Chapter 27: Electrostatic Discharge

27.1 When charging by induction, why should the (initially) neutral object to be charged have a small time constant relative to the period (of oscillation) of the external electric field and a small time constant relative to the contact time with the grounded object?

27.2 Discuss the validity of the statement, "To charge an object it must come in contact with another object."

27.3 In reference to the low-noise cable discussion in this chapter, repeat the entire analysis, including the discussion, for the period of time immediately after the air gap *closes* and the charge is partially neutralized at the interface.

27.4 Using the frequency-domain expressions provided in this chapter for the electric fields for both layers in a Maxwell's capacitor, determine the corresponding time-domain expressions.

27.5 A voltage source is applied to a small spherical electrode that produces a constant volume charge density of $\rho_V(a)$ at $r = a$. The medium around the electrode has an outward radial velocity of U/r^2. The conductivity and permittivity of the surrounding moving ohmic medium are σ and ε, respectively. Determine the steady-state volume charge density and electric field distributions. [Zahn]

27.6 Near the tip of a lit cigarette, ions of volume charge density $\rho(a)$ are generated at $r = a$. The smoke carries these ions radially outward from the tip with a velocity distribution of U/r^2, where r is the radial distance from the cigarette. Determine the steady-state distribution of charge everywhere around the cigarette as a function of I (the constant, steady-state current from the cigarette), b (the mobility of the ions in free space), $\rho(0)$, and r. Hint: the radial current density is equal to $I/\left(4\pi r^2\right)$.

27.7 The conductivity of the earth's atmosphere is given by

$$\sigma(r) = a + b(r - R)^2$$

where a, b, and R are constants (R is the radius of the earth). If the electric field at the earth's surface is given as $E_r(R)\hat{a}_r$, determine the steady-state current density distribution everywhere in the earth's atmosphere. What is the total current directed outward from the earth's surface? Hint: let $\vec{J} = J_r(r)\hat{a}_r$

27.8 A point charge is located midway between two, intersecting, large, grounded, conducting planes with an angle of 60° between them. If the grounded planes are replaced with image charges, clearly show the position and sign of all five of the image charges.

27.9 Verify that each of the following charge distributions appear like a point charge far from the distribution by using a series approximation for each of the electric field distributions. Clearly define "far" for each distribution.

a) finite-length line charge
b) uniformly charged circular ring
c) uniformly charged circular disk
d) linearly varying charged circular disk

27.10 Determine whether the electric field is generally zero everywhere (in the stated region) for each of the given charge distributions and materials. Use Gauss's law, superposition, and/or counterexamples to explain your reasoning.

a) inside a solid conducting sphere with a uniform distribution of charge along its surface
b) inside a solid conducting sphere with a nonuniform distribution of charge along its surface
c) inside the cavity of a thin conducting spherical shell with a uniform distribution of charge along its surface
d) inside the cavity of a thin conducting spherical shell with a nonuniform distribution of charge along its surface
e) inside a solid insulating sphere with a uniform distribution of charge along its surface
f) inside a solid insulating sphere with a nonuniform distribution of charge along its surface
g) inside the cavity of a thin insulating spherical shell with a uniform distribution of charge along its surface
h) inside the cavity of a thin insulating spherical shell with a nonuniform distribution of charge along its surface

How can a nonuniform distribution of charge be obtained along a spherical conducting body? How can a nonuniform distribution of charge be obtained along a spherical insulating body?

27.11 The voltage on an ESD bag decreases from 1 kV to 100 V over a time of 60 s. From this information determine as many characteristics of this bag as possible. State all assumptions.

27.12C For the situation shown in Figure 1, determine the electric field expression for each of the three regions, *a*, *d*, and *b*. Solve for all of the constants of integration. Neglect end effects. The dielectric constant of the slab of thickness *d* is equal to *k*. Although the free surface charges ρ_{S1} and ρ_{S2} are shown with equal magnitude and opposite sign, do not assume this in the analysis. If *a* is much less *b*, determine whether the electric field in region *b* is mainly determined by ρ_{S2}. Is this information useful when measuring the electric field in region *b* from ρ_{S2} only?

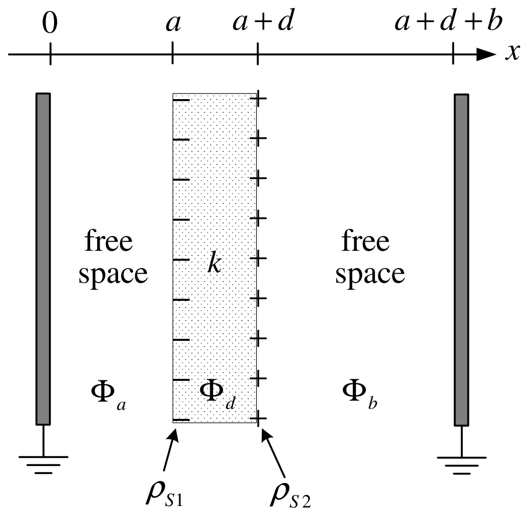

Figure 1

27.13E Using the method of images and

$$\Phi(r) = \iint_{S'} \frac{\rho_S(r')\,dS'}{4\pi\varepsilon_o|\vec{r}-\vec{r}\,'|}$$

