Resistance Measurements
Three- and Four-Point Method

Four-Point Resistance Measurements

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

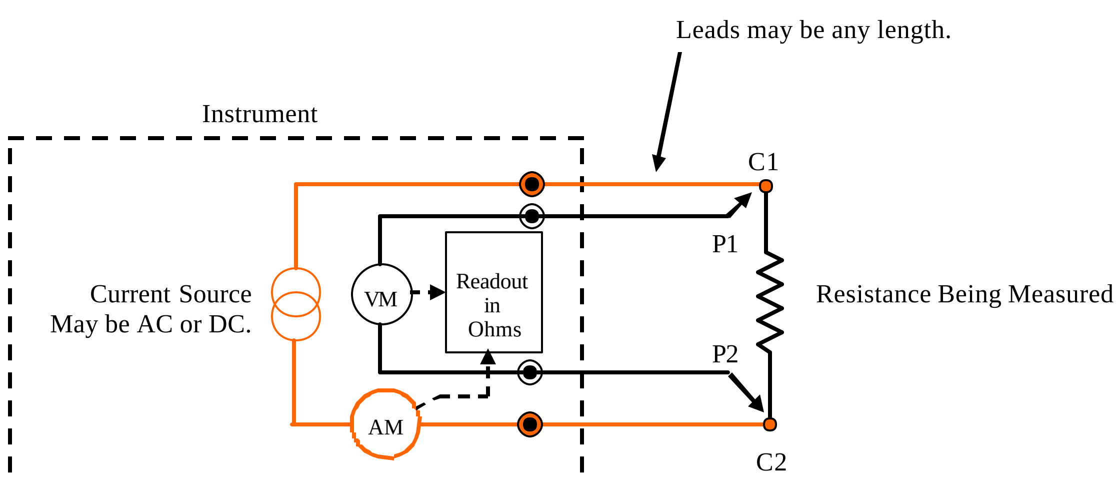
However, when measuring very low values of ohms, in the milli- or micro-ohm range, the two-point method is not satisfactory because test lead resistance becomes a significant factor.

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 and is employed on the TPI MFT5010 and the TPI ERT1500.

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

Purpose / TPI Instrument Features

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.

TPI Ground Test Instrument Characteristics

- To avoid errors due to galvanic currents in the earth, TPI 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 three-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.

Test Products International
Three-Point Fall-of-Potential Ground (Earth) Resistance Testers

TPI MFT5010 Multi-Function Tester
Uses 570 Hz signal at less than 50 Volts RMS for Ground (Earth) Testing.

TPI ERT1500 Earth Resistance Tester
Uses 800 Hz signal at less than 50 Volts RMS for Ground (Earth) Testing.

Ground Testing
Three-Point Fall-of-Potential Test Procedure

Ground Test Procedure
Refer to diagram and example graph on the following page.

In the Fall-of-Potential Method, two small ground rods - often referred to as ground spikes or probes - about 12 " long are utilized. These probes are pushed or driven into the earth far enough to make good contact with the earth (8" - 10" 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. When 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.

It is not absolutely necessary to make a number of measurements as described above and to construct a graph of the readings. However, 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.

The electrical fields associated with the ground grid and the remote electrode are illustrated on AN0009-5.
An actual ground test is detailed on AN0009-6, and a sample Ground Test Form is provided on AN0009-7.
See AN0009-8 for a simple shop-built wire reel assembly for testing large ground systems.

