Specimens for test on jacket compounds shall be taken from the completed cable and cut parallel to the axis of the cable. The test specimen shall be a segment cut with a sharp knife or a shaped specimen cut out with a die and shall have a cross-sectional area not greater than 0.025 square inch (16 mm^2) after irregularities, corrugations, and wires have been removed.

9.4.5 Preparation of Specimens of Insulation and Jacket

The test specimen shall have no surface incisions and shall be as free as possible from other imperfections. Where necessary, surface irregularities such as corrugations due to stranding shall be removed so that the test specimen will be smooth and of uniform thickness. If a jacket specimen passes the minimum requirement with irregularities, then their removal is not required.

9.4.6 Specimen for Aging Test

Specimens shall not be heated, immersed in water, nor subjected to any mechanical or chemical treatment not specifically described in this standard.

9.4.7 Calculation of Area of Test Specimens

Where the total cross-section of the insulation is used, the area shall be taken as the difference between the area of a circle whose diameter is the average outside diameter of the insulation and the area of a circle whose diameter is the average outside diameter of the conductor shield.

Where a slice cut from the insulation by a knife held tangent to the wire is used and when the cross-section of the slice is a segment of a circle, the area shall be calculated as that of the segment of a circle whose diameter is that of the insulation. The height of the segment is the wall of insulation on the side from which the slice is taken.

When the cross-section of the slice is not a segment of a circle, the area shall be calculated from a direct measurement of the volume or from the specific gravity and the weight of a known length of the specimen having a uniform cross-section.

The values may be obtained from a table giving the areas of segments of a unit circle for the ratio of the height of the segment to the diameter of the circle.

When the conductor is large and the insulation thin and when a portion of a sector of a circle has to be taken, the area shall be calculated as the thickness times the width.

This applies either to a straight test piece or to one stamped out with a die and assumes that corrugations have been removed.

When the conductor is large and the insulation thick and when a portion of a sector of a circle has to be taken, the area shall be calculated as the proportional part of the area of the total cross-section.

The dimensions of specimens to be aged shall be determined before the aging test.

9.4.8 Unaged Test Procedures

9.4.8.1 Specimens and Test Temperature

Physical tests shall be made at room temperature. The test specimens shall be kept at room temperature for not less than 30 minutes prior to the test. All three specimens shall be tested and the average of the results reported.

9.4.8.2 Type of Testing Machine

The testing machine shall be in accordance with ASTM D 412.

9.4.8.3 Tensile Strength Test

The tensile strength test shall be made with specimens prepared in accordance with 9.4.3 and 9.4.4. The length of all of the specimens for the test shall be equal. Gauge marks shall be 2 inches (51 mm) apart when using ASTM B or E Die size and 1 inch (25 mm) apart when using ASTM C or D Die size except that 1-inch (25-mm) gauge marks shall be used for polyethylene regardless of the die size. Specimens shall be placed in the jaws of the testing machine with a maximum distance between jaws of 4 inches (101.6 mm) except 2.5 inches (63.5 mm) for polyethylene. The specimen shall be stretched at the rate of 20 inches (508 mm) per minute jaw speed until it breaks.

The tensile and elongation determinations for compounds for which the compound manufacturer certifies that the base resin content is more than 50 percent by weight of high density polyethylene (having a density of 0.926 g/cm^3 or greater), or total base polyethylene resin content (having a density of 0.926 g/cm^3 or greater), shall be permitted to be tested at a jaw separation rate of 2 inches (51 mm) per minute as an alternate to 20 inches (508 mm) per minute.

Specimens shall break between the gauge marks to be a valid test. The tensile strength shall be calculated based on the area of the unstretched specimen. Specimen length, gauge mark distance, and jaw speed shall be recorded with the results.

9.4.8.4 Elongation Test

Elongation at rupture shall be determined simultaneously with the test for tensile strength and on the same specimen.

The elongation shall be taken as the distance between gauge marks at rupture less the original gauge length of the test specimen. The percentage of elongation at rupture is the elongation in inches divided by the original gauge length and multiplied by 100. Specimen length, gauge mark distance, and jaw speed shall be reported with results.

