NOTES ON
FAULT LOCATION IN CABLES

NOTE
BOOK
EF-53-441(1)
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LEEDS & NORTHRUP COMPANY
4907 STENTON AVENUE
PHILADELPHIA 44, PA.

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CABLE ADDRESS: "LEEDSNORTH"
BENTLEY CODE

LEEDS & NORTHRUP COMPANY
MEASURING INSTRUMENTS · TELEMETERS · AUTOMATIC CONTROLS
HEAT-TREATING FURNACES

4907 STENTON AVENUE - PHILADELPHIA 44, PA., U. S. A.

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FAULT LOCATION

Location of faults which occur on conductors used for communication transmission, and on those used for electric-power transmission, involves a relatively simple application of the fundamental principles of electrical science. In the practical application of these principles, a number of specific methods have been developed, each of which is especially adapted to the location of some particular type of fault.

This note book presents the principles involved and many of their applications. Its purpose is to give, in the simplest possible form, information helpful to a tester when locating each of a variety of faults. Although the specific applications mentioned are for conductors, such as the multiple-conductor cables used in communication transmission, many of the methods described are applicable also to faults which may occur: on short, submarine cables; on open-wire telegraph or telephone lines; and on power cables.

A number of the methods described were developed by the late Mr. Henry W. Fisher, of the General Cable Corporation. Others, developed by the American Telephone and Telegraph Company, have been taken with their permission from "Specifications for Cable Fault Locating".

TYPES OF FAULT

In many tests, application of the principles of fault location is simple. In others, their application may be complicated by a network of wires, by peculiarities of the faults, and by other causes. Experienced testers, however, with proper apparatus, can locate the great majority of faults.

The various faults which may occur are as follows:

(a) Grounds, due to defective insulation between conductor and ground or cable sheath

(b) Crosses, due to defective insulation between two wires, not necessarily forming a pair

(c) Shorts, due to defective insulation between the two wires forming a pair

(d) Opens, due to breaks in conductors

(e) Inductive crosses, resulting from splicing errors

The table on page 4 indicates (for communication circuits) the appropriate test for use under particular circumstances.

Since electrical methods are used to locate faults, the results of many of these tests are expressed in electrical units. For example, the formulae for locating grounds, crosses and shorts express fault location in terms of resistance. Methods for translating resistance into distance are discussed on page 34. In deriving the working formulae for locating opens and inductive crosses, the electrical units have been translated so that each formula gives the result directly in units of length.

FAULT LOCATION TESTS FOR COMMUNICATION CIRCUITS

Purpose	Name of Test	Remarks	Pg.	Fig.	Formula
Test for grounds and crosses	Continuity		5	1	....
Test for opens	Continuity		5	1	....
General Resistance measurement	Wheatstone Bridge	1 ohm to 10 megohms	6	2	2, 2a
Conductor Resistance measurement	Bridge method	Used with 3 good conductors	8	.....	3
Conductor Resistance measurement	Varley Loop method	Used with 2 good conductors	8	4	4
Conductor Resistance measurement	Fisher method	Used with 1 good and 2 bad conductors	9	5	5, 5a
Ground and cross location	Murray Loop	For short sections and faults near test locations	10	6, 6a	6, 6a, 6b
Ground and cross location	Murray Loop (Modified)	1 good wire only—length unknown	12	7, 7a	7
Ground and cross location	Varley Loop	General application good for high-resistance loops	14	8, 8a	8, 8a
Ground and cross location	Simple Varley	$R_g = R_b$	15	8, 8a	8b
Ground and cross location	Three Varley	Eliminates lead resistance and conductor inequality	17	9, 9a, 9b	9, 9a, 9b
Ground and cross location	Three Varley—even ratio	High resistance conductors	17	9, 9a, 9b	9
Ground and cross location	Three Varley even ratio Varley 1 reversed	Same, R_g less than R_b	17	9a, 9b, 9c	9c
Ground and cross location	Fisher Loop	Faulty wire of known length. Two good wires of unknown length	18	10, 10a	10, 10a
Ground and cross location	Moody Loop	For tests from Central Locating Desks	20	11, 11a	11, 11a
Ground and cross location	Hilborn Loop	Section lengths	22	12, 12a	12, 12a
Ground and cross location	Loops with capacitor-detector	Good and bad conductors in different cables, subject to inductive disturbances	23	13	....
Comparison of Capacitances	Capacitance bridge		24	14	14, 14a
Open Location	A-C Murray Loop	Quadded Cable	26	15, 15a	15, 15a, 15b
Open Location	A-C Murray Loop	Pairs	28	16, 16a	16
Split Pair Location	A-C Murray Loop	Using additional good pair	30	17, 17a	17
Split Pair Location	A-C Murray Loop	Using split pairs only	33	18, 18a, 18b, 18c	18

*5430-A 1 ohm to 1 megohm.

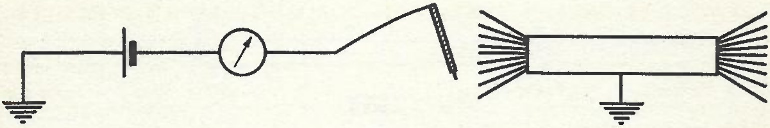


Fig. 1 Identification of Grounded Conductors

IDENTIFICATION OF FAULTY CONDUCTOR

Preliminary to the location of a fault, it is necessary to identify the faulty conductor—usually at both ends of a cable. For this purpose, a continuity test is made by applying voltage to the suspected wire and observing whether current flows through a suitable detector. The voltage may be that of a battery, using a galvanometer or a voltmeter as the detector. Battery and galvanometer may be those contained in a Wheatstone-bridge test set. Or, an a-c voltage from a buzzer (tone test) may be used, with phones as the detector.

(a) Identification of grounded conductor

With connections made as in Fig. 1, and each conductor open at the far end, a test prod is touched in turn to every conductor of the cable. Current will be indicated by the detector when a grounded conductor is touched.

(b) Identification of crosses or shorts

Assume that test (a) has been made, and no grounded conductor found. With all conductors clear at the far end, all are tied together at the test end and are connected to the cable sheath, which is grounded. One wire at a time is withdrawn from the bunch and touched with the prod. Passage of current indicates a faulty wire, which is then tagged and returned to the bunch. Good wires are left clear. After continuing this process until all wires have been tested, only the tagged, crossed wires will remain.

(c) Identification of open conductors

At the far end, all conductors are tied together and to the sheath or to a conductor known to be continuous. The test equipment is connected to the sheath or good conductor, and the test prod is touched to every conductor. An open conductor will be indicated by failure to pass current.

(d) Inductive crosses

The existence of inductive crosses is usually made known by the occurrence of cross-talk on the circuits involved.

To identify a faulty conductor at both ends of a cable, it may sometimes be necessary to make the test from both ends.

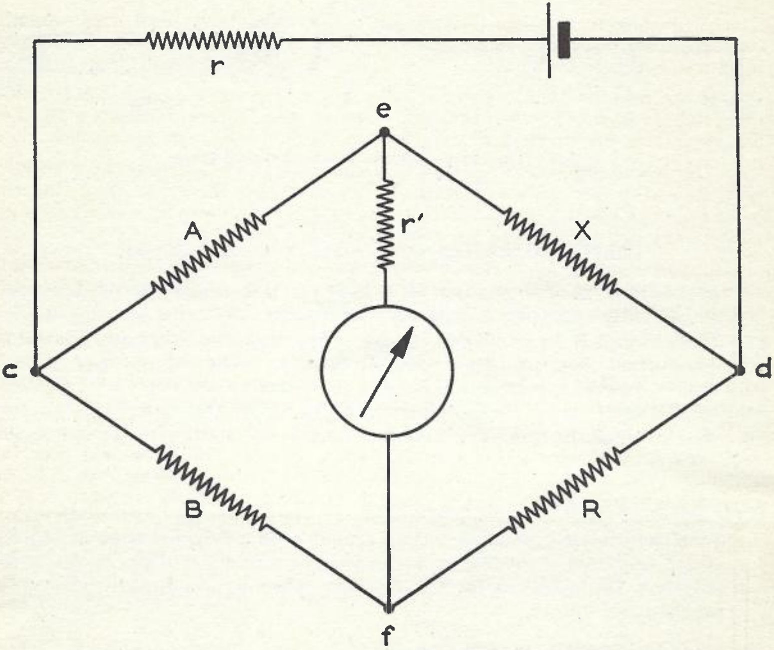


Fig. 2 **Wheatstone Bridge**

WHEATSTONE BRIDGE

Grounds and crosses on land lines and on short, submarine cables are generally located by so-called loop methods. Each of these methods utilizes a special arrangement of the Wheatstone-bridge circuit, and must satisfy Wheatstone-bridge balance conditions. When four resistors are grouped as shown in Fig. 2, and a battery and a galvanometer form part of the circuit, as shown, the combination is called a Wheatstone bridge. The bridge is balanced, and no current flows through the galvanometer, when the resistances have the relation

$$\frac{X}{R} = \frac{A}{B} \tag{2}$$

If the respective resistances of A, B and R are known, the value of X may be calculated. A and B are called the ratio arms. Their ratio only—not their individual values—need be known. R is called the rheostat arm. It should be adjustable in small steps of resistance over a wide range of values.

Each of the resistances, A, B, R and X, respectively, represents the total resistance, including lead and contact resistance, from a battery connection to the next galvanometer connection. Therefore, any lead and contact resistances introduced into one or more of the bridge arms must be considered in subsequent calculations.

If the positions of the galvanometer and battery are interchanged—with the galvanometer connected between c and d; the battery, between e and f—the conditions for balance, as expressed in Formula (2), are unchanged.

The introduction or variation of resistances (as represented at r and r') in the battery and galvanometer circuits does not affect the conditions of balance. The effect of such resistances is simply to reduce the sensitivity, and to vary the damping, of the galvanometer.

Physically, the Wheatstone bridge may be a self-contained instrument, or may be built up of three separate resistance boxes or groups of adjustable, known resistors.

Since A and B occur only as a ratio, these two arms may be combined as a single group of fixed resistors, with the battery connection a switch. Or, A and B may be the two sections of a continuous slidewire, divided by a moving-contact battery connection.

The value of the ratio A/B may be read from a suitable scale. If a single-dial ratio is used, the dial is usually engraved in multiplier values. For the slidewire type of ratio, it is more convenient to divide the scale into uniform divisions—usually 1000. Using such a slidewire ratio, the resistance A is equivalent to S scale divisions, and B is equivalent to 1000-S divisions, from which

$$X = \frac{A}{B} R = R \frac{S}{1000-S} \tag{2a}$$

To facilitate calculations with this type of bridge, values of $\frac{S}{1000-S}$ for various values of S are given in a table on pages 40 and 41.

RESISTANCE OF LEADS AND CONDUCTORS

Loop tests are so called because the faulty wire is connected at its distant end to a good wire. The two in combination make a loop, which the fault divides into two parts. Resistances in good and bad wires, respectively, must be known. These resistances may be known from previous tests. However, it is preferable to measure the resistance of each wire, which, of course, requires an additional connection to the distant end.

RESISTANCE OF LEADS

Usually, it is impractical to make a direct connection between the bridge terminals and the resistance to be measured. Consequently, leads must be used between the bridge and the unknown, and lead resistance must be subtracted from the measured value of the unknown resistance. Lead resistances are determined, either singly or together, by a simple bridge measurement (page 6).

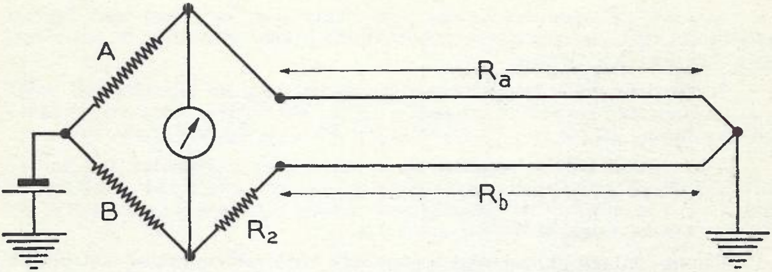


Fig. 4 Conductor Resistance by Varley Loop

RESISTANCE OF CONDUCTORS

(a) Three-Wire Method

The three wires are connected together at the distant end and the resistance of the loop formed by each pair is measured by the bridge. Calling the resistances of the individual wires R_a, R_b and R_c, and those of the loops R_1, R_2 and R_3,

$$R_1 = R_a + R_b, \qquad R_2 = R_b + R_c \qquad \text{and} \qquad R_3 = R_c + R_a$$

from which

$$R_a = \frac{R_3 + R_1 - R_2}{2}, \qquad R_b = \frac{R_1 + R_2 - R_3}{2} \qquad \text{and} \qquad R_c = \frac{R_2 + R_3 - R_1}{2} \tag{3}$$

(b) Two-Wire Method, Neither Wire Grounded

Since the resistance of the third wire need not be known, a ground return may be used instead, *if neither wire is grounded.* The resistance of the two wires and of the ground return may be found as in (a); or the resistance of the two-wire loop may be measured as $R_1 = R_a + R_b$, and the resistance of each wire found individually. This is done by grounding the distant end and applying the Varley Loop test (page 14), by means of the connections in Fig. 4. If R_2 is the resulting reading of the rheostat arm R,

$$\frac{A}{B} = \frac{R_a}{R_b + R_2}$$

from which

$$R_a = \frac{A}{A+B}(R_1 + R_2) \qquad \text{and} \qquad R_b = R_1 - R_a \tag{4}$$

An uneven ratio such as A/B = 1/9 or 1/10 is generally used, in order to measure the resistance of each wire to tenths of an ohm. This also avoids the necessity for interchanging R_a and R_b, if R_a should be less than R_b.

