Ground Testing for Communications

Megger
Power on

INTRODUCTION

We are told almost constantly that good “grounding,” and its twinned concept “bonding,” is vital to us in the communications industry. Yet, we are given contradictory standards as to the resistance value of this “good” ground. Where do these ground resistance values come from? Once we know the value of that good ground, what kind of testing can we perform to measure whether or not we have attained it?

What can we do to help make sure that, if we are installing a new ground, we achieve our target value? Or, if we are testing an existing ground and find that it does not meet the target resistance value, what can we do to improve that ground? This booklet will address these questions. These are primarily things that technicians and OSP engineers can influence.

While it is necessary to cover a certain amount of theory to understand the concepts, we will not dwell on that. There are many excellent books and papers that cover that. Instead, this is meant to be a companion to Megger’s two booklets, “Getting Down to Earth, A Practical Guide to Earth Resistance Testing” and “Guide to Clamp-On Ground Testing,” to look at grounding from a communications perspective.

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SAFETY

We will be mentioning safety throughout this discussion of grounding. However, before we start, it is important to note that there is an inherent safety problem in handling grounds and testing them that requires care and planning.

To be safe working around hazardous voltage, technicians need training to understand and maintain awareness of the dangers that will confront them.

For that training to be effective, they also need the right tools to detect hazardous voltage, which behaves differently from household levels with which we are most familiar. Because high voltage behaves differently and presents unique hazards, technician tools such as foreign voltage detectors must be designed for the job using the right materials to provide protection.

The possibility exists that a fault in the power system will cause high current to flow into the ground while we are working on or testing a ground. The person responsible must evaluate this risk, taking into account the fault current available and expected **step-and-touch potentials**. One standard that fully covers this is IEEE Standard 80 entitled "IEEE Guide for Safety in AC Substation Grounding."

WHAT IS A GROUND?

There are a number of technical definitions of a ground. One, from IEEE Standard 81, is: "a ground is a conducting connection by which an electrical circuit or equipment is connected to the earth or some conducting body."

Another definition is: low impedance conductor used to provide a safe path for the dissipation of:

- Fault currents
- Lightning strikes
- Static charges
- EMF/RFI signals

Another, a simple one, states that the characteristic of a grounded system is that there is a steady flow of current that is going to the path of least resistance. By this definition, **WE** could be the path of least resistance to ground. We do not want that path of least resistance to be through someone or some delicate equipment. We want it to be through a "ground electrode system." It may seem like an unnecessary complication to differentiate between "just any old ground" and a "ground electrode system." This current **WILL** find its way to ground and any old ground will do. We want to have a ground electrode system that takes the current where **WE** want it to go, not just to any old ground. We need to get used to thinking that we can be a path to ground and that current flowing through us can kill us just as easily at it can blow out a printed circuit board.

This current can be measured using an ammeter that measures milliamps. Often a ground will not have much current so an ammeter that is not sensitive enough – does not measure in milliamps – might indicate that there is no current flow when, in reality, there is. For safety's sake, if there are more than 2 amps, we likely have a ground fault that is unsafe.

Why do we need a good ground?

It is likely that no one reading this needs to be reminded of the many reasons why we need proper grounding. They are important to move electricity to places where it is harmless. This electricity ranges from lightning with its mega-amperages to the micro-amperages of a small static charge. Good grounding is vital for our safety and for that of our equipment and property. We used to worry about merely protecting **us**, as we were the most delicate parts of a circuit. Now it is likely to be a piece of electronic equipment that is the most delicate.

We do not mean to give short shrift to the "old reasons" that we had for caring about grounding, but there is a new reason for the recent emphasis on grounding and bonding. After all, the general categories of protecting our equipment and ourselves have been with us for a long time. It is worth digressing a bit to answer this question of "why now?"

We are often told that proper grounding and bonding improves the performance of computer, communication and other sensitive equipment. Let's go into that a bit. Unwanted electrical signals on the pairs in our cables are "noise." There are many ways to categorize this noise – coming from inside the cable (crosstalk) vs. coming from outside the cable (induced). We're concerned here with noise from outside telecom twisted-pair cables. The shields on these cables "capture" this induced noise and take it to ground, thus keeping it off the pairs. (This is from a telecom perspective. For CATV, it would be "center conductor" rather than "pairs.")

This induced noise that comes from outside the cable can also be divided into two types: steady state noise and impulse noise. Steady state noise is the same frequency and is continuous. Think of it as the hum that you hear on a circuit. Impulse noise is spontaneous or unpredictable. It occurs randomly. Think of it as the "pops and drops" that you hear on a circuit. In the **"POTS"** days, our brains could overcome the distraction of both types. We understood-by-context; our minds filled in the words that were obliterated by a pop or drop. For the steady state, we strained.

We now have data services that are digital – bits of plus and minus voltages. Without delving into why, data services can overcome the hum (steady state noise) but pops and drops (impulse noise) knock out data bits. We've had both data services and ground problems for a long time. Why are these problems suddenly important? Two factors:

- Without going too deeply into it, protocols used in these data services compare what they received with what was sent. If there is a discrepancy, the receiving device asks the sending device to retransmit. To some extent protocols, even going back to T-1, can recover a limited number of lost bits. If the customer noticed this at all, it was only as a slowing of the data rate.
- As we said, we have had data services since the 1980s with ISDN. That ISDN was 144 kbps. Today's ADSL2 is 8 Mbps and VDSL2 is up to 52 Mbps. So, as data rates increase, the same length "hit" knocks out more **bits**. Also, architectures and compression protocols allow each bit to carry more information, so the same length "hit" knocks out more **data**. We had this in ADSL and even ISDN. What changed with VDSL? The customer no longer just experiences a slowdown in throughput. VDSL is **REAL TIME** – pixilation in television vs. retransmits in internet access. Pixilation is unacceptable to the customer.

Impulse noise **ALWAYS** comes from outside the cable. It is **ALWAYS** a sign of bad grounding and bonding. If the shields were properly bonded together and grounded, the impulse noise would go to ground and not get on the cable pairs. Higher data rates and real-time services force us to clean up our bonding and grounding.

We can estimate the monetary costs of inadequate grounding and bonding in the costs of extra service calls, overtime and damaged equipment. Some of the "costs" of grounding and bonding problems, while probably greater, are harder to attach a monetary figure to. These include customer satisfaction, reputation of our company and its services, and perhaps even such things as liability if an alarm circuit fails.

How to get good grounds

We are going to attack the problem of getting good grounds as if we have a **greenfield** for which we need to design and install a ground, or that we have an existing ground that has been found to be inadequate and needs to be improved.