9.4.9 Aging Tests

9.4.9.1 Aging Test Specimens

Test specimens of similar size and shape shall be prepared from each sample selected, three for the determination of the initial or unaged properties, and three for each aging test required for the insulation or jacket being tested. Simultaneous aging of different compounds should be avoided. All three specimens shall be tested and the average of the results reported.

In the case of wire and cable 6 AWG and larger or with an insulation thickness of 90 mils (2.29 mm) or greater, samples shall be cut from the insulation with a cross-section not greater than 0.025 square inch (16 mm^2).

Die-cut specimens shall be smoothed before being subjected to the accelerated aging tests wherever the thickness of the specimen will be 90 mils (2.29 mm) or greater before smoothing.

The test specimens shall be suspended vertically in such a manner that they are not in contact with each other or with the side of the oven.

The aged specimens shall have a rest period of not less than 16 hours nor more than 96 hours between the completion of the aging tests and the determination of physical properties. Physical tests on both the aged and unaged specimens shall be made at approximately the same time.

9.4.9.2 Air Oven Test

The test specimens shall be heated at the required temperature for the specified period in an oven having forced circulation of fresh air. The oven temperature shall be controlled to ±1°C.

9.4.9.3 Oil Immersion Test for Polyvinyl Chloride Jacket

The test specimens shall be immersed in ASTM No. 2 or IRM 902 oil, described in ASTM D 471, at 70 ± 1°C for 4 hours. At the end of this time, the specimens shall be removed from the oil, blotted to remove excess oil, and allowed to rest at room temperature for a period of 16 to 96 hours. The tensile strength and elongation of the specimens shall then be determined in accordance with 9.4.8 at the same time that the original properties are determined.

9.4.10 Hot Creep Test

The hot creep test shall be determined in accordance with ICEA Publication T-28-562. The sample shall be taken from the inner 25 percent of the insulation.

9.4.11 Solvent Extraction

The solvent extraction shall be determined in accordance with ASTM D 2765.

9.4.12 Wafer Boil Test for Conductor and Insulation Shields

Any outer covering and the conductor shall be removed. A representative cross section containing the extruded conductor shield and insulation shield, shall be cut from the cable. The resulting wafer shall be at least 25 mils (0.64 mm) thick. The wafer may be further separated into concentric rings by careful separation of the shield from the insulation. This may include the use of a punch to separate the conductor shield or insulation shield from most of the insulation.

The resulting wafer(s) or rings shall then be immersed in boiling decahydronaphthalene with 1 percent by weight Antioxidant 2246 (or other reagents specified in ASTM D 2765, such as xylene) for 5 hours using the equipment specified in ASTM D 2765. (This solution may be reused for subsequent tests provided that it works as effectively as a fresh solution). The wafer(s) shall then be removed from the solvent and examined for shield/insulation interface continuity with a minimum 15-power magnification.

Total or partial separation of the semiconducting shields from the insulation is permissible. Partial loss of the shields is also permissible provided each shield is a continuous ring. If the semiconducting shield dissolves or cracks such that it does not maintain a continuous ring, the cable lot shall be rejected.

9.4.13 Amber, Agglomerate, Gel, Contaminant, Protrusion, Indent, Convolution and Void Test

9.4.13.1 Sample Preparation

Samples shall be prepared by cutting a suitable length of cable helically or in some other convenient manner to produce 20 consecutive thin wafers consisting of the conductor shield, insulation and insulation shield. Wafers shall be approximately 25 mils (0.64 mm) thick. The cutting blade shall be sharp and shall produce wafers with uniform thickness and with very smooth surfaces. The sample shall be kept clean and shall be handled carefully to prevent surface damage and contamination.

