CABLE TESTING—GENERAL
FAULT LOCATION IN COAXIAL CABLE

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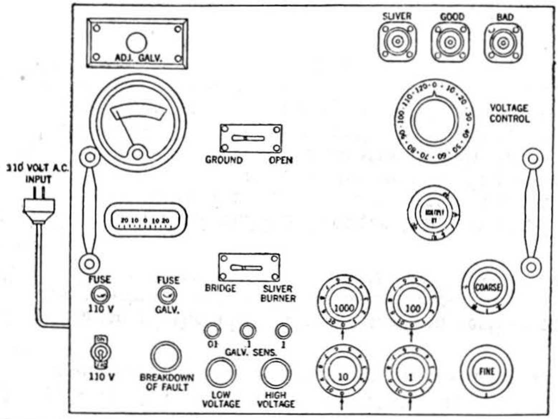
1. GENERAL

1.01 This section outlines the use of the 90A Test Set and superseded D-171237 Test Set in locating faults in coaxials.

1.02 Because of the high voltages used in testing coaxials, the workmen making such tests should be thoroughly familiar with the safety precautions outlined in Section G50.244.3.

1.03 The method of making Megger tests on coaxials and the procedure for burning out slivers with the 94A Test Set are covered in a separate section. The breakdown voltage of faulty coaxials can be measured with the 90A Test Set and this should be done in each case before making a Wheatstone bridge measurement to locate the fault. The arrangement of the apparatus and keys on the panel of the set is illustrated on the following page.



1.04 **Faults in coaxials** are located by the 3-Varley method described in Section G72.245. The Varley 2 measurement is made using the high voltage as bridge potential. Varley 1 and Varley 3 are made using the low voltage supply in the set.

1.05 The 3-Varley method of locating faults in coaxials is recommended for the following reasons:

(1) It corrects for differences in the resistance of the "good" and "bad" wires. Also, in the case of total failure of the coaxial cable, good wires from a separate cable can be employed, if available.

(2) Inequalities in the resistances of the leads are automatically taken into account.

(3) A simple means is provided for computing the actual resistance of the "bad" wire to compensate for temperature variations.

(4) Computing the feet-per-ohm value of the "bad" conductor for each measurement helps to check the accuracy of the bridge measurements and calculations, as well as the accuracy of the distances shown on the records. For instance the center conductors of the .270-inch and .375-inch coaxials normally run 500 feet and 950 feet per ohm, respectively. If the calculated feet-per-ohm value differs by more than 20 to 25 feet for .270-inch coaxials, or 40 to 50 feet for the .375-inch coaxials, it indicates the probability of errors in reading the bridge, in calculations, or in the cable lengths shown on the drawings.

(5) The sum of resistance values X and Y should equal F. By computing F, X and Y and the distances corresponding to X and Y for each set of readings, the accuracy of the computations can be verified.

1.06 The set can be used as a sliver burner when necessary in connection with fault locating operations. The standard sliver burner should normally be used in testing individual lengths of cable and in testing the cable after completion of splices.

1.07 **Resistance of Coaxial:** The following resistance values are given for convenience in converting the center coaxial conductor resistance to distance.

	Resistance per foot 70° F Ohm	Approximate Resistance per foot 70° F Ohm	Approximate Resistance per 1000 feet 70° F Ohm
Center Conductor of .27-inch Coaxial	.001999	.002	1.999
Center Conductor of .375-inch Coaxial	.001052	.001	1.05

2. COMMUNICATION CIRCUIT

2.01 In order to make high voltage tests on coaxials with safety, specially insulated apparatus is provided for communicating between the two ends of the cable under test.

2.02 The signaling circuit should be established as outlined in the section covering the apparatus provided.

3. DETERMINING VOLTAGE BREAKDOWN OF FAULT

3.01 This set lends itself readily to measuring the voltage breakdown of the fault and can be used for this purpose when necessary. The procedure is as follows:

(1) Establish an approved communication circuit between the ends of the section of cable under test in the usual way.