We are first going to consider two different but related measurements concerning grounds:

- Soil resistivity is the goodness of the soil for conducting electricity. It is measured in ohm-centimeters (ohm-cm). An ohm-cm is defined as the resistance of a cube of material, in this case earth, with the cube's sides being one centimeter.
- Ground resistance is what we usually think of when we consider grounds. It is opposition to current flow of the ground. For example, "We need a 25 Ohm ground."

Resistivity - we more or less instinctively know that some materials are better conductors of electricity than others. We just "know" that wet or moist materials are better conductors than are the same materials when they are dry. We know, for instance, that loamy topsoil is a better conductor than dry sand. Resistivity gives us a way to quantify this difference in materials as to their ability to conduct electricity. We can use this to help design a ground system that meets our objective.

Since resistivity might change as the depth changes, it is important to know resistivity at various depths to determine if we need more ground rods or longer ones to achieve a better, lower resistance ground.

We measure resistivity for several reasons:

- We measure at several places on a site to find the best location and depth for ground rod(s).
- Every company or location seems to have a "standard" or "generic" ground plan. They might use, for example, a single 8-ft (2.4 m) rod or a single 10-ft (3 m) rod or perhaps two 8-ft (2.4 m) rods. While this standard plan is based on experience, if they install that standard, they are not guaranteed that they will achieve their desired resistance. They might be surprised after going to the work of installing it and then find that it is not good enough. What then? Should they install a longer rod, install more rods, or use some method of augmenting the ground? If they had measured resistivity, they could have planned what they needed to do to achieve their goal and avoid surprises.
- In general, spots where the resistivity values are low tend to increase the potential for corrosion. So if this is the case, they might consider using galvanized rods and hardware.

There are no hard and fast rules but based on experience, we can say that with respect to resistivity measurements, when we want a ground of 25 ohms or less, if we get a resistivity of less than 15,000 ohm-cm, the standard design will likely work. Resistivity of between 15,000 and 25,000 ohm-cm may work. Resistivity of between 25,000 and 50,000 ohm-cm requires special consideration to augment the ground. Resistivity greater than 50,000 indicates that a 25 ohm ground may not be practical.

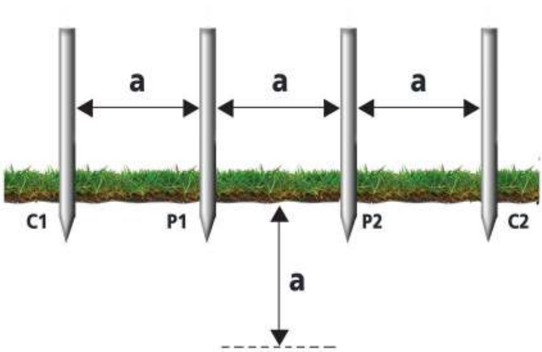
The following table from Evershed & Vignoles Bulletin 245 gives the resistivity of various materials both when they are wet and when they are dry.

RESISTIVITY OF DIFFERENT SOILS WET AND DRY	
Soil Type	**Resistivity Range Ohm-cm**
Loam	**100 – 5,000**
Clay	**200 – 10,000**
Shales	**500 – 10,000**
Limestone	**500 – 400,000**
Surface Limestone	**10,000 – 1,000,000**
Slates	**1,000 – 10,000**
Sandstone	**2,000 – 200,000**
Sand & Gravel	**5,000 – 100,000**
Granite, Basalt, Etc.	**100,000**

The numbers in this table are not, in and of themselves, important for our purpose of discussing grounds but rather to show a couple of things:

- For those soils that have a wide range of resistivity, such as surface limestone, the lower number is when it is wet or moist and the higher one is when it is dry. So we need to keep in mind dampness or wetness, as well as the range of dampness the site is likely to experience when measuring and designing ground systems.
- Some things, such as granite, will never make a good ground.

Resistivity is measured with a four-stake test set with the stakes placed in a line as shown in the illustration below.

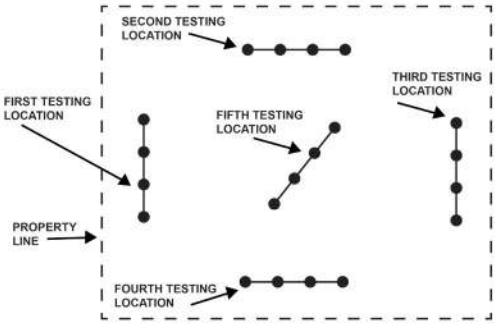


This measures the average soil resistivity to a depth equal to how far apart the stakes are. Let's say that our standard practice is to use an 8-ft (2.4 m) ground rod. (So, we want to measure the resistivity to a depth of 8 ft [2.4m].) To do this, place the stakes 8 ft (2.4 m) apart and put them in the ground in a line 1/20 of 8 ft (2.4 m) into the ground, which is approximately 5 inches (13 cm).

The point is that we can determine if the resistivity gets better or worse as we go deeper by moving the stakes further apart and putting them a little deeper. Perhaps our tests indicate that we need to do more to get the desired resistance. If resistivity gets better as we go deeper, we should use the same number of rods, just have them be longer. If it gets worse as we go deeper, we need more rods of the same length.

If we did not initially test resistivity and we discover that we did not get the resistance that we need after we install our ground rod, we might want to test resistivity at a different depth than that of our ground rod to see if it increases or decreases as we increase depth.

In addition to measuring resistivity at different depths, if we have the space, we measure it at different places in our site as shown in the diagram below. We “prospect” for the best place to put our ground rod.



Resistivity changes over time. Anything that changes the amount of moisture in the soil changes the resistivity. These are seasonal variations, climate changes such as drought, grading on or near the site, and building additions on or near the site.

For the reader who wants more technical information on resistivity including the mathematical underpinnings, Megger's aforementioned booklet, "Getting Down to Earth, A Practical Guide to Earth Resistance Testing" provides it.

Even if we never test resistivity, we need to understand the concept. Understand that resistivity varies with depth and location and that, because of various factors, it changes over time.

Resistance - Now that we have discussed resistivity, let's consider the second measurement: resistance. Resistance is the opposition to current flow. This is what we normally think of when we think of grounds.

In the communications industry there are all kinds of ground resistance standards or goals. Various equipment manufacturers and standards bodies establish these. They range from a single ohm upward. If the standards are all over the place, why do we keep hearing variations of "We need a 25 ohm ground?" That is because 25 ohms protects us. Both the National Electric Code (Section 250) and IEEE (STD81) specify that grounds be 25 ohms or less.

