Resistance Measurements
Three- and Four-Point Method

Four-Point Resistance Measurements

Ohmmeter measurements are normally made with just a two-point measurement method.

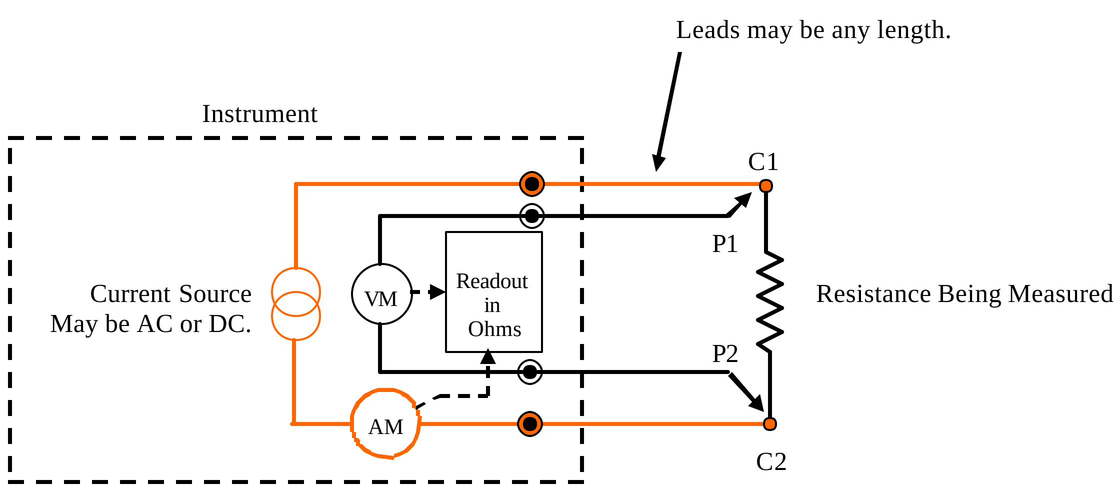
However, when measuring very low values of ohms, in the milli- or micro-ohm range, the two-point method is not satisfactory because test lead resistance becomes a significant factor.

A similar problem occurs when making ground mat resistance tests, because long lead lengths of up to 1000 feet, are used. Here also, the lead resistance, due to long lead length, will affect the measurement results.

The four-point resistance measurement method eliminates lead resistance. Instruments based on the four-point measurement work on the following principle:

- Two current leads, C1 and C2, comprise a two-wire current source that circulates current through the resistance under test.
- Two potential leads, P1 and P2, provide a two-wire voltage measurement circuit that measures the voltage drop across the resistance under test.
- The instrument computes the value of resistance from the measured values of current and voltage.

Four-Point Measurement Diagram



Three-Point Resistance Measurements

The three-point method, a variation of the four-point method, is usually used when making ground (earth) resistance measurements. With the three-point method, the C1 and P1 terminals are tied together at the instrument and connected with a *short* lead to the ground system being tested. This simplifies the test in that only three leads are required instead of four. Because this common lead is kept short, when compared to the length of the C2 and P2 leads, its effect is negligible. Some ground testers are only capable of the three-point method, so are equipped with only three test terminals. The three-point method for ground system testing is considered adequate by most individuals in the electrical industry.

The four-point method *is* required to measure soil resistivity. This process requires a soil cup of specific dimensions into which a representative sample of earth is placed. This process is not often employed in testing electrical ground systems although it may be part of an initial engineering study.

Ground Testing
Methods

Purpose

The purpose of electrical ground testing is to determine the effectiveness of the grounding medium with respect to true earth. Most electrical systems do not rely on the earth to carry load current (this is done by the system conductors) but the earth may provide the return path for fault currents, and for safety, all electrical equipment frames are connected to ground.

The resistivity of the earth is usually negligible because there so much of it available to carry current. The limiting factor in electrical grounding systems is how well the grounding electrodes contact the earth, which is known as the soil / ground rod interface. This interface resistance component, along with the resistance of the grounding conductors and the connections, must be measured by the ground test.

In general, the lower the ground resistance, the safer the system is considered to be. There are different regulations which set forth the maximum allowable ground resistance, for example: the National Electrical Code specifies 25 ohms or less; MSHA is more stringent, requiring the ground to be 4 ohms or better; electric utilities construct their ground systems so that the resistance at a large station will be no more than a few tenths of one ohm. Grounding methods and techniques for ground system improvement will be covered in a future article.

