CHAPTER 12

COMMUNICATIONS ELECTRONIC GROUNDINGS

12.1 GENERAL GROUNDING AND BONDING CONSIDERATIONS

The major factors to be considered in the designing of an adequate grounding system are:

- Personnel protection
- Equipment protection
- Interference reduction
- RF efficiency
- Signal ground distribution
- Separation of the Red and Black signal ground

In deference to the above, several general rules should be followed when a ground system is designed.

a. Personnel protection must be provided by installing an electrical path between the equipment and the earth. The resistance of the path must be less than that of the human body and cannot be greater than 25 ohms to the earth.

b. Building protection against lightning must be provided by a low resistance electrical path between the metal structural portions of the building and the earth.

c. RF interference caused by standing waves on ground leads must be eliminated by keeping the ground leads to lengths less than that of one wavelength.

d. Where possible, a single ground system must be installed. A single ground system prevents potential differences between systems and reduces to a minimum the possible circulation of ground currents.

Methods and practices for establishing satisfactory grounds are discussed in the following sections of this chapter. Topics included are: establishing satisfactory earth ground points, interconnecting ground systems, ground point testing and ground system distribution.

12.2 FUSED METAL-TO-METAL GROUND SYSTEM JOINTS

During the planning phase particular emphasis should be placed on the construction of the ground system. Many undesirable short- and long-range effects can be stemmed, if not eliminated completely, by specifying the approved standards for fusing metal to metal. The approved standards are the results of continued research into the best possible methods of preserving the qualities of the specific metals selected for individual installations.

Investigation of the causes of ground joint failures has disclosed many undesirable effects. Some of these are:

- Brittle fractures
- Annealing of strength members
- Tempering of flexible members
- Crystalization of base metals
- Cold joints (incomplete fusing)
- Burnout (due to overcurrent)
- Acidic reaction deterioration
- Breaking due to overstress

  Corrosion rust

- Electrolysis between dissimilar metals
- Dirt and flux residue within the joint

The following practices and standards are to be adhered to, as applicable, within the design specifications.

a. All connections shall meet the quality requirements of specification MIL-B-7883.

b. When torch brazing is not practical, heavy section wires or rods being joined together or to heavy section structural members of the same kind or dissimilar metals can be joined by exothermic, fused cast-in-place alloys of the appropriate type.

c. Small diameter or thin section copper or copper-clad wires can be fused to steel or other dissimilar metals by brazing with alloys per Federal Specification QQ-S-561, Class 4, using flux per Federal Specification O-F-499.

d. Small diameter or thin section copper or copper-clad wires or rods can be fused to the same or other copper by brazing with alloys per Federal Specification QQ-S-561, Class 3, without flux.

e. Aluminum or aluminum alloys can be fused to the same or dissimilar metals by following the requirements of specification Mil-B-5087B(ASG).

12.3 EARTH GROUND CONNECTION

The choice of the earth ground point can range from a metallic underground piping system to electrodes installed in the ground especially for this purpose. The National Electrical Code, (1968), articles 250-81 through 250-84, establishes basic criteria for the earth ground connection point applicable to personnel safety only. The possible earth ground points, in order of preference, are as follows:

a. A metallic underground water piping system, either local or one that supplies a community, provided the building interior cold-water system is also bonded to one or more installed electrodes.

b. Other continuous metallic underground piping systems, exclusive of a gas service piping system.

c. The metal frame of a building if the frame is effectively grounded.

d. Installed electrodes.

Installed electrodes commonly in use at communications stations are described in the following subparagraphs. When electrodes are installed for the safety of personnel, the resistance between the electrodes and the earth is not to exceed 25 ohms. Continuous metallic underground water systems in general have a resistance to ground of less than 3 ohms; metal frames of buildings and local metallic underground systems usually have a resistance substantially below 25 ohms.

12.3.1 Driven Electrodes

Driven electrodes, or ground rods, are used for the earth ground connection where bedrock is beyond a depth of 10 feet. Since these electrodes are subject to the corrosive action of the earth, they should be made of copper-clad steel. These electrodes, available commercially in various lengths and diameters, can be joined together to extend their length (figure 12-1).

Generally, the depth of the electrode determines the resistance of the earth ground connection. Rods should be driven deep enough to reach the permanent moisture level of the earth whenever possible. Failure to reach this level may result not only in high resistance, but may cause large resistance variations during seasonal weather fluctuations.

12.3.2 Multiple Driven Electrodes

Several driven electrodes may be used to obtain a specified minimum ground connection resistance. When multiple driven electrodes are used, their upper ends are bonded together with No. 4 AWG bare copper wire.