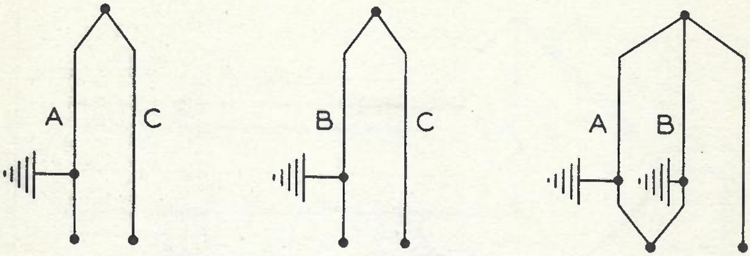


Fig. 5 Conductor Resistance with Faulty Wires

(c) One Good Wire and Two Faulty Wires

Sometimes, all the wires in a cable become defective, and it is difficult to obtain *two* good wires in order to apply the Three-Wire Method, page 8. If *one* good wire can be obtained which terminates at the same points as do the faulty wires, the separate resistances of the good and bad wires, respectively, can be determined by a method devised and used by the late Mr. Henry W. Fisher. This method may be applied when all the conductors in a cable are bad and only one aerial wire is available for the test.

Calling the faulty wires A and B and the good wire C, the resistance R_1 of the loop formed by A and C is measured and, similarly, the resistance R_2 of the loop formed by B and C. Finally, the combined resistance R_3 of A and B taken in parallel with each other and in series with C is measured, as shown in Fig. 5.

Then $R_1 = R_A + R_C$, $R_2 = R_B + R_C$ and $R_3 = R_C + \frac{R_A R_B}{R_A + R_B}$

from which

$$\begin{aligned} R_A &= R_1 - R_3 + \sqrt{(R_1-R_3)(R_2-R_3)}, \\ R_B &= R_2 - R_3 + \sqrt{(R_1-R_3)(R_2-R_3)} \qquad (5) \\ \text{and} \quad R_C &= R_3 - \sqrt{(R_1-R_3)(R_2-R_3)} \end{aligned}$$

If R_1 and R_2 do not differ by more than about 2% or 3%, the following approximations may be used:

$$\begin{aligned} R_A &= \frac{3R_1+R_2}{2} - 2R_3, \\ R_B &= \frac{3R_2+R_1}{2} - 2R_3 \qquad (5a) \\ \text{and} \quad R_C &= 2R_3 - \frac{R_1+R_2}{2} \end{aligned}$$

This method has given good results, but is not applicable unless the bad wires are faulty at the same point.

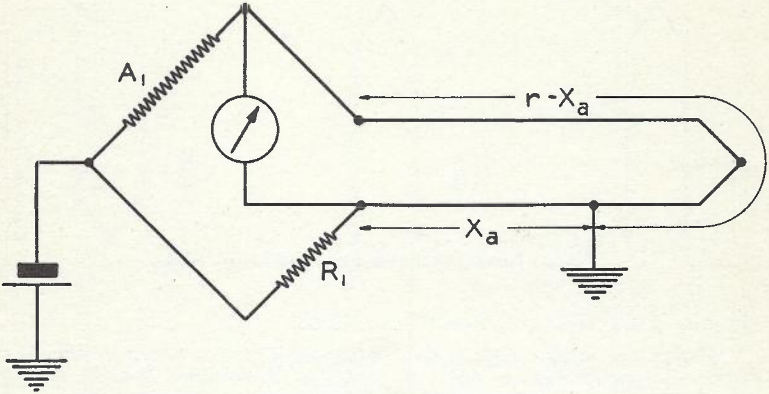


Fig. 6 Murray Loop

MURRAY LOOP

The Murray Loop test is particularly applicable when locating faults in relatively low-resistance loops, such as short lengths of communication cable (section loops) and power cables. In this test, the loop formed by the two conductors is divided by the fault into two parts, which form two arms of a Wheatstone bridge, as shown in Fig. 6. The fault is here shown as a ground. If it should be a cross, the battery 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, the battery is connected to the cable sheath.

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 R 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

$$X_a = \frac{R_1 r}{A_1 + R_1} \tag{6}$$

A check may be made by interchanging the good and bad conductors as shown in Fig. 6a. If R_2 is the value of the rheostat resistance which balances the bridge with these connections,

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

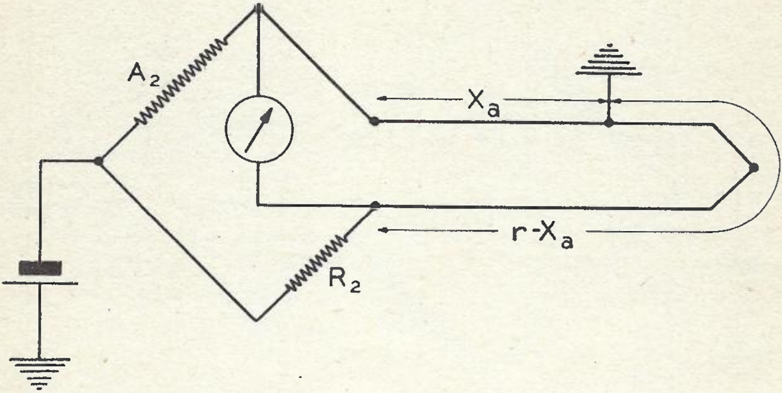


Fig. 6a Murray Loop (Check)

from which

$$X_a = \frac{A_2 r}{A_2 + R_2} \quad (6a)$$

The method for translating resistance into distance to the fault is discussed on page 34.

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 1000 ohms whenever practicable. 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 1000 In such cases, it is advisable to make A_2 equal to 100. When the fault is at the distant 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. It is thus possible to obtain some idea of the location of the fault simply by inspection of the values of R_1 and R_2

When applying the Murray Loop to fault location using the slidewire type of bridge, the loop is connected directly to the slidewire, with the faulty conductor at the zero end of the slidewire. Formula (6) is applicable, but in modified form. When the scale is divided into 1000 divisions, resistance R_1 is proportional to reading S, and A_1 is proportional to 1000–S.

Therefore $$X_a = \frac{R_1 r}{A_1 + R_1} = \frac{S}{1000} r \quad (6b)$$

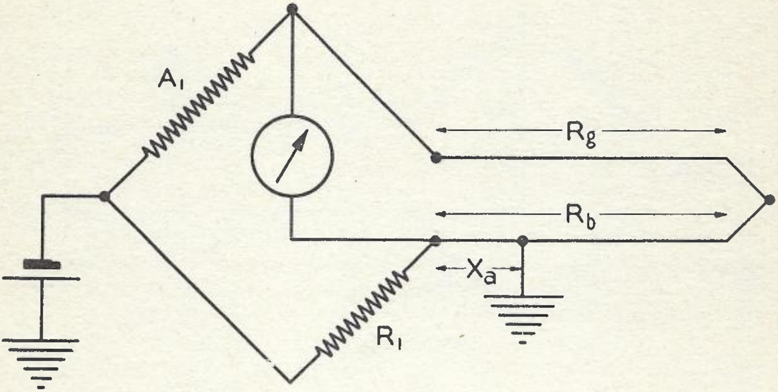


Fig. 7 Modified Murray Loop (1st Test)

MURRAY LOOP (Modified)

When only one good conductor, not of the same length and size as the faulty conductor, is available, the fault may be located by making a Murray Loop test at each end of the cable.

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 fault to the original test location. If R_1 is the rheostat value resulting in a balance with the connections of Fig. 7,

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

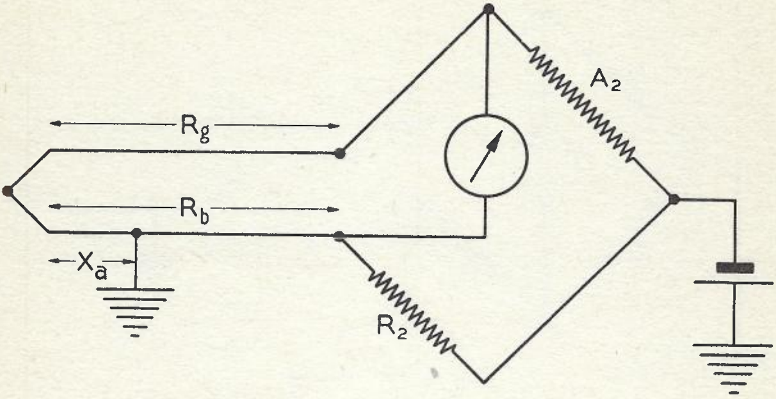


Fig. 7a Modified Murray Loop (2nd Test)

The test is then repeated at the other end with the faulty conductor connected to the same post as before (Fig. 7a).

$$\text{Then} \qquad \frac{A_2}{R_2} = \frac{R_g + X_a}{R_b - X_a}$$

where R_2 is the rheostat value resulting in balance under these conditions, and A is the same as before.

Eliminating R_g between the two equations,

$$X_a = \frac{R_1(A_2+R_2)R_b}{R_2(A_1+R_1)+R_1(A_2+R_2)} \tag{7}$$

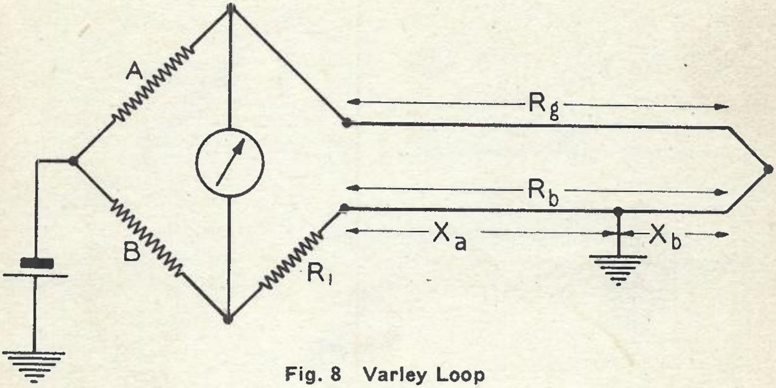


Fig. 8 Varley Loop

VARLEY LOOP

The Varley Loop test is best adapted to fault location in high-resistance loops. The arrangement differs from the Murray circuit in having a portion of the loop made up of rheostat resistances in the test set. To obtain satisfactory location of a fault, the ratio A/B should be as low as possible.

If connections are made as in Fig. 8,

$$\frac{A}{B} = \frac{R_g+R_b-X_a}{R_1+X_a}$$

where R_g is the resistance of the good conductor, R_b the resistance of the faulty conductor, X_a the resistance from the test set to the fault, and R_1 the rheostat reading when the bridge is balanced.

$$\begin{aligned} \text{Then} \quad X_a &= \frac{B(R_b+R_g)-AR_1}{A+B} \\ \text{and} \quad X_b &= R_b - X_a = \frac{AR_b-BR_g+AR_1}{A+B} \end{aligned} \tag{8}$$

Interchanging the good and bad conductors for a check, as in Fig. 8a,

$$\frac{A}{B} = \frac{X_a}{R_2+R_b+R_g-X_a}$$

where R_2 is the value of the rheostat at balance.

$$\begin{aligned} \text{Then} \quad X_a &= \frac{A(R_2+R_b+R_g)}{A+B} \\ \text{and} \quad X_b &= \frac{BR_b-AR_g-AR_2}{A+B} \end{aligned} \tag{8a}$$

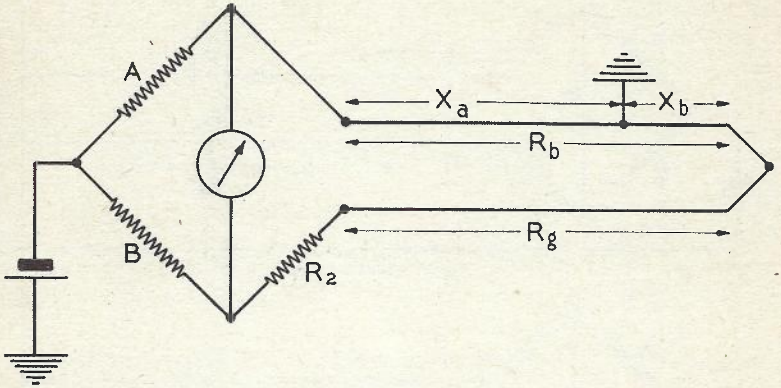


Fig. 8a Varlev Loop (Check)

SIMPLE VARLEY LOOP

When the resistances of the good and bad conductors are equal, a very simple expression may be obtained for X_b. If the ratio is made even, i.e., $A = B$, with connections as in Fig. 8,

$$X_b = \frac{R_1}{2} \tag{8b}$$

Expressed in words, the resistance from the fault to the distant end is equal to half the balancing-rheostat resistance. Under these conditions, a check balance can be obtained only by measurement from the other end. It should be observed that with the usual type of test set, in which the rheostat is subdivided into single ohms, accuracy of fault location using the simple Varley Loop is limited to the nearest half-ohm.