These “25 ohm” standards have been around for a long time. They date from when we were the most delicate part of a circuit. Since then, there are tougher standards because nowadays we are likely NOT the most delicate part of a potential circuit. Rather, very sensitive electrical equipment may be. So, if we want the ground circuit to be the path of least resistance, we often need a ground resistance of less than 25 ohms.

TESTING

When testing grounds, use a test set that is a dedicated ground tester. It is designed to measure grounds. Problems with other types of resistance testers are:

- When using a “regular” ohmmeter, low voltage DC can produce a resistance reading between ground and some arbitrary second point (for example, a water pipe), but not necessarily an accurate measurement. Pipe systems may have unexpectedly high resistance (repairs made with non-conductive materials). There may not be sufficient spacing between the two points of contact. DC transients in the soil can influence the readings.
- The insulation resistance tester’s high voltage DC is designed to measure at the opposite end of the resistance spectrum, with all the limitations discussed above.
- The ground test function of telecom multi-function testers is used to measure the resistance between the Central Office ground and the local ground. (The test can only be performed using a good working pair.)

There are two basic test sets for testing grounds, stake-type and clamp-on-type. We'll cover both but we'll do the stake-type first.

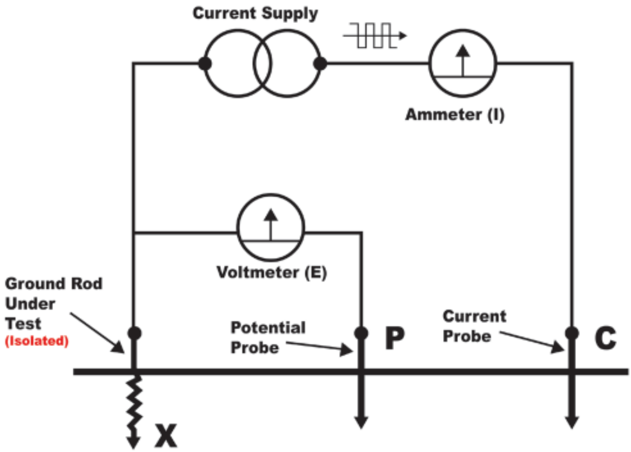
Stake-Type Testing - Ground testers use Ohm's Law so let's review that. Resistance, voltage and current are related such that if we know the value of two of these, we can calculate the value of the third. Ohm's Law can be stated in several ways but for our purposes:

Resistance = Voltage ÷ Current

or

Ohms = Volts ÷ Amps

So, if we know the voltage and current in a circuit, we can find the resistance. That is what the test sets do. With the push of a single button, they create a circuit involving the ground where they measure the voltage and the current and then calculate resistance.



This is how a stake-type ground tester works:

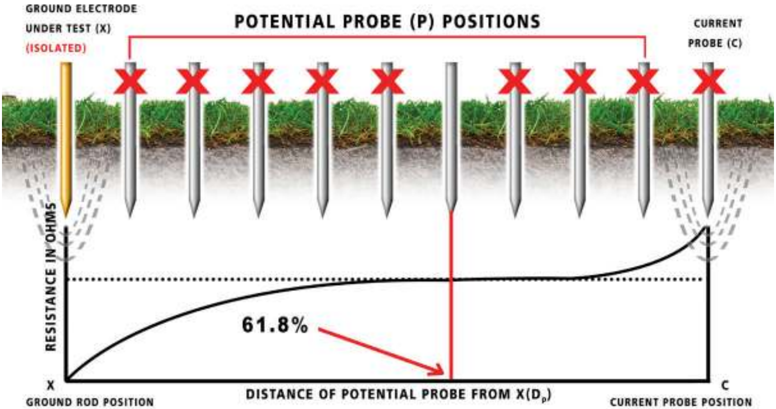
Assume that two stakes have been driven into the earth in a line some distance apart from an installed ground rod and a voltage applied between the two ends of the set-up:

- The **current** between X and C is measured by an ammeter.
- The **voltage** between X and P is measured by a voltmeter.

We now know the current and voltage of this circuit and, as we saw above, we can calculate the resistance which is the ground resistance.

All these measurements and calculations are performed automatically by the test set.

Note: When testing existing facilities, disconnect the ground from the power neutral and other grounds. The ground under test must be isolated.



How is this actually done with a stake-type tester? There is something that we need to understand first. "Shells" of earth surround the ground rod and stakes. These can be considered to be "spheres of influence." With increased distance from a rod, the earth shells are of greater surface area and, therefore, of lower resistance. If measurements are taken at various distances, a resistance curve can be plotted with resistance on the vertical axis and distance on the horizontal.

How do we do it? We move some distance from the isolated ground rod and put the "C" stake in the ground. Keep in mind the measurements we made in the previous drawing; this diagram is not depicting having nine "P" stakes in the ground but rather a single "P" stake being moved to nine different locations and a measurement taken at each.

As the "P" probe is moved away from the rod under test, the resistance values increase but only by a diminishing amount (due to the diminishing resistance of each earth shell) until a point is reached where the rate of increase becomes so small that it can be considered constant. (The earth shells between the rods have so great a surface area they add almost nothing to total resistance.) This is considered the point of true resistance.

As the "P" probe continues to move closer to the earth shells or spheres of influence of the current probe, the resistance rises in increasing increments.

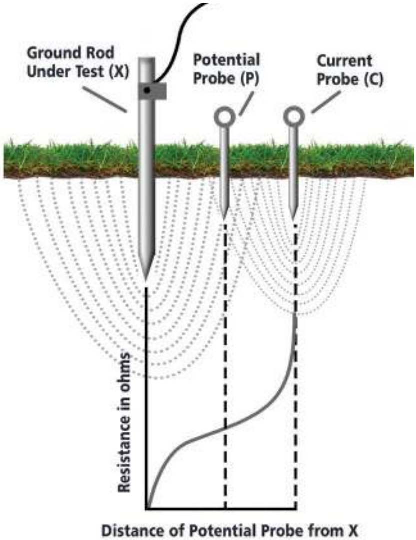
This is **"Fall of Potential" ground testing** and is the IEEE-recognized method. The true resistance of the ground rod falls in the area where the readings are not affected by the fields of influence from either the ground rod under test or the current probe. In other words, the level of true resistance of the ground rod occurs where the graph levels off before beginning a sharp upward climb as the potential probe gets close to the current probe; the flat part of the graph.