Short Cut Method
TPI MFT5010 & TPI ERT1500

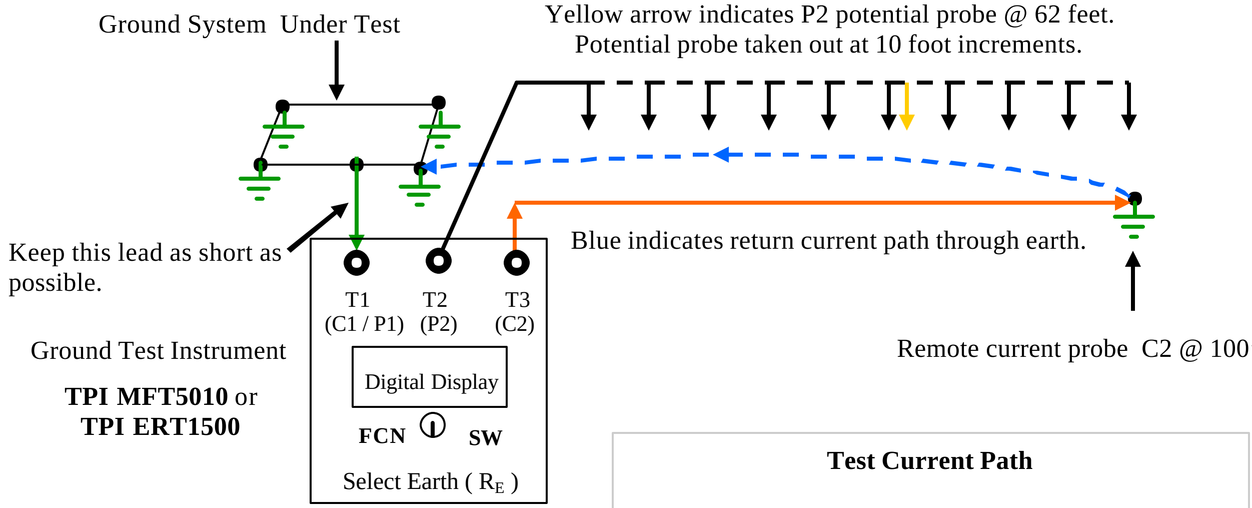
The short cut method described here determines the ground resistance value and verifies sufficient electrode spacing - a*nd it does save time*. This procedures uses the 65' leads supplied with the TPI instruments.

- Connect the T1 instrument jack with the 15' green lead to the ground system being tested.
- Connect the T3 instrument jack with the red lead to the remote current electrode (spike) placed at distance of 65' (full length of conductor) from the ground grid being tested.
- Connect the T2 instrument jack with the black lead to the potential probe placed at 40 feet (62% of the 65' distance) from the ground grid being tested and measure the ground resistance.
- Move the P2 potential probe 6' (10% of the total distance) to either side of the 40' point and take readings at each of these points. If the readings at these two points are essentially the same as that taken at the 40' point, a measurement plateau exists and the 40' reading is valid. A substantial variation between readings indicates insufficient spacing.

Ground Testing

Three-Point Fall-of-Potential Method

Instrument Set-Up



A Note on Instrument Labeling Conventions

The TPI MFT5010 and TPI ERT1500 use the terminal designations T1 (C1/P1), T2 (P2), and T3 (C2).

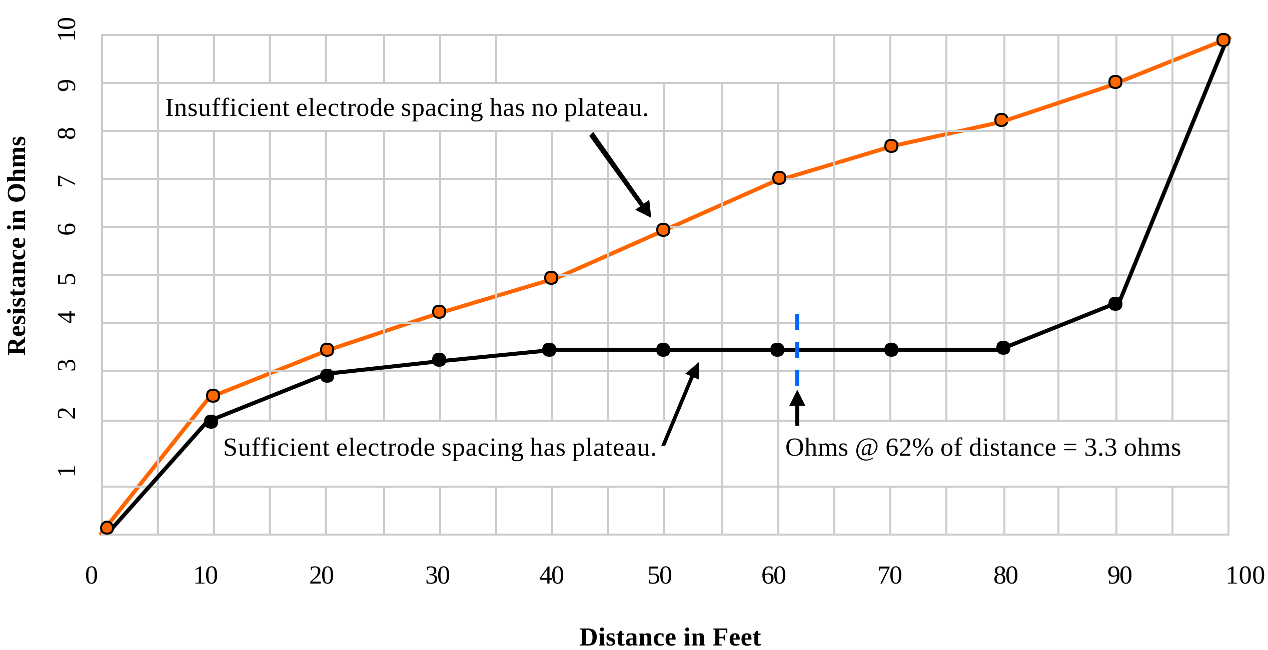
The corresponding lead designations on the MFT5010 are E (Earth), S & H.