THREE VARLEY METHOD

In the Murray and Varley Loop tests previously described, resistances of both good and bad conductors must be known, and correction must be made for the resistance of any additional leadwire used. The "Three Varley" method uses two good wires, of *any* resistance, and a ground connection. Simultaneously, it measures the resistance of the faulty conductor and the resistances from the fault to each end of the faulty wire. Even if leads are unequal, this method eliminates the effects of lead resistance, which makes it especially useful for tests from a central locating desk.

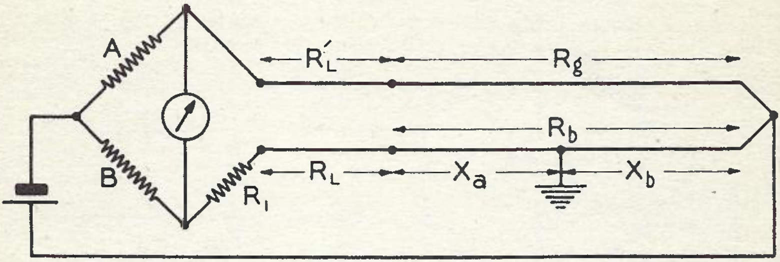


Fig. 9 "Varley 1" Test

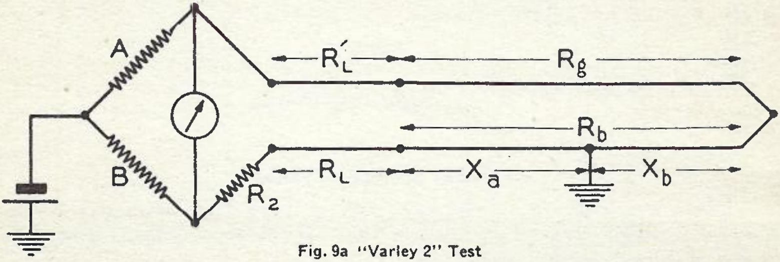


Fig. 9a "Varley 2" Test

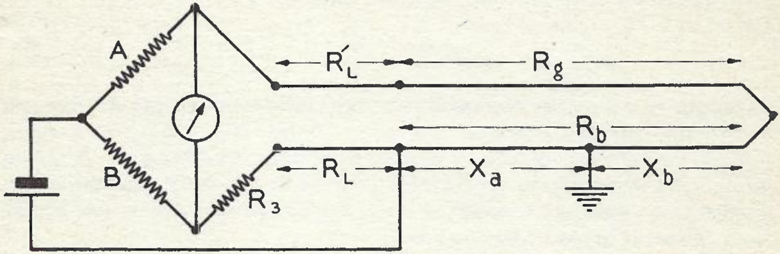


Fig. 9b "Varley 3" Test

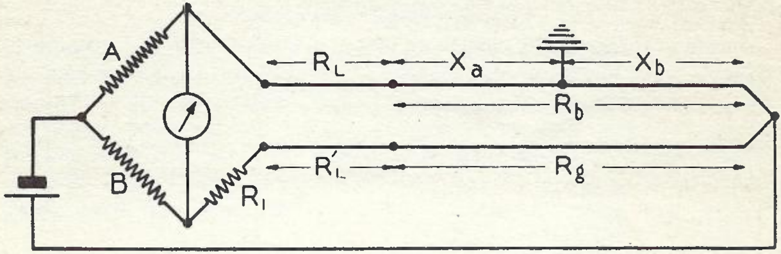


Fig. 9c Modified "Varley 1" Test

Three tests are made, known as "Varley 1", "Varley 2" and "Varley 3", using connections as shown in Figs. 9, 9a and 9b, respectively. The ratio A/B must be the same in each test. Calling the rheostat readings at balance R_1, R_2 and R_3, respectively, the basic equations are:

$$\frac{A}{B}=\frac{R'_L+R_g}{R_1+R_L+R_b},\quad \frac{A}{B}=\frac{R'_L+R_g+R_b-X_a}{R_2+R_L+X_a}\quad\text{and}\quad \frac{A}{B}=\frac{R'_L+R_g+R_b}{R_3+R_L}$$

from which may be obtained the working equations:

$$X_b=\frac{A}{A+B}(R_2-R_1),\qquad X_a=\frac{A}{A+B}(R_3-R_2)$$
$$\text{and}\qquad R_b=X_a+X_b=\frac{A}{A+B}(R_3-R_1) \tag{9}$$

To determine the resistance to the fault to tenths of an ohm, the ratio A/B must be approximately 1/10. The ratios 1/9 and 1/4 are convenient,* because their working equations reduce, respectively, to the forms:

$$X_b=\frac{R_2-R_1}{10},\qquad X_a=\frac{R_3-R_2}{10}\qquad\text{and}\qquad R_b=\frac{R_3-R_1}{10} \tag{9a}$$

$$\text{or}\qquad X_b=\frac{R_2-R_1}{5},\qquad X_a=\frac{R_3-R_2}{5}\qquad\text{and}\qquad R_b=\frac{R_3-R_1}{5} \tag{9b}$$

When the total resistance of the loop is more than about 1000 or 1100 ohms, it is impossible to balance the bridge when using ratios of 1/10 or 1/9. It may then be necessary to use $A/B=1$. Then, if the good wire is of lower resistance than the faulty wire, the bridge cannot be balanced in the "Varley 1" test. The good and bad wires *with their leads* must then be interchanged as in Fig. 9c, while making the "Varley 1" test only. The working equations under these conditions are:

$$X_b=\frac{R_2+R_1}{2},\qquad X_a=\frac{R_3-R_2}{2}\qquad\text{and}\qquad R_b=\frac{R_3+R_1}{2} \tag{9c}$$

To avoid the need for interchanging the good and bad conductors in the "Varley 1" test, a small resistor may be connected between the test set and the good conductor. It is used during all three tests. Any reasonable value of resistance may be used which is large enough to make the resistance of the good conductor higher than that of the bad one. Its value need not be known since it is automatically eliminated by the method of test.

*The 5430 Type U Portable Test Set (page 44) is provided with two special ratios: one of 1/9 in which A is 1 and B is 9, making the multiplier figure for $\frac{A}{A+B}$, 0.1; the other of 1/4, making the multiplier figure for $\frac{A}{A+B}$, 0.2. The use of the special ratio values permits easy computation of Varley Loop measurements. In the first case the rheostat reading is multiplied by 0.1; in the second, by 0.2.

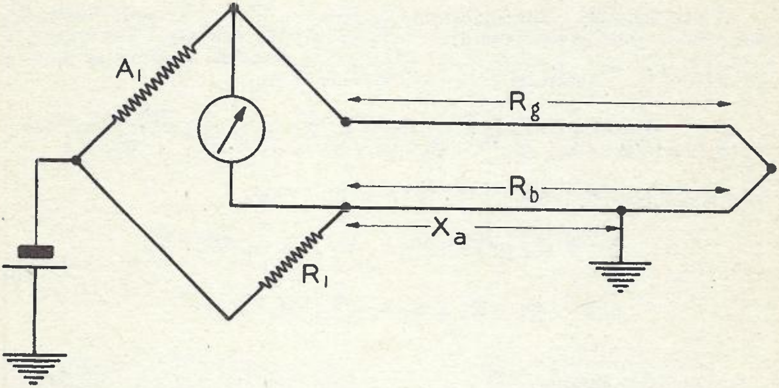


Fig. 10 Fisher Loop (1st Test)

FISHER LOOP

The Fisher Loop test is useful when all conductors in a cable are bad, making it necessary to use auxiliary conductors external to the cable. It requires two additional conductors, which may be of any size and length. The only requirement is that they terminate at the same points as does the faulty conductor.

Two tests are made. The first is identical with the Murray Loop test, and connections are made as in Fig. 10, using the first auxiliary conductor as R_g. In the second test (Fig. 10a), the battery is disconnected from ground and connected to the second good conductor, which is connected at the distant end to the junction of the first good conductor with the bad conductor.

From the first test,

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

From the second test,

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

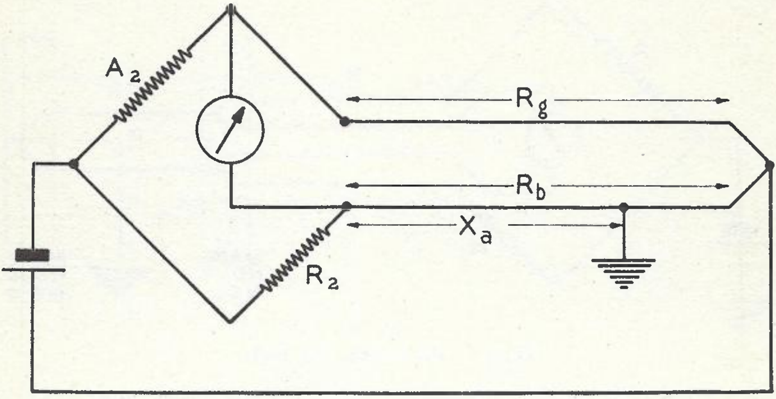


Fig. 10a Fisher Loop (2nd Test)

Eliminating R_g, there results

$$X_a = \frac{(A_2+R_2)R_1}{(A_1+R_1)R_2} R_b \tag{10}$$

or, if $A_1 = A_2$,

$$X_a = \frac{(A+R_2)R_1}{(A+R_1)R_2} R_b$$

In the slidewire type of test set, $A+R$ is constant and

$$X_a = \frac{R_1}{R_2} R_b \tag{10a}$$

If R_b is not known, it may be determined by the application of method (a) on page 8.

The "Three Varley" method, described on page 17, is also applicable under these conditions.

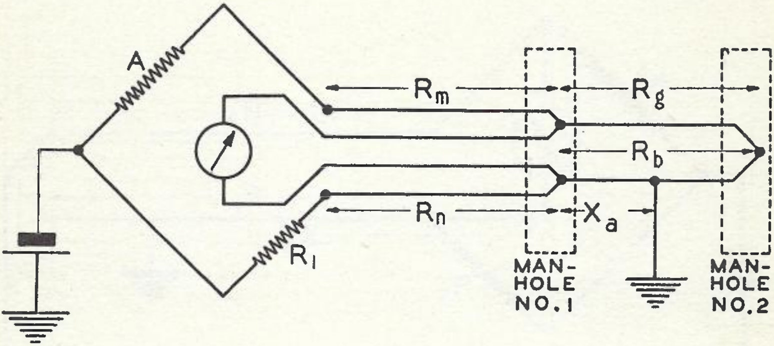


Fig. 11 Moody Loop (1st Test)

MOODY LOOP

The Moody Loop test is a modification of the Murray Loop test, and is particularly adapted to location, from central cable locating desks, of faults on distant sections. Two good auxiliary pairs are required between the test location and each of the distant manholes between which the fault lies. In addition, one good wire between manholes is required, which must be similar to the faulty wire. Connections are first made as shown in Fig. 11, using the pairs terminating in Manhole No. 1. It will be seen that the galvanometer is connected through one of the pairs to the good and bad conductors in the manhole. Since in some test sets it is impossible to disconnect the galvanometer completely without disturbing some of the permanent wiring, it may be desirable to use an external galvanometer. A key should be provided for opening and closing the galvanometer circuit.

With connections made as in Fig. 11,

$$\frac{A+R_m}{R_1+R_n} = \frac{R_g+R_b-X_a}{X_a}$$

from which

$$X_a = \frac{R_1+R_n}{A+R_1+R_n+R_m}\,r \tag{11}$$

where $r = R_g + R_b$.

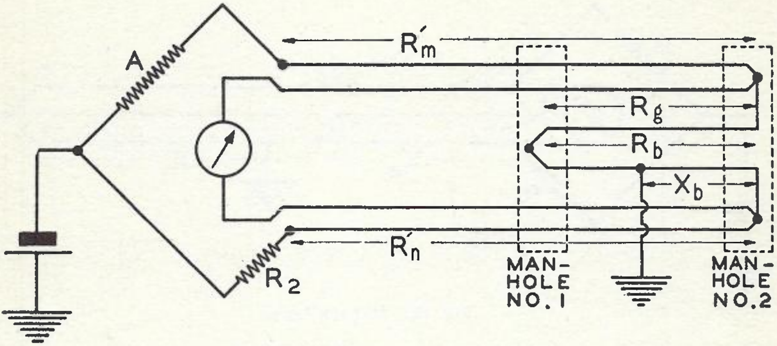


Fig. 11a **Moody Loop (2nd Test)**

To obtain a check, connections are changed to those shown in Fig. 11a, using the auxiliary pairs terminating in Manhole No. 2. With these connections,

$$\frac{A+R'_m}{R_2+R'_n}=\frac{R_g+R_b-X_b}{X_b}$$

from which

$$X_b=\frac{R_2+R'_n}{A+R_2+R'_m+R'_n}\qquad(11a)$$

As a check, X_a+X_b should be equal to R_b.