We discussed earlier about the "C" probe, the one farthest away from the ground rod, being "some distance" from the ground rod. How far is "some distance?" As a rule of thumb:

- Single ground rod - 50 ft (15 m).
- Small grid of 2 ground rods – 100 to 125 ft (30 to 38 m).
- Large system (several rods or plates in parallel) >200 ft (61 m).

Complex systems (large number of rods or other electrodes and other metallic structures bonded together) - far greater distances are required.

What happens if the distance between the ground rod and the current probe is too short? The earth shells around each will overlap and distort the measurement. Under the scenario pictured below, there is no leveling off of measured resistance as the "P" probe is moved away from the ground rod. The shells of the "C" probe add to the shells of the ground rod, so resistance keeps increasing. There is no flat spot.

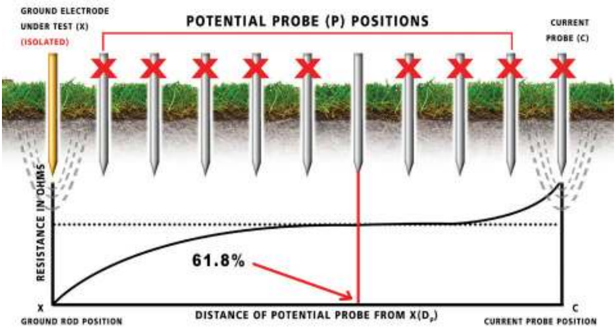


The Fall of Potential method is accurate and IEEE-approved. With the 4-wire configuration, even the resistance of the wires of the test set can be "zeroed out." This is important for measuring very low resistance (1-2¨Ω) grounds.

As mentioned above, it is accurate. However, it is also somewhat time consuming to make all the "P" probe measurements. But there is a faster way.

We saw in the Fall of Potential diagram above that there is a flat spot in the resistance curve. If the resistivity is the same across the distance, and the "C" probe is far enough away so that a flat spot exits, placing the "P" probe at a point 61.8% of the way from the ground rod toward the current probe will provide the true resistance. It is quite effective for simple rods such as a driven rod or even a small group of driven rods if we know the true electrical center accurately. We only need to make one measurement.

So, if we follow the Rule of Thumb above and place the "C" probe 50 ft (15 m) from the ground rod (X), we would need to place the "P" probe 61.8% from the ground rod or about 31 ft (9 m).



The above diagram illustrates the general condition that must be achieved for optimal testing:

- Uniform resistivity.
- Adequate spacing of the "C" probe and the ground rod (spheres of influence are separated).
- "P" probe is between "C" and the ground rod.

We have been talking about pushing our "C" and "P" probes into the dirt. What happens if we are dealing with a paved area? Referred to as the **"lazy spike" method**, some ground testers can perform Fall of Potential testing without the necessity of pushing the probes into the soil. Just laying the test probes on the surface often times works.

Some ground testers warn the operator if there is too much resistance in the test circuit, insufficient contact, to perform a test. If this happens, alternate conducting materials can be used that provide better surface contact such as coiled chains, ground rods and flexible metallized grounding mats.

If necessary, contact can be improved by pouring water on the probes. Using salt water can further improve contact as the dissolved ions help conduct current.

Watering the probes and/or using alternate materials does not "phony" the test. Remember that we are measuring the resistance of the ground rod, not the resistance of the test probes.

We have only considered two methods of stake-type testing here, Fall of Potential and the 61.8% methods. There are all kinds of testing methods. Just know that if we have something such as two skyscrapers whose walls abut each other, there is a method for measuring the resistance of the ground. The booklet “Getting Down to Earth” covers these. There are some very complex grounds and many accepted test methods available, some very specialized, to measure them.

Clamp-on, or Stakeless, testing

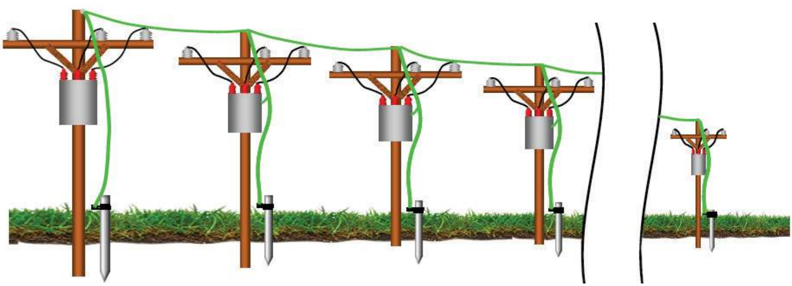
Let’s see how a clamp-on ground tester works. If we open the jaws of a clamp-on tester, we will see the ends of two coils. This tester also uses Ohm’s Law to calculate resistance. One coil of the set, the “transmit coil,” induces current of a known voltage onto a complete circuit. The other coil, the “receive coil,” measures the voltage and calculates the resistance as the stake-type tester did.

There is a big difference, however. With stake-type testing, the ground rod must be disconnected from other grounds from the power company's multi-ground neutral. The ground-under-test must be isolated. With the clamp-on method, the ground under test must be connected to another ground. That ground under test cannot be isolated. We will have more discussion of this distinction later.

For the reader who wants more information on the mathematical foundation of clamp-on testing, Megger's aforementioned booklet, "Guide to Clamp-On Ground Testing" provides it.

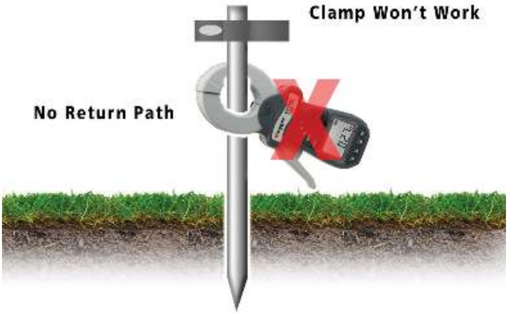
The clamp-on method seems very easy to use; so easy to use that it gets misused. If you remember the three conditions that we are about to cover, you will use it correctly.

The first of these conditions is that clamp-on testing is effective only in situations with multiple grounds in parallel such as pole grounds.



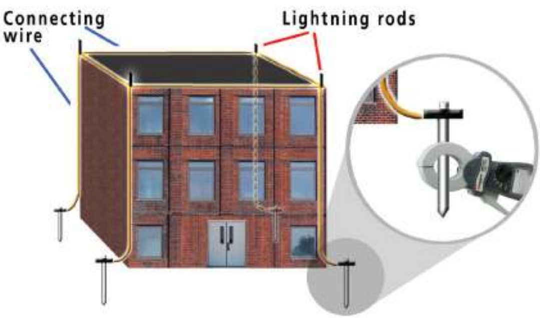
There are multiple ground paths and multiple grounds in parallel. If we clamp around a wire, the voltage induced by the transmit coil flows in all these multiple, parallel paths. We have many return paths for the voltage that we must measure.