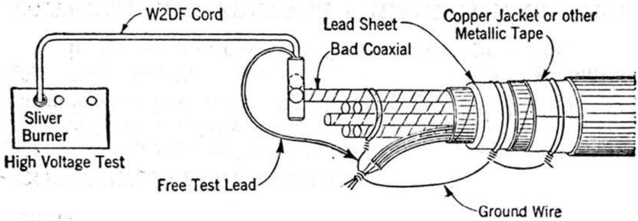
(2) Splicers at the far end and intermediate manholes should leave the splicing pits or manholes prior to the start of the tests, to avoid accidental contact with the wires under test.

(3) **At the distant end** clear the coaxials to be tested and protect the exposed core of the cable to avoid accumulation of moisture.

(4) **At the near end,** prepare the coaxials as necessary and connect the outer coaxial conductor to the sheath (and copper jacket or other metallic tapes when used). When tests are being made in a corrosion protected cable, the sheath of the cable under test should be connected to any plain lead sheath cable in the same manhole.

(5) Bunch and ground the paper insulated conductors as illustrated below.

(6) Connect the center conductor of the coaxial under test to the SLIVER BURNER jack with the black test cord and connect the free test lead to the outer coaxials, as illustrated below:



(7) Make sure that the VOLTAGE CONTROL knob is set at zero and the "110-V" switch is "Off". Connect the bridge to a source of 110-volt a-c power and allow the set to warm up about one minute. Then turn on the "110-V" switch.

(8) To determine the breakdown voltage, operate the upper lever key to OPEN and simultaneously operate the other lever key to SLIVER BURNER with the same hand. Then slowly turn the VOLTAGE CONTROL knob and observe the voltmeter carefully. The breakdown potential applied to .270-inch coaxials should be limited to approximately 2000 volts; for .375-inch coaxials, to 3000 volts. As soon as the fault breaks down, the voltmeter needle will kick toward zero and may kick intermittently thereafter. The voltage reading just prior to the first downward kick is the breakdown voltage.

(9) If it is necessary to repeat the test, return the VOLTAGE CONTROL knob to zero and repeat the operations described in (8).

(10) On completion of the test, the condensers in the set should be discharged by throwing the lever key to SLIVER BURNER and holding it one or two seconds. The voltmeter will then return to zero.

4. LOCATION OF ARCING FAULTS BY 3-VARLEY METHOD

Establishing Connections

4.01 In working cable, follow the approved procedure to obtain access to the coaxials.

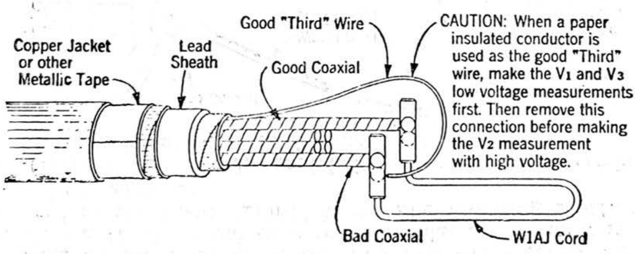
4.02 The portion of cable under test should be opened at each end. In making 3-Varley bridge measurements the defective coaxial and one that has high dielectric strength and high insulation resistance, as well as a third good conductor, which can be either a coaxial or a paper insulated wire, should be identified for use in making the test.

4.03 Establish a communication circuit between the ends of the cable under test in the usual way.

4.04 **Far End at an Open End of Cable**

(1) Prepare the far end of the "bad" and "good" coaxials so the center conductor of each projects about 1/2 inch beyond the outer conductor. The outer conductor should be cut off square and smoothed to fit the opening in the connector, and should be free of slivers.

