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Model 3610 & Model 3610 Kit

Receiving Your Shipment

Upon receiving your shipment, check that the contents agree with the packing slip. Notify your distributor at once of any shortages. If the equipment appears to be damaged, file a claim immediately with your carrier, and notify your distributor at once, giving a detailed description of the damages. Save the damaged packing container to substantiate your claims.

Packaging

Ground Resistance Tester Model 3610 (Cat. #1231.01) is supplied with meter, rubber “safety yellow” housing with carrying handle, batteries, and instruction manual.

Ground Resistance Tester Model 3610 Kit (Cat. #2110.18) is supplied with meter, one 16-ft lead, two 150-ft leads on spools with wind-up handles, two T-shaped ground rods, carrying case with a slot for the 3610, batteries, and instruction manual.

Description

The direct reading Ground Resistance Tester Model 3610 performs earth/ground resistance measurement from 0 to 50Ω and 0 to 500Ω quickly and accurately. Simply connect the Model 3610 in a three- or two-point con-figuration depending on your particular application and read the ground resistance directly. The Model 3610 has large, easy-to-read linear scales and rugged taut band movement. It features a built-in battery check, built-in calibration switch, and three-terminal operation.

This is the ideal instrument for electrical contractors, power technicians and inspectors who must check grounds to determine compliance with NEC®, OSHA and other specifications.

Optional Accessories and Replacements

Fuse, set of five, 100 mA, Cat. #1002.01.

Set of two T-shaped ground rods, Cat. #100.335.

Ground test kit includes three leads (98, 98, 16-ft), two T-shaped ground rods and carrying bag, Cat. #100.132A.

Ground test kit includes one 16-ft lead, two 150-ft leads on spools with wind-up handles, two T-shaped ground rods, and carrying case with slot for Model 3610, Cat. #2118.21.

Control and Connector Identification

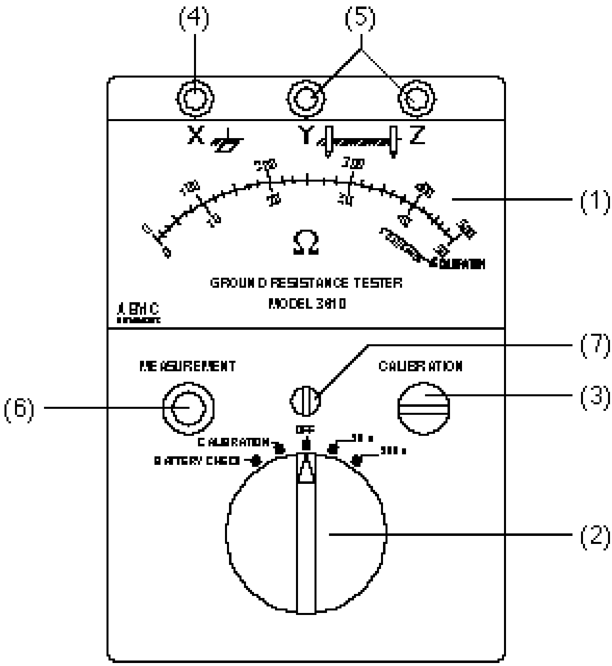


Fig. 1

(1) Direct reading scale (0 to 50Ω, 0 to 500Ω, battery check and calibration)

(2) Selection switch

(3) Auxiliary rod calibration adjustment

(4) Terminal to ground rod (X) under test

(5) Auxiliary potential (Y) and current (Z) electrode input terminals

(6) Measurement button

(7) Mechanical zero adjustment

Specifications

Ranges:
0 to 50Ω (25Ω midscale)
0 to 500Ω (250Ω midscale)

Accuracy: 3% of range

Measurement Current: 3.2 mA ± 10%

Auxiliary Electrode Influence:
Rz: Compensated by calibration to 5000Ω maximum
Ry: No influence to 5000Ω max.; 1.5% of range above 5000Ω

Stray Current Influence:
DC: 2% < for 5 V
50/60 Hz AC: 2% < for 2.5 V rms on 500Ω range

Operating Frequency: 325 Hz ±20% square wave

Meter Movement: rugged taut-band movement

Scale: 4.9 in (125 mm) white scale with black pointer; one scale per range

Power Supply: Three 1.5 V "AA" alkaline batteries (NEDA #15A) with built-in battery check

Battery Life: 3000 ten-second tests (typical)

Fuse: 100 mA slow-blow 5 x 20 mm

Dielectric Test: 2000 V rms

Operating Temperature: 14° to 122°F (-10° to 50°C)

Temperature Influence: Less than 0.5% after calibration

Relative Humidity: 0 to 90%

Dimensions:
Instrument: 7.7 x 5.1 x 2.5" (195 x 130 x 60 mm)
Rubber case: 10.5 x 7 x 3.5" (268 x 178 x 89 mm)
Carrying case (3610 Kit): 18.5 x 15 x 5.75" (470 x 381 x 146 mm)

Weight:
Instrument: 1 lb 8 oz (.65 kg)
In rubber case: 2 lb 9 oz (1.1 kg)

Battery and Fuse Replacement

NOTE: Disconnect instrument from service. Rubber housing may remain on Model 3610 while batteries are being changed.

Battery

a) Remove access panel screw until it clicks free from seat. Note: Screw will not separate from cover (captive screw).

b) Gently pull access panel up and down from the bottom to remove.

c) Remove all batteries and replace with three 1.5 V "AA" (alkaline recommended), noting polarity.

Fuse

a) Follow same steps as "a" and "b" above in battery replacement.

b) Remove fuse from holder and replace with spare fuse typically located on back side of access panel.

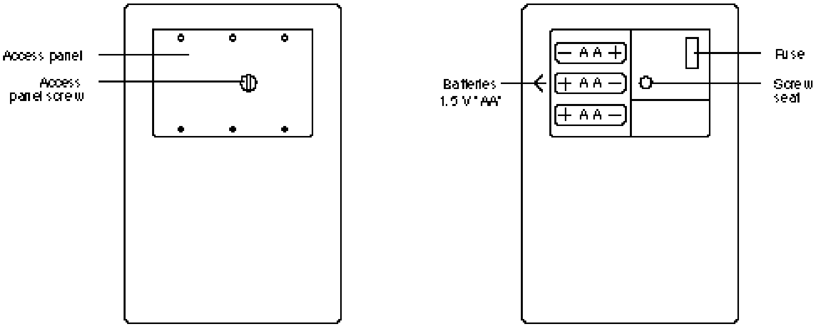


Fig. 2

Preparation for Measurement

Mechanical Zero Setting

Check whether the scale pointer is directly over "0" when at rest. If this is not the case, slowly turn the "Zero Adjust" screw in the appropriate direction until pointer is exactly on "0."

Battery Check

Turn selector switch to "battery check" position and note pointer deflection. The pointer should lie somewhere in the "BATTERY OK" section of the scale. If the needle falls to the left of the "BATTERY OK" section, replace the batteries before continuing.

Calibration

Calibration is performed only when the instrument is connected to the rods. This calibration compensates for the auxiliary rod resistance and temperature variations. Place selector switch on "calibrate" and push measurement button. Note the deflection of the pointer and adjust to lie directly on the position of the scale marked "CALIBRATION." If the instrument will not calibrate, check the connections between the input posts and the auxiliary electrodes. Also, it may be necessary to place water around the Z electrode to overcome excessive auxiliary ground resistance.

