Chapter 13: Transmission Lines and Matching

13.1 Why are the reflection and transmission coefficients for the current not equal to the reflection and transmission coefficients, respectively, for the voltage?

13.2 Determine the reflection coefficient and its magnitude for a line with a characteristic impedance of 50 – *j*15 Ω connected to a load of *j*50 Ω. If the frequency is 10 MHz, determine the inductance or capacitance of the load.

13.3 Determine whether the VSWR can be less than one. Determine the largest possible value for the VSWR.

13.4 For the complex load, $R_L + jX_L$, and the complex characteristic impedance, $R_o + jX_o$, determine under what conditions the magnitude of the reflection coefficient is greater than one. What is the VSWR when the reflection coefficient is greater than one? What does the phase angle of the reflection coefficient represent?

13.5C In reference to the VSWR and SWR discussion in this chapter, numerically plot the time-average value of the voltage waveform from $z = 0$ to 1 along the same 1 m long transmission line for $\rho = 0$, 0.5, and 1.

13.6 A log-periodic antenna with an approximate impedance of 290 Ω is connected via 50 Ω lossless coax to the 300 Ω input of a TV. Determine the VSWR and SWR on the line.

13.7 A transmitting antenna can be represented by a 1,200 pF capacitor in parallel with a 50 Ω resistor. If a 75 Ω lossless coaxial cable is connected to the antenna, determine the frequency(s) where the VSWR is a minimum.

13.8S Using a cable catalog, locate a 50 Ω coaxial cable with a loss of less than 2 dB per 100 ft at 144 MHz.

13.9 Why is the term "antenna tuner" a misnomer?

13.10 When is the output at a cable in dB not merely the input signal in dB minus the cable loss in dB?

13.11C A driver is connected to a 2 m long RG/8U cable. One-third of the way along the line, a splice occurs to another receiver. The length of the splice is 10 cm. Determine the input impedance seen by the driver initially and "after a long time" if the input signal is a transient low-to-high ramp digital signal. Then, assuming the input signal is sinusoidal, plot the sinusoidal steady-state input impedance seen by the driver as the frequency is varied. The frequency span of the variation for this plot should be such that at the lowest frequency all the lines are electrically short and at the highest frequency all the lines are at least one wavelength in length. Finally, determine plot the VSWR for each transmission line over the same frequency range. The driver resistance is 10 Ω, and the load impedance of both receivers is 15 kΩ. Discuss the results. The transmission lines are lossless.

13.12C A driver is connected directly to three 2 m long RG/8U cables. Identical receivers are connected at the end of each cable. Repeat Problem 13.11 for this new situation.

13.13C A driver is connected to a 2 m long RG/8U cable. At the end of the line, at the first receiver, a second 3 m long RG/8U cable is connected to a second identical receiver. Repeat Problem 13.11 for this new situation

13.14EC For the cable/receiver connections given in Problem 13.11, assume the rise time of the 0-to-5 V function (low-to-high transition) is 3 ns. Using a numerical package, plot the output voltage at either receiver so that at least 4 reflections have occurred at *each* receiver. Compare the rise time to the round-trip propagation delay for each of the lines. The error function should be used to represent the driver signal. Is the numerical steady-state voltage across this receiver expected? Compare with the analytical result.

13.15EC Repeat Problem 13.14 for the cable/receiver connections given in Problem 13.12.

12.16EC Repeat Problem 13.14 for the cable/receiver connections given in Problem 13.13.

13.17 For the situation given in Problem 13.11, determine the (maximum) length of the each of the lines so that the effects of the bouncing due to the mismatching at the receivers is negligible. Assume that the rise time of the input ramp signal is 3 ns. Then, repeat this analysis but allow the impedance of the receiver at the splice to be about 52 Ω. Then, repeat this analysis but allow the impedance of the other receiver to be about 52 Ω. Then, repeat this analysis but allow the impedance of both receivers to be about 52 Ω.

13.18 For the situation given in Problem 13.12, determine the (maximum) length of the each of the lines so that the effects of the bouncing due to the mismatching at the receivers is negligible. Assume that the rise time of the input ramp signal is 3 ns. Then, repeat this analysis but allow the impedance of one of the receivers to be about 52 Ω. Then, repeat this analysis but allow the impedance of two of the receivers to be about 52 Ω. Then, repeat this analysis but allow the impedance of all of the receivers to be about 52 Ω.

