Chapter 8: Cable Modeling

8.1 Sketch the electric and magnetic fields for a lossless coaxial cable. Sketch these same fields if the dielectric between the two conductors consists of two concentric slabs (of different dielectric constants) in direct contact.

8.2 Sketch the electric and magnetic fields for a lossless, open-air twin-lead line. Sketch these same fields for a shielded twin-lead line.

8.3 Sketch the electric and magnetic fields for a lossless strip line. Sketch these same fields for a lossless strip line between two large ground planes. Assume the dielectric constant of the substrate is one.

8.4 Sketch the electric and magnetic fields for two, lossless, parallel strip lines, equal distance above a ground plane, assuming that the ground plane is the return for both lines. This is referred to as the even or common mode of operation.

8.5 Sketch the electric and magnetic fields for two, lossless, parallel strip lines, equal distance above a ground plane, assuming that one strip line is the return for the other. This is referred to as the odd or differential mode of operation.

8.6 Repeat the analysis in the high-fidelity speaker wire example for a total of 8 independent wires each of #23 AWG braided together and then surrounded by PVC insulation. Assume that for the cable, R = 5 mΩ/ft, C = 20 pF/ft, and L = 0.085 μH/ft. Compare to Cables A, B, C, and D.

8.7 Repeat the analysis in this chapter for the high-fidelity speaker wire example for a pair of #12 AWG wires. Assume that for the cable, R = 10 mΩ/m, C = 76 pF/m, and L = 0.32 μH/m. Compare to Cables A, B, C, and D.

8.8C Repeat the numerical analysis and discussion given in the selecting the cable model discussion for a speaker with an impedance (magnitude) that varies from 5 Ω to 30 Ω from 20 Hz to 20 kHz. The speaker's impedance should be both capacitive and resistive over some frequencies and inductive and resistive over other frequencies.

8.9 When is the cable model type not critical?

8.10 Determine three simplified (but nontrivial) forms for the following effective relative permittivity equation for coplanar strips. State all assumptions. Study the resultant expressions and determine whether they are physically reasonable.

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} \left\{ \begin{array}{l} \tanh\left[0.775 \ln\left(\dfrac{h}{w}\right) + 1.75\right] \\ + \dfrac{kw}{h}\left[0.04 - 0.7k + 0.01\left(1 - 0.1\varepsilon_r\right)\left(0.25 + k\right)\right] \end{array} \right\}$$

8.11C Determine the validity of the guideline, "Low-voltage dc wires should be kept less than 1 mm apart."

8.12 The dielectric constant for FR-4 varies from 4.8 at 100 Hz to 4 at 1 GHz. For a microstrip line, determine the percent change in characteristic impedance at these two frequencies.

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8.13C Determine the effect of the strip thickness on the effective relative permittivity and characteristic impedance of a microstrip line. Also vary the dielectric thickness and strip width.

8.14 Determine the capacitance per meter for an open-air parallel line if the distance between the conductors is 0.5" and the wires are #12 AWG. Compare this to the capacitance of the other cables given in the modest listing of transmission lines and their properties table.

8.15 Determine the characteristic impedance of 165-mil diameter wire with 12-inch spacing (i.e., old-fashioned open-wire telephone wire). Repeat with 8-inch spacing.

8.16S Estimate the change in the capacitance when immersing two parallel #20 AWG gauge wires with a center-to-center distance of 1 cm and an insulation thickness equal to the conductor's radius into a sewer (dirty water). To simplify the analysis, why should the conductivity of the sewer water be assumed zero?

8.17E The inner conductor of a miniature coaxial cable is constructed of seven, #50 AWG silver plated copper alloy wires. The thickness of the dielectric, which has a dielectric constant of 2.05 (PVA), between the inner and outer conductor is 2.5 mils. The equivalent thickness of the stranded outer conductor is 1.56 mils. Determine the dc resistance per meter of this cable assuming the silver thickness is one-tenth of the copper alloy wire radius. Verify that the equivalent radius of the inner conductor is about 1.5 mils and the characteristic impedance is about 45 Ω. What are the obvious limitations of this miniature cable? The characteristic impedance of this coaxial cable is to be measured by connecting 0.5 inches long, #18 AWG test leads from the inner and outer conductors of the coax to the inputs of the test instrument (with a 50 Ω input impedance). The end of the miniature coax is left open circuited. Determine the effects of these test leads on the measurement. [Wood]