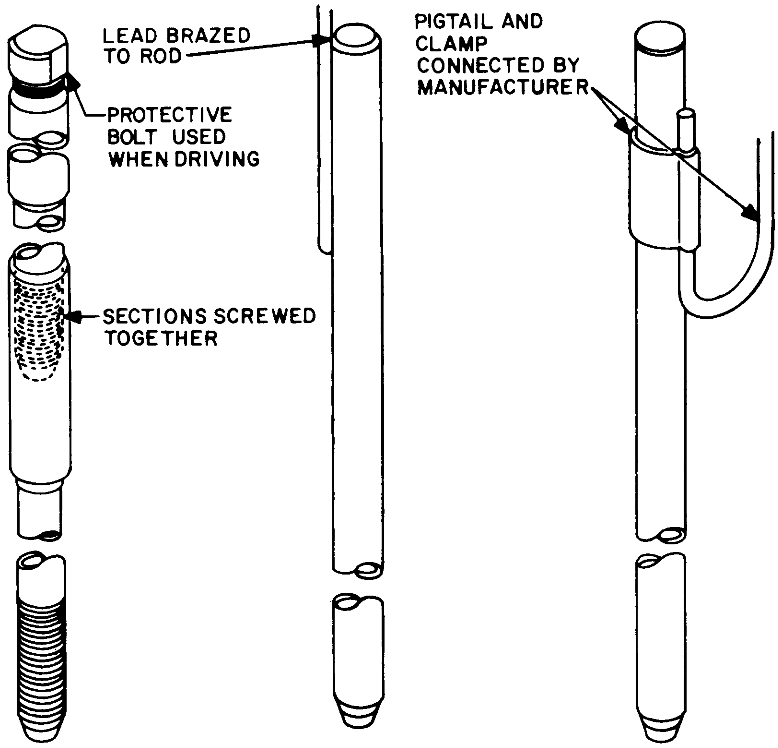

Figure 12-1. Grounding Rods

The resistance of the connection to the earth made by a driven electrode is distributed in a hemisphere of earth about the electrode. For this reason the direct reciprocal relationship for resistance in parallel is not obtained when multiple electrodes are driven. The hemisphere of one electrode will always tend to overlap that of the other. Figure 12-2 shows the amount of reduction of ground connection resistance to be gained by driving multiple electrodes spaced various distances apart. The separation between electrodes should be a minimum of 6 feet. As a general rule, multiple electrodes are spaced at 10 to 20 feet. With this configuration, the optimum ground connection is approached while practical considerations are satisfied.

The minimum ground resistance that can be obtained through the use of multiple electrodes depends upon the dimensions of the area available. Figure 12-3 shows the relationship between the conductance of a group of electrodes over a given area and the conductance of a single electrode. From this graph it can be seen that the maximum conductance possible with an unlimited number of electrodes in an area of 500 square feet is only 4.9 times the conductance of a single electrode. However, 10 electrodes equally spaced in this area would result in a conductance of 4.6 times that of a single electrode. Since this difference in conductance is not significant, a limited number of electrodes may be presumed practical for a given area. Figure 12-3 also shows that if 10 times the conductance of a single electrode is desired, the electrodes must be distributed over an area in excess of 2000 feet.