derive the integral potential expression for a uniformly charged disk of radius R at a distance of d from the center of a grounded conducting sphere of radius a:

$$\Phi = \frac{\rho_S}{4\pi\varepsilon_o}\int_0^{2\pi}\int_0^R \frac{\rho' d\rho' d\phi'}{\sqrt{(x-d)^2+(y-\rho'\sin\phi')^2+(z-\rho'\cos\phi')^2}}$$
$$-\frac{\rho_S}{4\pi\varepsilon_o}\int_0^{2\pi}\int_0^R \frac{a}{\sqrt{d^2+(\rho')^2}} \frac{\rho' d\rho' d\phi'}{\sqrt{\left(x-\frac{a^2 d}{d^2+(\rho')^2}\right)^2+\left(y-\frac{a^2\rho'\sin\phi'}{d^2+(\rho')^2}\right)^2+\left(z-\frac{a^2\rho'\cos\phi'}{d^2+(\rho')^2}\right)^2}}$$

Clearly shown all steps. To determine some of the angles for the projection, it might be helpful to examine the coordinate system transformation relationships given in the appendix.

27.14 In a newspaper production line, paper is rolled at high speeds along insulating rollers. How should the charge be "bled off?"

27.15 A worker pours benzene liquid from a plastic container through a metal funnel into a large plastic vessel. What steps should be taken to reduce the probability of an electrostatic discharge?

27.16 In one of the last assembly steps in a puzzle factory, the puzzle pieces travel down a funnel to the puzzle box. Unfortunately, the company is receiving complaints about missing pieces (a real disappointment). The company has determined that puzzle pieces are occasionally sticking to the funnel. Recommend a solution if the funnel is plastic. Recommend a solution if the funnel is metallic.

27.17 Most of the electrical hazards associated with the filling of portable gas cans occur with metal containers insulated from ground. It seems that very little sparking can be obtained between a grounded sphere and a charged plastic container. However, if a metal funnel is used in the mouth of the container, then a spark can be generated. Explain whether these statements are reasonable.

27.18E An electric field field mill is used to measure an electric field with a magnitude of E_n (normal to the sensor's plate). Assume that the exposed area of the sensing plate by the rotating blade, which has a radian frequency of ω, is a periodic triangular wave as shown in Figure 2.

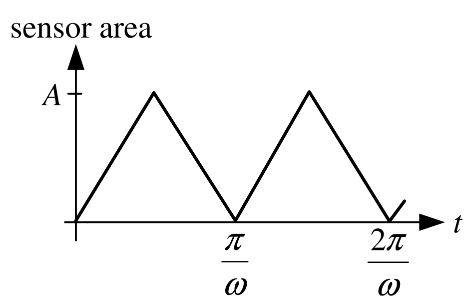

Figure 2

Using the Fourier series for the resultant current into a parallel *RC* circuit, determine the first three nonzero terms for the steady-state voltage across the *RC* circuit in the time domain. Using these three nonzero terms, determine the maximum amplitude of the voltage.

27.19 With an ESD simulator, why should an isolation transformer be used at the ac outlet for both the equipment under test and ESD simulator?

27.20 Would the 1 MΩ or 50 Ω input of a scope be more likely to sense the shuffling of feet along a rug? Explain

27.21 From the standpoint of reducing the effects of ESD, should the capacitance between the power conductor and ground be large or small ($Q = CV$)?

27.22 To help ensure that the input to a microprocessor is not due to an ESD event, the software checks the input state twice. Determine an appropriate time interval between the initial check and verification check.

27.23 A manufacturer claims to have a <u>wireless</u> wrist strap. Determine whether this can be done.

27.24 Several simple methods are available for reducing painful ESD discharges from the finger. A metal thimble or the tip of a metal key can be used to discharge the body to a grounded object. A specially made ring with a large metal head can also be used. The head of the ring is isolated from the rest of the ring, which is in direct contact with the finger. If the resistance from the ring's head to the band in contact with finger is 1.5 MΩ, estimate the capacitance required to dissipate most of the charge over about a one second interval. Determine the specific insulating material that could be used, as well as its (reasonable) dimensions. The material's dielectric strength should also be considered.