(2) Then connect the center conductor of the "bad" coaxial to the center conductor of the "good" coaxial using the strapping cord, as illustrated below. The thumb screw should be tightened firmly to ensure a low resistance connection. In making these connections on coaxials prepared for splicing, the thumb screw should not be turned down so hard as to damage the center conductor.



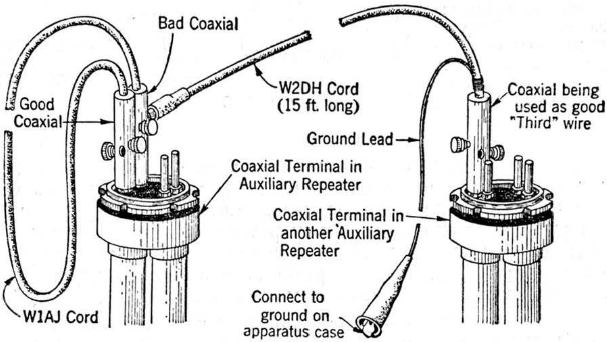
(3) Connect the good "third" wire to the connector associated with the "bad" coaxial, as illustrated above.

(4) If the center conductor of another "good" coaxial is used as the good "third" wire, the connection referred

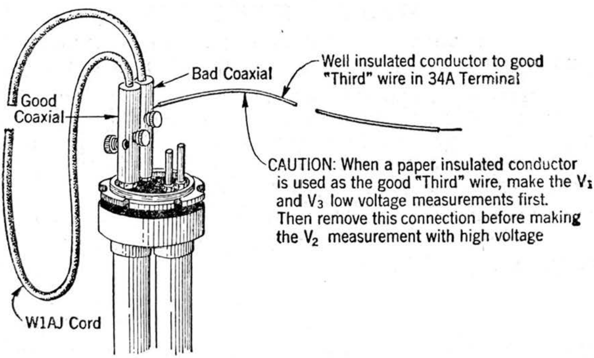
to in (3) can be made using a W2DH cord or short length of bare copper wire which should be kept clear of all other conductors.

4.05 **Far End at Coaxial Terminal:** The method of making connections at an auxiliary or main repeater station depends on the location of the Bad and Good coaxials and whether a Good coaxial or a paper insulated conductor is to be used as the Good "Third" Wire. The following illustrates typical connections:

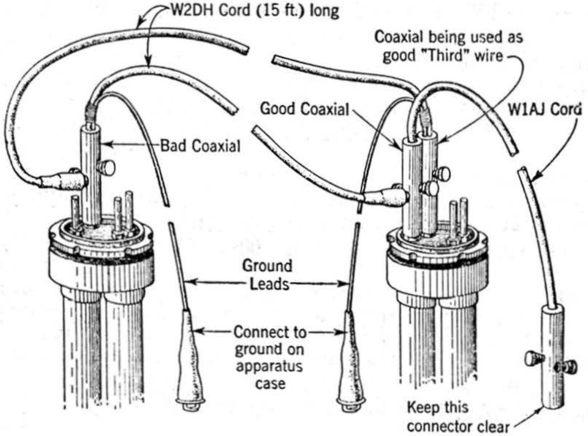
(1) Bad and Good coaxial in same 35 type terminal. Coaxial used as good "third" wire.



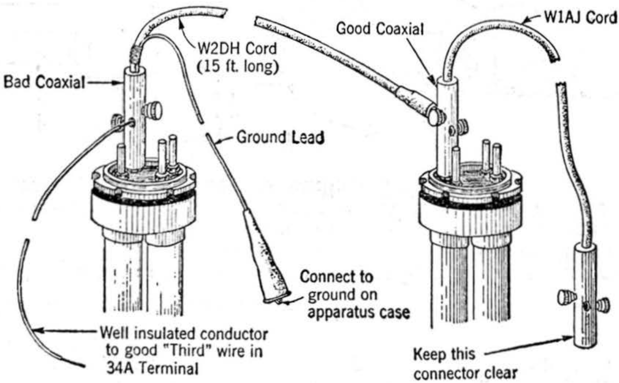
(2) Bad and Good coaxial in same 35 type terminal. Paper insulated wire used as good "third" wire.