9.4.13.2 Examination

The wafers shall be examined with 15-power magnification for voids, contaminants, gels, agglomerates, and ambers, as applicable, in the insulation. They shall also be examined for voids and protrusions between the insulation and the conductor and insulation shields and conductor shield convolutions. Unfilled insulations shall be examined using transmitted light. An optical coupling agent such as mineral oil, glycerin or silicone oil shall be used to enhance the observation of imperfections within the wafers. For mineral-filled cross-linked polyethylene insulation, EPR, and extruded shields, a reflected light method shall be used. For void count, as applicable, the volume of the insulation examined shall be calculated using any convenient technique. The results of this examination shall be recorded as pass or fail in the production test report.

9.4.13.3 Resampling for Amber, Agglomerate, Gel, Contaminant, Protrusion, Convolution and Void Test

If after examination according to 9.4.13.2, the size and/or number (as applicable) of voids, contaminants, agglomerates, gels, ambers, convolutions or protrusions exceeds the specified limits, the lot shall be divided into shipping lengths. One sample shall be taken from the beginning and end of each shipping length. For the shipping length to pass, both samples shall meet the requirements of this section. If either of the two samples from the shipping length fails, the shipping length shall be rejected.

9.4.13.4 Protrusion, Indentation and Convolution Measurement Procedure

To measure the size of protrusions, indentations and conductor shield convolutions in wafers examined in 9.4.13.2, the wafers shall be viewed in an optical comparator or similar device which displays the wafer so that a straight edge can be used to facilitate the measurement. Protrusion and indentations shall be measured as shown in Figure 9-1. Conductor shield convolutions shall be measured as shown in Figure 9-2. This procedure shall be used on cable wafers with the conductor, jacket and metallic shield removed.

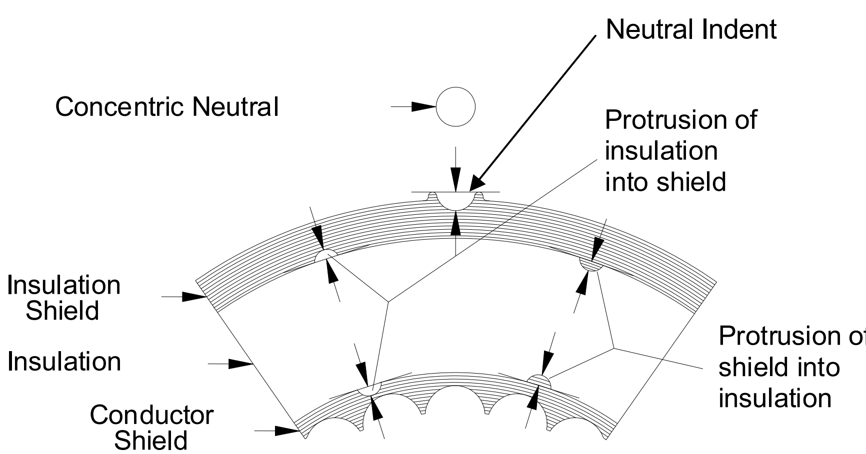

Figure 9-1
Procedure to Measure Protrusions and Indentations

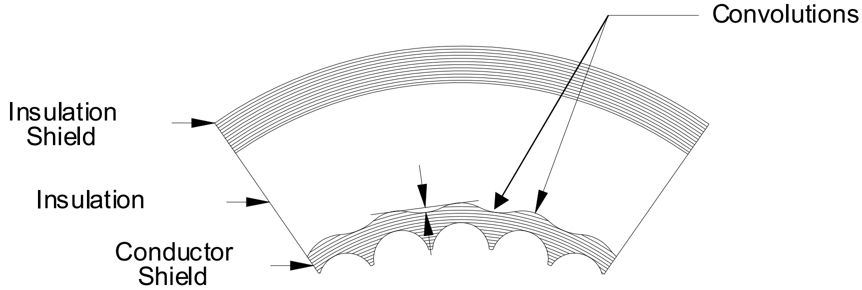

Figure 9-2
Procedure to Measure Convolutions

9.4.14 Internal Irregularity Test Procedure for Crosslinked Polyethylene Insulation (XLPE or TRXLPE) Only

9.4.14.1 Sample Preparation

This test shall be conducted on a 24-inch (610-mm) long sample cut into convenient lengths for the test apparatus. The insulation shield shall be removed. The insulation shall be made transparent by heating the samples to approximately 120°C. The preferred method is to place the samples into an oil bath at a maximum temperature of 120°C until the insulation becomes transparent. If an oil bath is not used, the samples shall be wetted with an optical coupling fluid such as silicone oil to enhance the viewing procedure.