TPI MFT5010 Multi-Function Tester
A Three-Point Fall-of Potential Instrument

Fall-of-Potential Instrument Characteristics

- To avoid errors due to galvanic currents in the earth, most ground test instruments use an AC current source.
- A frequency other than 60 hertz is used to eliminate the possibility of interference with stray 60 hertz currents flowing through the earth. The TPI instrument pictured at left uses 575 Hz @ less than 50 volts.
- A three- or four-point measurement technique is utilized to eliminate the effect of lead length.
- The test procedure, known as the *Fall-of-Potential Method*, is described on the following page.

Clamp-On Instrument Characteristics

The clamp-on ground test instrument is a relatively new concept which is particularly well suited for testing the effectiveness of individual equipment grounding conductors that are connected to an existing ground grid.

- Clamp-on type ground testers are simple and easy-to-use. The instrument injects a current pulse into the ground conductor and calculates the value of the ground conductor resistance from the current pulse amplitude.
- Some instruments can store the result of a number of readings which simplifies field record keeping.
- Calibration loop is included with instrument.

Clamp-On Type Ground Tester
Shown with calibration loop

Ground Testing

Three-Point Fall-of-Potential Test Procedure

Ground Test Procedure

Refer to Diagram and Example Graph on the Following Page.

The instrument connections shown on the following page are for a three-point instrument, so C1 and P1 are common on the instrument and only three test leads are used. To use a four-point instrument, simply tie the C1and P1 leads together (most four-point instruments have a removable shorting link between the C1 and P1 terminals for this purpose).

AC current of a non-standard frequency is usually used for ground testing to minimize the effect of galvanic (DC) currents as well as 60 Hz fundamental and harmonic currents which are present in the earth. The TPI 5010 Multi-function tester detailed in this article produces a 50 volt, 575 Hz test signal.

In the Fall-of-Potential Method, two small ground rods - often referred to as ground spikes or probes - about 16 " long are utilized. These probes are pushed or driven into the earth far enough to make good contact with the earth (8" - 12" is usually adequate). One of these probes, referred to as the *remote current probe*, is used to inject the test current into the earth and is placed some distance (often 100') away from the grounding medium being tested . The second probe, known as the *potential probe,* is inserted at intervals within the current path and measures the voltage drop produced by the test current flowing through the resistance of the earth.

In the example shown on the following page, the *remote current probe* C2 is located at a distance of 100 feet from the ground system being tested. The P2 *potential probe* is taken out toward the remote current probe C2 and driven into the earth at ten-foot increments.

Based on empirical data (data determined by experiment and observation rather than being scientifically derived), the ohmic value measured at 62% of the distance from the ground-under-test to the remote current probe, is taken as the system ground resistance.

The remote current probe must be placed out of the influence of the field of the ground system under test. With all but the largest ground systems, a spacing of 100 feet between the ground-under-test and the remote current electrode is adequate. With adequate spacing between electrodes exists, a plateau will be developed on the test graph. Note: A remote current probe distance of less than 100 feet may be adequate on small ground systems.

When making a test where sufficient spacing exists, the instrument will read zero or very near zero when the P2 potential probe is placed near the ground-under-test. As the electrode is moved out toward the remote electrode, a plateau will be reached where a number of readings are approximately the same value (the actual ground resistance is that which is measured at 62% of the distance between the ground mat being tested and the remote current electrode). Finally as the potential probe approaches the remote current electrode, the resistance reading will rise dramatically. The electrical fields associated with the ground grid and the remote electrode are illustrated on Sheet 5. An actual ground test is detailed on Sheet 6 and a sample Ground Test Form is provided on Sheet 7.