13.19 For the situation given in Problem 13.13, determine the (maximum) length of the each of the lines so that the effects of the bouncing due to the mismatching at the receivers is negligible. Assume that the rise time of the input ramp signal is 3 ns. Then, repeat this analysis but allow the impedance of the first receiver to be about 52 Ω. Then, repeat this analysis but allow the impedance of the second receiver to be about 52 Ω. Then, repeat this analysis but allow the impedance of both receivers to be about 52 Ω.

13.20 If a line is electrically short and the source and load impedance are not matched to the line, are reflections still occurring? Why are the reflections not usually noticeable? When are they noticeable?

13.21C Through the use of SPICE (or other circuit simulation package), verify <u>all</u> of the statements given in shunt diode matching discussion. Two examples are sufficient. The transmission line should be electrically long. When will the diode not function as a "matching" device?

13.22 Repeat the analysis given for the first two series matching methods discussed in this chapter in the series matching with multiple receivers section but assume four lines instead of two lines. Why would separate series matching resistors not work if the line lengths are different?

13.23EC Repeat the analysis in the settling time versus reflection coefficient discussion in this chapter but assume a reasonable value for the cable resistance per unit length, R. A new settling time equation is required in this case.

13.24 Repeat the analysis in this chapter for the shunt matching with a split termination for a TTL system but assume a 200 Ω transmission line.

13.25 Repeat the analysis in this chapter for the shunt matching with a split termination for a CMOS system but assume a 400 Ω transmission line.

13.26 Repeat the analysis in this chapter for the shunt matching with a split termination for an ECL system but assume a 150 Ω transmission line. Check against the rule-of-thumb given.

13.27 In reference to the split termination, assume a step generator with an internal impedance of R_s is available, and the termination resistors R_1 and R_2 are variable. If a step voltage of magnitude V is applied at the input of a transmission line of characteristic impedance Z_o not equal to R_s, determine the value of the voltage appearing at the receiver at T_D and at the driver at $2T_D$ (T_D is the one-way time delay of the line) as a function of R_1, R_2, R_s, and Z_o. How can these results be used to determine when the line is matched to its load?

13.28S In reference to the series matching and dynamic output resistance discussion in this chapter, verify the dynamic output resistances provided for the TTL logic from the *v*-*i* curves obtained from a databook.

13.29S In reference to the series matching and dynamic output resistance discussion in this chapter, verify the dynamic output resistances provided for the CMOS logic from the *v*-*i* curves obtained from a databook.

13.30S In reference to the series matching and dynamic output resistance discussion in this chapter, verify the dynamic output resistances provided for the ECL logic from the *v*-*i* curves obtained from a databook.

13.31 When is the characteristic impedance not purely resistive? Why is a complex characteristic impedance usually not desirable? Provide an example where a complex characteristic impedance could possibly be desirable.

13.32EC Show that when $R/L = G/C$ a line is distortionless and the characteristic impedance is real even when R and G are not zero. State all assumptions. Explain how this line is functioning as a distortionless line over a limited (low?) frequency range. Why is the given ratio of the transmission line parameters the optimum ratio? Can a cable distort a signal consisting of only one frequency? (Hints: what are the time constants of an *RC* and *RL* circuit? How are these time constants related to the cutoff frequencies of the corresponding *RC* and *RL* filters? Compare the amplitude <u>and</u> phase responses of these two filters.)

13.33 Determine the sensitivity of the Q to the resistance for a series *RLC* circuit.

13.34 A circuit has a high Q at a given frequency. Under what circumstances would the circuit not ring?

13.35S For a typical CATV cable, determine the maximum length of 75 Ω coax that is still considered electrically short. How will the voltage vary along such a line if not properly matched? How will the current vary along the line?

13.36 Design and analyze a TV splitter using a transformer that is capable of splitting one 75 Ω line into two 75 Ω lines. Assume that the TV receiver impedances are matched to the lines. What is the cost of using this device? The splitter should not generate any reflections.