The samples shall then be viewed for conductor shield smoothness and for contaminants. A flat glass surface or magnifying glass may be part of the viewing path. Curved glass surfaces such as the wall of a beaker shall not be used as part of the viewing path, because it can impede the detection of irregularities. A magnification of 1- to 10-power is appropriate. A high-intensity light shall be directed at the cable end to enhance the detection of irregularities. Further enhancement may be accomplished with a dark background or a darkened room.

Care shall be used in making the insulation transparent to prevent overheating which may deform the cable or create conditions, which did not already exist such as voids, protrusions, and cracks. This test method is not recommended for the detection of voids in the insulation.

9.4.14.2 Detection of Irregularities

Contaminants in the insulation and protrusions or deformations at the conductor shield shall be marked on the insulation surface. Wafers containing these irregularities shall be cut from the sample and viewed according to 9.4.13. To calculate the number of contaminants per in^3 (cm^3), the volume of insulation contained in the 24-inch (610-mm) sample shall be used. The irregularities shall not exceed the specified limits. The results of this examination shall be recorded in the production test report.

9.4.14.3 Resampling for Internal Irregularity Test

If the irregularity limits are exceeded and the irregularity is a discrete point, a second 24-inch (610-mm) long sample shall be taken from an adjacent length of cable in the same master length as the first sample. If this sample fails, the master length shall be divided into shipping lengths. One sample shall be taken from the beginning and end of each shipping length. For the shipping length to pass, both samples shall meet the requirements of this section. If one of the two samples from the shipping length fails, the shipping length shall be rejected.

If the irregularity is a continuous line through the sample, the master length shall be divided into shipping lengths. One sample shall be taken from the beginning and end of each shipping length. For the shipping length to pass, both samples shall meet the requirements of this section. If one of the two samples from the shipping length fails, the shipping length shall be rejected.

9.4.15 Physical Tests for Semiconducting Material Intended for Extrusion

9.4.15.1 Test Sample

One test sample shall be molded from each lot of semiconducting material intended for extrusion on the cable.

9.4.15.2 Test Specimens

For each test, three test specimens, each approximately 6 inches (152 mm) long and not greater than 0.025 square inch (16 mm^2) in cross-section, shall be cut out of the test sample with a die. All three test specimens shall be tested and the results averaged.

9.4.15.3 Elongation

This test shall be conducted in accordance with 9.4.8 and 9.4.9.

9.4.16 Retests for Physical and Aging Properties

If any test sample fails to meet the requirements of any test, either before or after aging, that test shall be repeated on two additional specimens taken from the same sample. Failure of either of the additional specimens shall indicate failure of the sample to conform to this standard.

9.4.17 Retests for Thickness

If the thickness of the insulation or of the jacket of any reel is found to be less than the specified value, that reel shall be considered as not conforming to this standard, and a thickness measurement on each of the remaining reels shall be made.

When ten or more samples are selected from any single lot, all reels shall be considered as not conforming to this standard if more than 10 percent of the samples fail to meet the requirements for physical and aging properties and thickness. If 10 percent or less fail, each reel shall be tested and shall be judged upon the results of such individual tests. Where the number of samples selected in any single lot is less than ten, all reels shall be considered as not conforming to this standard if more than 20 percent of the samples fail. If 20 percent or less fail, each reel, or length shall be tested and shall be judged upon the results of such individual tests.

9.5 DIMENSIONAL MEASUREMENTS OF THE METALLIC SHIELD

All metallic shielding wires or straps shall be removed from the insulated conductor. Measurements shall be made with a micrometer or other suitable instrument readable to at least 0.0001 inch (0.002 mm).