GROUND RESISTANCE MEASUREMENTS

Fall of Potential Method (Three-Point Measurement)

Refer to "Understanding Ground Resistance Testing" in this manual to ensure correct application test results and rod spacing. In particular, check that you are in the "plateau" region as described under "Position of the Auxiliary Electrodes" on page 31.

After completing "preparation for measurement," attach ground (X), potential (Y) and current (Z) electrodes respectively, as shown in the following figure. **Warning:** Do not disconnect the ground from a live circuit.

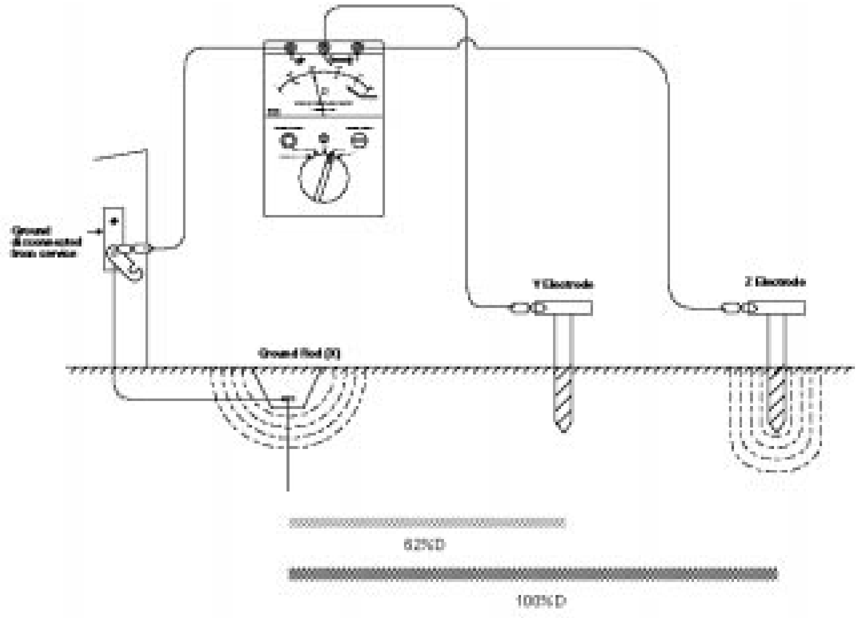


Fig. 3: Typical 3-point connection

Turn the selector switch to “calibration” and push measurement button. Note the deflection of the pointer and adjust to lie directly on the position of the scale marked “CALIBRATION.” If the instrument will not calibrate, check the connections between the input posts and the auxiliary electrodes; it may be necessary to pour water around the Z electrode to overcome excessive auxiliary ground resistance. Turn the selector switch to the “500Ω” range and push the measurement button to obtain ground resistance directly. If the pointer falls below 50 ohms on the scale, change the switch to “50Ω” and push the measurement button again. Read the ground resistance directly.

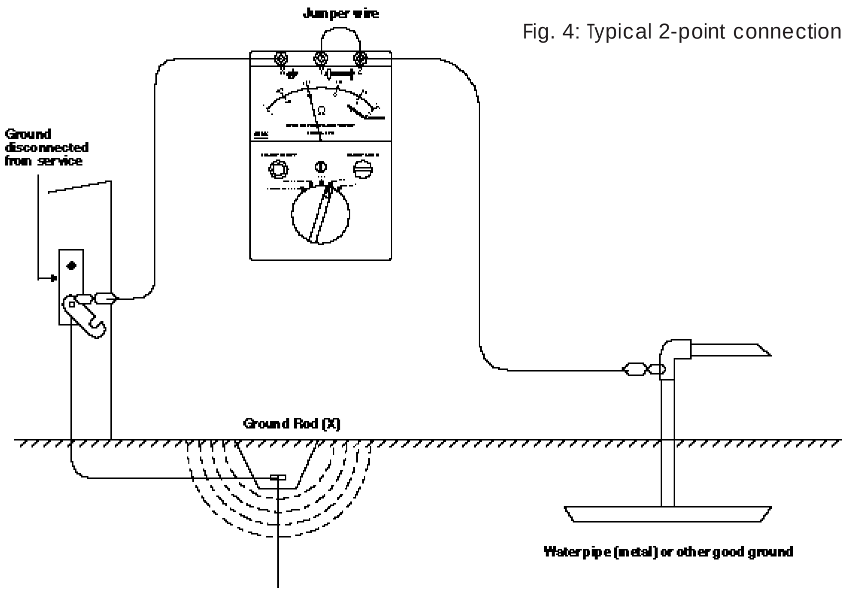
Two-Point Measurement (Simplified Measurement)

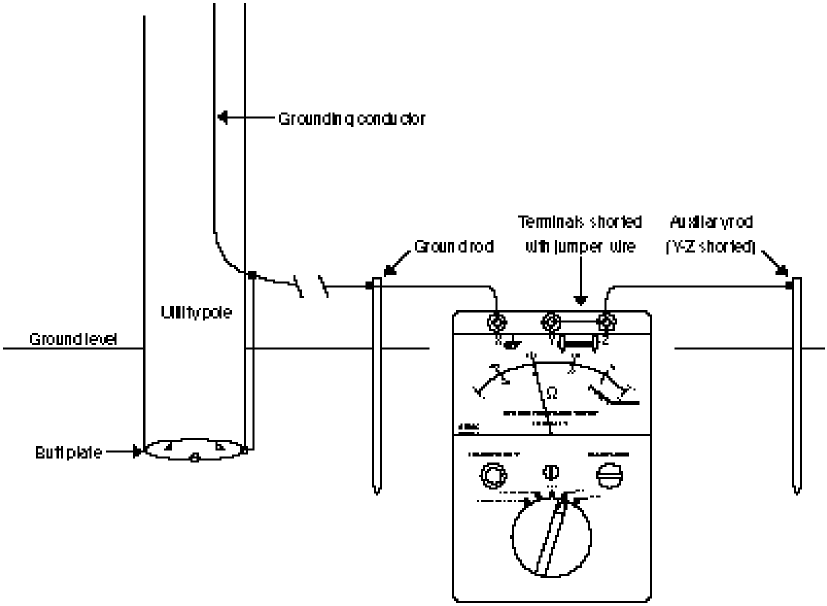
Refer to “Understanding Ground Resistance Testing” in this manual to ensure correct application and test results.

After completing “preparation for measurement,” attach X to ground under test and Z to a low resistance ground point. A jumper must also be placed between the Y and Z input posts. **Warning:** Do not disconnect the ground from a live circuit.

Turn the selector switch to “calibration” and push the measurement button. Note the deflection of the pointer and adjust with the calibration adjust knob to lie directly on the position marked “CALIBRATION” on the scale. If the instrument will not calibrate, check the connections between the input posts and the auxiliary rods. Next place the selector switch to “500Ω” range and push the measurement button to obtain ground resistance directly. Should the pointer fall below 50 ohms on the scale, change the selector switch to “50Ω,” and push the measurement button again.