(3) Bad and Good coaxial in separate terminals. Coaxial used as good "third" wire.



(4) Bad and Good coaxial in separate terminals. Paper insulated wire used as good "third" wire.

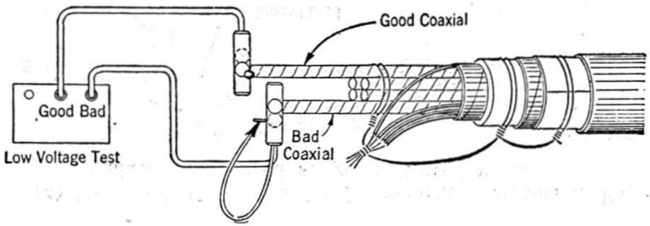


4.06 **Testing End:** Arrange the connections for making a 3-Varley measurement as described in the following paragraphs.

4.07 At the testing end, connect the center conductors of the "good" and "bad" coaxials to the bridge. (For convenience in identifying the leads the cord with the free test lead and the black connector should be used for the "Bad" coaxial.) Bunch and ground the paper insulated conductors as illustrated below.

Making Bridge Measurements

4.08 **Varley 3:** Connect the free test lead to the center conductor of the "bad" coaxial at the testing end. The clip can be connected to a short piece of bare wire clamped in the unused hole of the connector on the "bad" coaxial as illustrated; then proceed as outlined below:



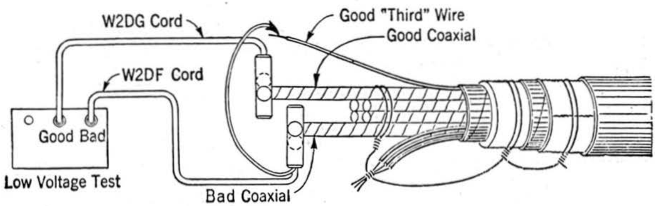
(1) Check to see that the switch marked "110-V" is "Off" and the VOLTAGE CONTROL dial is set at "0".

(2) Connect the set to 110-volt power, but do not turn on the "110-V" switch. This will light the galvanometer lamp. Then by means of the ADJ. GALV. knob, adjust the hair line in the galvanometer spot light to zero on the scale.

(3) In measuring 1500 feet or so of cable set the MULTIPLY-BY dial to 1/99 ratio. In longer lengths of cable, use the 1/9 ratio setting. The same ratio should be used for the V_1, V_2, and V_3 measurements. Set all other dials to "0".

(4) Depress the black LOW VOLTAGE key and operate the .01 GALV. SENS. key. Then proceed to balance the bridge with the 1000, 100, 10, and 1 dials and the .01, .1 and 1 GALV. SENS. keys in the usual way. The V_3 resistance value so obtained should be recorded.

4.09 **Varley 1:** Next connect the free test lead to the good "third" wire (coaxial conductor or paper insulated conductor) referred to in Paragraph 4.02, as illustrated and proceed as outlined below:

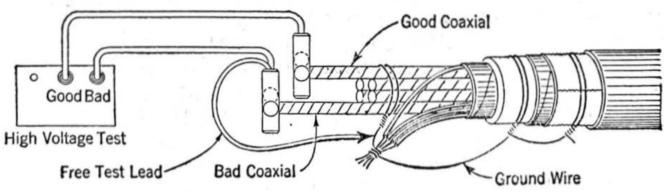


(1) Balance the bridge as outlined in (4) above and record the V_1 resistance value.

(2) If a paper insulated conductor was used for the good "third" wire in the test, instruct the man at the distant end to disconnect the paper insulated wire from the strapping cord, leaving the coaxials connected. This is necessary in order to avoid charging the paper insulated conductor to the high potential used in making the V_2 measurement, and thus prevent the possibility of damaging the insulating paper. If another coaxial is used as the "third" wire, it is not necessary to disconnect it as it has adequate dielectric strength.