The second of three conditions for using clamp ground testing is a corollary of the first. It requires a good return path so it cannot be used on isolated grounds.



There is no circuit so no current can flow.

The third of these conditions is that clamp-on testing cannot be used if an alternate, lower resistance return path exists not involving the soil. Let's look at some examples that illustrate this.



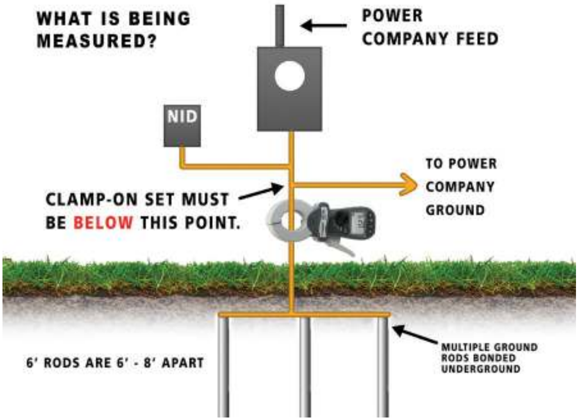
Above is a diagram of a building with lightning rods at the corners. These rods are connected by wire running along the edge of the roof. They are also connected to ground rods via wires running down the corners of the building.

What happens if we clamp around the wire that runs around the roof (the wire that connects the lightning rods)? As we saw, one coil of the clamp-on set induces current onto the wire. This seeks the PATH OF LEAST RESISTANCE back to the test set where voltage is measured. What is the path of least resistance? It is around the wire, which does not involve the soil. We are simply measuring the continuity of the wire. We will get a reading of an ohm or two which leads to a "rule" when using clamp-on testing: "If the reading seems too good to be true, it probably is."

Measuring continuity is not a bad thing; it is just not measuring the ground. If we measure anywhere below the lightning rods (as illustrated above), the only way that the electricity can get back to the set is through the soil, so we are getting a good ground resistance measurement when we do that.

Let's look at some more examples that illustrate this third rule.

The multiple ground rods in the following illustration will test as a single ground "system" so the resistance of the entire three-rod "system " is being measured by the set. From where the test set is placed, the path for the voltage is down the wire to the ground rods, through the dirt, to other grounds attached to the power company grounds and back through those grounds.



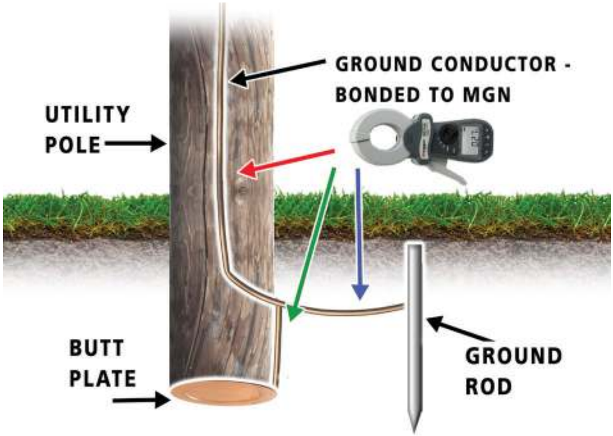
In the diagram above, what would be measured if the test set were clamped around the wire above where it branches off to the power company ground, for example, somewhere around where the wire from the **NID** is attached? The path of least resistance for the voltage induced by the transmit coil of the test set would be down to the wire labeled "to power company ground," onward on that wire to the power company ground, where it would travel via what is labeled "Power Company Feed" to the receive coil of the test set which would complete a metallic circuit. We would be measuring continuity of that metallic circuit and not the ground.

The above diagram makes it look easy to decide where to measure the ground. In reality, there might be several ground wires, Ufer grounds (discussed below) etc., to complicate things and what you actually might encounter is depicted in the pictures below.

Reality

The above photos at different places on the same building show what happens over the years as buildings and lots are modified, communication services are changed and wires are added. We do not know what is under the concrete. We can see that it was dug up for something but what is under the replaced pavement is unknown.

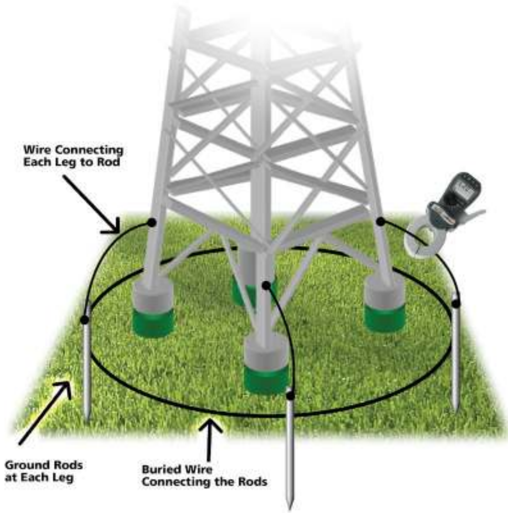
The question is where to measure. With all the weathering of connectors, and insulation in the form of paint being added at connections, even a metallic continuity can have a resistance that makes it look like a good ground. Is it a good ground? A measurement where the arrow is shown resulted in a reading of 6 Ohms. This is believable for either a good ground or for bad connectivity. Which is it? A current measurement showed no current. So, that is not a ground. What should be done? Open the housings, trace the wires and look for current flow.



The above is a diagram of an augmented **butt ground**. Here we are concerned with measuring the various grounds associated with it:

- To measure the combined resistance of both the ground rod and the butt ground, clamp around the wire where the red arrow indicates. The current goes up the wire and on to the next grounded pole, down its wire and through the dirt to all the grounds.
- To measure the resistance of only the butt ground, clamp around the wire where the green arrow indicates. The current flows as described above except that the added ground rod is not in the circuit.
- To measure the resistance of only the ground rod, clamp around the rod or the wire where the blue arrow indicates. In this case, the butt ground is not in the circuit.

Sometimes a technician will install a rod and then measure the ground where the blue arrow is pointing. This does not measure the total ground. As we said, the technician should measure where the red arrow points.