Short Cut Method

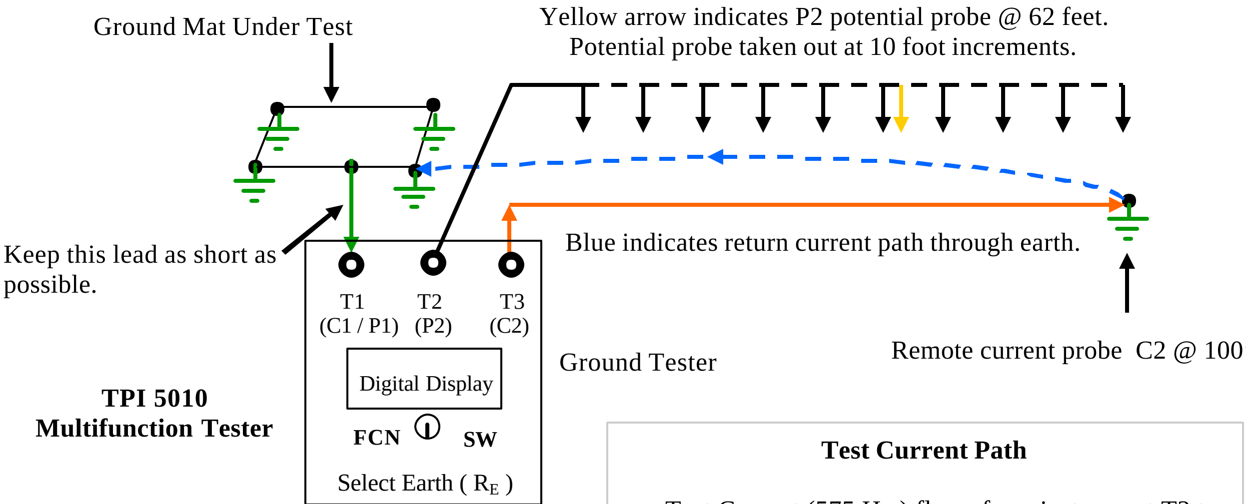
It is not absolutely necessary to make a number of measurements as described above and to construct a graph of the readings. We recommend this as it provides valuable data for future reference and, once you are set-up, it takes only a few minutes to take a series of readings. However, the short cut method described here determines the ground resistance value and verifies sufficient electrode spacing - a*nd it does save time*.

- Connect the instrument P1/C1 lead to the ground system being tested with a short conductor.
- Locate the remote current electrode C2 at distance of 100 feet from the ground grid being tested.
- Place the P2 potential probe at 62 feet from the ground grid being tested and measure the ground resistance.
- Move the P2 potential probe 10' to either side of the 62' point (this would be at 52' and 72' from the ground grid) and take readings at each of these points. If the readings at these two points are essentially the same as that taken at the 62' point, a measurement plateau exists and the 62' reading is valid.

Ground Testing

Three-Point Fall-of-Potential Method

Instrument Set-Up



A Note on Instrument Labeling Conventions

Most Ground Testers are single-function units and the test terminals are referred to as C1/P1, P2 & C2, as shown in parenthesis in the diagram above. The test leads carry the same designations.

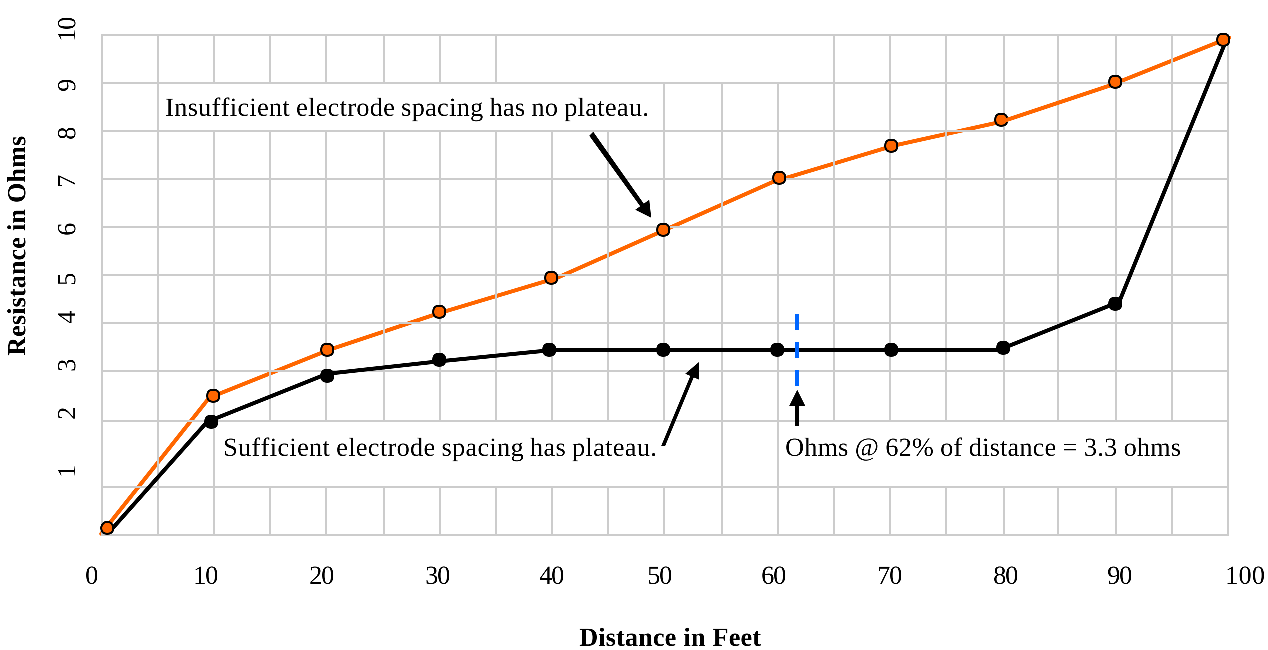
The TPI tester is a multifunction tester and uses the terminal designations T1, T2, & T3. The corresponding lead designations are E (Earth), S & H.