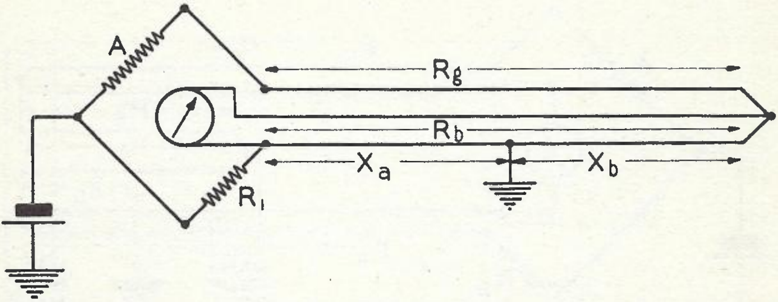


Fig. 12 Hilborn Loop

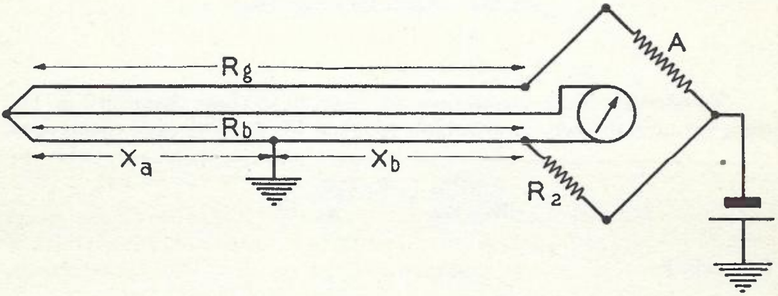


Fig. 12a Hilborn Loop (Check)

HILBORN LOOP*

Useful for locating faults in section lengths, this method requires two good wires, of which the resistance of one must be known. The connections shown in Fig. 12 differ from those of the Murray Loop in that the good conductor of known resistance is in the A arm of the bridge. When the bridge is balanced,

$$\frac{A+R_g}{R_1} = \frac{X_b}{R_b - X_b}$$

from which

$$X_b = \frac{A+R_g}{A+R_g+R_1} R_b \qquad (12)$$

A check test is made from the other end of the section with connections as shown in Fig. 12a, from which

$$X_a = \frac{(A+R_g)R_b}{A+R_g+R_2} \qquad (12a)$$

---

*The 5430-A Type U Portable Test Set (page 44) is arranged so that the internal galvanometer can be used for the Hilborn Loop test by turning the galvanometer key to HIL position and connecting the auxiliary test lead to GA-1.

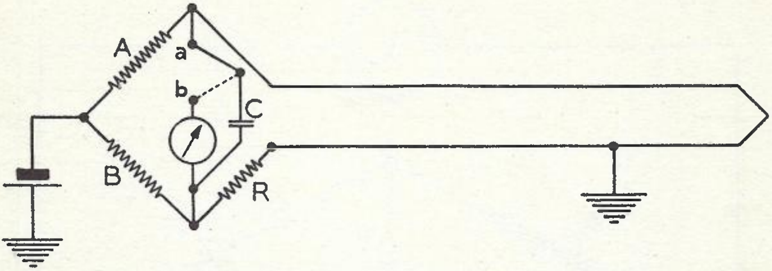


Fig. 13 Use of Auxiliary Capacitor to Minimize Disturbance

USE OF AUXILIARY CAPACITOR TO MINIMIZE DISTURBANCE

Occasionally, when the good wires are not in the same cable with the bad wire, it may be difficult to balance the bridge, because of inductive disturbances on the good wires which are not present on the bad wire, or vice versa. In such situations, the use of an auxiliary capacitor may prove helpful.

Connections are made in the usual way for the desired loop test, except that a capacitor and a switch are connected to the galvanometer as shown in Fig. 13. The capacitor should have a capacitance of about 12 to 14 microfarads.

The procedure is as follows: The capacitor is charged by throwing the switch to "a", after which it is discharged through the galvanometer by throwing the switch to "b". R is adjusted by successive approximations until, when the switch is thrown to "b", no kick is observed on the galvanometer, indicating no charge in the capacitor. When this condition exists, R is read, and the fault-location calculation is made in the usual manner.

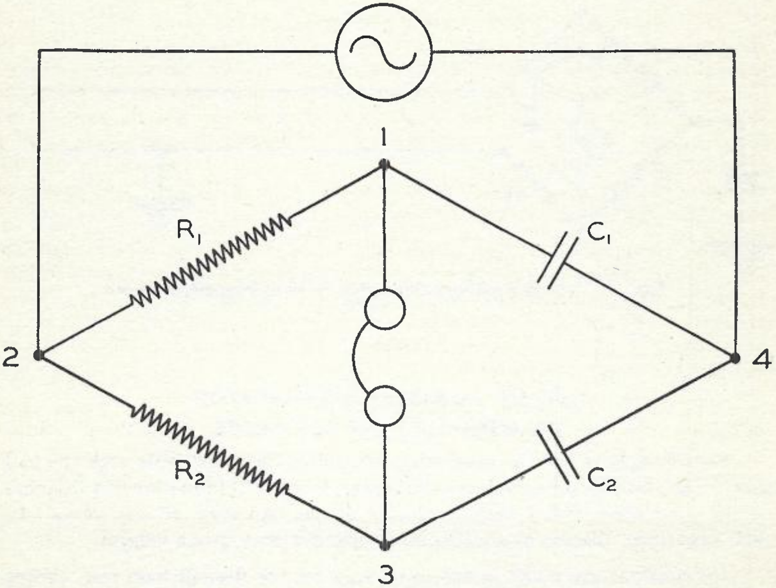


Fig. 14 Comparison of Capacitances

CAPACITANCE METHOD FOR LOCATION OF OPENS

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

When the conductor is uniformly spaced from its surroundings as, for example, a conductor in a cable, the capacitance is proportional to the length. Therefore, by measuring the capacitance of the conductor from one end to the break, the distance to the break may be determined, if the capacitance per unit length is known. This may be done by charging the capacitor (by applying a voltage) and then discharging it through a galvanometer. The resulting ballistic deflection or "kick", if calibrated by applying the same voltage to a standard capacitor, is a measure of the capacitance of the conductor to its surroundings and, hence, of the distance to the break. This method is, however, subject to objections: the capacitance may not be uniform throughout the length of the cable; and "dielectric absorption" (retention of a part of the charge by the dielectric) may introduce error.

By balancing the capacitance of the faulty conductor up to the point of the break against that of a good conductor *in the same cable*, these sources of error may be largely eliminated, as they affect both the faulty and good conductors in substantially the same way. This is accomplished by using the same apparatus which is used for locating grounds and shorts, except that direct current from a battery is replaced by pulsating or alternating current from a buzzer or "tone test" set, and the galvanometer is replaced by phones. A buzzer may be used for distances up to 1/2 mile, with lower frequencies or slowly-reversed, direct current for longer lines.

The connections used are essentially those of a Wheatstone bridge (see Fig. 2, page 6) with two of the resistors replaced by the two capacitors formed by the faulty conductor and the good conductor, as shown in Fig. 14. When the resistances are so adjusted that no sound is heard in the phones, the points 1 and 3 are at equal potentials. If the phones cannot be adjusted to silence, the point of minimum sound is determined.

The cable capacitances represented by C_1 and C_2 are charged to the same difference of potential, as indicated by no sound in the phones, and contain quantities of electricity proportional to their respective capacitances. The quantity flowing into each capacitor in any unit of time is limited, however, by the resistance in series with it and, hence, is inversely proportional to the resistance limiting the flow.

Therefore
$$\frac{R_1}{R_2} = \frac{C_2}{C_1} \tag{14}$$

Since the good and faulty conductors are subjected to the same conditions, their lengths may be taken as proportional to their capacitances, from which

$$\frac{R_1}{R_2} = \frac{L_2}{L_1} \tag{14a}$$

The question of allowance for leadwires does not arise unless the leads are very long or unless wire in a cable is used for leads to the faulty cable.

It is sometimes desirable to use this method for measuring the capacitances of wires in a cable by comparison with a standard capacitor. The different characteristics of the capacitor formed by the cable and the mica capacitor used as a standard may make it difficult to obtain a satisfactory balance due to inability to determine accurately the point of minimum sound in the phones. This difficulty may be largely overcome by inserting an adjustable resistor in series with the standard capacitor. Balance is obtained by alternately adjusting this resistor and the bridge resistors until the point of minimum sound is reached. The same equation is used, since capacitance-balance is unaffected by the value of the adjustable resistance in series with the standard.

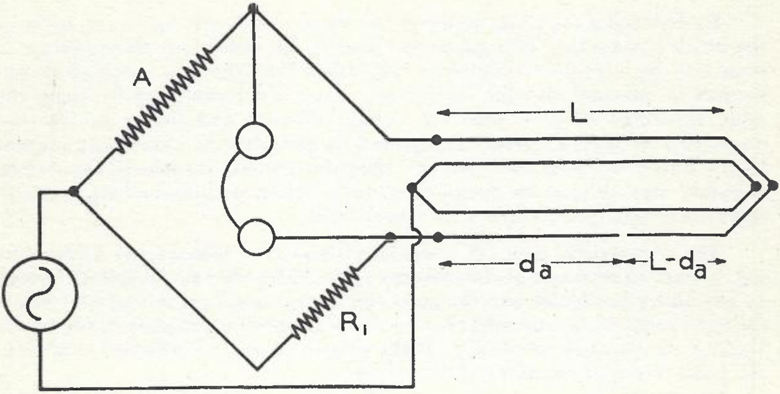


Fig. 15 Break Location in a Quadded Cable

LOCATION OF A BREAK IN A QUADDED CABLE

When a break in a conductor of a cable is to be located, the capacitance of the open conductor is compared with that of a good conductor which is as nearly like the faulty conductor as possible. In a quadded cable, the faulty pair is compared to the good pair of the same quad. Connections are made as in Fig. 15, where corresponding sides of each pair are connected as shown. The test set is connected as for ground location by the Murray Loop test, except that an a-c source and phones are substituted for battery and galvanometer.

When the rheostat arm is adjusted to the value R_1 which gives minimum sound in the phones,

$$\frac{A}{R_1} = \frac{d_a}{2L-d_a}$$

from which

$$d_a = \frac{2A}{A+R_1} L \qquad (15)$$

where L is the length of one conductor, and d_a is the distance to the fault in the same units.

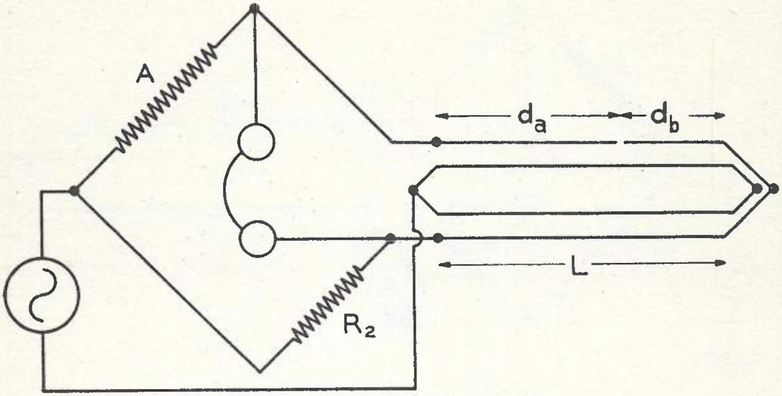


Fig. 15a Break Location in a Quadded Cable (Check)

A check is obtained by interchanging good and bad conductors (Fig. 15a). If R_2 is the balancing resistance,

$$\frac{A}{R_2} = \frac{2L-d_a}{d_a}$$

from which

$$d_a = \frac{2R_2L}{A+R_2} \tag{15a}$$

Since $d_a+d_b=L$, the check may also be expressed in the form

$$d_b = \frac{A-R_2}{A+R_2}L \tag{15b}$$

This test may also be applied to the location of opens in non-quadded cables by using any good pair, either in the same or a similar cable, as if it were the second pair of a quad.

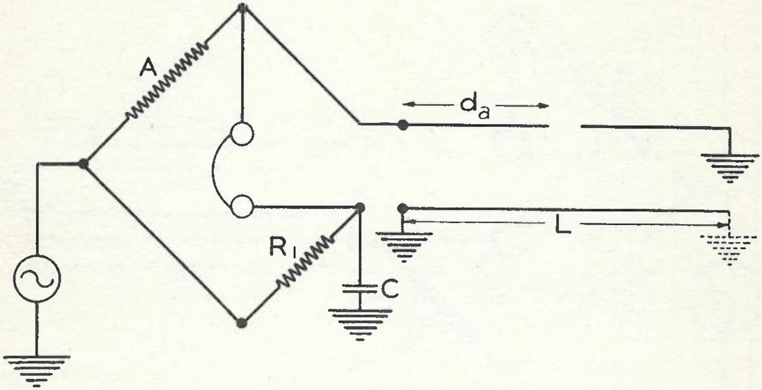


Fig. 16 Break Location (1st Test)

LOCATION OF A BREAK IN A PAIR

A break in one wire of a pair may be located by comparing, in turn, the capacitance of the broken wire, and that of the good wire of the same pair, with that of a capacitor.