The corresponding lead designations on the ERT1500 are E (Earth), P (Potential), C (Current).

Test Current Path

- Test Current (AC) 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.



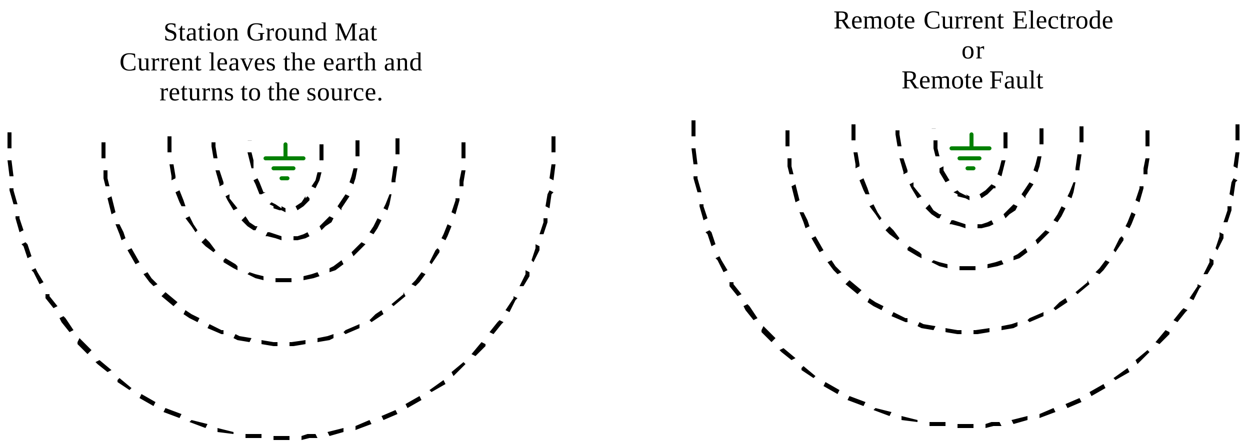
The Existence of Equal-Potential Planes

- 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.