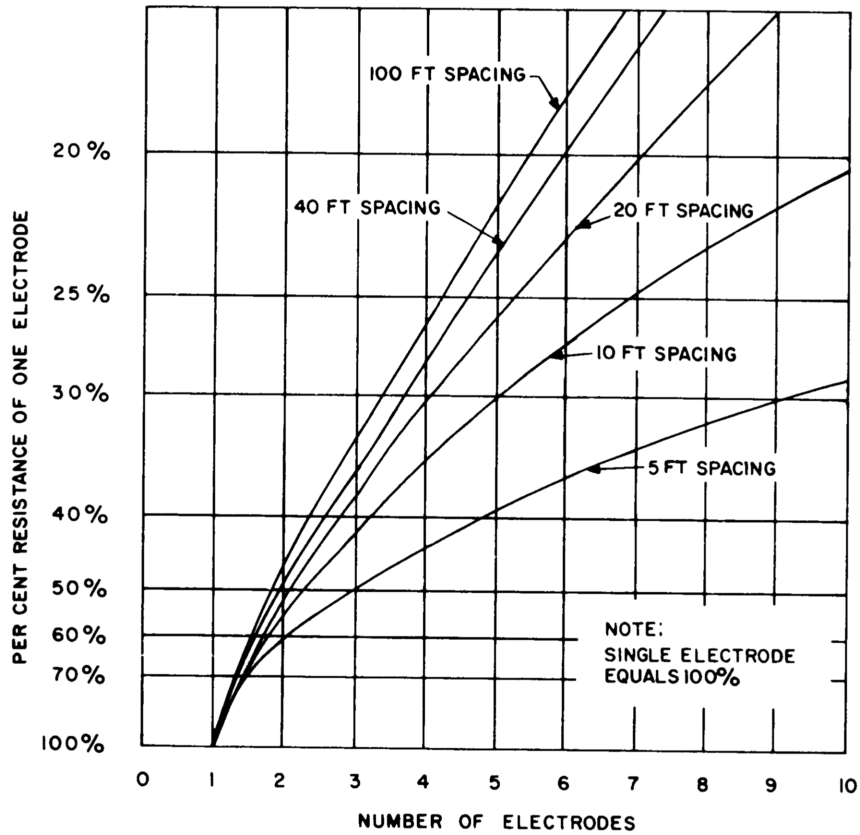

Figure 12-2. Comparative Resistance of Multiple Grounds

Figure 12-4 shows an acceptable plan for a system of driven electrodes used as the earth ground connection. The ground consists of seven 20-foot copper-clad rods driven into the earth in a radial pattern. Six rods are in a circle with the seventh rod driven in the center of the circle. Each outer rod is connected to the center rod by No. 4 AWG bare copper wire. One No. 4 AWG insulated wire connects the center rod of this ground rod array to the ground distribution system of the building.

12.3.3 Buried Plate Electrodes

Grounding plates are used when the physical configuration of the site prohibits use of more conventional ground point connections. These plates are sometimes used where immersion in water or damp soil is a practical grounding method. When grounding plates are used, each plate should present no less than two square feet of surface to the exterior soil.

The ground connection resistance of a grounding plate depends upon the overall dimensions of the plate. The variation of ground connection resistance with plate size is illustrated in figure 12-5, which is based on calculations for a circular plate in soil having uniform resistivity. This figure shows that quadrupling the size of the plate approximately halves the ground connection resistance. The

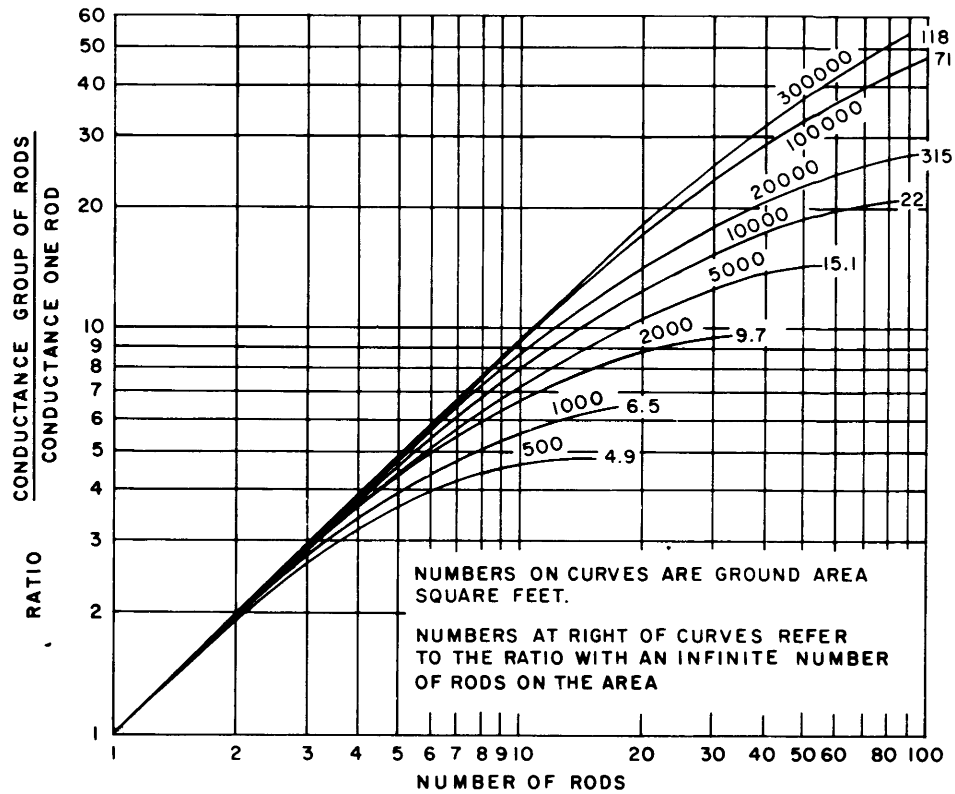

Figure 12-3. Conductance of Multiple Electrodes Versus Area

curve in figure 12-5 also shows that increasing the area of the plate beyond 25 to 30 square feet does not result in an appreciable decrease in ground connection resistance. This relationship is also valid for a rectangular plate, although the curve of figure 12-5 should be taken as an indication of the relationship, not as a check on it. When a large surface area is required, the use of two or more smaller plates will facilitate installation. The total surface area that the plates present to the earth governs the amount of resistance with respect to earth; no electrical parallel resistance relationship is obtained by the combination of plates. Grounding plates are composed of Everdur (alloy No. 1010), an alloy consisting of approximately 96 percent copper, 3 percent silicon, and 1 percent manganese. This alloy has a conductivitv approaching that of copper and a high resistance to corrosive or oxidizing elements. The connector between the plates and from the plate to the station ground distribution system is a strap 12 inches wide and 0.25 inch thick.