8.18SC Using the expression for the inductance of a single-layer, tightly wound coil and the capacitance of a coaxial cable, determine an approximate expression for the characteristic impedance and time delay of a coaxial cable where the inner conductor is a tightly wound coil. Plot the characteristic impedance versus coil diameter for various cable dimensions and coil parameters and determine the diameter corresponding to the maximum impedance. With this information, design a coaxial cable with a delay of 1 μs and determine its characteristic impedance. What is its maximum operating frequency? What are the electrical costs associated with using this cable as a delay line? Determine the maximum delay that can be obtained with an integrated circuit (IC) delay chip. (A delay line can also be constructed by converting the electromagnetic wave to an acoustic wave, which travels at a much slower velocity. The acoustic wave can travel across a rod, for example, and then be converted back to an electromagnetic wave. Magnetostrictive ferrites can be used to perform the conversion.) [Macalphine; Blackburn; Reference; Meeldijk]

8.19E Determine the optimum ratio of the outer radius to the inner radius, a/b, for a coaxial cable if only conductor attenuation is considered given the following relationship for the attenuation coefficient:

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$$\alpha \propto \frac{\sqrt{f\varepsilon_r}}{a}\frac{\left(1+\frac{a}{b}\right)}{\log\left(\frac{a}{b}\right)}$$

Is it equal to 3.6 as stated in this book? How sensitive is the attenuation near this optimum value to variation in a/b?

8.20 Explain why cable inductance increases rapidly with "larger" cables. Define "larger." Explain why many small insulated wires per conductor (with the appropriate Litz wire weaving) rather than one large conductor can result in a lower resistance (assume the overall diameter of the Litz wire conductor and the one large conductor are about the same). At audio frequencies, is the lower resistance or lower inductance more important? Qualitatively explain the relative differences between the resistance, capacitance, and inductance per foot for the cables described in the high-fidelity speaker wire discussion. Why is the capacitance of speaker wire cable sometimes actually helpful?

8.21 Determine the equation for the characteristic impedance of a lossy cable as the frequency becomes very large. Include the skin effect. How does the skin effect influence the result? For what frequencies does the skin effect have negligible affect on the characteristic impedance?

8.22C A capacitor microphone (C_s = 40 pF) is connected to 2 m of 100 Ω cable with C = 60 pF/m to an amplifier with an input impedance of 10 MΩ. Plot the magnitude of the sinusoidal steady-state voltage across the amplifier to the voltage at the microphone from 20 Hz to 20 kHz by assuming that the inductance and resistance of the cable and the resistance of the amplifier are not important. Plot this same ratio but include the inductance of the cable. Plot this same ratio but include the resistance of the amplifier. Finally, plot this same ratio but include both the inductance of the cable and resistance of the amplifier. For what frequency range is the cable inductance and amplifier resistance important?

8.23 Discuss an equivalent proximity effect for two or more capacitors. Why is this electric-field proximity effect usually not important?

8.24 Does the proximity effect increase the characteristic impedance of a twin-lead line and microstrip line? [Skilling; Anderson, '85]

8.25 What is the main disadvantage of 50 Ω twin-lead line? Determine the weight and electrical attenuation difference between a 75 Ω and 300 Ω twin-lead line (assuming the same dielectric material is used in both lines). Why is some 75 Ω twin-lead line disposable?

8.26S Using a cable catalog, determine typical R per meter values for five different cables and then compare these R values to their corresponding Z_o's, characteristic impedances.

8.27 It is stated that the characteristic impedance of typical wire-wrapped lines is 140 Ω ± 50%. Determine the validity of this statement.

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8.28 Using Shannon's formula, explain how a capacity of 100 kbps can be obtained from a bandwidth of 1 Hz. Determine a simple modulation scheme that can be applied to obtain this capacity.

8.29C For six different complex loads with impedance magnitudes much less, much greater, and approximately equal to the magnitude of the characteristic impedance of a 100 cm connecting line (R = 5 mΩ/m, C = 5 pF/m, and L = 1.8 μH/m), plot the input impedance of the line (using the lossy sinusoidal input impedance equation for a transmission line given in the *Transmission Lines and Matching* chapter) versus frequency. The frequency variation on these six graphs should be such that the line length varies from λ/1,000 to λ/10. Plot on these same graphs the actual impedance of the load and compare it to the transmission line result. Also, plot on these same graphs the frequency corresponding to λ/1,000, λ/100, and λ/10.

8.30C Repeat the analysis in the receiver loading discussion in this chapter assuming that each "receiver" is a series inductance of 10 nH rather than a shunt capacitance of 20 pF. The other parameters given in the problem remain unchanged. Provide a practical use of this inductive-loaded system.

8.31C In reference to the receiver loading discussion in this chapter, vary the final load impedance (not the individual receiver loads) on the modified line to determine if a better match exists than 11.9 Ω.

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