All round wires taken from the specimen shall be measured for diameter. The total cross-sectional area of the round wires can be calculated by the following equation:

$$TCSA = \left(d_1^2 + d_2^2 + d_3^2 + \cdots d_n^2\right) \times 10^6$$

Where:

$TCSA$ = Total Cross-sectional Area (cmil)
$d_{1,\ldots n}$ = measured diameter of each wire (inches)
n = number of wires

All flat straps taken from the specimen shall be measured for width and thickness. The total cross-sectional area of the flat straps can be calculated by the following equation:

$$TCSA = \left(1.273 \times 10^6\right) \times \left(w_1 t_1 + w_2 t_2 + w_3 t_3 + \cdots w_n t_n\right)$$

Where:

$TCSA$ = Total Cross-section Area (cmil)
$w_{1,\ldots n}$ = measured width of each flat strap (inches)
$t_{1,\ldots n}$ = measured thickness of each flat strap (inches)
n = number of flat straps

9.6 DIAMETER MEASUREMENT OF INSULATION AND INSULATION SHIELD

Measurement of the diameter over the insulation and the insulation shield shall be made with a diameter tape accurate to 0.01 inches (0.25 mm).

When there are questions regarding compliance to this standard, measurements shall be made with an optical measuring device or with calipers with a resolution of 0.0005 inch (0.013 mm) and accurate to 0.001 inch (0.025 mm). At any given cross-section, the maximum diameter, minimum diameter, and two additional diameters which bisect the two angles formed by the maximum and minimum diameters shall be measured. The diameter for the cross-section shall be the average of the four values. This average diameter value shall be used to determine if the cable meets the minimum and maximum limits given in Appendix C. All diameter measurements shall be made on cable samples that contain the conductor.

9.7 TESTS FOR JACKETS

9.7.1 Heat Shock (PVC only)

Samples of polyvinyl chloride jacketed cable shall be wound tightly around a mandrel having a diameter in accordance with Table 9-2, held firmly in place, and subjected to a temperature of 121 ± 1°C for 1 hour. The mandrel may be removed after the cable has been secured in place and before the cable is placed in the oven for testing. At the end of the test period, the sample shall be examined without magnification.

Table 9-2
Bending Requirements for Heat Shock Test

Outside Diameter of Cable		Number of Adjacent Turns	Diameter of Mandrel as a Multiple of the Outside Diameter of Cable
Inches	mm		
0-0.750	0-19.05	6	3
0.751-1.500	19.08-38.10	180-degree bend	8
1.501 and larger	38.13 and larger	180-degree bend	12

9.7.2 Heat Distortion

Heat distortion testing shall be performed in accordance with ICEA T-27-581/NEMA WC-53.

9.7.3 Cold Bend (PVC and CPE only)

Cold bend testing shall be performed in accordance with ICEA T-27-581/NEMA WC-53 on a single conductor completed cable. The mandrel shall have a diameter in accordance with the following table:

Table 9-3
Bending Requirements for Cold Bend Test

Outside Diameter of Single Cable		Diameter of Mandrel as a Multiple of the Outside Diameter of Cable
Inches	mm	
0-0.800	0-20.32	8
0.801 and larger	20.35 and larger	10

9.8 VOLUME RESISTIVITY

9.8.1 Conductor Shield (Stress Control)

The samples shall be cut in half longitudinally and the conductor removed. Two silver-painted electrodes shall be applied to the conductor shield spaced at least 2 inches (51 mm) apart.

The volume resistivity shall be calculated as follows:

$$\rho = \frac{R\left(D^2 - d^2\right)}{100L}$$

Where:

ρ = Volume resistivity in ohm-meters.
R = Measured resistance in ohms.
D = Diameter over the conductor stress control layer in inches.
d = Diameter over the conductor in inches.
L = Distance between potential electrodes in inches.