Fig. 4: Typical 2-point connection





Troubleshooting

I. Partial deflection of the calibration pointer:

If when attempting to calibrate the Model 3610 the pointer fails to reach proper positioning, the problem most likely belongs to excessive resist-ance at the Z current auxiliary rod. This problem can be alleviated by placing water around the Z rod, enabling the tester to calibrate.

II. No deflection of the calibration pointer:

If the calibration pointer does not move the problem may lie with the external connections to the Model 3610. To test this theory short the X, Y and Z posts together, then depress the calibration button. At this point you should be able to calibrate. If calibration is achieved then the problem lies with the external continuity connections to the ground under test or auxiliary rods.

Receiving Your Shipment

Upon receiving your shipment, check that the contents agree with the packing slip. Notify your distributor at once of any shortages. If the equipment appears to be damaged, file a claim immediately with your carrier, and notify your distributor at once, giving a detailed description of the damages. Save the damaged packing container to substantiate your claims.

Packaging

Ground Resistance Test Kit Model 3630 (Cat. #2110.17) is supplied with meter, one 16-ft lead, two 150-ft leads on spools with wind-up handles, two T-shaped ground rods, carrying case, and instruction manual.

Description

This complete ground resistance test kit is designed for utilities and ground specialists. Both two- and three-point measurements may be performed. Ground measurements are usually made using the fall-of-potential method with two auxiliary rods. Two-point measurements can be made when space limitations do not allow driving auxiliary rods, or if time scheduling is a factor. Two-point measurement with the Model 3630 is selected by a single pushbutton.

The 3630 also measures ground voltage to 30 V AC between the ground under test and the auxiliary rods, and rejects high stray voltages.

Optional Accessories & Replacements

Set of two T-shaped ground rods, Cat. #100.335.

Ground test kit includes one 16-ft lead, two 150-ft leads on spools with wind-up handles, two T-shaped ground rods, and a carrying case with a slot for the Model 3630, Cat. #2118.21.

Control and Connector Identification

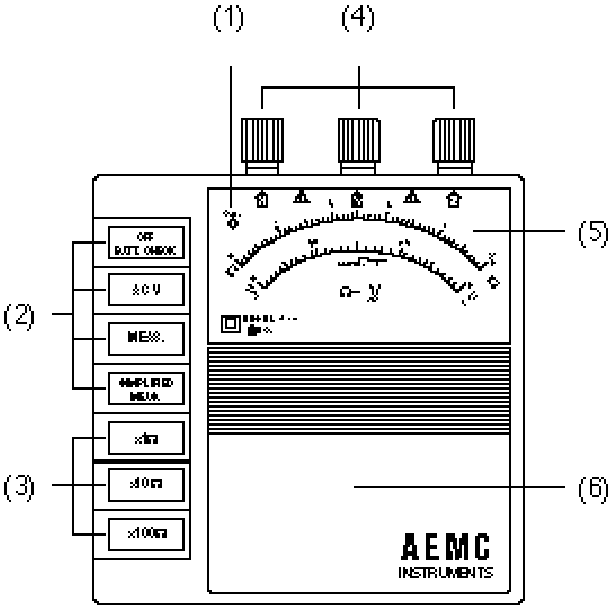


Fig. 6

(1) LED
(lights up when instrument is in operation)

(2) Function buttons

(3) Ohm range buttons

(4) Ground (X), potential (Y) and current (Z) electrode input terminals

(5) Scale plate

(6) Battery and zero adjust compartment cover

Specifications

GROUND RESISTANCE TEST (Fall-of-Potential)

Ranges:
0 to 10Ω
0 to 100Ω
0 to 1000Ω

Accuracy: ± 3% of FS

Maximum Earth Resistance for Auxiliary Rods:
20,000Ω

Test Current: 2 mA, 800 Hz approx.

Simplified Measurement (Two-pole):
Internally shorts the X and Y terminals
(pushbutton selectable)

GROUND VOLTAGE TEST

Range: 0 to 30 V AC

Accuracy: ± 3% of FS

GENERAL SPECIFICATIONS

Supply:
Eight 1.5 V “AA” alkaline batteries (NEDA #15A)

Built-in Battery Check

Dielectric Test: 1500 V, 1 minute

Meter Movement: Rugged pivot and jewel

Dimensions:
Instrument: 5.5 x 5.5 x 3.5" (140 x 140 x 90 mm)
Carrying Case: 18.5 x 15 x 5.75" (470 x 381 x 146 mm)

Weight (instrument): 1.8 lbs (800 g)

Battery Replacement

- Raise the panel up evenly from both sides 90 degrees until it locks.
- Push the holder gently toward the scale. The battery case will rise up slightly.
- Carefully pull out the battery case from the compartment.
- Remove the battery connector on the side of the case. Empty the battery case of its contents.
- Install eight 1.5 V “AA” batteries (alkaline recommended), noting the polarity markings.
- Attach the battery connector to the compartment, then push down the battery case until it locks into the holder.
- Slowly push cover down evenly until closed.

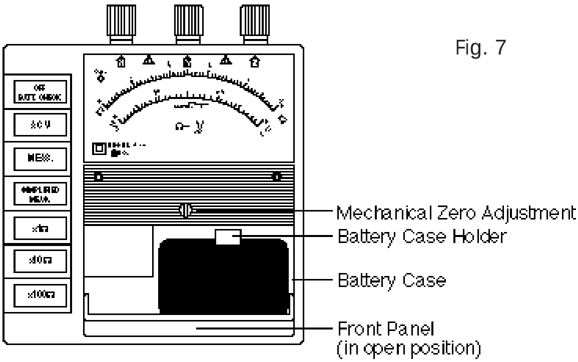


Fig. 7

Preparation for Measurement

Mechanical Zero Settings

Check to see if the meter pointer is adjusted exactly to the zero position of the “OHM” or “V” scale. If the pointer is not on zero when at rest, open the panel and turn the zero adjust screw accordingly. The panel can be lifted up 90 degrees by holding both sides as shown in Figure 7.

Battery Check

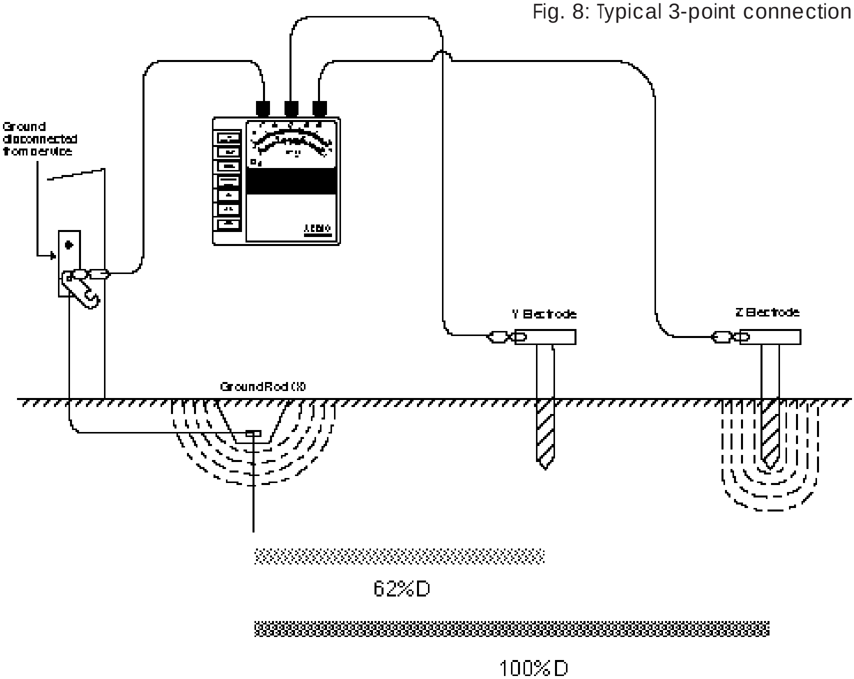
With the “OFF/BATTERY CHECK” button depressed check the reading and note that the LED light is on. Sufficient battery voltage is available when the pointer stays to the right of the “BATT/GOOD” mark. Replace the batteries if the pointer stays to the left of the “BATT/GOOD” mark.