4.10 **Varley 2:** This measurement is made using high voltage on the bridge (as high as 2000 volts for .270-inch coaxials; 3000 volts for .375-inch coaxials); consequently extreme caution must be exercised at both the far end and at the testing end to prevent accidental shock.

(1) Remove the free test lead from the "bad" coaxial at the testing end and connect the lead to "ground" (outer coaxial, sheath, and copper jacket or other metal tape when used) as illustrated below. Remove the short wire from the "bad" connector if one was used in making the V_3 measurement.



(2) Turn "On" the switch marked "110-V" and allow the set to warm up for about one minute.

(3) Return the "1000", "100", "10", and "1" knobs to "0".

(4) Set the MULTIPLY-BY dial at 1/9 or 1/99 and rotate the COARSE dial of the kick balancer to correspond to the setting of the MULTIPLY-BY dial.

(5) Depress the red HIGH VOLTAGE button. Rotate the VOLTAGE CONTROL dial slowly and observe the voltage reading on the voltmeter. When the fault breaks down the voltmeter needle will swing toward "0" and the neon lamp will glow. Adjust the voltage so that the neon lamp flashes two or three times a second when testing long cables. The flashes may be somewhat faster in testing over short lengths of cable.

(6) Operate the .01 GALV. SENS. key. The galvanometer spot will assume an average position to the right of zero. In addition the spot will kick sharply with each high voltage discharge across the fault. The average deflection to the right is caused by the unbalanced condition of the bridge, and the sharp "kick" by a current surge through the galvanometer.

(7) The "1000" and "100" dials should be adjusted so that the light spot moves near the center of the scale. The sharp kick can be minimized by adjusting the COARSE dial to the point where the kick is least noticeable. As resistance is added with the "1000" and "100" dials, the kick will increase and should be balanced further with the FINE dial.

(8) When the light spot remains a little to the right of center on the scale and the kick is reduced to a minimum, change to the .1 GALV. SENS. key and repeat the balancing operations with the 100, 10 and 1 dials. Then change to the 1 GALV. SENS. and refine the balance. When the full sensitivity of the galvanometer is being used, balance the kick with the FINE dial only; otherwise, the galvanometer may be damaged.

(9) The V_2 reading so made should be recorded.

4.11 If the galvanometer fails to deflect in the usual manner as the dials are rotated, two conditions should be looked for.

(1) The fault may have come clear at the particular setting of the VOLTAGE CONTROL dial. If this occurs the voltmeter reading will remain steady and the neon lamp will cease to glow.

(2) In this event it may be necessary to increase the applied bridge potential by means of the VOLTAGE CONTROL knob.

(3) If the fault breakdown is occurring properly and no galvanometer response is noted, the trouble may be due to a blown galvanometer fuse. This can occur if the kick adjustment is not set accurately before operating the 0.1 or 1 ratio galvanometer keys. It might also occur if too large a change is made in the resistance decades when the .1 or 1 galvanometer shunt key is operated. It can also occur in attempting to make measurements on short lines with a $\frac{1}{1}$ MULTIPLY-BY dial setting.

(4) The galvanometer fuse can be replaced as outlined in Section G86.062.1.

4.12 If the V_3, V_1, and V_2 can not all be made with the "1/99" setting of the ratio arms, change the ratio to "1/9" and repeat all three measurements.

4.13 As soon as the measurements have been made, return the VOLTAGE CONTROL to zero and turn "Off" the switch marked "110-V".

4.14 The condensers in the set should then be discharged by throwing the lever key to SLIVER BURNER and holding it one or two seconds. The voltmeter will then return to zero. The coaxial cable is automatically discharged when the red HIGH VOLTAGE button is released.