The Test Equipment Standards Laboratory, U.S. Navy Repair Facility, San Diego, uses an Everdur plate as the earth ground point. See figure 12-6. The plate is buried 10 feet deep with one foot of sand above and below the plate. The sand is dampened by sea water at high tide. A capped pipe, which protrudes above the ground, is used for supplementary moistening.

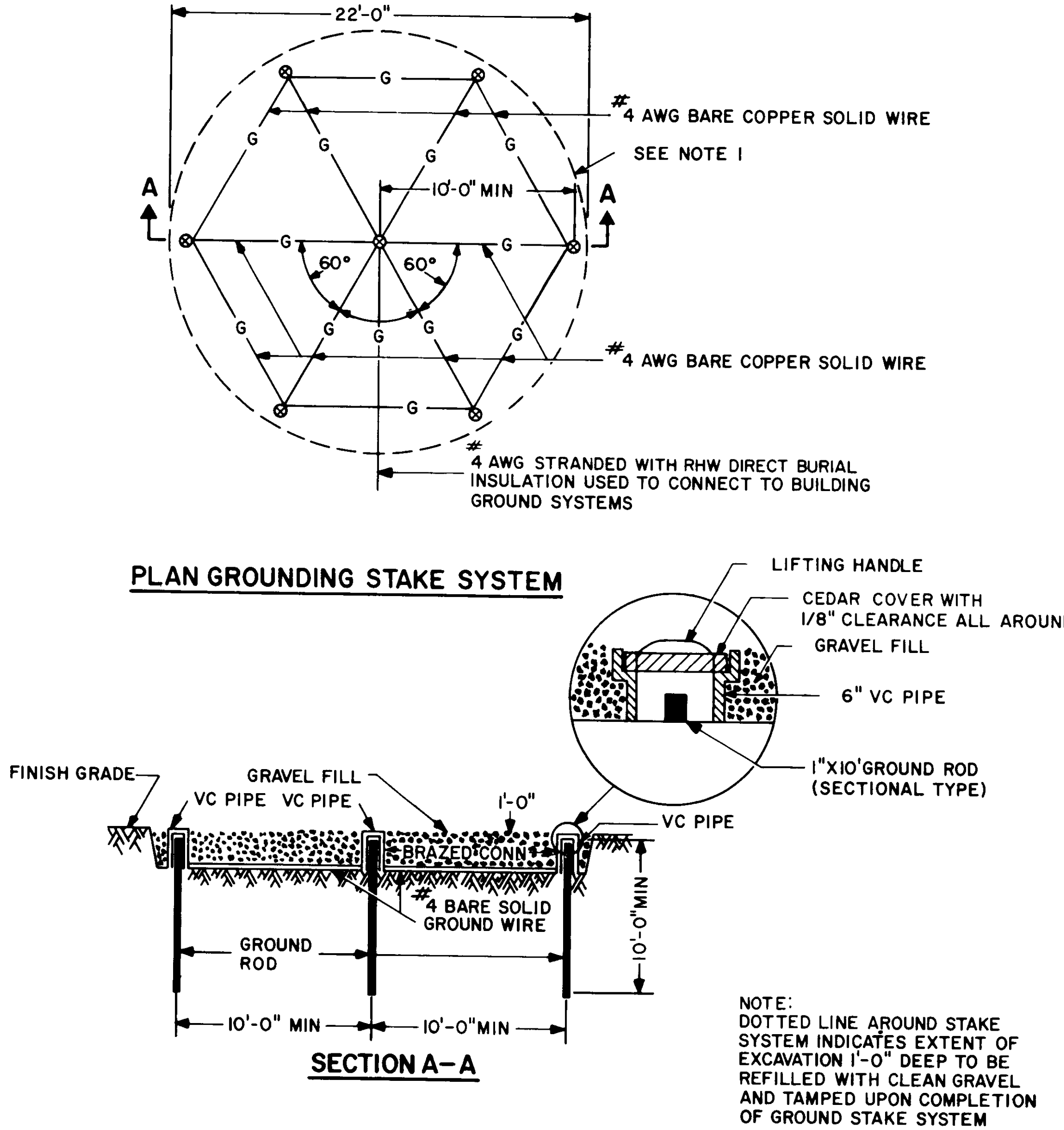

Figure 12-4. Multiple Driven Electrode Ground Plan

12.4 EARTH GROUND POINT TESTING

It is difficult to test an established earth ground point, and, if undertaken, the results are of questionable value. The effectiveness of an existing earth ground point is best determined by a review of the engineering and installation practices used to install the ground and by careful inspection to ensure the integrity of all welds used to bond the ground point to the grounding system.