Test Current Path

- Test Current (575 Hz) flows from instrument T3 to remote current probe C2 on the red lead.
- Test Current flows from remote current probe C2 back through the earth to the ground being tested as shown by dashed blue line.
- Test current flows out of ground grid back to instrument T1 on the short green lead.
- Black potential lead P1 is connected to instrument T2 and is taken out at 10' increments. It measures voltage drop produced by the test current flowing through the earth. (P1 to P2 potential.)

Sample Ground Resistance Plot

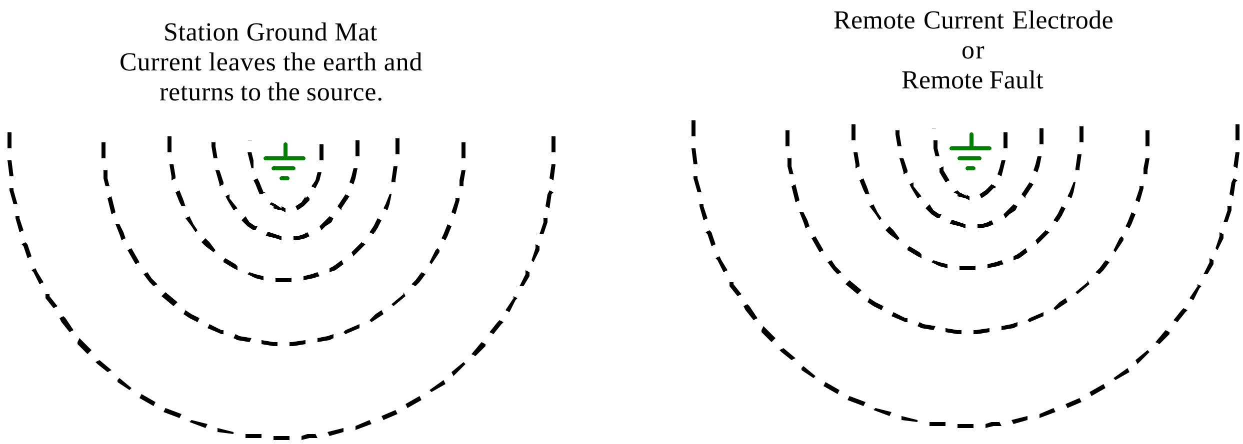
Remote current electrode C2 @ 100 feet.
Potential probe P1 taken out at 10 foot increments.



