnecessary to know its resistance. When the resistance to the fault is expressed, by formula, as a fraction of the resistance of the loop or the faulty conductor, the distance to the fault may be taken as the same fraction of the length of the loop or conductor.

(1) In the Murray loop test the resistance from the test set to the fault is given by the formula,

$$X_a=\frac{R_1 r}{A_1+R_1},$$

where r is the loop resistance. Let L be equal to the length of the loop; then the distance from the test set to the fault,

$$d_a=\frac{R_1 L}{A_1+R_1},$$

the length of the loop L being substituted for the resistance of the loop r.

(2) In the Three-Varley test, the resistance from the test set to the fault,

$$X_a=\frac{A}{A+B}(R_3-R_2)$$

and the resistance of the faulty conductor,

$$R_b=\frac{A}{A+B}(R_3-R_1),$$

from which,

$$X_a=\frac{R_3-R_2}{R_3-R_1}R_b.$$

Expressing this ratio in terms of distance,

$$d_a=\frac{R_3-R_2}{R_3-R_1}L$$

Where L is the length of the faulty conductor. It is desirable to use this method when possible, since it eliminates errors due to the lack of correct information regarding the temperature of the conductor, or due to the conductor's not being exactly to gauge.

(3) When the regular Varley loop test is used, the resistance from the test point to the fault,

$$X_a = \frac{B(R_b + R_g) - AR_1}{A + B}.$$

The relation between the resistance and length is given by:

$$d_a = \frac{X_a}{R_b} L,$$

where R_b is the resistance of the faulty conductor, L is the length of the faulty conductor, d_a is the distance from the test set to the fault, and X_a is the resistance of the bad conductor from the test set to the fault.

23. Accuracy

a. GENERAL. Several factors affect the accuracy of tests made with Test Set I–49. Keep in mind that the test set is designed to provide accurate measurements under certain conditions. If these conditions are not observed, accuracy cannot be maintained.

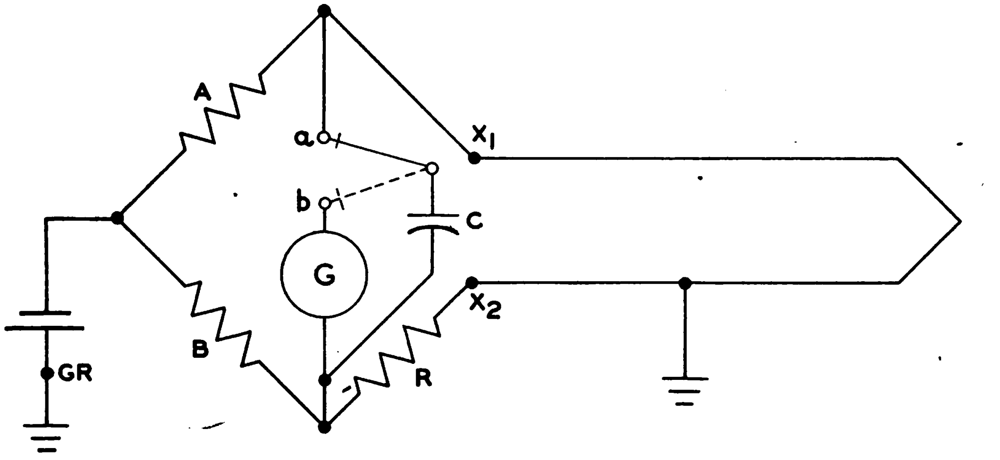


Figure 15. Use of capacitor to control foreign voltages.

b. POOR CONNECTIONS. Errors in the measurement of resistance and the locating of faults will result from poor connections. If a resistance of ¼ ohm is introduced in a circuit using No. 22 gauge wire and being tested by some loop methods, an error of 16 feet in the location of the fault will result.

c. STRAY CURRENTS. Foreign voltages are often induced in communication lines. They usually cause irregular deflections of the galvanometer. If necessary to overcome stray current effects, a higher-than-normal test voltage can be used within the limiting voltage for the test set.

(1) The use of a capacitor can be tried. Connections are made in the usual way for the desired loop test, except that a capacitor and switch are connected across the galvanometer (fig. 15). The capacitor

and switch combination, when used, should be connected between binding posts X_1 and Rh for resistance and Varley loop tests (fig. 6), and between binding posts X_1 and X_2 for Murray loop tests (figs. 9 and 10). The capacitor should have a value of 12 to 14 microfarads.

(2) The procedure is as follows: the capacitor is charged by throwing the switch to *a* (fig. 15), after which it is discharged through the galvanometer by throwing the switch to *b* (fig. 15). The *R* arm is adjusted by successive approximations until, when the switch is thrown to *b*, no kick is observed on the galvanometer, indicating that the capacitor is no longer being charged. The value of the *R* arm is then read and the location of the fault figured in the usual manner.