Connections are first made as shown in Fig. 16. The capacitance formed by the good wire and the portion of the faulty wire between the test set and the fault is compared with that of the capacitor C. In practice, C usually has a value of one or two microfarads.

At balance,

$$\frac{A}{R_1} = \frac{C}{Kd_a}$$

where R_1 is the rheostat reading at balance and K is the capacitance per unit length of the cable.

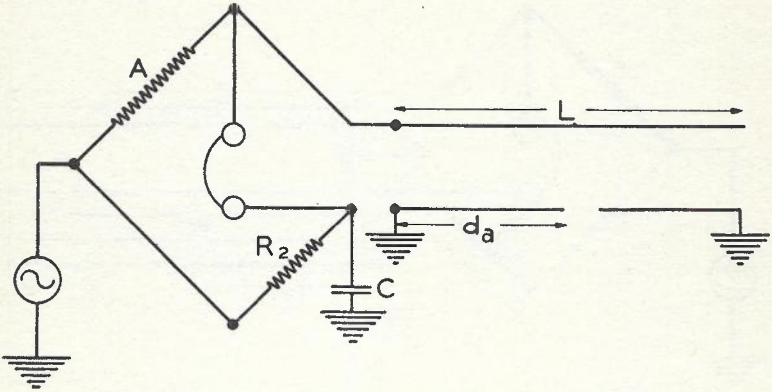


Fig. 16a **Break Location (2nd Test)**

By changing the connections to those of Fig. 16a, the capacitance of a pair of known length is compared with that of the capacitor C. If R_2 is the rheostat reading at balance under this condition and K is the capacitance per unit length of the cable,

$$\frac{A}{R_2} = \frac{C}{KL}$$

From these equations,

$$d_a = \frac{R_1}{R_2}L \tag{16}$$

The pair of known length may be either a second pair in the same cable or, preferably, the faulty pair in which both ends of the broken conductor are grounded. If difficulty is experienced in obtaining a satisfactory balance, an adjustable resistor may be added, as outlined on page 25.

The location of the break may be checked by making the same tests from the other end of the cable.

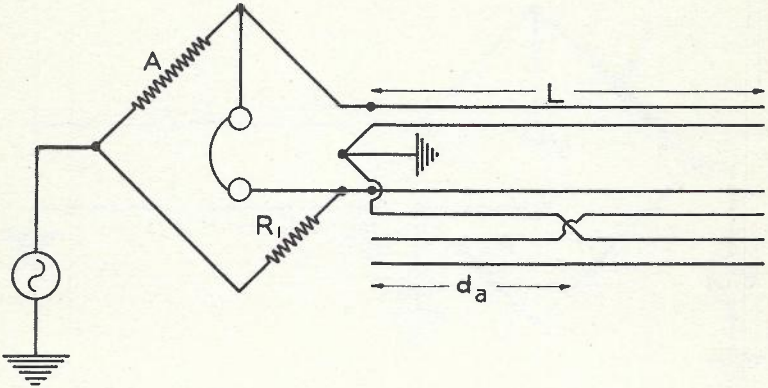


Fig. 17 Location of Split Pairs—Method I (1st Test)

INDUCTIVE CROSSES

Inductive crosses or split pairs, due to errors in splicing, are located by applying the same principle which is used for locating breaks. In an inductive cross, one wire of a pair is connected at some joint to one of the wires of a second pair. Inductive crosses may also be formed by one pair in one quad being joined at a splice to one of the pairs of another quad. In addition to causing confusion at the terminals, inductive crosses may cause cross talk between circuits.

LOCATION OF SPLIT PAIRS—METHOD I

To locate a split pair, advantage is taken of the change of average distance between conductors due to transposition. This causes a change of the constant of proportionality of capacitance with length. If connections are made as shown in Fig. 17, the capacitance of a normal pair is compared with that of a pair of conductors consisting in part of a normal pair and in part of a pair in which the distance between conductors is greater than normal.

Then $$\frac{A}{R_1} = \frac{Kd_a + K'(L - d_a)}{KL}$$

where K and K′ are the capacitances per unit length of the normal and faulty pairs, respectively; R_1 is the rheostat reading at balance; and L and d_a are the lengths, expressed in the same units.

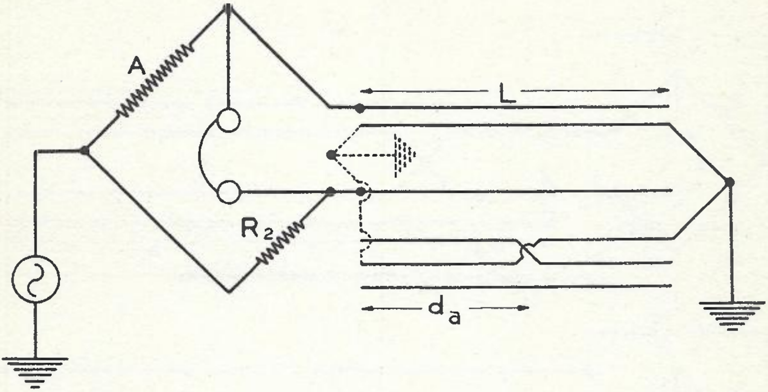


Fig. 17a Location of Split Pairs—Method I (2nd Test)

If the connections are changed to those of Fig. 17a, the lengths of normally and abnormally paired wires are interchanged.

$$\text{Therefore} \qquad \frac{A}{R_2} = \frac{K'd_a + K(L - d_a)}{KL}$$

where R_2 is the rheostat resistance for the condition of balance. By solving for the value of K' in the second equation, substituting this value in the first equation, and solving for d_a,

$$d_a = \frac{R_1(R_2 - A)L}{2R_2R_1 - A(R_1 + R_2)} \tag{17}$$

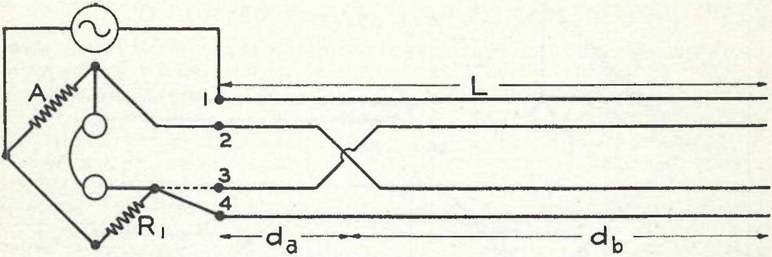


Fig. 18 Location of Split Pairs—Method II (1st Test)

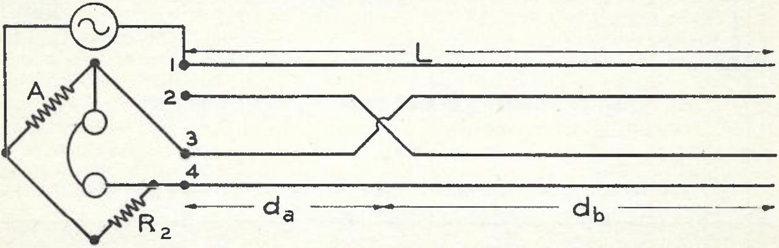


Fig. 18a Location of Split Pairs—Method II (2nd Test)

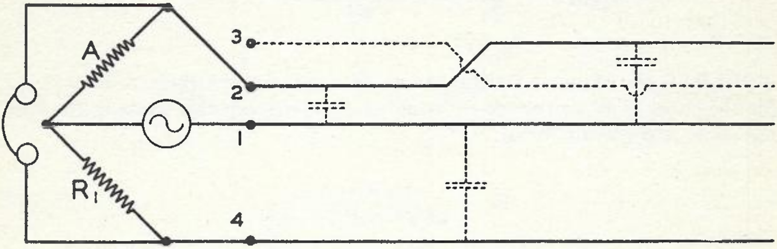


Fig. 18b Rearrangement of Fig. 18

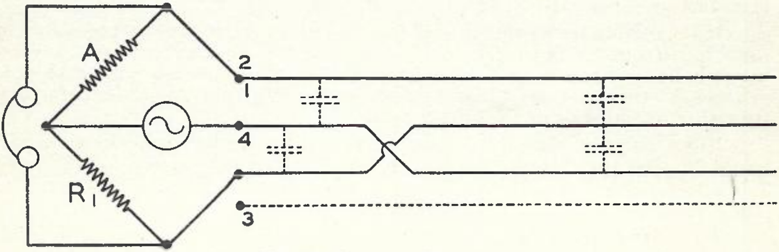


Fig. 18c Alternative Connections

LOCATION OF SPLIT PAIRS—METHOD II

A second method for locating split pairs, which may be used as a check, is similar to the first, except that the capacitance between the good wire of one pair and the good wire of the other pair is balanced against the capacitance between one good wire and each of the crossed wires in turn.

Connections are first made as in Fig. 18. Either wire of one crossed pair may be connected to the voltage source. It is here assumed that a "good" wire is so connected. A preliminary test is necessary to determine the similar wire of the second pair. This is done by balancing first with one wire, and then with the other, of the second pair connected to the rheostat arm, as shown by the full and dotted connections. The connection giving the larger value of R is the correct one. Let this value of R be called R_1.

Leaving the connection to the voltage source and that to the rheostat arm of the bridge as in Fig. 18, the connection from the A arm to the crossed wire is removed and connected to the other crossed wire, the connection to which was previously discarded by the preliminary test. These connections are shown in Fig. 18a. Let R_2 be the rheostat value at balance under these conditions, A being the same value as before.

The resulting conditions are easier to visualize if Fig. 18 is redrawn as in Fig. 18b. It will be easily recognized that the arm adjacent to the rheostat R is formed by the two straight wires and that the arm adjacent to A is formed by one straight wire and one or the other of the crossed wires.

The bridge equation resulting from Fig. 18 is

$$\frac{A}{R_1} = \frac{K'L}{Kd_a + K'(L-d_a)}$$

and that from Fig. 18a is

$$\frac{A}{R_2} = \frac{KL}{K'd_a + K(L-d_a)}$$

from which

$$d_a = \frac{(R_1 - A)L}{R_1 + R_2 - 2A}$$

or, since $d_b = L - d_a$, (18)

$$d_b = \frac{(R_2 - A)L}{R_1 + R_2 - 2A}$$

If the voltage source was originally connected to a crossed wire, the conditions are as shown in Fig. 18c. The final equations expressing d_a and d_b are the same in either case.

If the section under test is long (over a half-mile), it may be preferable to use a low-frequency (4 to 20-cycle) a-c source, such as a battery and a reversing switch; and to use an a-c galvanometer, or a d-c galvanometer with pole changer, as the detector. This method for locating split pairs is satisfactory for either quadded or non-quadded cable.

If the length of the cable is five miles or less, the error in the location will seldom exceed the distance between splices. If the split is not found in the splice first opened, it is advisable to make a new location from that splice. The second test will almost invariably locate the split.

To locate a split between two quads, the procedure is the same as in split-pair location, each pair of the quads concerned being treated as one wire.

INTERPRETATION OF RESULTS

In all the methods for ground (or cross) location which have been described, the fault is located by the resistance from one end or the other of the faulty conductor. To find the fault, it is necessary to translate this resistance into distance.

Distance to Fault

If the conductor or loop is composed throughout of the same size of wire, its length is directly proportional to its resistance. If the length is known, it is often unnecessary to know the resistance. When the resistance to the fault is expressed, by formula, as a fraction of the resistance of the loop or of the faulty conductor, the distance to the fault may be taken as the same fraction of the length of the loop or conductor. For example, in the Murray Loop test (page 10) the resistance from the test set to the fault is given by formula (6) as

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

where r is the loop resistance. Then, the distance to the fault is

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

where L is the length of the loop.

Similarly, in the Three Varley test (page 17), formulae (9) give

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

from which

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

where R_b is the resistance of the faulty conductor.

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

where L is the length of the faulty conductor. It is desirable to use this method when it is applicable, since it eliminates errors, such as that due to lack of correct information regarding the temperature of the conductor, or that due to the conductor being not exactly to gauge.

When the resistance to the fault is given by a formula such as (8) (see Varley Loop test, page 14), the relation between resistance and length is expressed as

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

where R_b and L are the resistance and length, respectively, of the faulty conductor.