9.8.2 Insulation Shield

Two silver-painted electrodes shall be applied to the insulation shield spaced at least 2 inches (51 mm) apart.

The volume resistivity shall be calculated as follows:

$$\rho = \frac{2R\left(D^2 - d^2\right)}{100L}$$

Where:

ρ = Volume resistivity in ohm-meters.
R = Measured resistance in ohms.
D = Diameter over the insulation shield layer in inches.
d = Diameter over the insulation in inches.
L = Distance between potential electrodes in inches.

9.8.3 Test Equipment

A suitable instrument (e.g., Wheatstone, Kelvin Bridge or Ohmmeter) or instruments (e.g., voltmeter and ammeter) shall be utilized for determining resistance and provide a source of 49-61 Hz ac or dc voltage. The energy released in the conducting component shall not exceed 100 milli-watts.

A convection-type forced-draft, circulating air oven, shall be utilized capable of maintaining any constant (± 1°C) temperature up to 140°C, e.g., Hot Pack Model 1204-14, Blue M Model OV-490, or Precision Type A.

9.8.4 Test Procedure

9.8.4.1 Two-electrode Method

Connect the electrodes to an ohmmeter.

9.8.4.2 Four-electrode Method

The four-electrode method may be used as a referee method.

Conductor shield: The samples shall be cut in half longitudinally and the conductor removed. Four silver-painted electrodes shall be applied to the conductor shield. The two potential electrodes (inner) shall be at least 2 inches (51 mm) apart. A current electrode shall be placed at least 1 inch (25 mm) beyond each potential electrode.

Insulation shield: Four annular-ring electrodes shall be applied to the surface of the insulation shield layer. The two potential electrodes (inner) shall be at least 2 inches (51 mm) apart. A current electrode shall be placed at least 1 inch (25 mm) beyond each potential electrode.

Connect the two outer electrodes (current) in series with the current source and an ammeter or the current leads of a bridge. Connect the two inner electrodes (potential) to potentiometer leads of a bridge or to a voltmeter. A dc or 49-61 Hz ac source can be used.

9.8.4.3 Measurement

The resistance of the conducting component between the electrodes shall be determined at the specified temperature.

9.8.5 Semiconducting Jacket Radial Resistivity Test

This procedure is designed for testing short samples of cable having semiconducting jackets in contact with concentric wire neutrals.

The resistance of the jacket is obtained from measuring the voltage drop across the sample at room temperature. This is created by passing a constant dc or 49-61 Hz ac current through the sample in a radial direction. The apparent resistivity of the jacket shall be calculated from the electrical measurement and geometry of the cable.

9.8.5.1 Sample Preparation

A sample of cable at least 6 inches (152 mm) long will be prepared as shown in Figure 9-3. The concentric wires form one measuring electrode and a 2-inch (50-mm) band of conducting paint covering the surface of the jacket provides the second measuring electrode. Two separate bands of conducting paint 1/2 inch (13 mm) wide and covering the surface of the jacket form the guard electrodes. The bands are separated approximately 1/8 inch (3.2 mm) from the measuring electrode.

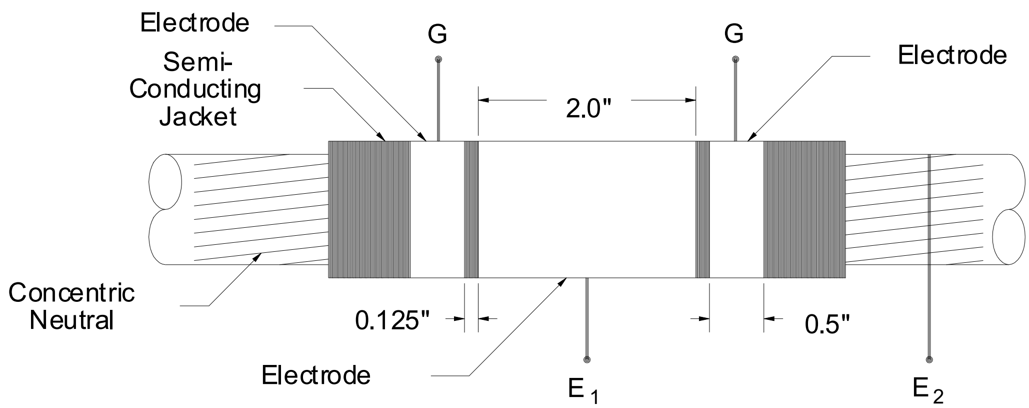

Figure 9-3
Sample Preparation for Radial Resistivity Measurement of Semi-Conducting Jackets