(3) If neither of these expedients makes it possible to obtain an accurate location of the fault, it may be necessary to use another loop or to postpone the test until conditions are more favorable.

d. DISAPPEARING GROUNDS. (1) Disappearing grounds are sometimes found while attempting to locate a fault, usually reappearing in a short time. Use a high voltage (not exceeding 200 volts), and by taking a quick reading the fault may be located.

(2) The application of ringing current to the faulty wire will occasionally reduce or permanently burn out the leak to ground. Before applying ringing current, all equipment must be disconnected from the line.

e. TWO FAULTS ON ONE WIRE. Two variable-resistance faults at different points, or one fault of considerable extent such as might be caused by moisture over a distance of several feet or more of cable, are indicated when it is impossible to balance the bridge on a loop test. Make tests from both ends of the line. If the calculated locations are alike, within the limits of error of measurement, usually only one fault exists. If the calculations differ, there are probably two or more faults.

f. INEQUALITIES IN LINE RESISTANCE. All fault locations by loop methods are based on the assumption that the wires have a uniform resistance per unit length. Unless the wire inequalities balance each other, which they do in many cases, the calculated locations will be in error in proportion to the inequalities in resistance. Among the causes of unbalanced lines are poor splices; loose or dirty contacts on cord assemblies and stubs; slight variations in wire gauges; loose or dirty terminal strips; and unequal temperatures of different parts of the line. The loop test should be made, whenever possible, by using the faulty wire and its mate, since the two are subject to the same conditions of twist, temperature variations, etc.

g. INCORRECT ASSUMPTIONS IN REGARD TO LINE RESISTANCE. Various factors cause errors if the calculations are based on resistance values obtained from wire tables. This class of error may be avoided by the use of those methods and formulas which determine the distance to the fault as a fraction of the total length of the loop circuit. For this reason, such methods are preferred when applicable.

h. ACCURATE RESISTANCE LIMITS OF TEST SET I–49. The resistance change from zero setting of the dial switches of the *R* arm to new settings is accurate to within a limit of error of the quantity ± (0.1 percent + 0.01 ohm), when measuring resistance in the range from 1 ohm to 40,000 ohms, using the self-contained batteries and inclosed galvanometer. The limit of error of the ratio resistors is ± 0.05 percent. The sensitivity of the bridge is not sufficient to permit very great accuracy of resistance measurements at values higher than 100,000 ohms unless a higher voltage is used. Contact resistance enters as the controlling factor in the measurement of resistance values lower than 1 ohm. A megohm-meter or an electronic device should be used for high-resistance measurements, and a Kelvin-type double bridge should be used for values below 1 ohm.

24. Composite Conductors

a. When the circuit consists of more than one size of wire, reference usually must be made to tables giving the resistance of the conductors in ohms per unit length, generally per 1,000 feet or the loop resistance per mile. Such tables are correct for the specified temperature only, usually 68° F. For any other temperature, the values given in the tables will require correction.

b. For the purpose of fault location, sections of wire and cable systems are usually considered to be that part of the system which is composed of the same size wire or gauge conductors. In circuit testing from terminal to terminal, more than one size of wire may be encountered. Thus, a measurement of the resistance to the fault or use of the percent method in calculating the distance to the fault will be in error, unless compensation for the variation in the wire sizes is utilized.

ACTUAL GAUGE		FACTOR TO DETERMINE EQUIVALENT GAUGE							
		10	13	16	19	22	24	26	28
10	MULTIPLY BY	1.	.500	.255	.126	.062	.039	.024	.015
13		2.	1.	.510	.252	.125	.078	.049	.030
16		3.92	1.98	1.	.494	.246	.153	.095	.060
19		7.94	3.97	2.02	1.	.496	.310	.193	.121
22		16.0	7.99	4.07	2.01	1.	.624	.389	.244
24		25.6	12.80	6.52	3.22	1.60	1.	.623	.391
26		41.1	20.6	10.5	5.18	2.57	1.61	1.	.628
28		65.4	32.7	16.7	8.24	4.09	2.56	1.59	1.

TL91256

Figure 16. Wire conversion table.

c. When dealing with circuits composed of sections of different-sized conductors, reducing them to an equivalent footage which each would have if composed of the same size of gauge wire as that selected as a standard will insure uniform resistance throughout the conductor under test and is necessary for the purposes of fault location. For convenience in determining which size wire to use as a standard, select the largest gauge wire in the composite conductor under consideration. Wire conversion tables (fig. 16) are convenient and should be used when available.

Examples: (1) It is desired to convert 200 feet of 22-gauge conductor to an equivalent length of 19-gauge conductor. The conversion factor is obtained from the table (fig. 16), moving down the vertical column on the left to number 22 and then horizontally to the right, selecting the factor in the vertical column marked 19. This factor is 2.01, which means that a 22-gauge conductor has 2.01 times as much resistance as a 19-gauge conductor of the same length. The problem is solved as follows: 200×2.01=402 feet, or the length of 19-gauge conductor having the same resistance as 200 feet of 22-gauge conductor. In this example 19-gauge is used as the standard.