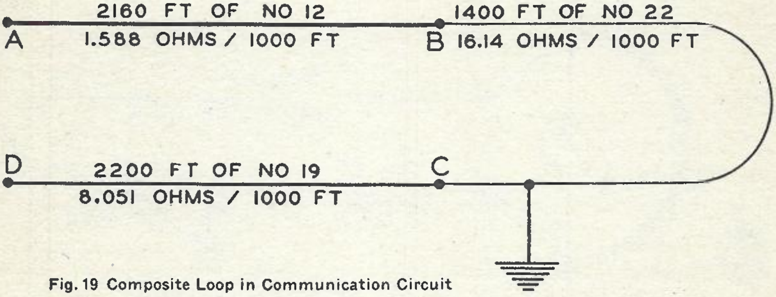


Fig. 19 Composite Loop in Communication Circuit

Composite Conductors

When the conductor consists of more than one size of wire, reference must usually be made to tables giving the resistance per thousand feet of conductor as on page 42. It should be understood that such tables are correct at one temperature only—usually 68 F. For other temperatures, the tabular value of ohms per 1000 feet should be increased or decreased by 0.00218 times the tabular value for each degree Fahrenheit above or below 68 degrees. The length of some one size of wire is determined which would have the same resistance as that of the composite conductor. For example, if r_u, r_v and r_w are the resistances per 1000 feet of conductors of size u, v and w, respectively, and L_u, L_v and L_w are their respective lengths, then the length L'_u of conductor size u would have the same resistance as the composite conductor, if

$$L'_u = L_u + \frac{r_v L_v}{r_u} + \frac{r_w L_w}{r_u}, \qquad (19)$$

since the resistance of a conductor is directly proportional to its resistance per unit length. For example, consider the composite conductor shown in Fig. 19, which is composed of three sections of different sizes having, at 68 F, the respective lengths and resistances per 1000 feet which appear in the diagram. Reducing to the equivalent length of No. 22 wire,

$$\begin{aligned} L'_u &= 1400 + \frac{8.051}{16.14}2200 + \frac{1.588}{16.14}2160 \\ &= 1400 + 1097 + 212.5 \\ &= 2709.5 \text{ ft of No. 22 wire} \end{aligned}$$

If a test shows that the fault is at a resistance of 21.72 ohms from the test set connected at the No. 19 end, the distance to the fault would be 1346 feet, if this were all No. 22 wire; but the first section DC consists of a length of No. 19 gauge wire equivalent to 1097 feet of No. 22 wire. Subtracting 1097 feet from 1346 feet leaves 249 feet. Since the next section CB consists of No. 22 wire (the size used for calculation), 249 feet is the actual distance from junction C to the fault.

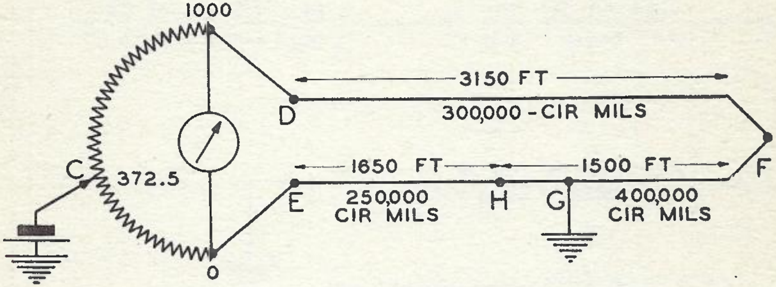


Fig. 20 A Composite Power-Cable Loop

As another illustration, suppose that a power cable, as shown in Fig. 20, were being tested by means of the L&N Power Cable Fault Bridge. Reducing this cable to the equivalent 400,000-circular-mil length by taking the resistance inversely proportional to the cross-section, the length of equivalent 400,000-circular-mil cable is

$$\begin{aligned} L'_u &= 1500 + 1650\,\frac{400{,}000}{250{,}000} + 3150\,\frac{400{,}000}{300{,}000} \\ &= 1500 + 2640 + 4200 \\ &= 8340 \text{ ft} \end{aligned}$$

If the bridge balances at 372.5 after the fault has been reduced to low resistance by carbonizing, it indicates that the apparent distance of the fault from the test location is $\frac{372.5}{1000} \times 8340 = 3106.7$ ft from E. Since the first section consists of 250,000-circular-mil cable, equivalent in length to 2640 ft of 400,000-circular-mil cable, the fault is located $3106.7 - 2640 = 466.7$ ft beyond this point. This is the actual fault location, since the second section is composed of 400,000-circular-mil cable.

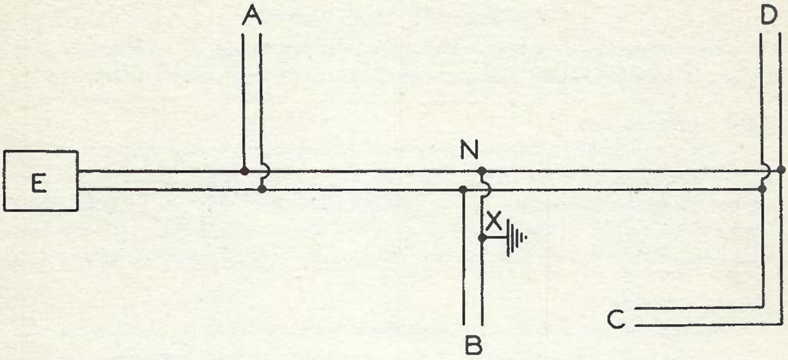


Fig. 21 Branched Circuit

Branched Circuits

Another situation which may arise involves branched circuits, as shown in Fig. 21. Assume that there is a fault at X. If the test is made from E and the two wires at C are connected together, the loop ENC is formed. The apparent location of the fault will be found at N, the point of connection of the branch containing the fault. By removing the connection at C and connecting the wires at B, forming the loop ENB, another test may be made which will determine the location of the fault in terms of distance along this path.

After the distance to a fault has been determined, a physical inspection of the cable should be made near the point thus located. If no signs of the trouble are observed, the nearest splice should then be opened. However, if the location has been made from a central locating desk, 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.

CAUSES OF INACCURACY

The following are a few of the more frequent causes of trouble and inaccuracy in locating faults, and some suggestions for overcoming them.

Poor Connections

Since any resistance caused by poor connections in the loop-circuit will enter directly as an error in the location, the importance of good connections cannot be over emphasized. If, in joining the faulty wire to the good one, a poor connection is made, introducing a resistance of 1/4 ohm, for instance, where the wire is No. 22 B&S copper, the location will be about 16 feet in error.

Stray Currents

Not infrequently, stray currents from light, power and traction circuits, or currents induced from such circuits, are found in telephone and telegraph wires. These currents are generally irregular and cause irregular deflections of the galvanometer. When they occur, the use of a capacitor, as described on page 23, may be tried; or the voltage may be made as high as possible, so that galvanometer deflections due to the test current may be larger than those due to the stray current. If neither of these expedients makes it possible to obtain sufficiently accurate location, it may be necessary to use another loop, or to postpone the test until conditions are more favorable.

A Disappearing Ground

Occasionally, a disappearing ground is encountered while trying to locate a fault. Sometimes, by waiting for a short time, the ground will reappear. By employing more battery, so as to get a higher voltage, and by taking a quick reading, it is sometimes possible to catch a location.

Sometimes, the ground resistance can be decreased, or permanently burned out, by applying a ringing generator to the faulty wire. Before doing this, the testing apparatus should be disconnected. If these methods are unsuccessful, it is best to leave the trouble until it becomes worse. A ground which is sufficiently conducting to make a line noisy can, as a rule, be located.

In power cables, high-resistance faults may occur in the insulation. As a result, a fault current passes with service voltage, but the testing voltage is insufficient to cause any appreciable current through the fault. It is then necessary to reduce the fault to low resistance by applying a high potential so as to carbonize the insulation, thus making a low-resistance path for the battery current. As an alternative, a high d-c testing voltage may be applied which will pass sufficient current through the fault to enable the test to be made.

Two Faults on One Wire

Sometimes, when making a loop test, it is impossible to get a balance. This is generally an indication of two variable-resistance faults at different points, or one of considerable extent, such as might be caused by the presence of moisture over 50 or 100 feet of cable.

Under these conditions, an accurate determination of the location of either fault is most unlikely. Usually, the calculated result will be nearest the fault of lower resistance. The calculated distance will lie somewhere between the two faults but, because there is no practical way to find the respective resistances to the faults, the probable location cannot even be estimated. The best procedure is to make a rough measurement and calculation, cut the cable at this point, and then determine separately the distance to the fault in each section of cable.

To find whether there are two faults on a faulty conductor, make tests from both ends. If the calculated locations are alike, within the limits of error of measurement, only one fault exists; if they differ, there are probably two or more.

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. This is never exactly true and is sometimes far from true. Unless the wire inequalities balance each other, which they do in many cases, the calculated location will be in error in proportion to the inequalities. Among the causes of inequalities are introduced resistances, such as poorly soldered sleeves, slight variations in gauge, and inequalities in the temperature of different parts of the line. It is generally impossible to correct for these inequalities. In long lines, there may be inequalities in temperature, but the resulting resistance variations may be calculated and allowed for. Another cause of inequality is unequal twisting of the pairs in a cable. For this reason, the loop should be made, whenever possible, by connecting the faulty wire to its mate, since the two will then be subject to the same conditions of twist, temperature, etc.

Incorrect Assumptions in Regard to Line Resistance

If calculations are based on resistances determined from wire tables, errors may occur due to all of the causes mentioned in the preceding paragraph. This class of error may be obviated by using the methods and formulae which determine the distance to the fault as a fraction of the total length of the loop of the faulty wire. For this reason, these methods, when applicable, are always to be preferred.

Use Mate for Good Return

If the mate of the faulty wire is good, it should always be used, because more accurate location of the fault can be made with the mate than with some other wire. When the good wire is in one pair and the faulty one in another, one wire may be longer than the other, thus introducing a slight error in the distance to the fault.

SLIDEWIRE RATIO VALUES

VALUES OF $\frac{S}{1000-S}$ FOR ALL SCALE READINGS

100's	10's		VALUES OF S UNITS									
			0	1	2	3	4	5	6	7	8	9
	0	.00	0000	1001	2004	3010	4016	5025	6036	7049	8064	9082
	1	.0	1010	1112	1214	1317	1420	1523	1626	1730	1833	1937
	2	.0	2041	2145	2250	2354	2459	2564	2670	2775	2881	2987
	3	.0	3093	3199	3306	3413	3520	3627	3735	3843	3950	4058
	4	.0	4167	4275	4384	4493	4602	4712	4820	4931	5042	5152
	5	.0	5263	5374	5485	5596	5708	5820	5932	6044	6156	6269
	6	.0	6383	6496	6610	6724	6838	6952	7066	7180	7296	7412
	7	.0	7527	7643	7759	7875	7992	8109	8225	8342	8460	8578
	8	.0	8696	8814	8933	9051	9170	9290	9408	9528	9649	9770
	9	.0	9890	.1001	.1013	.1025	.1037	.1050	.1062	.1074	.1086	.1099
1	0		.1111	.1123	.1136	.1148	.1160	.1173	.1186	.1198	.1211	.1223
1	1		.1236	.1248	.1261	.1274	.1287	.1300	.1312	.1325	.1338	.1351
1	2		.1364	.1377	.1390	.1403	.1416	.1429	.1442	.1455	.1468	.1481
1	3		.1494	.1507	.1521	.1534	.1547	.1561	.1574	.1587	.1601	.1615
1	4		.1628	.1641	.1655	.1669	.1682	.1695	.1710	.1723	.1737	.1751
1	5		.1765	.1778	.1792	.1806	.1821	.1834	.1848	.1862	.1876	.1890
1	6		.1905	.1919	.1933	.1947	.1962	.1976	.1990	.2005	.2019	.2034
1	7		.2048	.2063	.2077	.2092	.2106	.2121	.2136	.2151	.2165	.2180
1	8		.2195	.2210	.2225	.2240	.2255	.2270	.2285	.2300	.2315	.2331
1	9		.2346	.2361	.2376	.2392	.2407	.2423	.2438	.2454	.2469	.2485
2	0		.2500	.2516	.2532	.2547	.2563	.2579	.2595	.2610	.2625	.2642
2	1		.2658	.2674	.2690	.2706	.2722	.2739	.2755	.2772	.2788	.2804
2	2		.2820	.2837	.2853	.2870	.2887	.2903	.2920	.2937	.2954	.2971
2	3		.2987	.3004	.3020	.3038	.3055	.3072	.3089	.3106	.3123	.3140
2	4		.3157	.3175	.3192	.3210	.3228	.3245	.3262	.3280	.3298	.3316
2	5		.3333	.3351	.3369	.3387	.3405	.3423	.3440	.3459	.3477	.3495
2	6		.3513	.3532	.3550	.3568	.3587	.3606	.3624	.3643	.3662	.3681
2	7		.3699	.3717	.3736	.3755	.3774	.3793	.3812	.3831	.3850	.3869
2	8		.3889	.3908	.3928	.3947	.3966	.3986	.4005	.4024	.4044	.4064
2	9		.4084	.4104	.4124	.4144	.4164	.4185	.4205	.4225	.4245	.4265
3	0		.4285	.4306	.4326	.4347	.4368	.4389	.4409	.4430	.4450	.4471
3	1		.4493	.4514	.4535	.4556	.4577	.4598	.4619	.4640	.4661	.4683
3	2		.4705	.4727	.4749	.4771	.4793	.4814	.4836	.4858	.4881	.4903
3	3		.4925	.4947	.4969	.4992	.5015	.5038	.5060	.5083	.5106	.5129
3	4		.5152	.5174	.5197	.5220	.5244	.5267	.5290	.5313	.5336	.5360
3	5		.5384	.5407	.5431	.5455	.5480	.5504	.5528	.5553	.5576	.5600
3	6		.5625	.5650	.5674	.5698	.5723	.5748	.5773	.5798	.5823	.5848
3	7		.5873	.5899	.5924	.5949	.5974	.6000	.6025	.6051	.6077	.6103
3	8		.6129	.6155	.6181	.6207	.6233	.6260	.6286	.6313	.6340	.6367
3	9		.6394	.6420	.6447	.6474	.6502	.6529	.6557	.6584	.6611	.6638
4	0		.6666	.6694	.6722	.6750	.6778	.6806	.6834	.6862	.6891	.6920
4	1		.6949	.6978	.7007	.7036	.7065	.7094	.7123	.7152	.7181	.7211
4	2		.7241	.7271	.7301	.7331	.7361	.7391	.7421	.7451	.7482	.7512
4	3		.7543	.7574	.7605	.7636	.7667	.7698	.7729	.7760	.7792	.7824
4	4		.7857	.7889	.7921	.7953	.7986	.8018	.8050	.8084	.8117	.8150
4	5		.8182	.8215	.8248	.8282	.8316	.8349	.8382	.8416	.8450	.8484
4	6		.8518	.8552	.8586	.8620	.8655	.8691	.8727	.8762	.8798	.8834
4	7		.8868	.8904	.8939	.8975	.9011	.9048	.9084	.9120	.9157	.9194
4	8		.9231	.9267	.9304	.9341	.9379	.9417	.9454	.9493	.9531	.9570
4	9		.9609	.9649	.9687	.9725	.9764	.9803	.9842	.9881	.9920	.9960