Ground Resistance Measurements

Fall-of-Potential Method (Three-Point Measurement)

Refer to “Understanding Ground Resistance Testing” in this manual for correct application test results and rod spacing. In particular, check that you are in the “plateau” region as described under “Position of the Auxiliary Electrodes” on page 31. **Warning:** Do not disconnect the ground from a live circuit.

Fig. 8: Typical 3-point connection



After completing “preparation for measurement,” attach ground (X), potential (Y) and current (Z) electrodes respectively, as indicated in Figure 8. Select function button “MEAS” to perform three-point measurement. Then choose the appropriate ohm range button (x1Ω, x10Ω or x100Ω). Read the ohm scale directly, then multiply by the ohm range selected.

Example: Scale reads 4.2

Ohm Range	
x1 :	4.2 x 1 = 4.2
x10 :	4.2 x 10 = 42
x100 :	4.2 x 100 = 420

Two-Point Measurement (Simplified Measurement)

Refer to “Understanding Ground Resistance Testing” in this manual for correct application test results and rod spacing. **Warning:** Do not disconnect the ground from a live circuit.

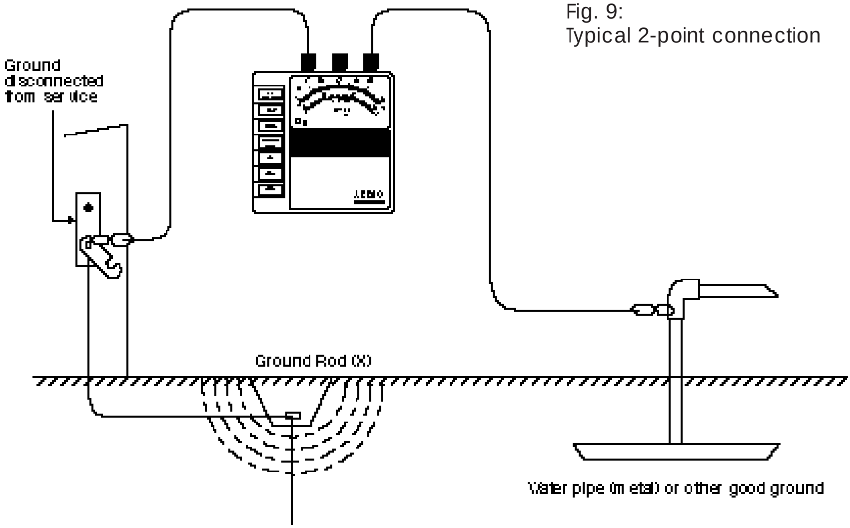
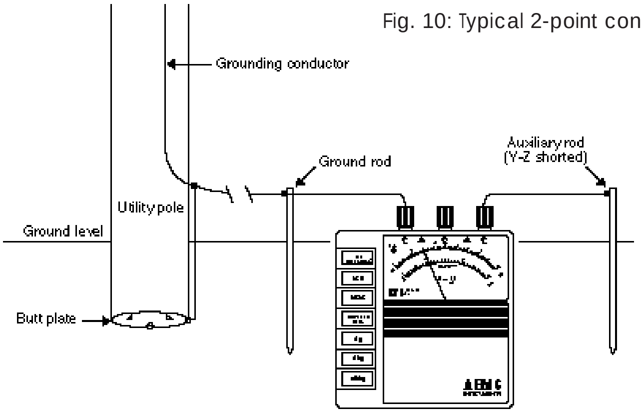


Fig. 9:
Typical 2-point connection

Fig. 10: Typical 2-point connection



After completing "preparation for measurement," attach ground (X), potential (Y) and current (Z) as indicated in Figure 10. Depress function button "SIMPLIFIED/MEAS." This shorts Y and Z terminals internally to establish a two-point measurement. Then select an appropriate ohm range button (x1Ω, x10Ω and x100Ω). Read the ohm scale directly, then multiply by the ohm range selected.

Example: Scale reads 8.4:

Ohm Range	
x1 :	8.4 x 1 = 8.4
x10 :	8.4 x 10 = 84
x100 :	8.4 x 100 = 840

Earth Voltage Test

Press the "AC V" button and check the earth voltage by reading the vol-tage directly on the "V" scale (the ohm range multiplier buttons have no bearing on this test). This can be done in either the 2- or 3-point method. Earth voltage is more commonly called stray voltage. When the earth voltage is more than 10 V it may affect the accuracy of the earth resistance measurement. To avoid this problem, make the earth resistance measurement with all nearby power sources shut down or realign the auxiliary rods away from all overhead power lines.

Understanding Ground Resistance Testing

Definition

The term "ground" is defined as a conducting connection by which a circuit or equipment is connected to the earth. The connection is used for establishing and maintaining as closely as possible the potential of the earth on the circuit or equipment connected to it. A "ground" consists of a grounding conductor, a bonding connector, its grounding electrode(s), and the soil in contact with the electrode.

Grounds have several fundamental protection applications. For natural phenomena, such as lightning, grounds are used to discharge the system of current before personnel can be injured or system components damaged.

For foreign potentials due to faults in electric power systems with ground returns, grounds help in ensuring rapid operation of the protection relays by providing low resistance fault current paths. This provides for the removal of the foreign potential as quickly as possible. The ground should drain the foreign potential before personnel are injured and the power or communications system is damaged.

Ideally, to maintain a reference potential for instrument safety, to protect against static electricity, and limit the system to frame voltage for operator safety, a ground resistance should be zero ohms. In reality, as we describe further in the text, this value cannot be obtained.

Lastly, but not least, low ground resistance is essential to meet NEC®, OSHA and other electrical safety standards.

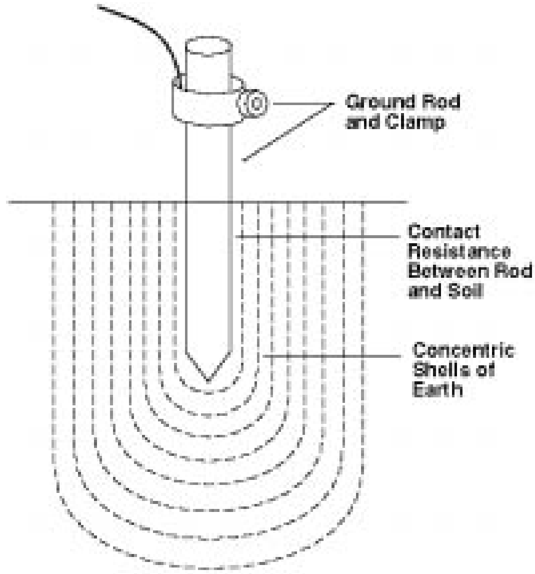
Grounding Electrode Resistance

Figure 11 illustrates a grounding rod. The resistance of the electrode has the following components:

(A) the resistance of the metal and that of the connection to it.

