Chapter 28: Grounding

28.1 Provide an example of a wire or an object (not discussed in this chapter) that is both a return and safety.

28.2 Rewrite the following phrase to avoid ambiguity: "The ground connecting the disk drive to the computer should be connected to the reference lug."

28.3 Locate and correct a misuse of the word ground, reference, and return anywhere in this book.

28.4 Write a reasonable and clear sentence that uses the word ground. Repeat for the word grounded. Repeat for the word grounding.

28.5 Using the Underwriters Laboratories' limits given in this book for the maximum voltage across a charged capacitor (wet and dry environments), plot the corresponding energy versus capacitance. Let the capacitance vary from 1 nF to 1 mF. Are any of these energies not "safe?"

28.6 Using the rms expression

$$f_{rms} = \frac{A}{\sqrt{6}} \approx 0.41A$$

for the half-rectified triangular wave shown in Figure 1, determine the safe range of values for A (based on the UL limits provided in this chapter for a single-pulse current source). Assume the actual current waveform only exists from 0–T seconds where T ranges from 1 μs to 1s.

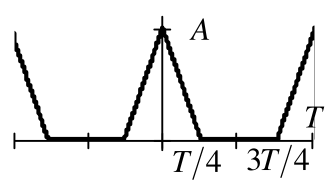

Figure 1

28.7 When should an isolation transformer be used?

28.8 Carefully explain why some noisy currents are mostly self contained at a lab station when an isolation transformer is used. Does the isolation transformer help isolate fault currents generated at the station? Explain.

28.9 For two-wire products using an isolation transformer, why are the plugs polarized? Hint: study the parasitic capacitance across the transformer.

28.10S By locating and then analyzing a schematic that uses an isolation transformer, determine whether one side of the secondary of an isolation transformer is actually directly connected to the chassis. Discuss.

28.11 A building has two different service panels, corresponding to two separate sets of power lines entering the building. Discuss the best way of grounding the neutrals of these two service panels.

28.12 In a popular movie from the 1990's, both hands of a precocious boy are grabbing onto one conductor of an unenergized electric fence (designed to keep huge prehistoric animals in their "pen") while his feet are standing on another conductor. Unexpectedly, the power is turned on to the fence and the boy is propelled from the fence to the earth. Explain under what circumstances this could occur.

28.13 A student accidentally miswired a piece of laboratory equipment: the student connected the black wire of the power cord to the safety ground prong and the green wire of the power cord to the hot prong. Determine the major negative consequence of this miswiring.

28.14 Outlets in modern homes in North America have three prongs: hot, neutral, and ground. Large appliances frequently have their own circuit and breaker (with three wires brought straight back to the service panel). Other outlets are placed in parallel and brought back to one breaker in the service panel. The number of outlets on one breaker is a function of the expected load on those outlets. If a special low-noise outlet for computer use is to be installed in a home, how should this outlet be wired to the service panel? Explain.

28.15 A sensitive computer system and noisy generator use the same neutral and ground wire but different hot wires. Why is this power connection a bad idea? Recommend a better powering scheme.

28.16 What safety advantage is provided by grounding one location of the secondary of a potential transformer?

28.17S Determine the maximum voltage difference between the earth ground and the grounded metal chassis of an ac powered (60 Hz) two-wire product of your choice. The length of #12 AWG wire between the earth ground, located at the service panel, and the outlet where the product is plugged in is 50 ft.

28.18 How can electrical products powered by 120 V rms be safe when used or immersed in an aquarium or a swimming pool?

28.19 An electric device to harvest earthworms known as the electric worm probe consists of a metal probe (with an insulated handle) about the size of a large knitting needle. The probe is connected directly to the hot of a 120 V rms power source. The probe is inserted into the ground resulting in about 1-2 A rms injected current into the ground. Why is this device considered unsafe? If the single conductor leading to the probe is connected to a GFCI, will the device function and will the probe be safer to use? What occurs if the probe makes contact with a grounded metal object such as an electrical conduit? [Greenwald]

28.20 Power is required at a location approximately 300 ft from a home. A layperson uses heavy duty zip wire (two conductor) to carry the hot and neutral wires from the main panel to this remote site. A receptacle is then placed at this location. Discuss the safety problems associated with this remote site. A friend recommends that a GFCI be placed at the remote location for safety reasons. Discuss the safety problems of this GFCI "protected" outlet. What if a separate ground rod is placed at the remote outlet and the neutral is connected to this ground rod? What if the GFCI is placed at the main panel instead of at the remote site?