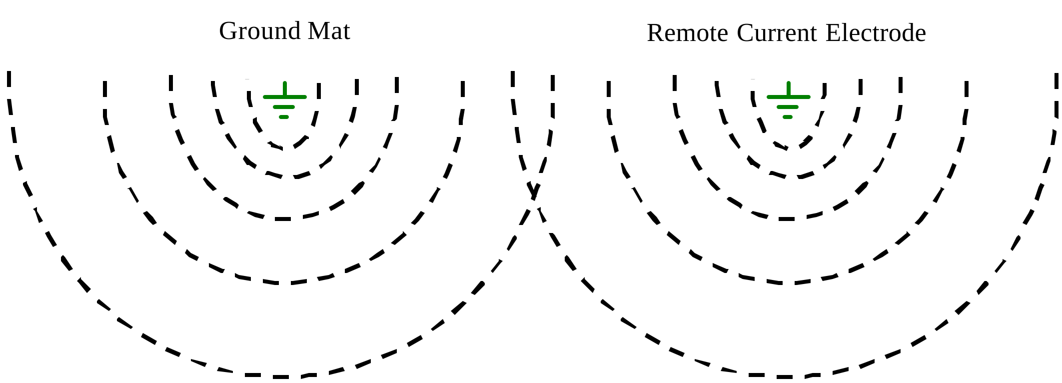
- The concentration of the voltage surrounding a grounding element is greatest immediately adjacent to that ground. This is shown by the close proximity of lines at the point where the current enters the earth and again at the point where the current leaves the earth and returns to the station ground 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 AN0009-6 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 MFT5010 tester was connected to the transformer case ground with the 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.