(2) A cable from a central office to a terminal is composed of three sections of different gauge wire. Section 1, leaving the central office, is 300 feet long and is composed of 19-gauge conductors; section 2, connected to section 1, is 200 feet long and is composed of 22-gauge conductors; section 3, connected to section 2, is 100 feet long and is composed of 24-gauge conductors. 19-gauge is used as the standard. Section 1 is 19-gauge, therefore the equivalent length is 300 feet. Section 2 is 22-gauge and the conversion factor is 2.01; 200×2.01=402 feet, equivalent length. Section 3 is 24-gauge and the conversion factor is 3.22; 100×3.22=322 feet. The actual length of the cable is 600 feet and the equivalent length is 300+402+322=1,024 feet. A test is made from the central office on a grounded conductor in the above circuit. The resistance from the central office to the fault measures 6.25 ohms.

$$\text{The feet per ohm} = \frac{\text{Equivalent length in feet}}{\text{total resistance in ohms}} = \frac{1{,}024}{8.21} = 124.7.$$

The distance from the central office to the fault 124.7 (feet per ohm) × 6.25 (resistance from central office to the fault)=779.375 equivalent feet, 19-gauge. Inspection shows that sections 1 and 2 have a length of 702 equivalent feet. Since the distance in equivalent feet is 779.375, the first two lengths, or 702 equivalent feet, can be subtracted from 779.375, leaving 77.375 equivalent feet. The actual number of feet from the end of section 2 to the fault is found by converting the remaining equivalent feet to actual feet; or 77.375×0.310=23.986 actual feet. Therefore, the actual footage of the first two sections + 23.986 actual feet of the third section = 523.986 feet, the distance from the central office to the fault. The location of the fault should be verified as follows: distance from the terminal to the fault = feet per ohm × resistance (from terminal to the fault) = 124.7×1.96=244.412 equivalent feet. Converting this value to actual feet, 244.412×0.310=75.767 actual feet. 523.986+75.767= 599.75 feet. The cable print shows 600 feet. Thus, the error is 0.25 foot.

d. In the absence of the correct conversion table, the equivalent length may be solved by using resistance values and the following equation: let r_u, r_v, and r_w equal the resistances per 1,000 feet of the conductors of size u, v, and w, respectively, and let L_u, L_v, and L_w be their respective lengths. Since the resistance of a conductor is directly proportional to its resistance per unit length, then L_u' of conductor size u would have the same resistance as the composite conductor if

$$L_u' = L_u + \frac{r_v L_v}{r_u} + \frac{r_w L_w}{r_u},$$

where L_u' is the equivalent length of the selected conductor.

Example: A circuit is composed of three sections of different sizes of wire. The lengths of the three sections, the wire gauges, and the resistance per 1,000 feet, respectively, are: 2,160, No. 12, 1.588 ohms; 1,400 feet, No. 22, 16.14 ohms; and 2,200 feet, No. 19, 8.051 ohms. In this case, these values will be reduced to the equivalent length of No. 22-gauge wire. Let L_u equal the length of the No. 22-gauge wire, L_v equal the length of the No. 19-gauge wire, and L_w equal the length of the No. 12-gauge wire. Substituting in the equation,

$$L_u' = 1{,}400 + \frac{8.051}{16.14}\,2{,}200 + \frac{1.588}{16.14}$$

2,160 is equal to 1,400+1,097+212.5, or 2,709.5 feet of No. 22-gauge wire. A test set is connected to the end of the circuit composed of No. 19-gauge wire and shows a ground on the circuit. The measured resistance from the test set to the fault is 21.72 ohms. If the entire length of the wire were No. 22 gauge, the distance to the fault would be $\frac{21.72}{16.14}$ or 1,346 feet. But No. 19-gauge wire has an equivalent length of 1,097 feet. Subtracting, 1,346−1,097=249 feet. The actual length of the section of No. 19-gauge wire is 2,200 feet, so the distance from the test set to the fault is 2,200 +249=2,449 actual feet.

25. Resistance Correction for Temperature Variations

a. Tables of different gauge wire usually indicate the resistance of the desired size wire in ohms per unit length at a specified temperature. When the table values are use in calculating the location of circuit faults, if the surrounding temperature varies appreciably from that specified in the table, then the resistance value for the size of wire in question should be corrected.

Example: If the temperature specified in the wire table is 68° F., and the surrounding temperature is higher, the resistance value of a conductor in ohms per unit length will be larger. To determine this value for any temperature higher than 68° F., $R_t = R_a\,[1 + 0.00218\,(t - 68°)]$, where R_t is the resistance of the desired wire size per unit of length at the surrounding temperature, R_a is the resistance of the desired wire size per unit of length at 68° F., t is the surrounding temperature in degrees Fahrenheit, and 0.00218 is a constant. Should the surrounding temperature be lower than 68° F., the formula is $R_t = R_a\,[1 - 0.00218\,(68° - t)]$.

b. The temperature of underground conductors ranges from 35° to 50° F. The temperature of aerial cable or open wire lines follows closely the temperature of the atmosphere, except where the conductors are exposed to the direct rays of the sun.