4.15 The test leads can then be removed. If the far end of the cable is attended the all clear signal can now be given.

4.16 In making a location of an arcing fault for the purpose of digging to clear the trouble, it is advisable to make the 3-Varley measurements from both ends of the test section. The values obtained in the two measurements should be averaged in computing the location.

5. LOCATION OF HIGH RESISTANCE FAULTS BY 3-VARLEY METHOD

Establishing Connections

5.01 The connections at the near and far ends of the cable under test should be made as outlined in Paragraphs 4.01 to 4.07 inclusive.

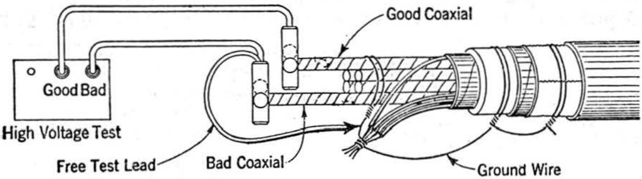
Making Bridge Measurements

5.02 **The Varley 3 and Varley 1** measurements are made as outlined in Paragraphs 4.08 and 4.09.

5.03 **Varley 2:** If the fault remains at high resistance, the measurement is made using 200 to 300 volts on the bridge. If the fault breaks down to an arcing fault while testing, the measurements will be made at a higher potential. Therefore, care must be exercised at both the near and far end to prevent accidental shock.

5.04 To make the Varley 2 measurement proceed as follows:

(1) Remove the free test lead from the "Bad" wire at the testing end and connect the lead to "Ground" as illustrated below. (Remove any unused wires from the connectors.)



(2) Turn "On" the switch marked "110-V" and allow the set to warm up for about one minute.

(3) Return the "1000," "100," "10" and "1" knobs to "0".

(4) Adjust the VOLTAGE CONTROL dial to give 200 or 300 volts.

(5) Depress the red HIGH VOLTAGE button and proceed to balance the bridge in the usual manner. The V_2 reading so made should be recorded. The kick balancer need not be used when locating a non-arcing fault.

(6) If the fault breaks down to an arcing fault while making the measurement, repeat the Varley 2 measurement following the procedure outlined in Paragraphs 4.10 to 4.16, inclusive.

(7) The test leads should then be removed.

6. COMPUTING LOCATION OF FAULT

6.01 The resistance of the faulty inner coaxial conductor (F), resistance from the distant end to the fault (Y), and from the near end to the fault (X) are as follows:

With 1/99 Ratio

$$F = \frac{1}{100} (V_3 - V_1)$$

$$Y = \frac{1}{100} (V_2 - V_1)$$

$$X = \frac{1}{100} (V_3 - V_2)$$

With 1/9 Ratio

$$F = \frac{1}{10} (V_3 - V_1)$$

$$Y = \frac{1}{10} (V_2 - V_1)$$

$$X = \frac{1}{10} (V_3 - V_2)$$

6.02 The "feet-per-ohm" value for the faulty wire should be determined by dividing the length of the cable in feet by the resistance F. The value so found should be multiplied by the computed resistance values Y and X, to convert these values to feet.

6.03 **Example:**

V_3 1953.3 ohms LOW VOLTAGE Bridge Battery
V_1 867.7 ohms LOW VOLTAGE Bridge Battery
V_2 1850 ohms HIGH VOLTAGE Bridge Battery
measurements made with 1/9 Ratio
Length of Cable under test = 55,030

$$F = \frac{1953.3 - 867.7}{10} = 108.56 \text{ ohms} \quad \text{Resistance of Faulty Wire}$$

$$\frac{55{,}030 \text{ ft.}}{108.56 \text{ ohms}} = 506.91 \text{ ft. per ohm in Faulty Wire}$$

$$Y = \frac{1850 - 867.7}{10} = 98.23 \text{ ohms} \quad \text{From Far End to Fault}$$

$$X = \frac{1953.3 - 1850}{10} = 10.33 \text{ ohms} \quad \text{From Near End to Fault}$$