Standard methods of determining the effectiveness of an earth ground point are based upon the establishment of reference grounds for the taking of test data. Each reference ground established must have a resistance to ground that is less than 10 times that of the earth ground point under test. If the test is to be effective, the

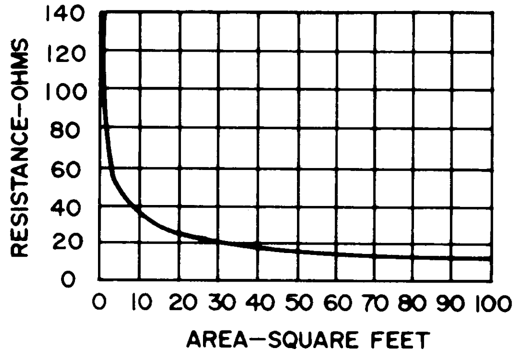

Figure 12-5. Resistance as a Factor of Contact Area for Circular Plate

earth ground point must be isolated from all grounding systems. NAVFAC DM-4 — "Electrical Engineering" recommends the three-electrode method or the fall-of-potential method for measuring the resistance of an installed ground.

12.4.1 Three-Electrode Test Method

Driven and plate electrodes may be tested for earth connection effectiveness using the "three-electrode method." This method, illustrated by figure 12-7, utilizes two reference ground points in addition to the earth ground point under test. A standard megger is used to determine the resistance in ohms between each pair of ground points. The resistance in ohms of the ground point under test is then determined from the following equation:

$$R_a = \frac{(R_{a,b}) + (R_{a,c}) - (R_{b,c})}{2} \qquad (12\text{-}1)$$

R_a = Ground connection resistance of the rod or plate under test.

$R_{a,b}$ = Measured resistance between ground points a and b.

$R_{a,c}$ = Measured resistance between ground points a and c.

$R_{b,c}$ = Measured resistance between ground points b and c.

This test is performed by driving rods for the reference ground points four feet into the earth to form a 100-foot equilateral triangle with the ground connection under test. The ground points are designated as shown in figure 12-7. The resistance between a and b, a and c, and b and c is then measured and the resistance of the ground point under test is calculated from equation 12-1.

12.4.2 Fall-of-Potential Test Method

Figure 12-8 illustrates the fall-of-potential test method which involves the use of an ungrounded alternating current power source to circulate a constant current between the ground mat under test and a fixed reference ground probe G_1. The test