(B) the contact resistance of the surrounding earth to the electrode.

(C) the resistance in the surrounding earth to current flow or earth resis-tivity, which is often the most significant factor.



More specifically:

(A) Grounding electrodes are usually made of a very conductive metal (copper or copper clad) with adequate cross sections so that the overall resistance is negligible.

(B) The National Bureau of Standards has demonstrated that the resistance between the electrode and the surrounding earth is negligible if the electrode is free of paint, grease or other coating, and if the earth is firmly packed.

(C) The only component remaining is the resistance of the surrounding earth. The electrode can be thought of as being surrounded by concentric shells of earth or soil, all of the same thickness. The closer the shell to the electrode, the smaller its surface; hence, the greater its resistance. The farther away the shells are from the electrode, the greater the surface of the shell; hence, the lower the resistance. Eventually, adding shells at a distance from the grounding electrode will no longer noticeably affect the overall earth resistance surrounding the electrode. The distance at which this effect occurs is referred to as the effective resistance area, and is directly dependent on the depth of the grounding electrode.

In theory, the ground resistance may be derived from the general formula:

$$R = \rho \frac{L}{A} \qquad \text{Resistance} = \text{Resistivity} \times \frac{\text{Length}}{\text{Area}}$$

This formula illustrates why the shells of concentric earth decrease in resistance the farther they are from the ground rod:

$$R = \text{Resistivity of soil} \times \frac{\text{Thickness of Shell}}{\text{Area}}$$

In the case of ground resistance, uniform earth (or soil) resistivity throughout the volume is assumed, although this is seldom the case in nature. The equations for systems of electrodes are very complex and often expressed only as approximations. The most commonly used formula for single ground electrode systems, developed by Professor H. R. Dwight of the Massachusetts Institute of Technology, is the following:

$$R = \frac{\rho}{2\check{s}L}\left\{\frac{(\ln \times 4L)-1}{r}\right\}$$

R = resistance in ohms of the ground rod to the earth (or soil)

L = grounding electrode length

r = grounding electrode radius

ρ = average resistivity in ohms-cm.

Effect of Ground Electrode Size and Depth on Resistance

Size: Increasing the diameter of the rod does not materially reduce its resistance. Doubling the diameter reduces resistance by less than 10%.

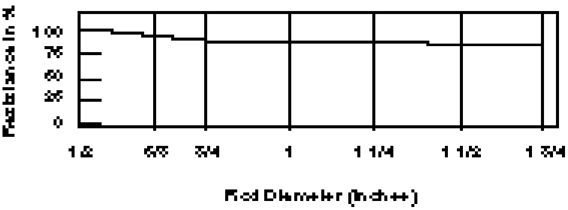


Fig. 12

Depth: As a ground rod is driven deeper into the earth, its resistance is substantially reduced. In general, doubling the rod length reduces the resistance by an additional 40% (Figure 13). The NEC 2005 250.52 (A)(5) requires a minimum of 8 ft (2.4 m) to be in contact with the soil. The most common is a 10-ft (3 m) cylindrical rod which meets the NEC code. A minimum diameter of 5/8" (1.59 cm) is required for steel rods and 1/2" (1.27 cm) for copper or copper clad steel rods NEC 2005 250.52(A)(5)(a)(b). Minimum practical diameter for driving limitations for 10 ft (3 m) rods are:

- 1/2 inch (1.27 cm) in average soil
- 5/8 inch (1.59 cm) in moist soil
- 3/4 inch (1.91 cm) in hard soil or more than 10 ft driving depths

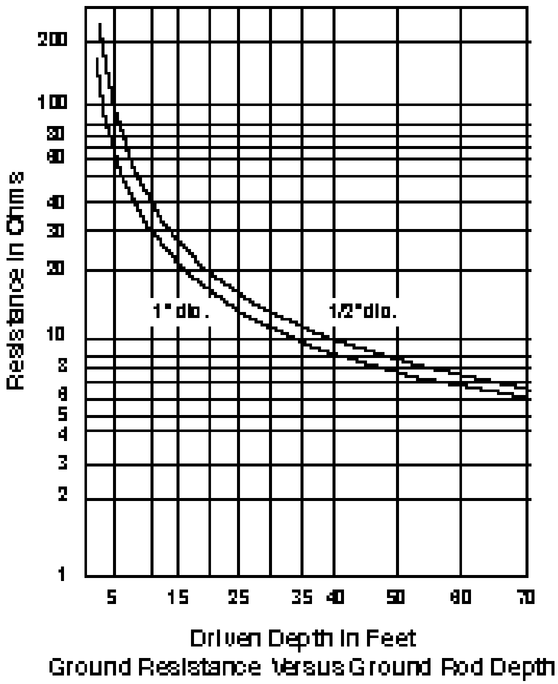


Fig. 13

Effects of Soil Resistivity on Ground Electrode Resistance

Dwight's formula, cited previously, shows that the resistance to earth of grounding electrodes depends not only on the depth and surface area of grounding electrodes but on soil resistivity as well. Soil resistivity is the key factor that determines what the resistance of a grounding electrode will be, and to what depth it must be driven to obtain low ground resistance. The resistivity of the soil varies widely throughout the world and changes seasonally. Soil resistivity is determined largely by its content of electrolytes, consisting of moisture, minerals and dissolved salts. A dry soil has high resistivity if it contains no soluble salts (Figure 14).

	Resistivity, Ω-cm		
Soil	**Min.**	**Average**	**Max.**
Ashes, cinders, brine, waste	590	2,370	7,000
Clay, shale, gumbo, loam	340	4,060	16,300
Same, with varying proportions of sand and gravel	1,020	15,800	135,000
Gravel, sand, stones with little clay or loam	59,000	94,000	458,000

Fig. 14

Factors Affecting Soil Resistivity

Two samples of soil, when thoroughly dried, may become in fact very good insulators, having a resistivity in excess of 10^9 ohm-centimeters. The resistivity of the soil sample is seen to change quite rapidly until approximately twenty percent or greater moisture content is reached (Figure 15).

Moisture content, percent by weight	Resistivity, -cm	
	Top soil	Sandy loam
0	>10^9	>10^9
2.5	250,000	150,000
5	165,000	43,000
10	53,000	18,500
15	19,000	10,500
20	12,000	6,300
30	6,400	4,200

Fig. 15

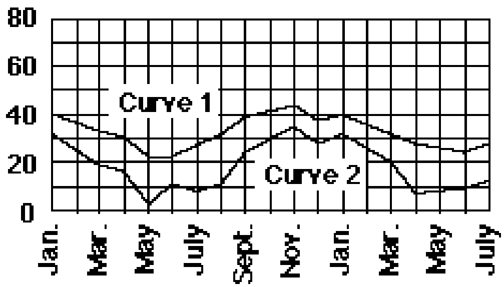
The resistivity of the soil is also influenced by temperature. Figure 16 shows the variation of the resistivity of sandy loam, containing 15.2% moisture, with temperature changes from 20° to -15°C. In this temperature range the resistivity is seen to vary from 7200 to 330,000 ohm-centimeters.