26. Wire Tables

a. In the wire tables given in this manual, some confusion may arise in the mind of the reader as to the different resistance values for wire of the same diameter and apparently the same material. Most types of wire consist of various alloys, and all available resistance values for the different alloys are included.

b. Wire exposed to the effects of the weather soon becomes corroded and hard to identify. If the conductor in question cannot be identified as to type, it is suggested that if a short piece of the wire in question is available, the resistance of a measured length be measured carefully with Test Set I–49 and the resistance value noted. A wire of sufficient length to give a resistance of 1 ohm or more should be used. This will prevent inaccuracies likely to occur when the test set is used for resistance measurements of less than 1 ohm.

Caution: The resistance values given in the tables are per *loop mile.* If the resistance per mile per *single conductor* is required, divide the value of resistance obtained from the table by 2.

FIELD WIRE

Signal Corps type No.	Number of conductors	D-c resistance per loop mile (at 68° F.)
W–50	2	26
W–110	2	260
W–110–B	2	190
W–130	2	590
W–143	2	35
W–150	2	590

CABLES (rubber and lead-covered)

Signal Corps type No.	Number of pairs	D-c resistance per loop mile (at 68° F.)
WC–534	5	85. 8
WC–535	10	85. 8
WC–548	2	78. 0*
WC–407	50	85. 8
WC–504	20	177. 5

*Cable is supplied in ¼-mile lengths with a loading coil in each length. The resistance of four lengths of cable and four loading coils is 78 ohms.

RESISTANCE OF CONDUCTORS

Signal Corps type No.	Diameter (inch)	D-c resistance per loop mile (at 68° F.)	Material
W-73	0. 045	85. 0	Bronze
	0. 081	17. 5	HDC
W-153	0. 080	42. 8	40% CS
	0. 081	42. 6	40% CS
W-76	0. 083	115. 0	GI
W-144	0. 083	131. 2	HSS
	0. 102	35. 8	30% CS
W-74	0. 104	10. 3	HDC
	0. 104	25. 3	40% CS
	0. 104	33. 8	30% CS
	0. 109	67. 0	GI
W-145	0. 109	76. 5	HSS
	0. 128	6. 8	HDC
	0. 128	22. 7	30% CS
	0. 134	44. 2	GI
	0. 134	51. 3	GS
W-75	0. 148	36. 3	GI
	0. 165	4. 1	HDC
	0. 165	29. 2	GI

HDC—Hard drawn copper.
GI—Galvanized iron wire.
GS—Galvanized steel wire.
30% CS—Copper-steel wire having approximately 30% conductivity of equivalent gauge copper wire.
HSS—High strength steel wire.
40% CS—Copper-steel wire having approximately 40% conductivity of equivalent gauge copper wire.

RESISTANCE OF CONDUCTORS*

Diameter (inch)	D-c resistance per loop mile (at 68° F.)	Material	Diameter (inch)	D-c resistance per loop mile (at 68° F.)	Material
0. 083	97	EBB GI	0. 134	44	BB GI
0. 083	119	BB GI	0. 134	44	GHS
0. 083	119	GHS	0. 134	52	GS
0. 083	136	GS	0. 148	30	EBB GI
0. 109	59	EBB GI	0. 148	36	BB GI
0. 109	68	BB GI	0. 148	36	GHS
0. 109	68	GHS	0. 148	43	GS
0. 109	76	GEHS	0. 165	24	EBB GI
0. 109	79	GS	0. 165	29	BB GI
0. 134	37	EBB GI	0. 165	34	GS

HDC—Hard drawn copper.
GI—Galvanized iron.
GHS—Galvanized, high tensile strength steel.
GEHS—Galvanized, high extra tensile strength steel.

*Commercial sizes and specifications.

MISCELLANEOUS CONDUCTORS

Signal Corps type No.	Number of conductors	D-c resistance per loop mile *	Signal Corps type No.	Number of conductors	D-c resistance per loop mile *
W-7	1	70	W-50	2	26
W-16	1	288	W-69A	2	177
W-34	2	88.5	W-71	1	112
W-38	2	192	W-108	2	174

---

* Resistance values will be assumed to be at a temperature of 68° F. unless specified otherwise.

SECTION IV

PREVENTIVE MAINTENANCE

27. Precautions

a. GENERAL. Test Set I–49 should be inspected at regular intervals to check or prevent any condition that might impair or totally disrupt the operation of the test set.

b. OPERATION. The operating procedure of Test Set I–49 should be followed as outlined. The steps are arranged in a sequence designed to lessen the possibility of mistakes in operating procedure and subsequent injury to the test set. To insure trouble-free operation of the test set, there are several practices which must be observed at all times.