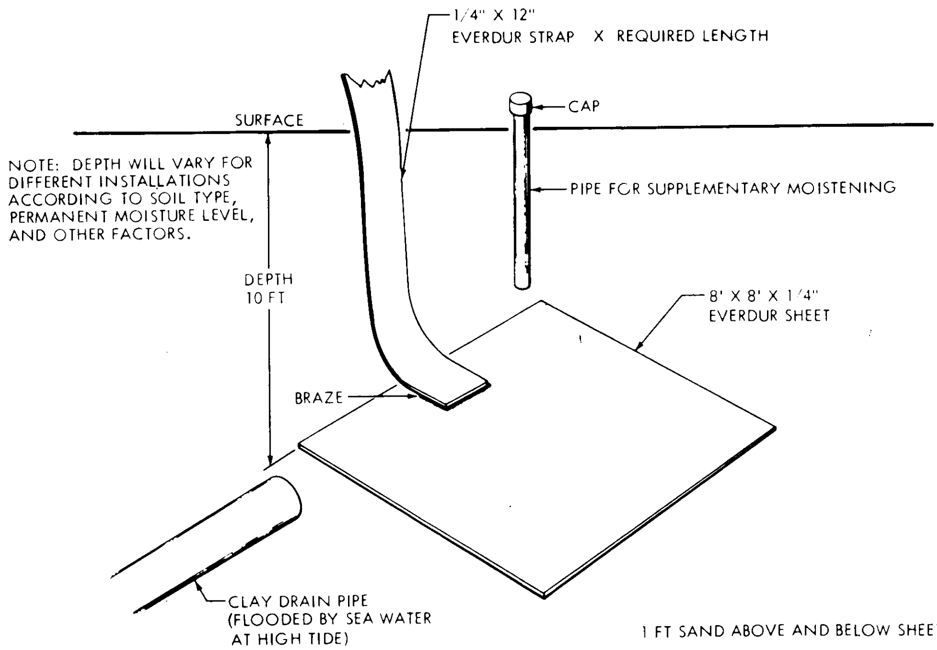

Figure 12-6. Everdur Ground Installation at USNRF, San Diego

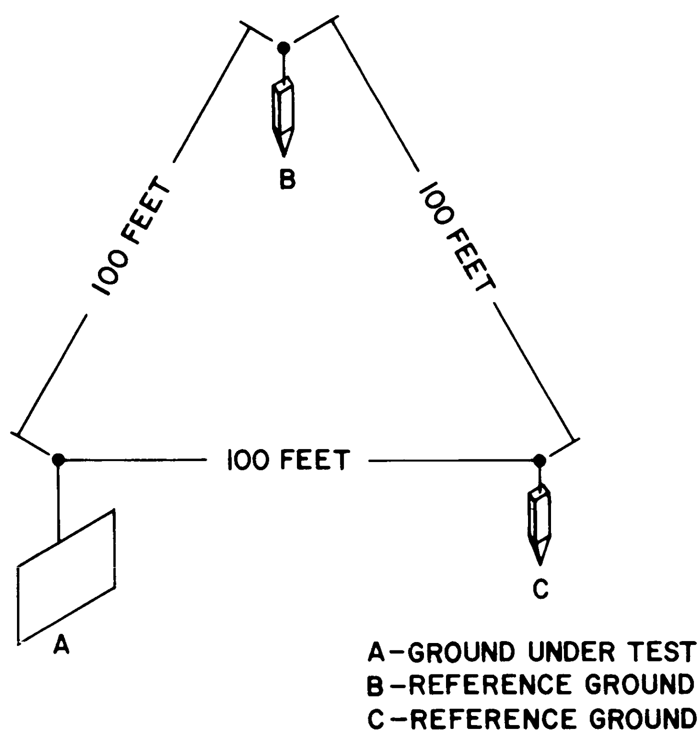

Figure 12-7. Three-Electrode Method of Measuring Resistance of Earth Ground Points

is conducted with the assumption that there is negligible resistance from fixed ground probe G_1 to the area of the ground mat and that the resistance measured is the contact resistance between the mat and the earth in the vicinity of the mat. In the fall-of-potential method a constant current (set by the adjustment of the variable resistance, figure 12-8) is passed between current return electrode G_1 and the ground mat under test. The potential electrode P is placed midway between the current source, and a voltmeter is connected between the potential electrode and the ground mat. The resistance R, of the ground mat can be computed from Ohms law:

$$R = \frac{E}{I} \qquad (12\text{-}2)$$

The test is similar to measuring the IR drop across a resistor, the resistor in this case being the contact resistance between the mat and the earth in the vicinity of the mat. Success of the method depends upon a low-resistance ground path between the ground mat and probe P.

In this test, ground stakes are driven and connected to meters and the power source as indicated by figure 12-8. The current and length of instrumentation leads constitute hazards to personnel; therefore, this method is not recommended unless the installation of a facility is in the planning stage or it can be otherwise justified. The voltmeter is connected between the ground mat terminal and probe P. The current is adjusted to one or more amperes to produce a center-scale reading on the voltmeter. This current must sustain throughout the test, but no further adjustment should be required unless the line voltage changes. Probe P is then moved from position to position along a path in a straight line between fixed point G_1 and the ground mat being tested, taking care to ensure that the probe is driven to the same depth at each position. A voltage reading is taken at each position of P and the current reading is checked to ensure that it is at the value previously set. The constant voltage reading and the current which produces the voltage are substituted into equation 12-2 to determine the resistance to ground of the mat being tested. In order for the results of this test to be meaningful the voltage reading for all positions of probe P must be the same over about two-thirds of the distance between the ground mat and G_1. If a constant voltage cannot be maintained with a constant current over about two-thirds of the distance, results might be improved by driving stakes P and G_1 further into the ground. If erratic results persist, other ground test methods should be employed.

12.5 IMPROVING EARTH GROUND POINT EFFICIENCY

If the earth ground point fails to meet a specified minimum resistance to ground it may be improved by use of deep-driven or multiple electrodes, or by chemical treatment of the earth surrounding the ground point.

12.5.1 Deep-driven Electrodes

Increasing the depth of the electrode is the simplest and most effective means of reducing ground connection resistance. Figure 12-9 shows the improvement that may be expected from an increase in electrode depth. The major limiting factor to applying this method is that rock may be encountered at greater depths in the earth.