Temperature		Resistivity,
C	F	Ohm-cm
20	68	7,200
10	50	9,900
0	32 (water)	13,800
0	32 (ice)	30,000
-5	23	79,000
-15	14	330,000

Fig. 16

Because soil resistivity directly relates to moisture content and temperature, it is reasonable to assume that the resistance of any grounding system will vary throughout the different seasons of the year. Such variations are shown in Figure 17. Since both temperature and moisture content become more stable at greater distances below the surface of the earth, it follows that a grounding system — to be most effective at all times — should be constructed with the ground rod driven down a considerable distance below the surface of the earth. Best results are obtained if the ground rod reaches the water table.

Fig. 17



Seasonal variation of earth resistance with an electrode of 3/4 inch pipe in rather stony clay soil. Depth of electrode in earth is 3 ft for Curve 1, and 10 ft for Curve 2.

In some locations, the resistivity of the earth is so high that low-resistance grounding can be obtained only at considerable expense and with an elaborate grounding system. In such situations, it may be economical to use a ground rod system of limited size and to reduce the ground resistivity by periodically increasing the soluble chemical content of the soil. Figure 18 shows the substantial reduction in resistivity of sandy loam brought about by an increase in chemical salt content.

Chemically treated soil is also subject to considerable variation of resistivity with changes in temperature, as shown in Figure 19. If salt treatment is

THE EFFECT OF SALT* CONTENT ON THE RESISTIVITY OF SOIL

(Sandy loam, Moisture content, 15% by weight, Temperature, 17°C)

Added Salt (% by weight of moisture)	Resistivity (Ohm-centimeters)
0	10,700
0.1	1,800
1.0	460
5	190
10	130
20	100

Fig. 18

THE EFFECT OF TEMPERATURE ON THE RESISTIVITY OF SOIL CONTAINING SALT*

(Sandy loam, 20% moisture. Salt 5% of weight of moisture)

Temperature (Degrees C)	Resistivity (Ohm-centimeters)
20	110
10	142
0	190
-5	312
-13	1,440

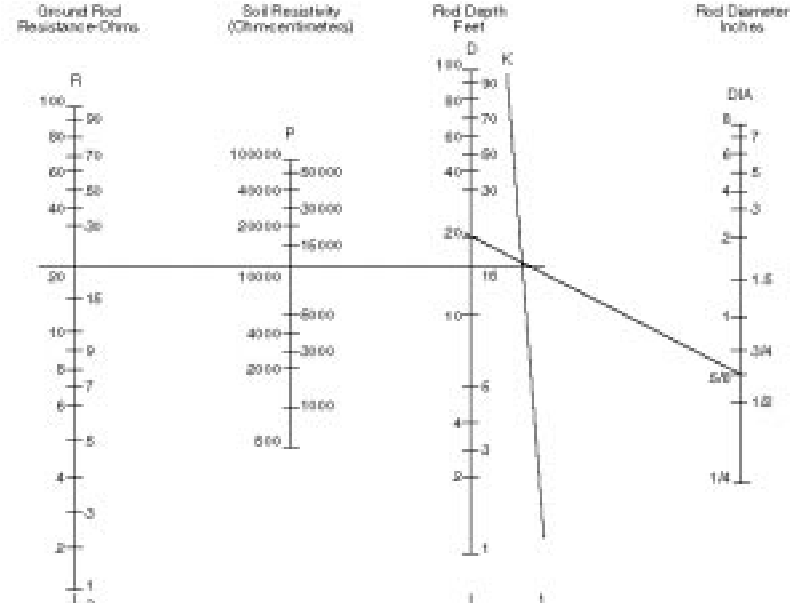
* Such as copper sulfate, sodium carbonate, and others. Salts must be EPA or local ordinance approved prior to use.

Fig. 19

employed, it is, of course, necessary to use ground rods which will resist chemical corrosion.

Effect of Ground Electrode Depth on Resistance

To assist the engineer in determining the approximate ground rod depth required to obtain a desired resistance, a device called the Grounding Nomograph may be used. The Nomograph, shown in Figure 20, indicates that to obtain a grounding resistance of 20 ohms in a soil with a resistivity of 10,000 ohm-centimeters, a 5/8" OD rod must be driven 20 feet. Note that the values indicated on the Nomograph are based on the assumption that the soil is homogeneous and, therefore, has uniform resistivity. The Nomograph value is an approximation.



Grounding Nomograph

1. Select required resistance on R scale.
2. Select apparent resistivity on P scale.
3. Lay straightedge on R and P scale, and allow to intersect with K scale.
4. Mark K scale point.
5. Lay straightedge on K scale point and DIA scale, and allow to intersect with D scale.
6. Point on D scale will be rod depth required for resistance on R scale.

Ground Resistance Values

NEC® 2005 250.56: Resistance of man-made electrodes:

"A single electrode consisting of a rod, pipe, or plate which does not have a resistance to ground of 25 ohms or less shall be augmented by one additional of any of the types specified in section 250.52 (A)(2) through (A)(7). Where multiple rod pipe or plate electrodes are installed to meet the requirements of this section, they shall be not less than 6 ft (1.83 m) apart."

The National Electrical Code® (NEC)® states that the resistance to ground shall not exceed 25 ohms. This is an upper limit and guideline, since much lower resistance is required in many instances.

"How low in resistance should a ground be?" An arbitrary answer to this in ohms is difficult. The lower the ground resistance, the safer, and for positive protection of personnel and equipment, it is worth the effort to aim for less than one ohm. It is generally impractical to reach such a low resistance along a distribution system or a transmission line or in small substations. In some regions, resistances of 5 ohms or less may be obtained without much trouble. In others, it may be difficult to bring resistance of driven grounds below 100 ohms.

Accepted industry standards stipulate that transmission substations should be designed not to exceed one ohm resistance. In distribution substations, the maximum recommended resistance is for 5 ohms or even 1 ohm. In most cases, the buried grid system of any substation will provide the desired resistance.

In light industrial or in telecommunication central offices, 5Ω is often the accepted value. For lightning protection, the arrestors should be coupled with a maximum ground resistance of 1Ω.

These parameters can usually be met with the proper application of basic grounding theory. There will always exist circumstances which will make it difficult to obtain the ground resistance required by the NEC® or other safety standards. When these situations develop, several methods of lowering the ground resistance can be employed. These include parallel rod systems, deep driven rod systems utilizing sectional rods and chemical treatment of the soil. Additional methods, discussed in other published data, are buried plates, buried conductors (counterpoise), electrically connected building steel, and electrically connected concrete reinforced steel.

Electrically connecting to existing water and gas distribution systems was often considered to yield low ground resistance; however, recent design changes utilizing non-metallic pipes and insulating joints have made this method of obtaining a low resistance ground questionable and in many instances unreliable.

The measurement of ground resistances may only be accomplished with specially designed test equipment. Most of these instruments use the Fall-of-Potential principle of alternating current (AC) circulating between an auxiliary electrode and the ground electrode under test; the reading will be given in ohms and represents the resistance of the ground electrode to the surrounding earth. AEMC has also recently introduced clamp-on ground resistance testers.

Note: The National Electrical Code® and NEC® are registered trademarks of the National Fire Protection Association.

