Chapter 5: Skin Depth, Wire Impedance, and Nonideal Resistors

5.1. Will the Eddy currents increase if the conductivity of the medium increases? Explain.

5.2. It is stated that the inductance of a bond is mainly a function of the length and shape of the bond, while the capacitance of the bond is mainly a function of the area of the two materials that are bonded together. Is this reasonable?

5.3C. Of the four approximations given in this chapter for the ac resistance of a round solid wire, which equation is best for use at both low and high frequencies?

5.4C. By comparing to the exact (Bessel function based) expression given in the book for the internal impedance of a round, solid isolated wire, plot (on the same set of axes) the percent error versus r_w/δ (from 0.1 to 10) for each of the following approximate expressions for the ac resistance due to the skin effect. Provide all programs used in the plotting. Use log scales when appropriate.

a) r_{DC}

b) $r_{DC}\left[1+\frac{1}{48}\left(\frac{r_w}{\delta}\right)^4\right]$

c) $\dfrac{r_{DC}}{2\dfrac{\delta}{r_w}-\left(\dfrac{\delta}{r_w}\right)^2}$

d) $r_{DC}\left(\frac{r_w}{2\delta}+\frac{1}{4}\right)$

e) $r_{DC}\frac{r_w}{2\delta}$

f) $r_{AC}=\dfrac{r_{DC}}{2\dfrac{\delta}{r_w}}\left[1+\dfrac{\delta}{2r_w}+\left(\dfrac{\delta}{2r_w}\right)^2\right]$

5.5 It is stated that aluminum wires are less affected by the skin depth than copper wires. Explain why and when this is true. Which wire has the greater ac resistance?

5.6 It is stated that tubes with thin walls are less affected by the skin depth than tubes with thick walls. Explain why and when this is true. Which tube has the greater ac resistance?

5.7 A student states (for a given wire radius) that

> "Since the skin depth for silver is less than the skin depth for copper, then the ac resistance for a silver wire is greater than the ac resistance of a copper wire of the same radius because the current has less cross-sectional area to pass through."

Determine the validity of this statement.

5.8EC Repeat the entire analysis given in this chapter for an equilateral triangle cross-section wire instead of a rectangular cross-section wire. Will the actual ac resistance of the triangle wire be less or greater than the calculated result using this "fast" skin depth approach.

5.9 Derive the expression given in the book for the dc and ≈ HF resistance of a "Rectangular conductor (with rounded corners)."

5.10 Derive the expression given in the book for the dc and ≈ HF resistance of a "Tubular round conductor."

5.11 Derive the expression given in the book for the dc and ≈ HF resistance of "Two parallel wide flat conductors."

5.12 Derive the expression given in the book for the dc and ≈ HF resistance of "Two concentric circular conductors."

5.13C It is stated that a 12 inch steel "I" beam can have a greater RF impedance than a #6 AWG copper wire! Determine whether this is a reasonable statement by plotting on the same axes the ac resistance of a typical 12 inch "I" beam and the ac resistance of a #6 AWG copper wire versus frequency. The frequency range should be sufficiently large to support your conclusion. [Whitaker]

5.14C For the lower and upper frequency limits of the VLF band, determine the gauge of wire where the skin depth is equal to the radius of the wire.

5.15C Plot the ratio of the ac resistance of a #20 AWG solid wire to the ac resistance of the stranded wires (each individually insulated from each other) as a function of the frequency. Assume that the overall radius of the solid wire is about equal to the overall radius of the bundled set and neglect the field coupling between the wires. Allow the number of stranded wires to be equal to 10, 100, and 1,000. Clearly show the frequency where the skin depth is equal to and one-tenth of the wire radius. What is a potential inexpensive material that could be used to insulate the wires? (Actually, the field coupling, which is also known as the proximity effect, is a very important factor in the operation of Litz wire. Furthermore, the insulation thickness of the strands is not negligible.)