(1) The galvanometer in the test set (fig. 2(13)) is a sensitive and delicate d-c instrument. A locking clamp (fig. 2(12)) is provided to lock the moving element when the test set is not in use. Slide the CLAMP button in the direction of the arrow as soon as the bridge is balanced. This will insure the locking of the moving element prior to the moving of the test set.

(2) When balancing the bridge, use GA SENS switch .01 (fig. 2(9)) for the first reading of the galvanometer. Use GA SENS switch .1 (fig. 2(10)) after the deflection of the galvanometer has been reduced to a minimum. *Do not use* the GA SENS switch 1 (fig. 2(11)) until the deflection of the galvanometer has been reduced to a point where it is no longer noticeable. Following this procedure will avoid injuring the galvanometer movement by excessive currents.

(3) Limit the current in the resistance coils (fig. 17(1), (2), (3), and (4)) to 5 milliamperes when the 1,000 dial switch is used, and to 40 milliamperes when the 1,000 dial switch is at 0 and the 100 dial switch is used. This insures staying within the 0.3-watt energy dissipation per resistance coil as recommended by the manufacturer.

(4) Keep the test set in a dry place. Dampness will cause troublesome key and switch manipulation, and incorrect readings due to current leakage within the test set. The case, carrying strap, and hardware will also be affected.

(5) Inspect the self-contained batteries at least twice weekly when using the test set in climates with humidity. In case the test set is used only occasionally, remove the batteries from the case after completing the test. *Never store Test Set I–49 with the batteries in the case.* When replacing the batteries, be sure that the negative terminal of the cell (the case of Battery BA–30 is negative) is inserted first. The positive terminal of the last cell inserted (the center terminal is positive) will make contact with the retaining plate (fig. 18(19)).

(6) When using an external source of voltage, make sure that the correct polarity is observed when connecting the external source to the

binding posts marked BA + and —. For any voltage exceeding 45 volts, a resistance of 10 ohms for each volt in excess of 45 volts must be connected in series with the external voltage and the test set. Do not use voltages higher than 200 volts direct current.

(7) The screws holding the panel in the case, the screws under the dial knobs which hold the parts to the under side of the panel, and the dial knob screws must be kept tight.

(8) Rub a small amount of wax or clean, heavy oil into the case to prevent it from cracking. Be careful that none enters the lock or hinges. Work a few drops of neatsfoot oil, or equal, into the strap after washing it with a mild soap. The amount and frequency of application will depend upon the conditions under which the test set is being used.

28. Lubrication

a. Test Set I–49 is lubricated by the manufacturer and normally does not require lubrication for the first year of operation. Inspect the rotary contacts every 6 months thereafter, and relubricate if the contacts are dry or dirty. Also, when the test set is to be moisture-proofed and fungiproofed, the baking of the equipment prior to varnishing will cause the lubricant to melt and run off the contact surface.

b. Remove the four screws holding the panel in the case. Remove the panel from the case. Wipe the contacts on the bases of the five dial switches clean with a clean, soft cloth. Clean the case of any dust or dirt. Proceed with the drying and varnishing as outlined in paragraph 35.

c. When the test set has been varnished and dried, apply a light coating of Vaseline, Signal Corps stock No. 6G2205, or Grease, Lubricating, Special, specification AXS–637, on the contacts on the bases of the dial switches. Wipe the contacts off with a soft cloth after applying the lubricant, leaving a very thin film of lubricant on the contacts. Do not expose the lubricated contacts to dust or dirt. Replace the panel in the case and replace the four screws holding the panel in the case.

SECTION V

FUNCTIONING OF PARTS

29. Ratio Arms

The dial switch (fig. 2(5)) marked *MULTIPLY BY* on the dial, controls the ratio of the *A* and *B* arms of the bridge for resistance measurements and Varley loop tests, and provides settings for ratios in Murray loop tests. The dial switch has reliable low-resistance contacts, positive-action brush arm, and click-stop positioning. Multiplying values of 1/1000, 1/100, 1/10, 1/9, 1/4, 1/1, 10/1, and 100/1 are provided for resistance measurements and Varley loop tests. Settings of $\frac{M}{1000}$, $\frac{M}{100}$, and $\frac{M}{10}$ are provided for Murray loop tests. The accuracy of the ratio resistors is ±0.05 percent.