WARNING

6.02 Lighting Arrester Ground Tests

These grounds fall in a special category because of the extremely high short-duration currents carried by lighting arrester grounds. These currents may be in excess of 50,000 amperes for surge currents, with a possibility of power-follow currents in the case of a defective arrester. An isolated lighting arrester ground should never be tested when the arrester is in service because of the potential gradient around the ground connection.

6.03 Small Isolated Ground Tests

If there is no possibility of fault currents into the ground to be tested, the only precaution concerns possible high-potential gradients around the test electrodes. If current is passed into a remotely located electrode, as in the fall-of-potential method, it is worthwhile to insure against a curious person being allowed near the current electrode while tests are in progress. To a much lesser extent, in rural areas grazing cattle should not be allowed near the test current electrode.

--Reprinted from IEEE std. 81-1962

7.6 Ground Resistance Measurement

Ground resistance is the resistance of the soil to the passage of electric current from the electrode into the surrounding earth.

Grounding system resistance, expressed in ohms, should be measured after a system is installed and at periodic intervals thereafter. Usually, precision in measurement is not required. Measurement of ground resistance is necessary to verify the adequacy of a new grounding system with the calculated value, and to detect changes in an existing grounding system. It is important that specified or lower resistance be obtained, since all calculations for personnel and equipment safety are based on the specified grounding resistance. The margin of safety will be reduced if the resistance exceeds the specified value.

Three components constitute the resistance of a grounding system:

(1) The resistance of the grounding electrode conductor and grounding conductor connection to the electrode

(2) Contact resistance between the grounding electrode and the soil adjacent to it

(3) The resistance of the body of earth immediately surrounding the electrode.

Grounding electrodes are usually of sufficient size or cross-section, and grounding connections are usually made by proven clamps or welding, so that their resistance is a negligible part of the total resistance. If the grounding electrode is free from paint or grease and the earth is packed firmly around the electrode, contact resistance is also negligible. Rust on an iron electrode has little or no effect.

When the current flows from a grounding electrode to earth, it radiates current in all directions. It can be considered that current flows through a series of concentric spherical like earth shells, all of equal thickness, surrounding the grounding electrode. The shell immediately surrounding the electrode has the smallest cross-sectional area and so offers greatest resistance. As the distance from the electrode increases, each shell becomes correspondingly larger in cross-section and offers less resistance. Finally, a distance from the electrode is reached where additional shells do not add significantly to the total ground resistance. Therefore, the resistance of the surrounding earth is the largest component of the resistance of a grounding system.

It is possible, however, to calculate the resistance of any system of grounding electrodes. But several factors can affect the calculated value due to considerable variation in soil resistivity at a given location. Soil resistivity depends on soil material, the moisture content, and the temperature. If all factors are considered, formulas for calculating the performance of grounding systems become very complicated and involve so many indeterminate factors that they are of little value. Many formulas have been developed, but they are only useful as general guides. The actual ground resistance of a grounding system can be determined only by measurement.

--Reprinted from ANSI/IEEE Std. 141.1986

Ground Resistance Testing Principle (Fall of Potential — 3-Point Measurement)

The potential difference between rods X and Y is measured by a voltmeter, and the current flow between rods X and Z is measured by an ammeter. (Note: X,Y and Z may be referred to as X, P and C in a 3-point tester or C1, P2 and C2 in a 4-point tester.) (See Figure 21.)

By Ohm's Law E = RI or R = E/I, we may obtain the ground electrode resistance R. If E = 20 V and I = 1 A, then

$$R = \frac{E}{I} = \frac{20}{1} = 20 \text{ ohms}$$

It is not necessary to carry out all the measurements when using a ground tester. The ground tester will measure directly by generating its own current and displaying the resistance of the ground electrode.

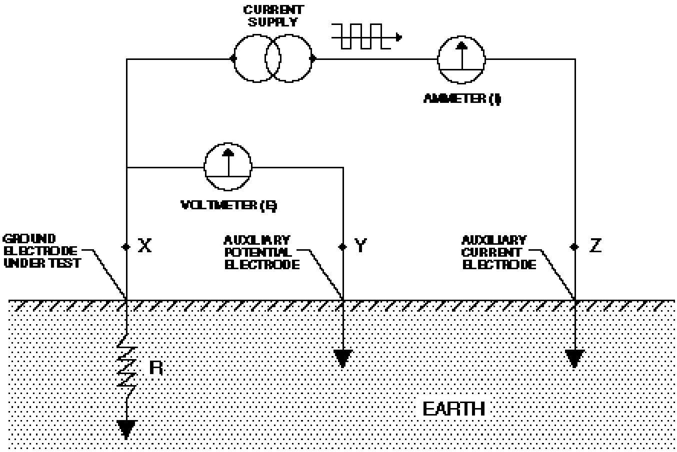


Fig. 21

Position of the Auxiliary Electrodes on Measurements

The goal in precisely measuring the resistance to ground is to place the auxiliary current electrode Z far enough from the ground electrode under test so that the auxiliary potential electrode Y will be outside of the effective resistance areas of both the ground electrode and the auxiliary current electrode. The best way to find out if the auxiliary potential rod Y is outside the effective resistance areas is to move it between X and Z and to take a reading at each location. If the auxiliary potential rod Y is in an effective resistance area (or in both if they overlap) (Figure 22), by displacing it, the readings taken will vary noticeably in value. Under these conditions, no exact value for the resistance to ground may be determined.

On the other hand, if the auxiliary potential rod Y is located outside of the effective resistance areas (Figure 23), as Y is moved back and forth the reading variation is minimal. The readings taken should be relatively close to each other, and are the best values for the resistance to ground of the ground X. The readings should be plotted to ensure that they lie in a “plateau” region as shown in Figure 23. The region is often referred to as the 62% area.

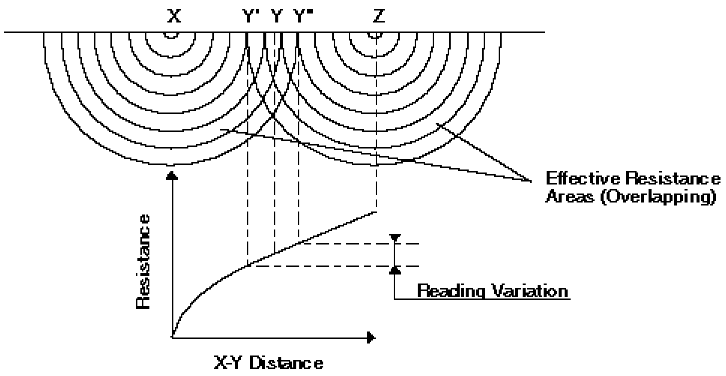

X
Y' Y Y"
Z
Effective Resistance
Areas (Overlapping)
Resistance
Reading Variation
X-Y Distance