SLIDEWIRE RATIO VALUES

VALUES OF $\frac{S}{1000-S}$ FOR ALL SCALE READINGS

100's	10's	VALUES OF S UNITS									
		0	1	2	3	4	5	6	7	8	9
5	0	1.000	1.004	1.008	1.012	1.016	1.020	1.024	1.028	1.032	1.036
5	1	1.041	1.045	1.049	1.053	1.058	1.062	1.066	1.071	1.075	1.079
5	2	1.083	1.088	1.092	1.097	1.101	1.105	1.110	1.114	1.119	1.123
5	3	1.128	1.132	1.137	1.141	1.146	1.151	1.155	1.160	1.165	1.169
5	4	1.174	1.179	1.183	1.188	1.193	1.198	1.203	1.208	1.212	1.217
5	5	1.222	1.227	1.232	1.237	1.242	1.247	1.252	1.257	1.262	1.267
5	6	1.273	1.278	1.283	1.288	1.294	1.299	1.304	1.309	1.314	1.320
5	7	1.326	1.331	1.336	1.342	1.347	1.353	1.359	1.364	1.370	1.375
5	8	1.381	1.386	1.392	1.398	1.404	1.410	1.415	1.421	1.427	1.433
5	9	1.439	1.445	1.451	1.457	1.463	1.469	1.475	1.481	1.487	1.494
6	0	1.500	1.506	1.513	1.519	1.525	1.531	1.538	1.544	1.551	1.557
6	1	1.564	1.571	1.577	1.584	1.591	1.597	1.604	1.611	1.618	1.625
6	2	1.632	1.639	1.645	1.652	1.659	1.667	1.674	1.681	1.688	1.695
6	3	1.703	1.710	1.717	1.724	1.732	1.740	1.747	1.755	1.763	1.770
6	4	1.778	1.786	1.793	1.801	1.809	1.817	1.825	1.833	1.841	1.849
6	5	1.857	1.865	1.873	1.882	1.890	1.899	1.907	1.916	1.924	1.933
6	6	1.941	1.950	1.958	1.967	1.976	1.985	1.994	2.003	2.012	2.021
6	7	2.030	2.039	2.048	2.058	2.068	2.078	2.087	2.096	2.106	2.115
6	8	2.125	2.135	2.145	2.155	2.165	2.175	2.185	2.195	2.205	2.215
6	9	2.225	2.236	2.247	2.257	2.268	2.278	2.289	2.300	2.311	2.322
7	0	2.333	2.344	2.355	2.367	2.378	2.389	2.401	2.413	2.425	2.436
7	1	2.448	2.460	2.472	2.485	2.497	2.509	2.521	2.534	2.546	2.559
7	2	2.571	2.584	2.597	2.610	2.623	2.636	2.650	2.663	2.676	2.690
7	3	2.703	2.716	2.731	2.745	2.759	2.774	2.788	2.802	2.817	2.831
7	4	2.846	2.861	2.876	2.891	2.907	2.922	2.937	2.953	2.968	2.984
7	5	3.000	3.016	3.032	3.049	3.065	3.081	3.098	3.115	3.132	3.150
7	6	3.168	3.185	3.202	3.220	3.237	3.255	3.273	3.291	3.310	3.329
7	7	3.348	3.367	3.386	3.405	3.425	3.445	3.464	3.484	3.505	3.525
7	8	3.546	3.566	3.587	3.608	3.630	3.652	3.674	3.695	3.717	3.740
7	9	3.762	3.785	3.808	3.831	3.854	3.878	3.902	3.926	3.950	3.975
8	0	4.000	4.025	4.050	4.075	4.102	4.127	4.154	4.181	4.209	4.236
8	1	4.263	4.290	4.319	4.348	4.376	4.405	4.435	4.464	4.494	4.525
8	2	4.556	4.587	4.618	4.650	4.682	4.715	4.748	4.781	4.814	4.848
8	3	4.882	4.917	4.953	4.988	5.025	5.061	5.097	5.135	5.173	5.211
8	4	5.250	5.290	5.330	5.370	5.411	5.451	5.493	5.536	5.580	5.623
8	5	5.666	5.711	5.757	5.803	5.850	5.898	5.945	5.994	6.043	6.093
8	6	6.143	6.194	6.247	6.300	6.353	6.407	6.463	6.519	6.576	6.634
8	7	6.693	6.752	6.812	6.873	6.937	7.000	7.064	7.129	7.196	7.264
8	8	7.334	7.403	7.474	7.546	7.620	7.696	7.772	7.849	7.928	8.009
8	9	8.091	8.175	8.259	8.346	8.434	8.524	8.616	8.709	8.804	8.901
9	0	9.000	9.101	9.204	9.309	9.416	9.526	9.638	9.753	9.870	9.989
9	1	10.11	10.23	10.36	10.49	10.63	10.76	10.90	11.05	11.19	11.34
9	2	11.50	11.66	11.82	11.99	12.16	12.33	12.51	12.70	12.89	13.08
9	3	13.28	13.49	13.71	13.93	14.15	14.38	14.62	14.87	15.13	15.40
9	4	15.66	15.95	16.24	16.54	16.86	17.18	17.52	17.87	18.23	18.61
9	5	19.00	19.41	19.83	20.28	20.75	21.22	21.73	22.26	22.81	23.38
9	6	24.00	24.64	25.32	26.03	26.77	27.57	28.41	29.30	30.25	31.26
9	7	32.33	33.49	34.70	36.04	37.46	39.00	40.67	42.48	44.44	46.62
9	8	49.00	51.63	54.55	57.83	61.50	65.67	70.43	75.93	82.33	89.91
9	9	99.00	110.1	124.0	141.9	165.7	199.0	249.0	332.3	499.0	999.0

ANNEALED COPPER WIRE TABLE

B & S Gauge	Diameter in mils	Area in Circular mils	*Ohms per 1000 feet at 20 C (68 F)	Feet per ohm at 20 C (68 F)
....	......	500,000	†0.02116	47,270
....	......	400,000	†0.02644	37,810
....	......	350,000	†0.03022	33,090
....	......	300,000	†0.03526	28,360
....	......	250,000	†0.04231	23,630
0000	460.0	211,600	0.04901	20,400
000	409.6	167,800	0.06180	16,180
00	364.8	133,100	0.07793	12,830
0	324.9	105,500	0.09827	10,180
1	289.3	83,690	0.1239	8070
2	257.6	66,370	0.1563	6400
3	229.4	52,640	0.1970	5075
4	204.3	41,740	0.2485	4025
5	181.9	33,100	0.3133	3192
6	162.0	26,250	0.3951	2531
7	144.3	20,820	0.4982	2007
8	128.5	16,510	0.6282	1592
9	114.4	13,090	0.7921	1262
10	101.9	10,380	0.9989	1001
11	90.74	8234	1.260	794
12	80.81	6530	1.588	629.6
13	71.96	5178	2.003	499.3
14	64.08	4107	2.525	396.0
15	57.07	3257	3.184	314.0
16	50.82	2583	4.016	249.0
17	45.26	2048	5.064	197.5
18	40.30	1624	6.385	156.6
19	35.89	1288	8.051	124.2
20	31.96	1022	10.15	98.5
21	28.46	810.1	12.80	78.11
22	25.35	642.4	16.14	61.95
23	22.57	509.5	20.36	49.13
24	20.10	404.0	25.67	38.96
25	17.90	320.4	32.37	30.90
26	15.94	254.1	40.81	24.50
27	14.20	201.5	51.47	19.43
28	12.64	159.8	64.90	15.41
29	11.26	126.7	81.83	12.22
30	10.03	100.5	103.2	9.69

*For each degree Fahrenheit above or below 68 F, increase or decrease "Ohms per 1000 feet" by 0.00218 times the tabular value.

†Cable-Resistance given 2% greater than equivalent solid conductor to allow for stranding.

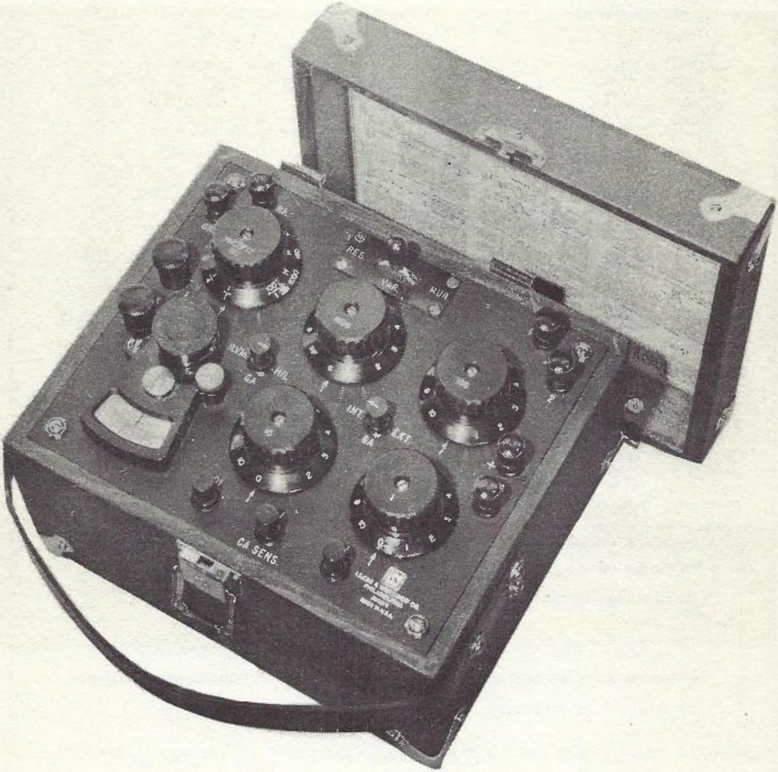
L&N TEST SETS FOR FAULT LOCATION

Briefly described in the following pages are three portable test sets for fault location. These instruments, by Leeds & Northrup, are typical of those used for making the various tests described in this note book. To any one interested, we will gladly send literature which covers more fully the specifications for each of these instruments.

The Type U Test Set (page 44) is especially adapted for locating faults in communication circuits. It embodies a number of features which are the direct suggestions of telephone engineers.

The Type S Test Set (page 47) is a general-purpose Wheatstone bridge, convenient for ordinary resistance testing as well as for locating faults in communication circuits.

The L&N Power Cable Fault Bridge (page 50) is specifically designed for locating faults in power cables by the Murray Loop method.

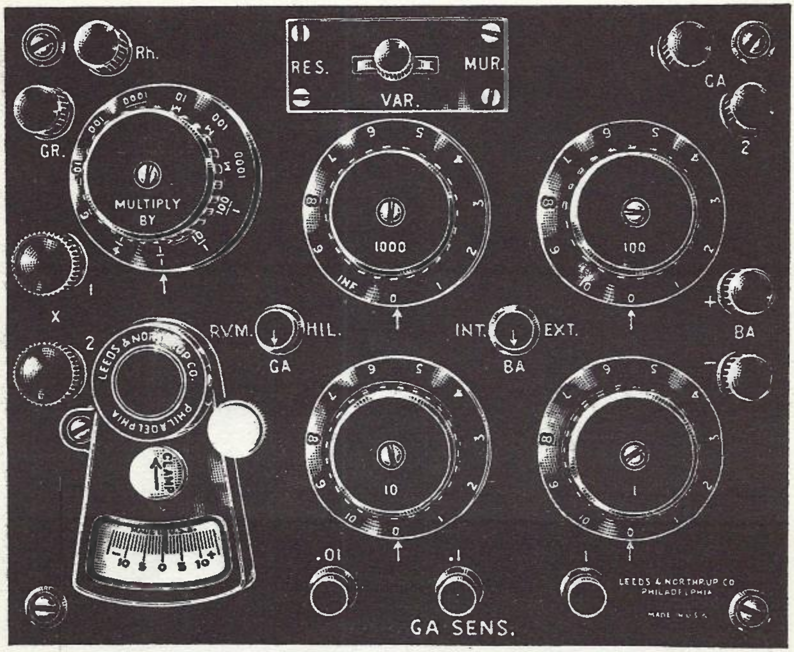


Type U Test Set is especially adapted for locating faults in communication circuits

TYPE U TEST SET

For locating faults on telephone and telegraph cables, and in other communication circuits, linemen appreciate the speed, flexibility and accuracy of the Type U Test Set. A specialized Wheatstone bridge, it is used to identify faulty wires in a cable; to locate grounds, shorts and crosses by Murray, Varley, Hilborn and other loop tests; to locate opens by capacitance methods; and to measure conductor resistance.