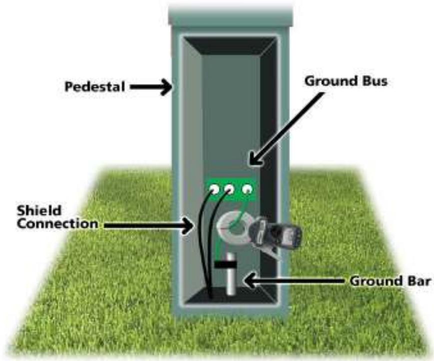


The above illustration is another example of why and where we measure are vital to getting a good measurement of ground resistance. The tower has four ground rods, one at each leg. The tops of the ground rods are below ground level. A buried wire connects these rods. The wire is connected to each leg of the tower by another wire.

If we measure around this last-mentioned wire as illustrated, we are only measuring the continuity of any of several metallic paths that are the path of least resistance back to the test set. We are not even measuring the continuity of the wire connecting the rods.

As mentioned earlier, there are other methods for measuring the resistance of this ground but in order to measure the resistance of one of the ground rods with a clamp-on set, we need to dig a hole and put the clamp around the rod BELOW where it is connected to the wire and then the other rods.

We could “cut” the other three wires from the tower to the wire ring and measure the resistance of the four-rod ground “system” as illustrated above, but someone would certainly object before we got too far. In other words, this situation is not a good application for clamp-on ground testing.



The above is a diagram of the proper way to measure a ground at a pedestal, around the ground wire. If we clamped around either of the cables, the path of least resistance is along the shield of that cable to the next pedestal, across the ground bus and back along the other shield. Therefore, we would be measuring the continuity of the shield. We could clamp around BOTH cables to measure the ground, but that is sometimes cumbersome to do.

There could be a problem when measuring grounds in a pedestal when a flat, braided copper ground strap is used to bond the cable shields to the pedestal ground. For purposes of measuring the grounds of each cable, rather than using the strap to “daisy chain” the grounds of each cable (connecting them in series) as the picture below shows, the shields must be “home runned” (independently grounded with grounds in parallel) to the pedestal ground so we can clamp around the ground of each cable and determine if there is current flowing to ground. When they are daisy chained, we get cumulative flow from all cable shields. It does not affect the resistive value of the ground to daisy chain them but rather it affects our ability to determine if each of the cables is grounded.

The following image is a ground hand-hold. We can easily test the resistance of the ground rod by clamping around the rod below where the wire is welded on to it as indicated by the arrow. It would be ideal if all hand-holds resembled this.

What do we do to measure the ground in the picture below? We can't get the clamp of a clamp-on ground tester around the rod. Perhaps we can get a small ammeter that measures in milliamps around it to determine if there is a ground at all or perhaps a ground fault. The connector is mechanical so we could disconnect it and use a stake-type ground tester but, if the bonding is welded or compression-type, we're out of luck. Sometimes it is very difficult to test.

Above is an illustration to point out that it could be worse. There could be no access. Imagine a pair of remote cabinets with a ground wire from each cabinet disappearing into the dirt underneath them. We clamp around either of the wires and get a reading of half an ohm. We know that we are measuring continuity. We get to dig around and find the ground system if we want to measure it with a clamp-on tester.

IMPROVING GROUNDS

Things that OSP technicians and OSP engineers can affect.

We commonly talk about ground rods as if grounds are always rods, so is it merely excessive "tech speak" to refer to grounds, as we have done here, as "ground electrodes?" Ground electrodes do not have to be "rods."

Solid copper ground plates are used at the corners of buildings when a very low-resistance ground is required or the soil is not deep enough or otherwise unsuitable for rods.

Ground mesh made of copper or copper-bonded steel is used as an alternative to ground plates. Power companies also use ground mesh underneath their substations to take the induced energy from the substation to ground.

Even when a ground electrode is a rod, it may be different lengths, different shapes and made of different kinds of materials and enhanced in many ways.

And, if the ground electrodes **are** rods, they can be used singly or in multiple-rod electrode arrays such as we use by putting them at the corners of a remote cabinet or in a string with large numbers of them in parallel when we ground our poles and bond them to the cable shield.

There are some factors that we need to take into consideration when selecting the type and number of ground electrodes (or rods) that we should use in a given situation.

One of these factors, perhaps the important one and something with which we are familiar, is the resistivity of the soil. If it is too high, we may need to use enhanced ground electrodes or perhaps even ground enhancement materials (more on this later). If it is low, we might want to consider galvanized rods and hardware to minimize the effects of corrosion.

Let’s look at some ways to enhance ground electrodes:

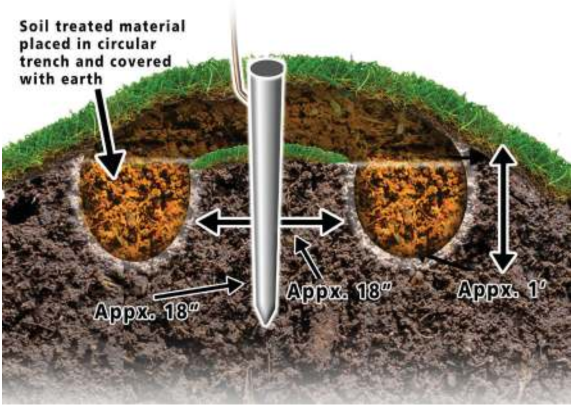
Ufer Ground - A Ufer ground is where we tie in the existing ground to the rebar used in the concrete foundation or to wire placed in the concrete for this purpose. The concrete does not have to be specially treated. While Ufer grounds should not be used as the only ground, using them often augments tower and building grounds.

As a historical note, in the early days of WWII, the U.S. was building air bases across the Southwest where good grounds were sometimes very difficult to obtain. But nevertheless, good grounds were necessary to prevent explosions in concrete ammunition bunkers. Herbert Ufer discovered that good grounds could often be obtained by tying in the existing grounds to the rebar in the concrete of the bunkers.

Chemical Improvements - Low-resistance chemicals can be back filled around ground rods or used in special systems in high resistivity soils. These vary from expensive materials that are customized for any of myriad different conditions at one end of the spectrum all the way to rock salt at the other end. They all have pluses and minuses.

Chemical treatment is not a permanent way to improve ground rod resistance. The chemicals are gradually washed away by rainfall and natural drainage, and need to be replenished. The period for replacement varies depending upon type of chemical and the “system” in which it is deployed, the porosity of the soil and the amount of rainfall. It may even be several years before another treatment is required.

Generally speaking, we only consider chemical enhancement when using longer rods or more rods is not practical.