Fig. 22

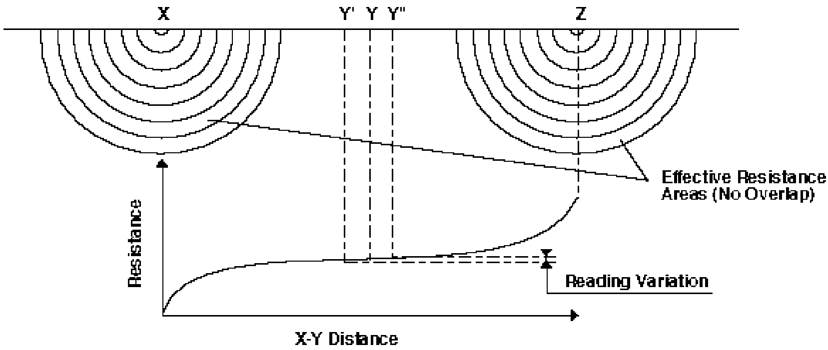
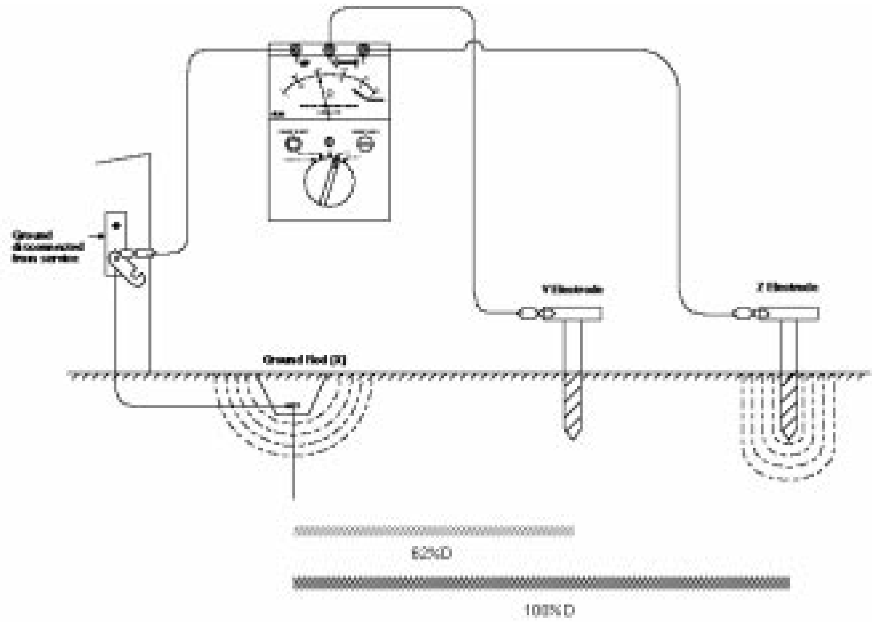

X
Y' Y Y"
Z
Effective Resistance
Areas (No Overlap)
Resistance
Reading Variation
X-Y Distance

Fig. 23

Measuring Resistance of Ground Electrodes (62% Method)

The 62% method has been adopted after graphical consideration and after actual testing, and is best used after ensuring that the user is in the “plateau” region. It is the most accurate method but is limited by the fact that *the ground tested is a single unit.*

This method applies only when all three electrodes are in a straight line and the ground is a *single* electrode, pipe, or plate, etc., as in Figure 24.



Consider Figure 25, which shows the effective resistance areas (concentric shells) of the ground electrode X and of the auxiliary current electrode Z. The resistance areas overlap. If readings were taken by moving the auxiliary potential electrode Y towards either X or Z, the reading differentials would be great and one could not obtain a reading within a reasonable band of tolerance. The sensitive areas overlap and act constantly to increase resistance as Y is moved away from X.

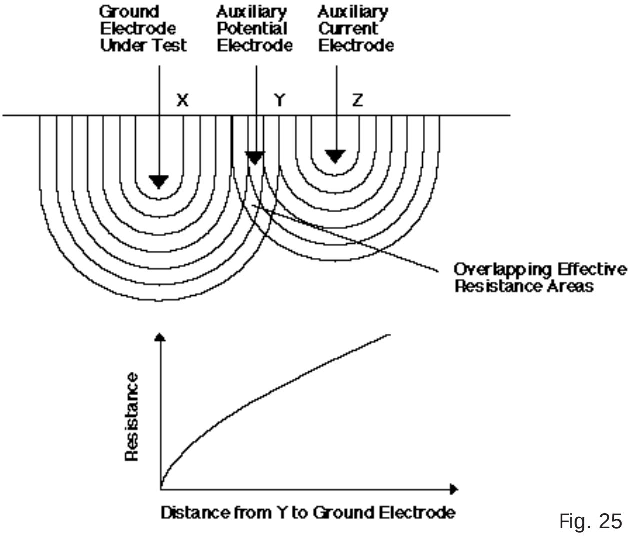
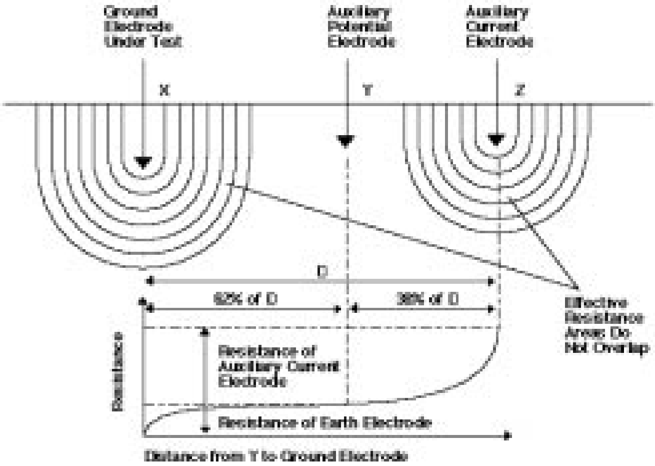


Fig. 25

Now consider Figure 26, where the X and Z electrodes are sufficiently spaced so that the areas of effective resistance do not overlap. If we plot the resistance measured we find that the measurements level off when Y is placed at 62% of the distance from X to Z, and that the readings on either side of the initial Y setting are most likely to be within the established tolerance band. This tolerance band is defined by the user and expressed as a percent of the initial reading: ± 2%, ± 5%, ± 10%, etc.



Auxiliary Electrode Spacing

No definite distance between X and Z can be given, since this distance is relative to the diameter of the electrode tested, its length, the homogeneity of the soil tested, and particularly, the effective resistance areas. However, an approximate distance may be determined from the following chart which is given for a homogeneous soil and an electrode of 1" in diameter. (For a diameter of 1/2", reduce the distance by 10%; for a diameter of 2" increase the distance by 10%.)

Approximate distance to auxiliary electrodes using the 62% method

Depth Driven	Distance to Y	Distance to Z
6 ft	45 ft	72 ft
8 ft	50 ft	80 ft
10 ft	55 ft	88 ft
12 ft	60 ft	96 ft
18 ft	71 ft	115 ft
20 ft	74 ft	120 ft
30 ft	86 ft	140 ft

2-Point Measurement (Simplified Method)

This is an alternative method *when an excellent ground is already available.*

In congested areas where finding room to drive the two auxiliary rods may be a problem, the two-point measurement method may be applied. The reading obtained will be that of the two grounds in series. Therefore, the water pipe or other ground must be very low in resistance so that it will be negligible in the final measurement. The lead resistances will also be measured and should be deducted from the final measurement.

This method is not as accurate as three-point methods (62% method), as it is particularly affected by the distance between the tested electrode and the dead ground or water pipe. This method should not be used as a standard procedure, but rather as a back-up in tight areas. See Figure 27.

Fig. 27