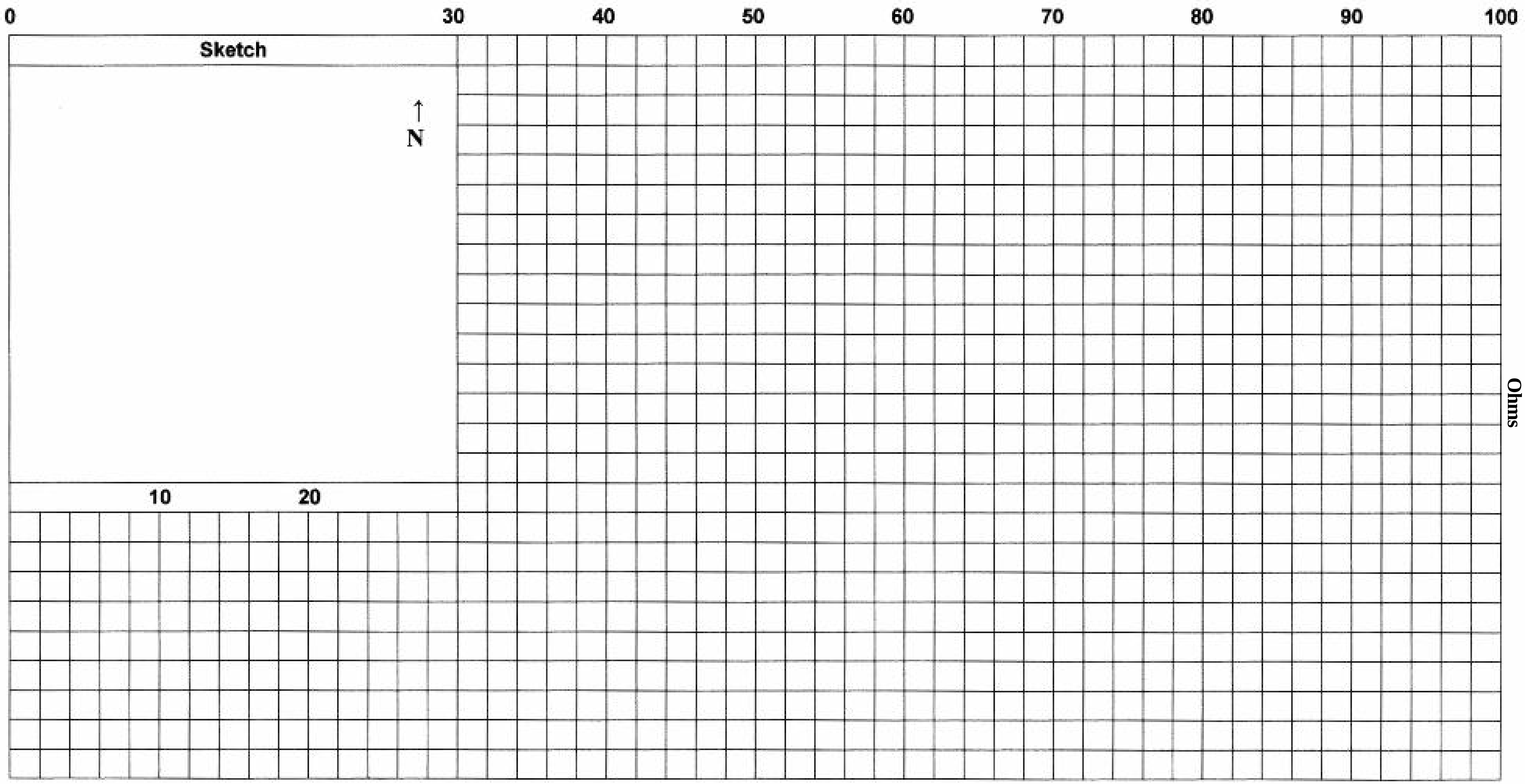
Dist	Dial	X	Ohms

www.kilowattclassroom.com Kilowatt Classroom, LLC. Phone/Fax 307-265-2665

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
▼



A Shop-Built Ground Test Wire Reel Assembly

This simple, low-cost, and easy-to-build wire reel assembly is handy for making Ground (Earth) Resistance measurements on large ground systems. The unit shown below has 500 feet of wire for testing medium-to-large ground fields typical of those found in industrial plants and substations. For testing even larger systems, such as those installed for power generating plants, wire lengths of 1000 feet can be used. Wrap-on wire markers are installed every ten feet on the current lead to simplify placement of the remote current and potential probes. Your electrical distributor will probably have empty surplus reels available for the asking - the ones shown below are about 12 inches in diameter. The conductor is standard #12 THHN. Even though the TPI ERT1500 and the MFT5010 use an AC test signal, the test results are unaffected by the inductance of any wire left on the reels.

Surplus Plastic Wire Reels
(2 required)

5/16” bolt inserted in tee-nut
locks center shaft in position.

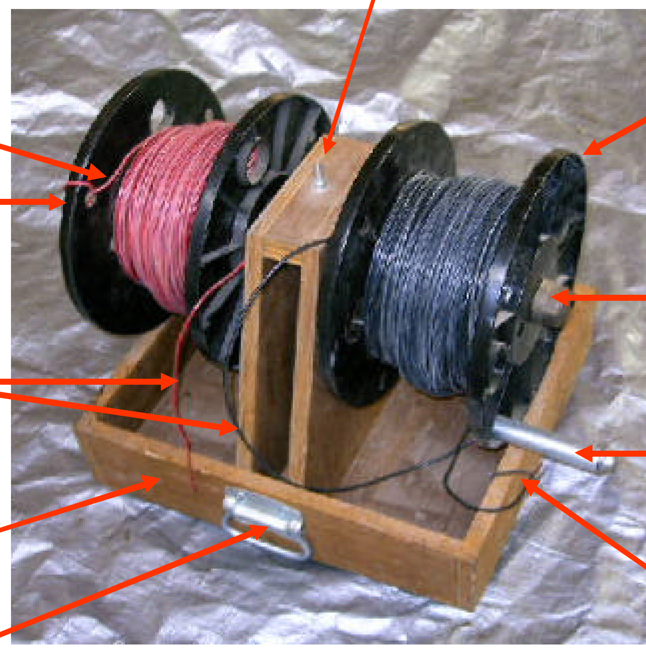
Outside conductor is
connected to remote
current ground stake.

Remote Current Lead
Mark at ten-foot intervals with
numbered wire markers to
simplify probe placement.

Bring short length of inside
conductor out from each reel for
connection to instrument.

3/4” Plywood Reel Support

Carrying Handle (2 Required)
Do not lift assembly by reel
handles.



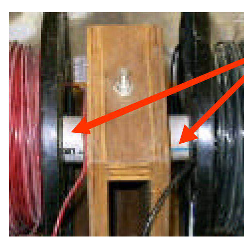
Remote Potential Lead
Take out at ten-foot intervals
toward remote current stake.

3/4” GRC Reel Shaft.
Thread ends and use pipe cap
on each end.

1/2” GRC Reel Crank Handle (2)
with 3/8” bolt center shaft.
Fasten bolt solidly to reel but leave
handle free to turn on shaft.

Outside conductor is
connected to potential
ground stake.

Detail
Center Shaft Spacers



1-1/4” PVC Spacers