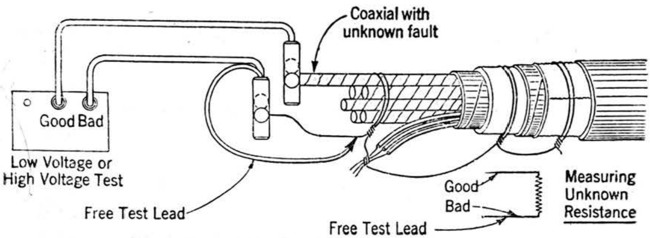
$10.33 \times 506.91 = 5{,}236$ ft. From Near End to Fault
$98.23 \times 506.91 = 49{,}794$ ft. From Far End to Fault

7. MAKING ORDINARY RESISTANCE MEASUREMENT

7.01 Ordinary resistance measurements may be made with the test set, using the LOW VOLTAGE battery. This voltage provides ample bridge sensitivity in most circumstances. However, in measuring resistance between ten thousand and one hundred thousand ohms, as in determining the resistance of a fault, a higher testing potential may be required. In this event, the HIGH VOLTAGE supply in the bridge can be used by restricting voltage, as indicated by the meter, to 100-200 volts.

7.02 The procedure for making ordinary resistance measurements with the set is outlined below.

(1) Connect the unknown resistance between the GOOD and BAD jacks using the cords provided, as illustrated below:



(2) Connect the bridge to a source of 110 volts a-c to light the galvanometer lamp, but leave the switch marked "110-V" in the "Off" position. Turn the VOLTAGE CONTROL knob to "0".

(3) Turn the resistance dials to "0" and set the MULTIPLY-BY dial to the desired ratio, based on the following table:

Unknown Resistance	"Multiply By" Setting	Bridge Voltage
Less than 100 ohms	1/100	LOW
100 to 1000 ohms	1/10	LOW
1000 to 10,000 ohms	1/1	LOW
10,000 to 100,000 ohms	10/1	HIGH (100-200 volts)

(4) Depress the LOW VOLTAGE button and balance the bridge in the usual manner. Then record the resistance value so obtained.

(5) If a satisfactory balance is not obtained because of the high resistance, turn "On" the "110-V" switch; then adjust the VOLTAGE CONTROL knob to a meter reading of 100 to 200 volts.

(6) Then depress the HIGH VOLTAGE button, balance the bridge in the usual manner, and record the resistance value so obtained.

(7) The value of the unknown resistance can be determined by means of the following formula:

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

Where X = unknown resistance in ohms.
R = reading of the resistance dials.
$\frac{A}{B}$ = setting of the MULTIPLY-BY dial.

7.03 **Example:**

If the MULTIPLY-BY dial is set at 10/1 and the bridge is balanced at 9045, the unknown resistance is:

$X = 10/1 \times 9045 = 90{,}450$ ohms.

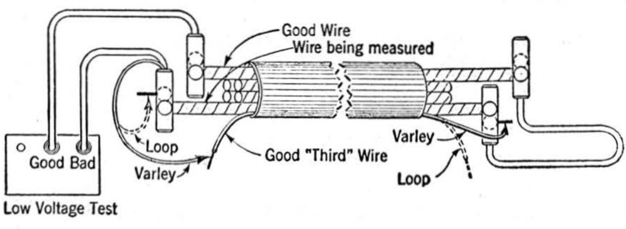
8. MEASURING RESISTANCE OF INDIVIDUAL CABLE CONDUCTORS

8.01 The resistance of a cable conductor between two points can be determined in several ways. However, only the method of making a Varley and Loop measurement utilizing two "good" wires is outlined herein, as it avoids the necessity of correcting for the resistance of the leads and is applicable whether the conductor under test is good or defective.

8.02 **The Varley** measurement is made as follows:

(1) At the far end, strap the conductor to be measured to a "good" conductor (its mate, if paper insulated) and to a good "third" wire as indicated below.