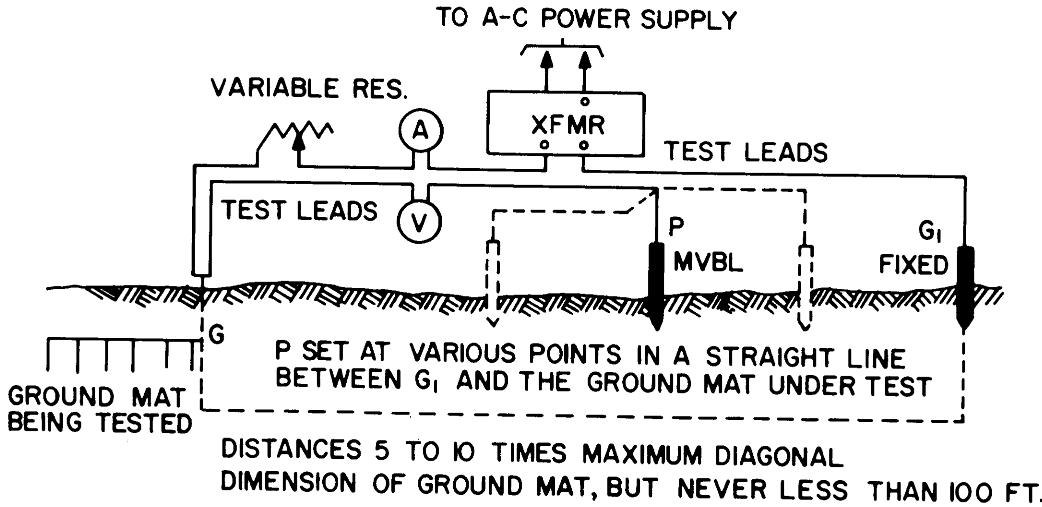

Figure 12-8. Fall-of-Potential Test Method

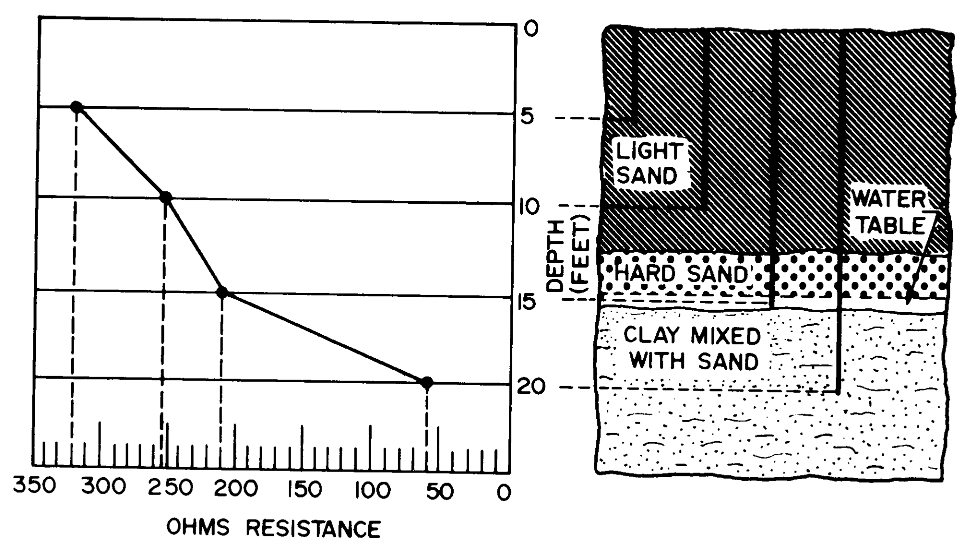

Figure 12-9. Electrode Depth Resistance

12.5.2 Multiple Electrodes

Multiple electrodes connected in parallel will tend to reduce the resistance of an earth ground connection. Refer to paragraph 12.3.2 for the procedures for using multiple driven electrodes.

12.5.3 Chemical Treatment

Where it is not feasible to use deep-driven or multiple electrodes, chemical treatment of the earth surrounding the electrode is an effective means of lowering ground connection resistance. Chemical treatment may also be used where plates are employed. An added advantage of this method is that the chemicals reduce seasonal variations in ground connection resistance caused by rainfall and lower the freezing point of the surrounding soil.

Several substances are used to reduce the resistivity of the soil immediately surrounding the electrode. The better known are:

Magnesium sulfate ($MgSO_4$) - epsom salts

Copper sulfate ($CuSO_4$) - blue vitriol

Calcium chloride ($CaCl_2$)

Sodium chloride (NaCl) - common salt

Potassium nitrate (KNO_3) - saltpeter

Magnesium sulfate is most frequently used, since it combines low cost with high electrical conductivity and low corrosive effect. The initial effectiveness of chemical treatment is greatest where soil is somewhat porous, because the solution permeates a considerable volume of earth, which results in increasing the effectiveness of the electrode. In compact soil the initial chemical treatment is not as effective as in porous soil because the solution tends to remain where placed for a longer period of time. It is necessary to use initially between 40 and 90 pounds of the chemical to retain the effectiveness of the ground for 2 or 3 years. Each replenishment of the chemical will extend its effectiveness for a longer period so that future treatments will be needed less and less frequently.

12.6 GROUND DISTRIBUTION SYSTEMS

12.6.1 AC Protective Ground

An AC protective ground distribution system is required to safeguard life and equipment. Such a system provides an electrical connection to the earth ground point for the protection of personnel and equipment from AC power potentials, lightning hazards, and electrical circuit failures. In this system a ground bus interconnects all equipment chassis; equipment cabinets and racks; all ferrous shields and covers; all conduits, raceways, cellular flooring, cable racks, and superstructures; ferrous shields of cables and transformers; and the protective ground of local telephone systems. The ground bus is normally composed of the metal-to-metal contact of ferrous conduit installed in the AC power distribution system. The integrity of the AC protective ground system is assured by running an additional unbroken, insulated, green wire with the AC power feeders that supply the equipments. This wire, which is connected between the case of the equipment and the case of the power panel that supplies the equipment, is designated the green-wire protective ground feeder. The green-wire protective ground feeder is required even though the AC power feeders are supported in metallic conduit or other supports.

NOTE

The green-wire protective ground feeder does not replace the color-coded white or natural gray wire used for the return side of all AC power feeders.