28.21 Why are fuses and circuits breakers installed along the hot lines instead of the neutral lines?

28.22 A high-voltage power line contacts the earth. If an individual is standing nearby to this location, state any advantages in "hopping" away from the contact point versus stepping away in small "baby" steps.

28.23 Discuss a situation where the measured resistance of the earth is different on the same day.

28.24 If a three-wire plug must obtain power from a two-wire outlet, is it better to cut-off the third prong (the safety) or allow the pigtail to hang free not connected to anything?

28.25 Why do many lamps not have a safety wire (i.e., they are connected to the outlet using only a two-wire cord)? It this a safety hazard?

28.26 When automobile *A* is giving automobile *B* a "jump," very carefully explain why (1) the hot (or red) cable is first connected to the "+" terminal of *B* and then this hot cable is connected to the "+" terminal of *A*, and (2) the ground (or black) cable is connected to the "–" terminal of *B* and then this ground cable is connected to the "–" terminal of *A*. Also, determine the best order of disconnecting the hot cable and ground cable. (Automobile *A*'s battery is fully charged while automobile *B*'s battery is almost depleted.)

28.27C Assuming the length of the "arms" are identical, plot on the same set of axes the net dc resistance versus the burial depth for each of the star arrangements (e.g., three-point star) given in the table in this chapter for the electrode-to-ground resistance. Let $L = 3$ m, $a = 0.25''$, and $\rho = 200$ Ω-m. Let d vary from 0.1 to 10 m. Which star arrangement provides the lowest dc resistance to ground? If the total length of rod used for each star is kept constant, which star arrangement provides the lowest dc resistance to ground?

28.28C Three hemispherical electrodes with identical radii ($= a$) are embedded in a straight line along the surface of a homogeneous earth of resistivity ρ. The distance, d, between any neighboring electrodes is large compared to a. If a current I is injected into the center electrode and it splits evenly between the two outer electrodes, determine the expression for the step voltage anywhere directly between the electrodes. Then, as in this chapter, determine approximations for these step voltages near any of the electrodes. Using reasonable parameters, plot the electric field between the electrodes.

28.29C Two hemispherical electrodes with identical radii ($= a$) are embedded along the surface of a homogeneous earth of resistivity ρ. The surface of the earth is located in the xz plane, one electrode is located at (0, 0, 0) and the other electrode is located at (d, 0, 0). Assume the air above the surface of the earth, located at $y > 0$, is perfectly insulating, and the distance, d, between the centers of the electrodes is large compared to a. If a current I is injected into the pair of electrodes, and the current splits evenly between them, determine the expression for the electric field in the earth at (x, y, 0). Then, with the zero-volt reference taken at this point of interest (x, y, 0), write the integral expression for the potential of the electrode at (0, −*a*, 0). Then, numerically determine the potential at (*d*, −*a*, 0) of the other electrode if $I = 1$ A, $\rho = 150$ Ω-m, $a = 0.4$, and $d = 20$ m. Is this result expected? Then, determine the potential of the electrode at (0, −*a*, 0) assuming the reference potential is located at each of the following locations: (100*d*, −100*a*, 0), (*d*, −100*a*, 0), (0, −100*a*, 0), (−10*d*, −10*a*, 0). For each of these locations, determine the resistance of the electrodes to "distant" ground. Are these results approximately equal to one-half the resistance of a single hemispherical electrode of radius *a* to distant ground? How do the results change as *d* decreases for a fixed *a*?