27.25 Rug rats (babies who crawl over carpets) are quite susceptible to electrostatic shock. This is due to the tribocharging between the child and the synthetic or wool carpet. Imagine that one overly active child reaches a potential of 15 kV immediately before touching the family kitty! (This voltage is relative to ground that exists beneath the rug.) Unfortunately, the kitty was charged to a value of −0.5 μC (the cat had previously rubbed against the couch). The self capacitances and the coefficient of induction prior to child-kitty contact follow:

$$c_{bb} = 130 \text{ pF}, \ c_{kk} = 100 \text{ pF}, \ c_{kb} = -70 \text{ pF}$$

The subscripts b and k represent the baby and the kitty, respectively. Determine the total charge on the child, the voltage of the cat, and the total energy associated with the child and the cat.

27.26 In reference Problem 27.25, imagine that the air between the child and cat breaks down just prior to contact; in other words, the child and the kitty get an old-fashioned shock. Determine the final voltage of and charge on this rambunctious child and the cat after this shock (when they are touching). Now, what is the total energy associated with the child and the cat?

27.27 In reference to Problem 27.25, repeat the analysis if the cat is not charged prior to contact. The initial voltage of the child is still 15 kV. Is this a good assumption? Explain. Is the shock intensity less than, equal to, or greater than the charged case? Explain.

27.28 In reference to Problem 27.25, estimate the self capacitance of the child and the cat after touching? Discuss the problems associated with the following parameters:

$$c_{bb} = 130 \text{ pF}, \ c_{kk} = 40 \text{ pF}, \ c_{kb} = -70 \text{ pF}$$

27.29 The coefficient of self capacitance of a little red wagon was measured using a battery-powered electrometer. All objects surrounding the wagon were grounded, and the wagon had insulating wheels. One input of the electrometer was connected to the cable connected to the wagon and the other input of the electrometer was connected to a test voltage V_T. The electrometer measured the charge residing on the wagon due to the test voltage V_T. (Before the application of this test voltage, the wagon was temporarily grounded to dissipate any charge on the wagon, in the electrometer, and in the cable.) Unfortunately, there is always instrumentation loading. Assume the shunt input capacitance of the electrometer is C_E, and the capacitance of the cable connecting the instrument to the wagon is C_c. Determine a relationship for the coefficient of self capacitance of the wagon in terms of V_T, C_E, C_c, and Q_{EM}, where Q_{EM} is the charge measured by the electrometer.

27.30 In reference to Problem 27.29, determine a relationship for the actual voltage of the wagon relative to ground as a function of V_T, C_E, C_c, and C_W, where C_W is the actual capacitance of the wagon.

27.31 In reference to Problem 27.30, when is

$$C_W = \frac{Q_{EM}}{V_T}$$

and an exact value for C_c not required? The electrometer essentially measures the voltage across the known capacitance C_E. Assume that V_T =100 V, C_E = 0.01 μF, and C_c = 100 pF. In this case, is the instrumentation loading negligible?

27.32 In reference to Problem 27.29, why was a *battery*-powered electrometer specified? What should the outer shield of the cable, at the wagon end, be connected to?

27.33 An explosion has occurred at a bran-flake food processing plant. The plant manager has hired you to determine whether this was (potentially) an electrostatic-based explosion. Assume that the bran dust concentration was in the explosive range. The facts provided by the plant manager follow: (1) the flake product emerges from a screw feeder at 1.5 kg/s with a density of approximately 240 kg/m^3, filtered through a screen, and forced with air pressure through an 5 inch diameter metallic tube; (2) the metallic tube extends from the fourth floor to the first floor; (3) typically one-half of the tube is filled; (4) one nonmetallic, PVC ($k \approx 3.2$), 1/8 inch thick, 1 inch long, 5 inch inner diameter tube section exists midway along the metallic tube where metal detectors are usually located; and (5) on the first floor, product (with plenty of dust) is accumulated into 100 pound, plastic-lined boxes. (The metal detectors are used to detect harmful metallic objects in the bran.) During a typical operation, the field exterior to the PVC tube, when carrying the flake product, is greater than 10 kV/cm. This field was determined using a field meter held 1 inch from the tube.

1) Estimate the charge per meter in the tube (in C/m).
2) Estimate the corresponding flake charge per kg (in C/kg).
3) Estimate and sketch the potential distribution and the electric field inside the metal pipe assuming the metal pipe is grounded.
4) Estimate the total charge accumulated in the 100 lb box and electric field at the top of the bran flake heap. Is the field sufficient to break down the air and ignite the dust?

27.34 Generally, the capacitance increases with the area of the conductors and decreases with spacing between the conductors. For the capacitance formula *X* (provided by your instructor) given in this chapter's capacitance table, qualitatively vary *each* of the parameters and determine whether the capacitance increases or decreases. Determine whether these qualitative results are in agreement with the given general capacitance statement. Finally, allow one of the parameters in the capacitance formula to become very large or very small. Then, compare this new result with another capacitance formula for another configuration.

27.35 The capacitance of a person inside a vehicle is given as 330 pF while a person outside a vehicle is given as 150 pF. Determine under what assumptions these numbers are reasonable. [General]