12.6.2 Signal Ground

The signal ground distribution system is used as a zero reference level between communications circuits and as an electrical connection to the earth ground point. The primary purpose for the signal ground distribution system is to provide the highest signal-to-noise ratio possible on the signal circuits between equipments. The governing criteria for a signal ground system are contained in the latest issue of NAVELEX Instruction 011120.1. The following general requirements must be met by the design of a signal ground system.

a. The signal ground system may have its own ground connection point. NAVELEX Instruction 011120.1 specifies the type of ground connection to be used for both large and small systems.

b. Separate ground distribution systems are required for Red and Black signal grounds. NAVELEX Instruction 011120.1 specifies when and where these two systems are to be interconnected. A Red signal ground distribution system connects the ground side of all signal loops and the nonferrous shields of all signal and signal control cables that may carry plain-text classified information to the earth ground point. A Black signal ground distribution system connects the ground side of all signal loops and nonferrous shields of all signal and control cables that may carry unclassified and encrypted information to the earth ground point.

12.6.3 Security Fence Ground

A security fence at a transmitter site may require a grounding system to insure personnel safety. Grounding of fencing may also be required at various sites to prevent reradiation of signals. An approved method of grounding a fence is shown in figure 12-10. When a gate is incorporated as part of the fence its hinges must be bonded with flexible No. 8 AWG copper wire. These wires are to be connected to the gate post and the frame of the gate using exothermic welding or approved pressure connectors.

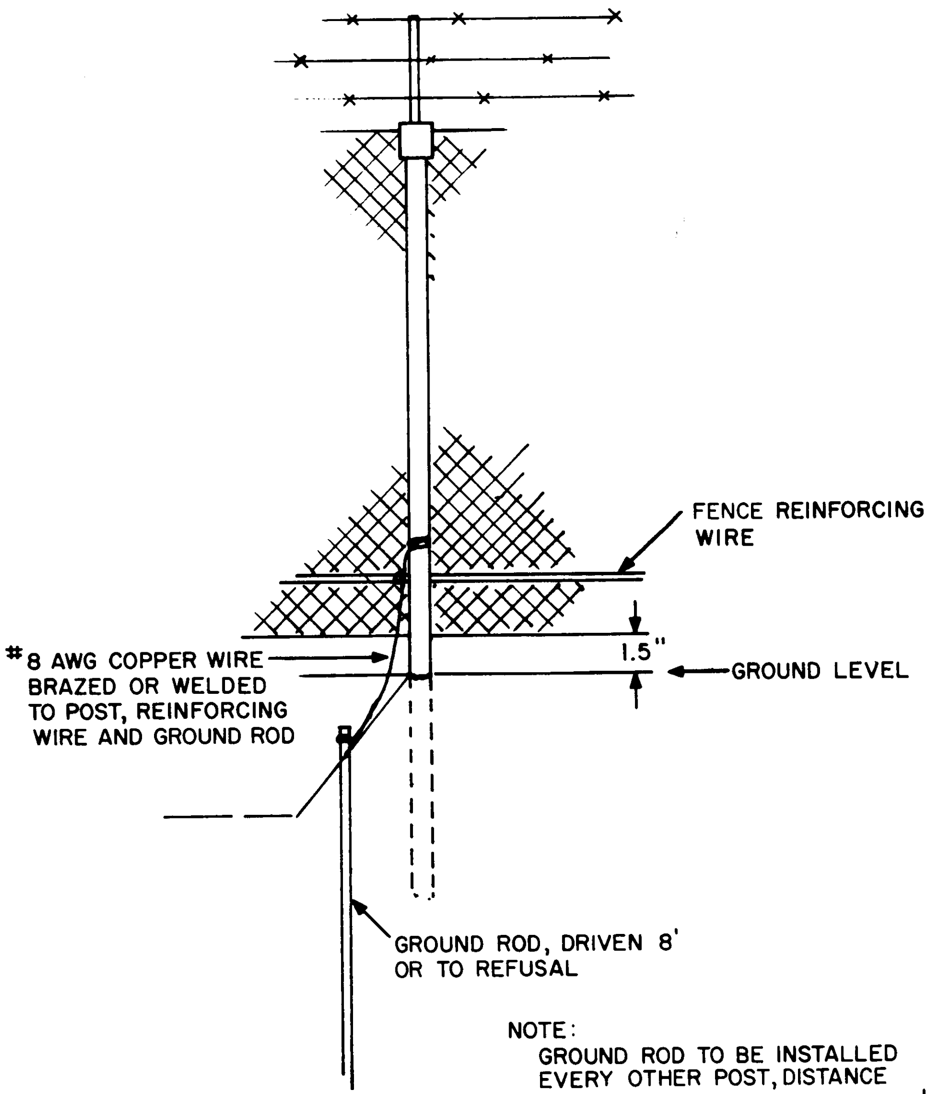

Figure 12-10. Typical Fence Grounding Plan