5.16 Two parallel conductors, each with a radius of 1.5 mm, have a 0.5 mm thick insulative coating. Determine the minimum center-to-center distance between the wires so that the proximity effect can be mostly neglected.

5.17 Show that for #8 AWG solid copper wire, the ac resistance will be twice the dc resistance at 20 kHz. What is the major disadvantage (besides cost) in using a larger wire to reduce these losses? What can be done instead?

5.18 If the dc component of the current exceeds the amplitude of the ac component by a factor of approximately ten, why are the stated advantages of using Litz wire not as obvious?

5.19 Determine why Litz wire is used when the ratio of the ac to dc resistance is greater than two. Assume a "packing" factor of 50%. If the "packing" factor is 80%, for what ratio of ac to dc resistance should Litz wire be used?

5.20 Determine any electrical advantages in using a bimetallic conductor that contains a magnetic core. For power cables, steel is used as the core to increase the strength of the conductor permitting greater distances between the poles supporting the cables. Determine any electrical advantages in using a bimetallic conductor that consists of a copper core with a magnetic coating.

5.21C Determine the frequency where the inductance reactance is usually greater than the ac resistance for a three inch long #12 AWG wire.

5.22S Are the equations provided in this chapter relating AWG and wire cross section also valid for #1/0, #2/0, and #3/0 wire?

5.23 What happens when a copper wire is soldered to an aluminum chassis? How can the problems be overcome?

5.24 Why are gold connectors sometimes used?

5.25 Why are nickel-plated connectors sometimes used?

5.26 What metals are near copper in the electrochemical series? Why is this information important?

5.27 Will a hole punched through tin-plated steel have a greater potential for corrosion than a hole punched through galvanized (zinc) plated steel? In each case, what metal is acting like the anode (active portion) and which metal is acting like the cathode (passive portion)? If the anode is much greater in size than the cathode, why is the corrosion rate determined by the size of the cathode?

5.28 Explain why for those circuits in which high Q is not required, the skin effect is often included when the skin depth is equal to or less than one-half the wire radius.

5.29 In reference to the Mathcad plot given in grounding jumper wire discussion, how is the break frequency shown related to R and L?

5.30 Provide an example (not discussed in this book) where the internal inductance is important.

5.31 Improve either of the RLC models given in this chapter for a real resistor by adding one additional passive element. Then, determine the expression for its resonant frequency. Under what conditions is this expression approximately equal to the commonly quoted equation

$$\frac{1}{2\pi\sqrt{LC}}\ ?$$

5.32 Without performing the rather lengthy mathematics associated with determining the actual resonant frequency of a circuit, how can one determine (almost by inspection) when the resonant frequency of the circuit is approximately equal to the commonly quoted equation

$$\frac{1}{2\pi\sqrt{LC}}\ ?$$

Test your method on three different RLC circuits. Hint: see the discussion on high-Q approximations in this book.

5.33S In reference to the resistor type discussion given this chapter, verify and document all the statements given for the carbon film resistors. If there are any important advantages or disadvantages not mentioned, include them. Finally, provide one real, practical specific case where a carbon film resistor would be clearly selected over all the other types given in this discussion.

5.34S Repeat Problem 5.33 for Metal Film resistors.

5.35S Repeat Problem 5.33 for Wirewound resistors.

5.36 Provide two uses for resistors with values less than 1 Ω.

5.37 In reference to the exotic cable discussion in this chapter, why is the conduction current much greater than the displacement current for good conductors? Physically explain the difference between conduction current and displacement current inside a conductor.

5.38 Is μ metal or copper more effective in absorbing plane waves?

5.39 It is argued that since the various frequencies of an audio signal travel down a ordinary copper wire at different frequencies, dispersion occurs. However, with novel speaker wire consisting of a solid copper core and μ-metal sheath, this dispersion problem is supposedly reduced. Discuss the validity of this statement.

5.40C Determine the resistance of 30 ft of #18 AWG wire at 20 Hz and 20 kHz. Is this frequency-dependent loss a source of distortion? What is the difference between distortion, dispersion, and attenuation?