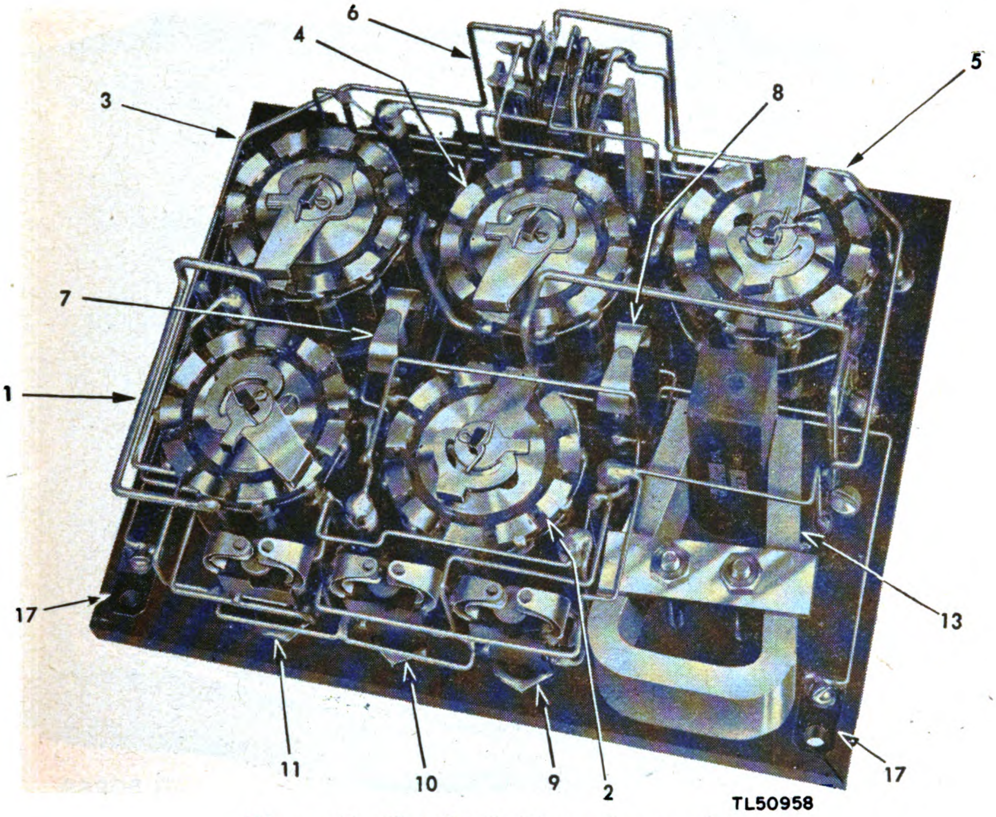


Figure 17. Test Set I–49 panel, rear view.

30. Rheostat

The rheostat, or *R* arm of the bridge, is composed of four inclosed dial switches. The four dial switches provide resistance values from zero to 10,110 ohms in steps of 1 ohm and a position for infinity setting. When the 1000 dial switch (fig. 17(4)) is used, the current through the resistors should not exceed 5 milliamperes. When the 1000 dial switch is set at zero and the 100 dial switch (fig. 17(3)) is used, the current should not exceed 40 milliamperes. The energy dissipation for each resistance coil is 0.3 watt. The resistance change of the rheostat arm from zero settings of the dials equals the dial readings ± the quantity (0.1 percent + 0.01 ohm).

31. Galvanometer

The galvanometer (fig. 17 (13)) is a sturdy, replaceable, d-c unit with a coil-protecting clamp. The coil resistance of the galvanometer is 250 ohms. The sensitivity of the coil is such that 1 microampere flowing through the coil will cause a deflection of at least one scale division. The galvanometer is protected against excessive currents and injury by shunts controlled by three push type switches (fig. 17 (9), (10), and (11)). Switch (9) provides a sensitivity of 0.01, switch (10), a sensitivity of 0.1, and switch (11), maximum sensitivity. The switches are designed to close the battery circuit before the galvanometer circuit, and to open the galvanometer circuit before the battery circuit, thus protecting the galvanometer from current surges caused by inductive effects.