While there are different kinds of complex, chemically enhanced ground electrode systems that have many components, the drawing above illustrates a simple method. Dig a trench around the rod that is approximately a foot deep with an inside diameter of about 18 inches (46 cm). Fill it with “magic dust” and cover with dirt. (There are many kinds of chemicals available to enhance grounds. All have pluses and minuses.)

Corrosion - As a ground rod corrodes, its resistance rises and it loses its effectiveness. We know that current flows in a grounded system. When this happens we have electrolysis and corrosion. Depending on the acidity of the soil and the amount of current, this can happen quickly.

Soil consideration – Some sites have only a few inches (or none) of soil on top of bedrock. We saw previously that bedrock such as granite has a high resistivity all the time. It does not absorb water so it does not get moist internally. In cases where we have some dirt, we need to consider plates, mesh, or chemically enhanced horizontal rods to meet the resistance goal.

Thicker rods - We might want to use a thicker ground rod. But, doubling the diameter of a rod only reduces its resistance by 10% so we use thicker rods only when strength is important.

Longer rods – Assuming that the resistivity is the same at the relevant depths, doubling the length of a ground rod reduces its resistance by 40%.

Additional rods – Probably the most used solution for reducing the resistance of a ground is adding rods. Two well-spaced rods provide parallel paths. While they are, in effect, two resistances in parallel, the Law of Parallel Resistances (which would cut the resistance of the combined, two equal, rods to half the resistance of one) does not completely hold. The reduction for equal-resistance rods is about:

- 40% for 2 rods
- 60% for 3 rods
- 66% for 4 rods

The "well-spaced" mentioned above is very important to achieve the maximum reduction in resistance. A "rule of thumb" is that the rods need to be at least as far apart as they are long. As the following table shows however, the amount of separation increases as the number of rods increases.

No. of Rods	Spacing Factor
2	1.16
3	1.29
4	1.36
8	1.68
12	1.80
16	1.92
20	2.00
24	2.16

This is not to say that additional ground rods are not effective if they are not properly spaced. Rather, they are just not as effective as they would otherwise be. Remember the earlier discussion of "spheres of influence." If the rods are spaced too close together, they are too close to each other's spheres of influence.

For the reader who wants more technical information on using thicker, longer and additional rods, Megger's aforementioned booklet, "Getting Down to Earth, A Practical Guide to Earth Resistance Testing" provides it.

THINGS WE CAN DO.

Let's consider some situations where we have a ground problem or think that we might have one.

Torque - A common response to "Let's get our grounds in shape" is to go to each pedestal and tighten all the bonds. Proper torque is important to achieve the proper connectivity of mechanical bonds such as "bullet bonds." Our tendency might be to over tighten. The torque specification is printed on the hardware's package but is usually close to 40 inch-pounds ± 5 inch-pounds.

To prove that proper torque is important, put an ammeter that measures in milliamps around a ground as you tighten a bullet bond and watch the amperage, the current flow. It increases as you approach proper torque and then goes down as you over tighten.

So, to make sure you are getting the best ground possible, use any of the torque wrenches made for this. Also, contractors that locate and mark your buried cables need to have them and know how to use them.

Determine soil condition - One way to ground poles is to run the ground wire down the pole to a butt plate located under the pole as illustrated previously. We'll just consider an unaugmented butt ground. What we need to consider is:

- They are attached to the nonconducting pole. This puts a big resistor in the "sphere of influence" that we have discussed earlier.
- How deep are they? (RUS Specs require from 6.0 to 7.5 ft (1.8 to 2.3 m) below ground. What is the resistivity of the "disturbed soil" next to and under the pole? The RUS specifies "undisturbed soil." (See Resources section for RUS, IEEE and NEC references to specifications.)

Spacing of additional ground rods – When the resistance of the butt ground just discussed is measured, it is found to be too high. The technician decides to augment it by adding a ground rod. Where should that rod be placed? Even in the absence of a butt ground, the RUS states "Ground rods shall be driven to their full length in undisturbed earth, a minimum of 2 ft (60 cm) from the face of the pole. The tops of the ground rods shall be at least 12 inches (30 cm) below the surface of the earth."

But what about the butt ground? We already discussed spacing of ground rods. RUS does not offer any guidance in this situation. When discussing butt grounds IEEE does not mention spacing between the butt ground's wire and an additional rod except to note that placing them too close together limits their effectiveness.

So, good grounding practice dictates that the additional rod be at least as far away from the wire that comes down the pole to the butt ground as the rod is long to get maximum efficiency from both. We can augment a butt ground with a rod placed a foot from the pole, we just won't get the maximum benefit from that rod.

We've discussed augmenting a butt ground because it presents interesting challenges. When we measure the resistance of any ground rod, whether it is at the bottom of a pole or next to a building and find that it needs to be augmented, we must take into account the need for adequate spacing of the rods.

GROUNDING IN COMMUNICATIONS BUILDINGS

So far, we have been concerned primarily with grounding outside plant. Let's now consider some aspects of grounding in communications buildings such as central offices, hubs and headends. We are not going to consider a lot of the physics involved in designing such grounds but rather points that cause us operational problems.

Having good grounds in hubs and headends has always been important. We have always been concerned about the damage to personnel and equipment caused by lightning and, for almost as long, static electricity. Our grounds evolved to handle those threats.

Just having good grounds in buildings that protect against these hazards is not sufficient today. We have to be concerned also with noise mitigation and the effect that ground circuits have on that. We already discussed the relation of noise to grounding on outside plant. It is also important in our hubs, headends, etc. But, we are concerned with a different aspect of grounding that goes beyond the resistance to ground. We are concerned with the BALANCE of the resistance of the elements of these hub and headend grounds, which are just as important as having a low resistance for the ground itself.

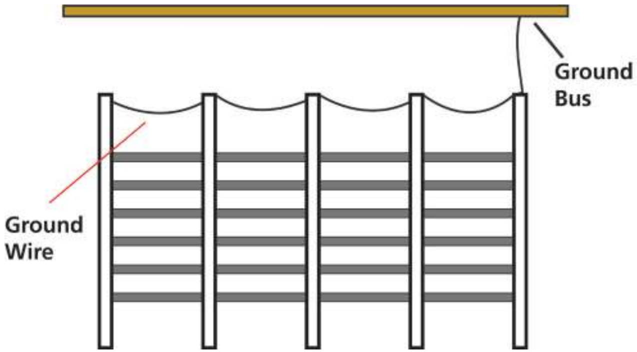
What are the "elements" of the hub and headend ground (not just the main ground bus bar)?