28.30 The electric field along the surface of the earth between two, long, vertical, slender rods both of length l_{th} and radius of *a* is given by

$$E_x = \frac{Vl_{th}}{x^2 \ln\left(\frac{2l_{th}}{a}\right)}$$

where *V* is the voltage applied across the two rods. The variable *x* is the distance from the center of one of the rods. The rods are embedded in the earth of resistivity ρ, and they are far from each other. Neglecting all resistances in the circuit except the earth resistance, determine the step voltage along the earth near one of the electrodes. Use the same variables as in this chapter. Compare with the results given in this chapter. [Moon, '61]

28.31 The concept of positive image current can be used to determine the electric field and current density from a spherical current source, *I*, located a distance *d* below the surface of a flat earth (of resistivity ρ). Using the concept of positive images, the insulating region above the earth is replaced by a region of resistivity ρ. Furthermore, another spherical current source of strength *I* is placed directly above the "real" source at a distance 2*d* from it in this region that was insulating. Using superposition and working in spherical coordinates, determine the total current density from both the real and image current sources. Then, working in Cartesian coordinates, determine the expression for the electric field anywhere along the surface/air interface. Is there a electric field component normal to the interface? Explain why this result is reasonable. Next, working in spherical coordinates, derive the expression

$$V_2 - V_1 = \frac{\rho I}{4\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

for the potential difference between two radial locations r_1 and r_2 from a single, spherical current source, *I*, located in a homogeneous conducting medium. The reference voltage is at r_1. The potential difference is the same whether or not these radial locations are in the same direction. Explain why this is true. Using this potential expression, derive the following equation obtained by Frank

Wenner in 1915 provided in this chapter for the resistance between two embedded spherical electrodes:

$$R = \frac{\rho}{4\pi}\left(\frac{1}{r_{12}} - \frac{1}{r_{13}} + \frac{1}{r_{34}} - \frac{1}{r_{24}} + \frac{1}{r_{25}} - \frac{1}{r_{35}} + \frac{1}{r_{36}} - \frac{1}{r_{26}}\right)$$

28.32 For the four-probe electrode configuration shown in Figure 2, determine the expression for the resistance between the potential electrodes. All of the electrodes are at a depth of b. Approximate this expression if $c >> a$, if $a >> c$, and if $a >> b$.

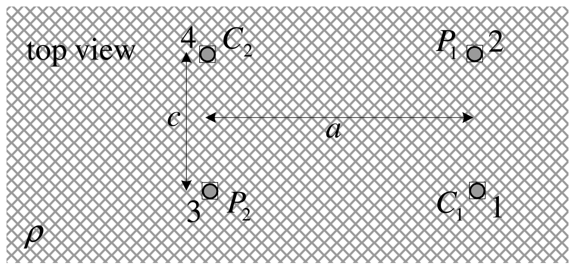

Figure 2

28.33 In some situations, there is insufficient space available to measure an earthing electrode's resistance using the fall-of-potential method; that is, there is not enough space between the current electrode and earthing electrode to generate the "flat" resistive region. It has been suggested that the potential electrode be placed on the opposite side of the earth electrode as shown in Figure 3 thereby allowing the current electrode to be placed closer to the earthing electrode. Discuss why this method should not be used. [Tagg]

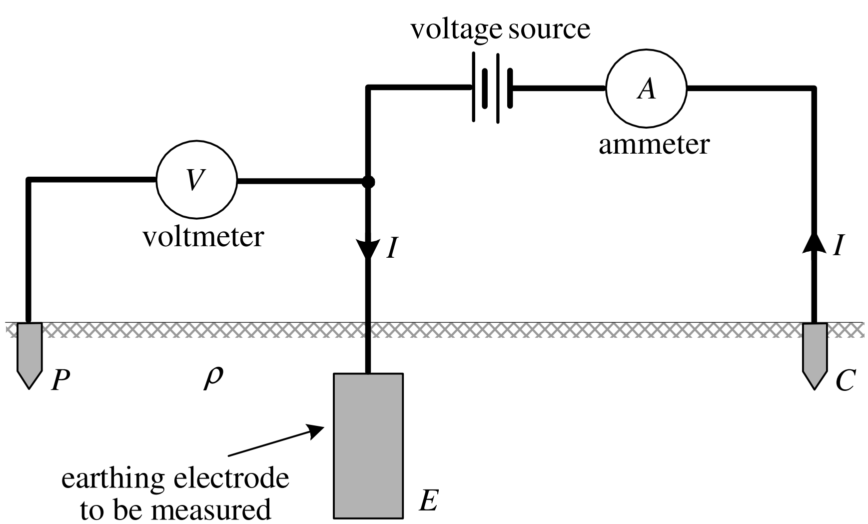

Figure 3