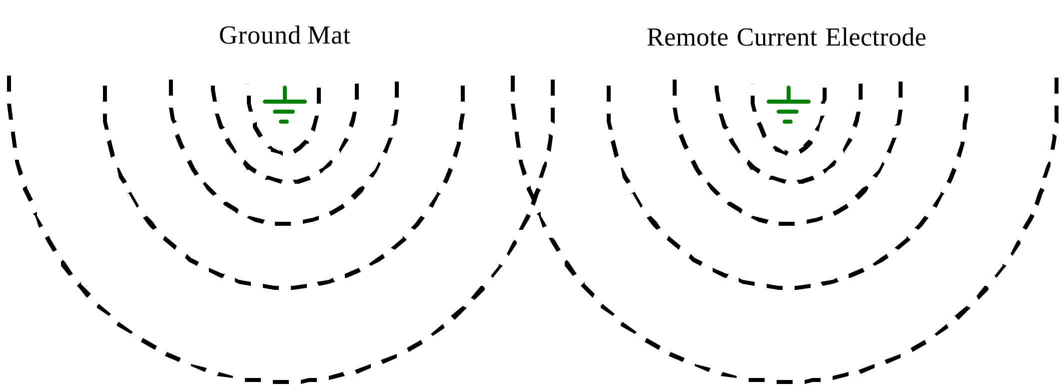
Ground Testing
Equal-Potential Planes

The Existence of Equal-Potential Planes

- When current flows through the earth from a remote test electrode (in the case of a ground test) or remote fault, the voltage drop which results from the flow of current through the resistance of the earth can be illustrated by equal-potential planes. The equal-potential planes are represented in the dashed lines in drawings below where the spacing between concentric lines represents some fixed value of voltage.
- The concentration of the voltage surrounding a grounding element is greatest immediately adjacent to that ground. This is shown by the close proximity of lines at the point where the current enters the earth and again at the point where the current leaves the earth and returns to the station ground mat.
- In order to achieve a proper test using the Fall-of-Potential Ground Test Method, sufficient spacing must exist between the station ground mat being tested and the remote current electrode such that the equal-potential lines do not overlap. As shown by the black line in the Sample Plot on the previous page, adequate electrode spacing will result in the occurrence of a plateau on the resistance plot. This plateau must exist at 62% of the distance between the ground mat and the remote electrode for the test to be valid. Insufficient spacing results in an overlap of these equal-potential planes, as illustrated at the bottom of this page and by the red line on the Sample Plot on the previous page.
- See the Safety Note on Sheet 6 for information on the hazards of Step and Touch-Potentials.



Representation of Equal-Potential Planes
Showing adequate spacing of electrodes



Representation of Equal-Potential Planes
Showing inadequate spacing between the established ground and remote test electrode.

Ground Testing
Actual Field Test

This actual ground test was conducted on a pad-mount transformer in a rural mountain area. The single-phase transformer is supplied by a 12470/7200 volt grounded wye primary and the transformer is grounded by its own ground rod as well as being tied to the system neutral which is grounded at multiple points along the line. The distribution line is overhead with just the "dip" to the transformer being underground.

Setting-Up the Ground Tester
Red arrow shows location of C2 probe.

TPI MFT5010 Instrument
Showing the 50 foot reading of 4.0 Ohms.

Ground Test Data

Remote Current Probe C2 @ 100 Feet

P2 Distance from Transformer in Feet	Instrument Reading in Ohms
10	1.83
20	3.59
30	3.85
40	3.95
50	4.0
60	4.25
62*	4.3
70	4.5
80	5.4
90	7.3
100	25.02

* Actual Ground resistance.

Test Procedure

Terminal T1 of the TPI 5010 tester was connected to the transformer case ground with a short green lead.

The remote Current Probe C2 was driven in the ground at a location 100 feet from the transformer and connected to Terminal T3 of the instrument with the red test lead.

Terminal T2 of the tester was connected, using the 100' black lead, to the P2 potential probe. This ground stake was inserted into the ground at 10' intervals and a resistance measurement was made at each location and recorded in the table at the left.

The relatively constant readings in the 4 ohm range between 40 and 70 feet is a definite plateau that indicates sufficient lead spacing. The initial readings close to the transformer are lower, and there is a pronounced "tip-up" as the P2 probe approaches the remote current electrode C2.

The measured ground resistance at 62 feet (62% of the distance) was 4.3 ohms and is taken as the system ground resistance. This is an excellent value for this type of an installation.

Safety Note - Possible Existence of Hazardous Step and Touch Potentials
It is recommended that rubber gloves be worn when driving the ground rods and connecting the instrument leads. The possibility of a system fault occurring at the time the ground test is being conducted is *extremely* remote. However, such a fault could result in enough current flow through the earth to cause a possible hazardous step potential between a probe and where the electrician is standing, or hazardous touch potential between the probes and the system ground. The larger the system, in terms of available fault current, the greater the possible risk.

Dist	Dial	X	Ohms

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Ground Resistance Test

Company		Mat Location		Date
Test By	Instr. Type	Current Probe @ Ft.	Mat Resistance	
Weather	Surface Condition		Soil Type	
Remarks				

Feet

Ground Resistance @ 62 % Distance ▼

0 10 20 30 40 50 60 70 80 90 100

Sketch

↑ N

Ohms