(2) At the testing end, connect the corresponding conductors to the GOOD and BAD jacks of the test set as illustrated and strap the free test lead to the good "third" wire.



(3) Set the resistance dials at "0" and the MULTIPLY-BY dial at 1/99. (This setting will usually be satisfactory.)

(4) Depress the LOW VOLTAGE button and balance the bridge in the usual way. Record the resistance value so obtained and designate it R_1.

8.03 **The Loop** measurement is made as follows:

(1) At the far end, remove the connection to the "third" wire, but retain the strap between the other two conductors.

(2) At the testing end, remove the free test lead from the "third" wire and connect this lead to the wire under test at the connector, as illustrated on the preceding page by dotted lines.

(3) Balance the bridge as before and record the resistance value obtained and designate it R_2.

8.04 The resistance of the conductor being measured (G) is determined in accordance with the following formula:

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

Where G = Resistance of wire being measured.

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

$$\frac{A}{A + B} = \frac{1}{1 + 99} = \frac{1}{100}$$

R_1 = Varley resistance measurement.

R_2 = Loop resistance measurement.

8.05 **Example**

If the MULTIPLY-BY dial is set at 1/99 and R_1 and R_2 were found to be 146 and 317 ohms, respectively,

$$G = \frac{1}{1 + 99} (317 - 146) = \frac{1}{100} (171) = 1.71 \text{ ohms.}$$

9. USE OF SET AS SLIVER BURNER

9.01 When it is necessary in connection with fault locating operations to burn out a sliver, it can be done with the 90A or D-171237 Test Set.

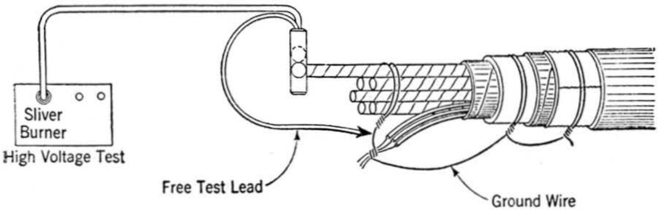
9.02 The operations in burning out slivers are as follows:

(1) Establish a communication circuit between the ends of the section of cable under test in the usual way.

(2) At the distant end clear the coaxials to be tested and protect the exposed core of the cable to avoid accumulation of moisture.

(3) At the near end, prepare the coaxials as necessary and connect the outer coaxials to the sheath (and copper jacket or other metal tape when used).

(4) Connect the free test lead to the outer coaxials and connect the center conductor of the coaxial under test to the SLIVER BURNER jack with the black test cord, as illustrated below:



(5) Make sure that the VOLTAGE CONTROL knob is set at zero and the "110-V" switch is "Off". Then connect the set to a source of a-c power, allow the set to warm up about one minute and then turn "On" the "110-V" switch.

(6) To burn out a sliver, rotate the VOLTAGE CONTROL knob until the meter registers 1500 to 2000 volts for .27-inch coaxials, or 2500 to 3000 volts for .375-inch coaxials.

(7) Operate and hold the upper cam key to OPEN and then operate the lower cam key to SLIVER BURNER. As the second key is operated, the voltmeter reading will drop toward zero and, if the sliver burns out, the reading will restore itself. If the sliver does not burn out, the voltmeter reading will remain at zero or will drop and restore itself intermittently.

(8) If the voltage remains at zero, release the cam keys, since the fault is presumably one which cannot be burned out and must be located with the low voltage bridge.

(9) If the voltage drops intermittently leave the voltage on for not over 30 seconds. If the fault has not then burned out it must be located with the high voltage bridge.

(10) At the end of the test, release both lever keys and rotate the VOLTAGE CONTROL knob to zero. Then throw the lever key to SLIVER BURNER to discharge the condenser in the set.

(11) The leads can then be removed.