Legend: E_1 - Measuring electrode, conducting paint on the surface of the jacket

E_2 - Measuring electrode, concentric neutral wires tied together

G - Guard electrode, conducting paint on the surface of the jacket

The sample shall be tested in air at room temperature.

9.8.5.2 Test Equipment Setup

The equipment needed to perform the test consists of two high input impedance (>1 megohm) voltmeters, an ammeter, an adjustable resistor and an adjustable voltage dc or 49-61 Hz ac power supply.

The measuring circuit shall be connected as shown in Figure 9-4.

Adjustable resistor R_c is used to control the potential of the guard electrodes to the same value as E_1. This is done to prevent surface current from affecting the measurement. As it is adjusted, the measured voltage V_1 may go through a minimum point. The voltage V_2 and current measurements shall be made with R_c adjusted such that V_1 is as close to zero as possible.

Current density through the sample should be limited to 1mA/cm^2. Higher current density may cause inconsistency in the measurements due to heat generated in the semiconducting material.

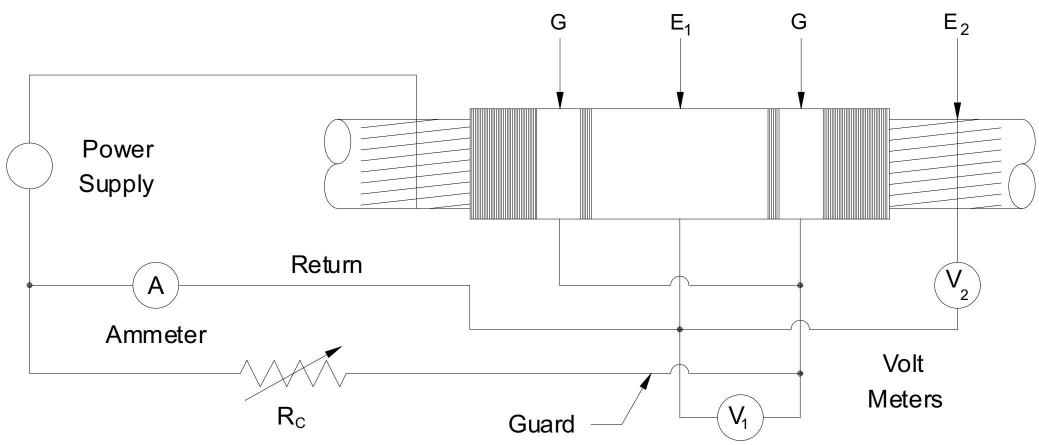

Figure 9-4
Circuit for Radial Resistivity Measurement
of Semi-Conducting Jackets

Legend: E_1, E_2 and G are the same notations used in Figure 9-3.

9.8.5.3 Calculation

Calculate the resistance R of the cable jacket from the measurements of voltage (V_2) and current (I) obtained using the circuit in Figure 9-4 ($R = V_2/I$). Using the value R and the appropriate dimensions of the cable sample, calculate the apparent resistivity as follows:

$$\rho_v = \frac{R \; x \; 2\pi \; x \; L}{\ln\left(\frac{D}{d}\right)}$$

Where:

- ρ_v = apparent resistivity in ohm-meters
- R = calculated resistance in ohms
- L = electrode length in meters
- D = diameter over the semiconducting jacket in mm
- d = pitch diameter* of the concentric wires in mm

* The pitch diameter d shall be measured from center to center of two concentric wires which are diametrically opposite from each other.