- Shelves are bonded to racks with screws and wire.
- Racks are bonded together to make aisles.
- Aisles are bonded to bus bars.

Aspects that can cause bonds to be bad and also to have slightly different resistances from like bonds are:

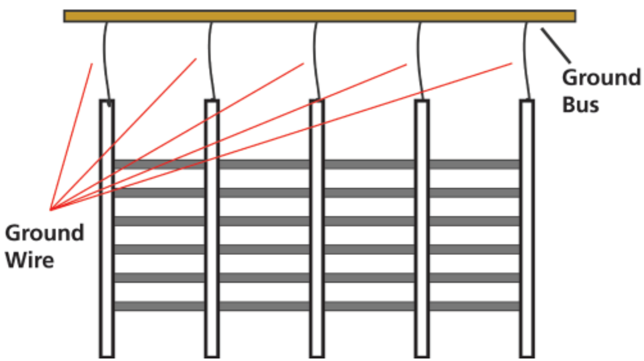
- Paint – Is there non-conducting paint between a screw-head and a rack?
- Torque – Are all connections torqued to manufacturers' specifications? Remember, over-torqueing can be as bad as under-torqueing.
- Washers – Are washers specified? If so, are the proper washers used?
- Length of cables – Resistance increases with length.
- Makeup of ground wires and cables – Are they of the proper gauge and construction?

Ground circuits can be “daisy-chained” as in the illustration below. The grounds of the racks are connected in series and at the end the last one is grounded to the bus bar.



The ground resistance of a shelf in the bottom of the left-most rack, while perhaps meeting the spec for ground resistance, even in a best-case scenario, is higher than that of a shelf at the top of the right-most rack. They will have unbalanced grounds.

As shown in the illustration below, ground circuits can be “home runs” where each rack has a ground connected in parallel with the other rack grounds to the ground bus.



Several grounds that are daisy-chained, because of the different number of bonds and greater difference in length, will likely have more variation in their resistance (be unbalanced) than would several home run grounds with their fewer bonds and similar lengths.

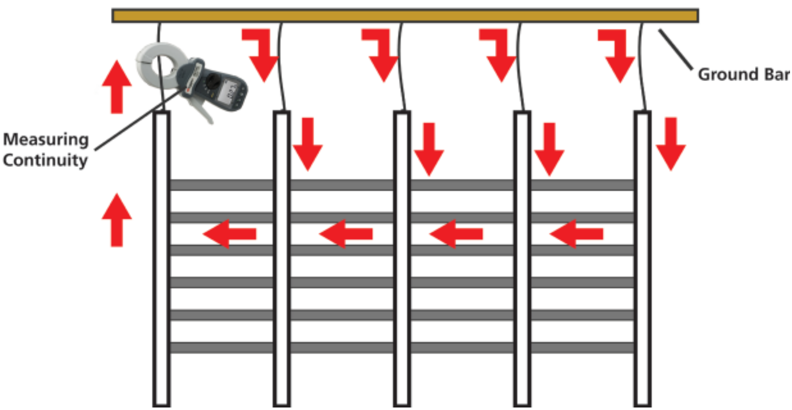
Why is balance important and how much imbalance is a problem? The diagrams above represent a real-life scenario in a DOCSIS environment. There were noise problems in a headend. Personnel thought that this might be related to grounding and bonding problems. The resistance of the building ground was acceptable. In checking continuity of the grounds to look for bad bonds, the bonds were found to be good enough so as not to adversely affect the protection ability of the ground. But, the resistance of these daisy-chained grounds varied by 1.0 ohm from rack #1 to rack #5. In other words, these grounds were unbalanced. When the grounds were changed to home runs (and thus much closer to being balanced), the noise was reduced by 8 dBmV.

Lab experiments and experiments in actual hubs confirmed that if an unbalance of 0.8 ohms in the ground circuits can be reduced to 0.3 ohms, the noise floor in the 5 MHz to 50 MHz spectrum can be reduced by 8 dBmV.

TESTING PROCEDURE

It is impossible to measure the resistance value of a ground at a shelf or similar place in a hub or headend. We can, however, easily measure and compare the balance of the various ground circuits of a hub or headend.

To measure ground balance in the real world of a hub or headend, a clamp-on ground tester that is accurate to a tenth of an ohm is required. We discussed above that a limitation of such a test set in measuring the resistance of a ground is that it cannot measure ground resistance if an alternate, lower resistance, return path exists that does not involve the soil. We can turn this limitation to an advantage in looking for unbalanced ground circuits. In such a situation, the current induced by the test set merely follows the (metallic) path of least resistance back to the test set which allows the test set to measure the resistance of that path. Remember that this is not a measurement of the resistance-to-ground of this ground circuit. It is a measurement of continuity. If the resistance measurements on different ground circuits are the same, they are balanced.



RECOMMENDATIONS

Test continuity of the ground circuits to verify that they are balanced.

If they are not balanced:

- Change daisy-chained ground circuits to home runs.
- Make sure that the bonds are installed to manufacturers' specifications.
- If necessary, individual bonds can be measured with a digital low-resistance ohmmeter.

No one is going to become an expert on grounding and ground testing by reading this. The aim here is take a bit of the mystery out of these topics, to point out some of the things that a technician can do to improve grounds and to provide a foundation for asking questions.

GLOSSARY

Step-and-touch potentials

POTS

Greenfield

Pops and drops

ISDL

ADSL

VDSL

NID

Butt ground

Daisy chain

Headends

DOCSIS

REFERENCES:

"Getting Down to Earth, A Practical Guide to Earth Resistance Testing" available at megger.com

"Guide to Clamp-On Ground Testing" available at megger.com

United States Department of Agriculture, Rural Utilities Service

RUS Bulletin 1728F-804

Subject: Specifications and Drawings for 12.47/7.2 kV Line Construction

Section H - Construction Specifications for Grounding

"Noise Reduction Techniques in Electronic Systems", Henry Ott, Wiley & Sons

"Transient Voltage Aspects of Grounding", T.A. Brinner & R.A. Durham, IEEE Transactions on Industry Applications, Volume 6, No 46, September/October 2010

"Bonding and Grounding, The Continuing Saga", D. McCarty, December 2016, ISE Magazine

National Electric Code (NEC) Article 800, Communications Circuits

National Electric Code (NEC) Article 250, Bonding and Grounding

Institute of Electrical and Electronics Engineers (IEEE) Standard 80, Ground System Design

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2621 Van Buren Ave

Norristown, PA 19403