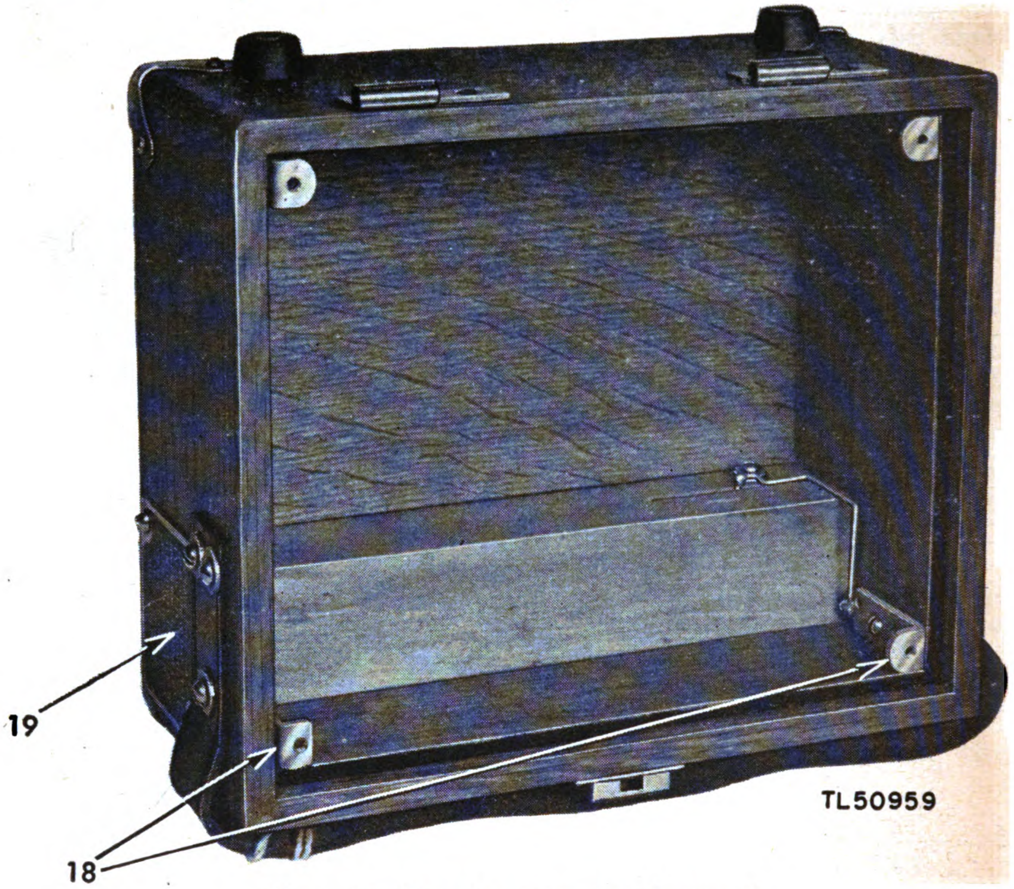


Figure 18. Carrying case—panel removed.

32. Switches

Cam and lock-down switches adapt the bridge circuits for resistance measurements and for loop tests. A cam-type switch (fig. 17 (6)) controls the setting of the bridge for resistance measurements, and for Varley and Murray loop tests. A lock-down switch (fig. 17 (7)) marked BA on the panel face, controls the use of the self-contained batteries or an external voltage source. A lock-down switch (fig. 17 (8)) marked GA on the panel face controls the use of the galvanometer in resistance measurements, Varley, Murray, and Hilborn loop tests.

33. Case

The case is sturdy, made of oak with metal-protecting corners, and provided with a removable lid and carrying strap. The three standard flashlight cells (Battery BA–30) comprising the 4.5-volt self-contained power source are inclosed in a small compartment in the bottom of the case. The cells can be removed without removing the panel by taking out two screws which hold a plate (fig. 18(19)) to the case. Connections from the cells to the panel are made by two brackets (fig. 18(18)). The brackets are threaded and are clamped to two metal contacts on the panel (fig. 17(17)) by the screws holding the panel in the carrying case.

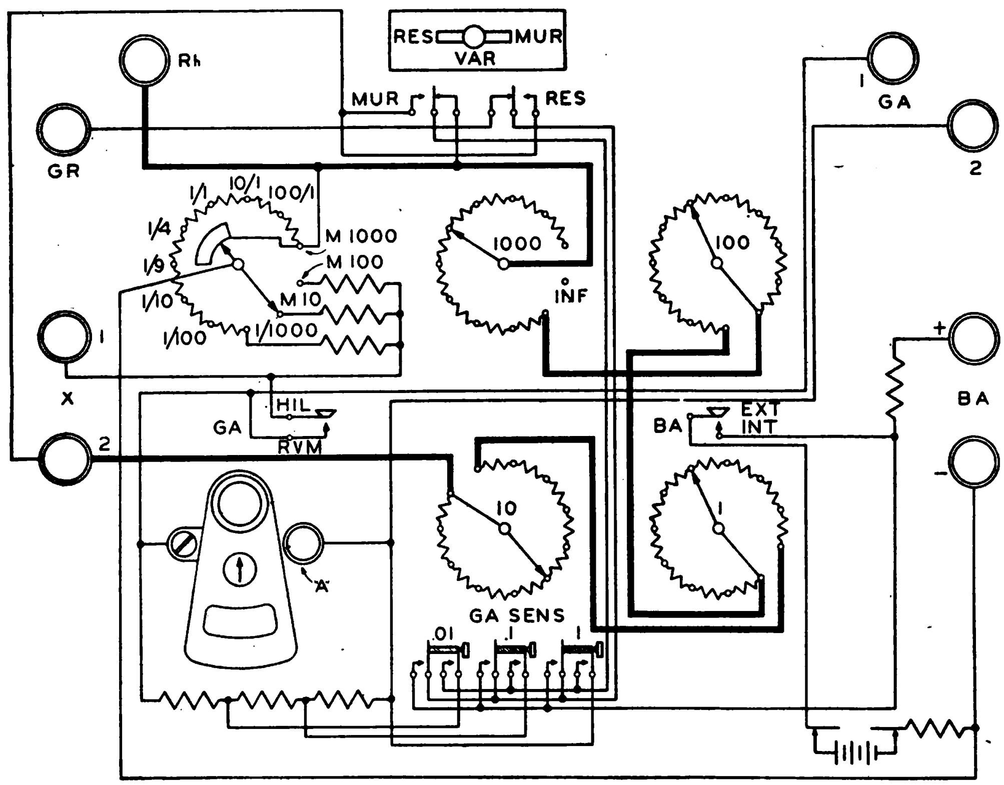


Figure 19. Test Set I–49—schematic diagram.