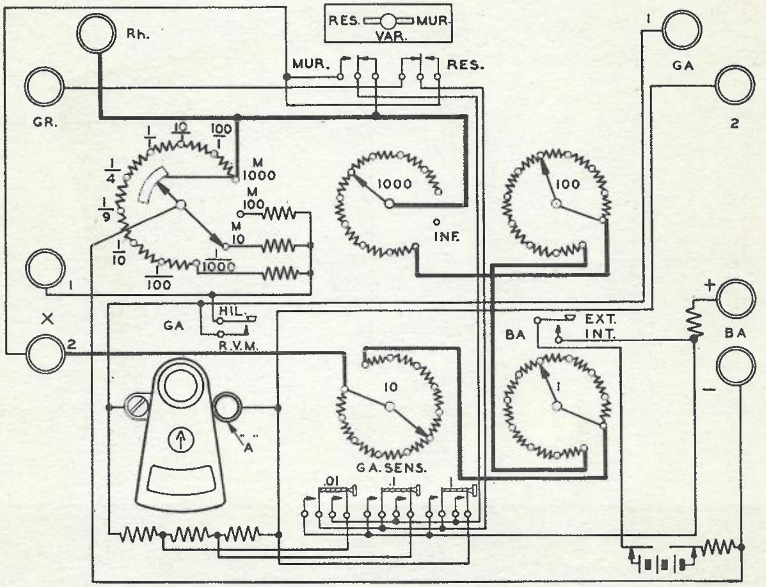
Embodying features recommended by telephone engineers, this test set is rapid in operation, light in weight, small in size, compact. It enables a



Switches, keys and binding posts are arranged for convenient field use

lineman to do his work with a degree of accuracy which would be sufficient for similar laboratory tests. Operating devices are designed for convenience in the field. All contacts are enclosed. The dial switch has positioning stops. Knobs are undercut. Switches, keys and binding posts are so placed that a man wearing gloves can manipulate them easily. Connections for the various loop tests and for resistance measurements are made with a single cam-type key.

A 4-dial rheostat, 10(1+10+100)+9×1000 ohms, with an infinity position is provided. When these dials are turned to make a measurement, the resistance change from zero settings of dials to the new settings is accurate to within a limit of error of ±(0.1 per cent+0.01 ohm). Resistors are wound on ceramic spools, with ten resistors per decade. A single-dial ratio unit provides multipliers of 1/1000, 1/100, 1/10, 1/9, 1/4, 1/1, 10/1 and 100/1. The 1/9 and 1/4 ratios are especially convenient for Varley Loop tests. Dial settings of M1000, M100 and M10 are provided for ratios in Murray Loop tests. Limit of error of ratio resistors is ±0.05%. An extra binding post, Rh, is provided so that the rheostat may be used independently as a resistance box.



In the Type U Test Set, connections for the various loop tests and for resistance measurements are made with a single cam-type key

The galvanometer in the Type U Test Set is a sturdy, replaceable unit with a coil-protecting clamp. Coil resistance is 250 ohms. Sensitivity is such that one microampere flowing through the coil will cause a deflection of at least one scale-division. Three keys provide sensitivities of 0.01, 0.1 and 1 for the galvanometer circuit. Each key closes first the battery and then the galvanometer circuit.

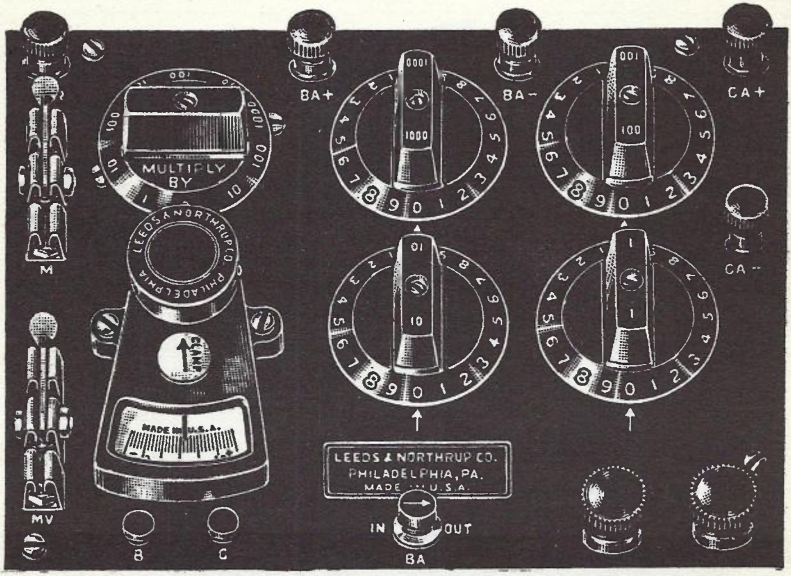
Binding posts are provided so that an external, high-voltage (90 to 200-volt) d-c source, or a more sensitive galvanometer, or both, may be employed to increase the sensitivity of measurement. The self-contained, 4.5-volt battery consists of three standard flashlight cells. Contained in a stout oak case, with metal protecting corners and removable lid, the set is 8⅞" long x 7⅜" wide x 5¾" high, weighs about 8 pounds.

For a more complete description of the 5430-A Type U Portable Test Set, ask for Catalog E-53-441(1).

Type S Test Set is useful for ordinary resistance testing and for locating faults in communication circuits

TYPE S TEST SET

This Type S Test Set is especially useful for ordinary resistance testing in laboratory, plant and field. Manufacturers use it extensively for testing small-gauge wire, electrical appliances, etc. It is also convenient for use by outside plant construction and maintenance forces for locating faults in communication circuits—for identifying faulty wires in a cable, for measuring

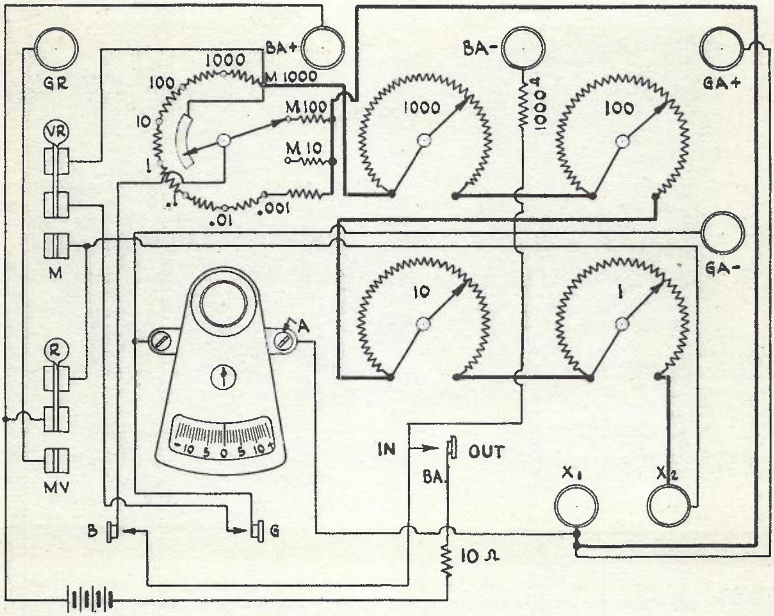


Type S provides ample room for manipulation of dials, switches and binding posts

conductor resistance, for locating grounds and crosses in a cable by Murray and Varley Loop methods.

Simple in arrangement, easy to operate, thoroughly reliable, this self-contained Wheatstone bridge is conveniently portable for shop and field use. It is small in size, light in weight. Extremely sturdy, it withstands all ordinary use without injury to bridge or galvanometer. Compact as it is, there is ample room for convenient manipulation of dials, switches and binding posts. With it, resistance can be measured to a very satisfactory degree of accuracy, and faults can be located within narrow limits. Changes in bridge circuits required for resistance measurements and for loop tests are made by means of two small knife-switches.

A 4-dial rheostat, 9(1+10+100+1000) ohms is provided. When these dials are turned to make a measurement, the resistance change from zero settings of dials to the new settings is accurate to within a limit of error of ±(0.1 per cent+0.01 ohm). Resistors are wound on insulated, metal spools. A ratio dial provides multipliers of 0.001, 0.01, 0.1, 1, 10, 100 and 1000 for resistance measurements and for Varley Loop tests. Settings of M1000, M100 and M10 are provided for ratios in Murray Loop tests. Limit of error of ratio resistors is ±0.05%.



Changes in bridge circuits required for resistance measurements and for loop tests are made by means of two small knife-switches

The galvanometer is a sturdy, replaceable unit with a coil-protecting clamp. Coil resistance is 250 ohms. Sensitivity is such that one microampere flowing through the coil will cause a deflection of at least one scale-division. A galvanometer key and a battery key are provided.

There are binding posts for connecting an external, high-voltage (90 to 200-volt) d-c source, or a more sensitive galvanometer, or both, which may be employed to increase the sensitivity of measurement. The self-contained, 4.5-volt battery consists of three standard flashlight cells. Contained in a stout oak case, with lock and handle, the set is 8⅞″ long x 7⅜″ wide x 5½″ high, weighs about 8 pounds.

For a more complete description of the 5300 Type S Portable Test Set, ask for Catalog E-53(3).

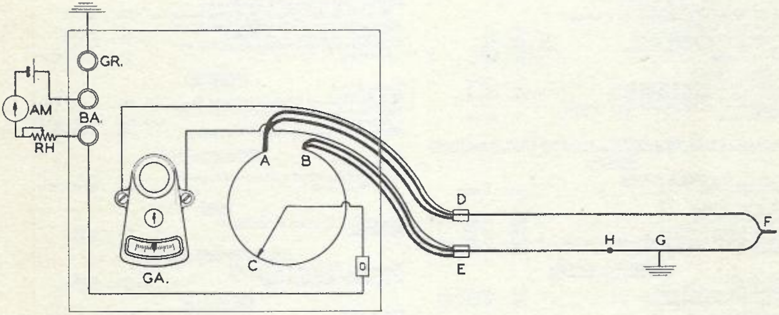
L&N Power Cable Fault Bridge is designed for locating faults in power cables by the Murray Loop method

L&N POWER CABLE FAULT BRIDGE

Portable, self-contained except for its potential source, the L&N Power Cable Fault Bridge is specifically adapted to the location of faults in heavy power cables by the Murray Loop method.

This specialized Wheatstone bridge employs an adjustable, slidewire ratio. The slidewire, mounted on a disk 8¼ inches in diameter. consists of a single turn of heavy wire. Resistance is low, about 0.1 ohm. It will carry a normal test-current of 5 amperes continuously; 8 amperes for a short time.

So that connections to cable, switch or bus bar can be made with negligible contact resistance, the instrument is equipped with strong, flexible leads, about 8 feet long, which terminate in stout clamps. Each clamp comprises two heavy blocks, drawn together with thumb screws. From each end of the slidewire, there are two separate leads, one to each block of one of the clamps.



This self-contained test set comprises adjustable slidewire ratio, galvanometer, and strong, flexible leads, about 8 feet long

In addition, galvanometer leads are brought out to the clamps. Leads from the ends of the slidewire, therefore, constitute extensions of the slidewire, and their resistance is included in the calibrated ratio arms of the bridge. By thus extending the ratio arms to the terminals, errors due to lead resistance are avoided.

The scale has 490 graduations, uniformly spaced and numbered from 10 to 990. It is readable to one-thousandth of the total resistance of slidewire and leads. The bridge has binding posts for battery and ground connections.

The galvanometer is a sturdy, replaceable unit with a coil-protecting clamp. It has a short period, about 3 seconds. Coil resistance is 20 ohms. Sensitivity is such that four microamperes flowing through the coil will cause a deflection of at least one scale-division. The source of potential for the bridge is an external storage battery. Ordinarily, after a fault has been carbonized with high potential, a 6-volt battery is used. To regulate current, there should be, in series with the battery, a 15 to 20-ohm rheostat (RH in the diagram) with current-carrying capacity of 5 to 8 amperes; and an ammeter (AM in the diagram) to show that current is within the allowable limit.

Contained in a stout oak case, with removable cover and leather handle, the set is 25″ long x 9¾″ wide x 6″ high, weighs about 27 pounds.

For a more complete description of the 5365 Power Cable Fault Bridge, ask for Catalog E-53-441(4).

LITERATURE DESCRIBING STANDARD L&N EQUIPMENT

CATALOGED BY TYPE OF EQUIPMENT

Operating Supplies for L&N Equipments	Cat.	ENT-W

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Galvanometers and Dynamometers	Cat.	ED
Notes on Moving Coil Galvanometers	Note Book	ED(1)
Keys and Switches	Cat.	EU 2

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Power Plant

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Power Plant

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Power Cable Fault Bridge	Cat	E-53—441(4)

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Homo Method for Nitriding	Cat	T-624
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