SECTION VI

CORRECTIVE MAINTENANCE

NOTE: Failure or unsatisfactory performance of this equipment will be reported immediately on W. D., A. G. O. Form No. 468. If form is not available, see TM 38–250.

34. Repairs

a. Maintenance parts are not available for Test Set I–49. If temporary repairs are attempted, check the bridge with a resistor of known value and of the highest accuracy before using it for testing.

b. The clamp knob on the galvanometer may loosen. To tighten it, proceed as follows:

(1) Remove the panel from the case.

(2) Remove the galvanometer from the panel.

(3) The screw holding the clamp knob can now be reached. Tighten it with the correct size screw driver. Replace the galvanometer in the panel. Replace the panel in the case.

35. Moistureproofing and Fungiproofing

a. GENERAL. The operation of Signal Corps equipment in tropical areas where temperature and relative humidity are extremely high requires special attention. The following items represent problems which may be encountered in operation:

(1) Resistors fail.

(2) Electrolytic action takes place in resistors causing eventual break-down.

(3) Hook-up wire and cable insulation break down. Fungus growth accelerates deterioration.

(4) Moisture forms electrical leakage paths on terminal boards and insulating strips, causing flash-overs and crosstalk.

(5) Moisture provides leakage paths between battery terminals.

b. TREATMENT. A moistureproofing and fungiproofing treatment has been devised which, if properly applied, provides a reasonable degree of protection against fungus growth, insects, corrosion, salt spray, and moisture. The treatment involves the use of a moisture- and fungi-resistant varnish, applied with a spray gun and/or brush. Refer to TB SIG 13 for a detailed description of the varnish-spray method of moistureproofing and fungiproofing.

Caution: Varnish spray may have toxic effects. Use a respirator if available; otherwise, fasten cheesecloth or other cloth material over the nose and mouth.

c. STEP-BY-STEP INSTRUCTIONS FOR TREATING TEST SET I–49. (1) *Preparation.* (*a*) Make all repairs and adjustments necessary for the proper operation of the test set.

(*b*) Clean all dirt, dust, rust, fungus, oil, grease, etc., from the equipment to be processed.

(*c*) Wipe the contacts on the bases of the five dial switches clean with a soft, clean cloth (fig. 17(1), (2), (3), 4), and (5)).

(2) *Disassembly.* (*a*) Remove the four screws holding the panel and attached equipment in the case.

(*b*) Remove the panel from the case.

(*c*) Remove the two screws holding the small plate on the end of the case (fig. 18(19)).

(*d*) Remove the batteries from the case. (Batteries will not be processed.)

(3) *Masking.* (*a*) Mask the contact surfaces of the two threaded brackets (fig. 18(18)) in the case with masking tape.

(*b*) Do not mask any parts of the panel and attached equipment as the spray gun will not be used on the panel.

(4) *Drying.* Place the carrying case *minus the batteries* (do not apply heat to batteries) and the panel with attached equipment in the oven or under heat lamps, and dry them for 2 to 3 hours at 160° F.

(5) *Varnishing.* (*a*) Spray the inside of the case with three coats of moisture- and fungi-resistant varnish, allowing each coat to dry before applying the following coat.

(*b*) Using a small brush, apply three coats of moisture- and fungi-resistant varnish to the fiber rings at the base of the resistors, the phenolic rings (insulating rings) of the multiplier switches, and the edges of the phenolic spacers of the RES-VAR-MUR switch.

Caution: Special care should be taken to avoid getting varnish on the switch contacts.

(*c*) Thoroughly dry the varnished parts.

(6) *Reassembly.* (*a*) Remove all masking tape.

(*b*) Clean all contacts with varnish remover and burnish the contacts.

(*c*) Lubricate the contacts of the five dial switches, as outlined in paragraph 28.

(*d*) Reassemble the test set and test its operation.

(7) *Marking.* Mark MFP and the date of treatment on the equipment.

Example: MFP 5/11/44.

SECTION VII

SUPPLEMENTARY DATA

---

36. Maintenance Parts

Maintenance parts are not available for Test Set I–49. Return Test Set I–49 to the San Francisco Signal Corps Depot or to the Philadelphia Signal Corps Depot for the replacement of parts.

U. S. Government Printing Office: 1945 628026—TM1129