13.37 In reference to the "hair-ball" network discussion in this chapter, show that for N cables meeting at a junction, the matching resistance of each splitter resistor should be

$$Z_o\left(\frac{N-2}{N}\right)$$

13.38 In reference to the "hair-ball" network discussion in this chapter, show that the loss of the splitter in dB is

$$loss_{dB} = 20\log(N-1)$$

13.39C Show that for a lossless line the maximum and minimum possible magnitudes of the input impedance are

$$|Z_{in}|_{max} = \frac{|V|_{max}}{|I|_{min}} = (\text{VSWR})Z_o,\ |Z_{in}|_{min} = \frac{|V|_{min}}{|I|_{max}} = \frac{Z_o}{\text{VSWR}}$$

Then, plot the magnitude of the input impedance versus length (over at least one full wavelength) for a lossless line with a characteristic impedance of 50 Ω for each of the following loads: $Z_L = 10 + j10\,\Omega$, $Z_L = 10 + j100\,\Omega$, $Z_L = 50\,\Omega$, $Z_L = 100 + j10\,\Omega$, and $Z_L = 100 + j100\,\Omega$. Verify that the magnitude of the input impedance is indeed within the bounds given by $|Z_{in}|_{max}$ and $|Z_{in}|_{min}$ for each load.

13.40 For a lossless transmission line with a reflection coefficient of ρ at the load, determine (by inspection) whether the following time-domain expression is a reasonable description for the steady-state voltage along the line:

$$v(t) = A\cos(\omega t - \beta z) + \rho A\cos(\omega t + \beta z)$$

The transmission line is in the z direction, and β is the phase constant for the line.

13.41C Assuming a matched system, determine the maximum difference in phase, loss (in dB), and delay time between the input and output voltage of an "*RC*" transmission line. Let the frequency vary from 250 Hz to 2.7 kHz and the line length from 1 to 1 km. Use the values for *R*, *L*, and *C* provided in this chapter for a telephone line. Repeat the analysis for the input and output current.

13.42 Provide a possible reason why some audio low-pass filters placed near speakers use inductors instead of capacitors. These filters are referred to as crossover networks.

13.43 A transmitting antenna can be represented by a 1,200 pF capacitor in parallel with a 50 Ω resistor. A 75 Ω lossless coaxial cable is connected to the antenna.

Determine the position and value of a shunt passive element "near" the antenna that will minimize the VSWR. Assume a reasonable frequency. "Near" is any position within one wavelength of the antenna.

13.44ES Determine the general equations for the current along an open-circuited lossless transmission line of impedance Z_o with a total length of l_{th} that is series loaded at $l_{th}/2$ with an inductance of L_{ex}. When the transmission line is electrically small, verify that the current is approximately uniform along the line. Does the average value of the current magnitude increase with L_{ex}? This is referred to as inductive loading. [Collin, '85]

13.45ES Determine the general equation for the current along a lossless transmission line of impedance Z_o with a total length of l_{th} that is loaded at its end with a capacitance of C_{ex}. If the transmission line is electrically small, verify that the current is approximately uniform along the line. Does the average value of the current magnitude increase with C_{ex}? This is referred to as capacitive loading. [Collin, '85]

13.46 Show for cables operating at low frequencies, $RC > GL$. Do not assume that G is negligible.

13.47 In the transmission-line parameter expression table in this chapter, verify all of the approximations given in the table for R_o, X_o, α, β, and v for the frequency condition X (provided by your gregarious instructor).

13.48 Estimate the maximum number of TTL receiver loads that can be connected at the same point before they excessively affect a typical incoming TTL transient signal. State all assumptions.

13.49C Through two low-to-high transition examples, numerically verify using SPICE (or other circuit simulation package) the mismatch "blimp" equation given in this chapter.

13.50 In reference to the discussion in this chapter related to the "blimp" from the capacitance of a receiver, determine the time-domain expression for the reflected signal and its maximum amplitude if the input signal is the double exponential function

$$v(t) = C\left(e^{-\alpha t} - e^{-\beta t}\right)u(t)$$

13.51EC For high-speed systems when a trace is required to make a 90° turn, it is sometimes broken into two 45° turns as shown in Figure 1 (or the corner is rounded off). Supposedly, this is to reduce reflections. Assume that the major consequence of the right-corner turn is an increase in the capacitance introduced by the greater trace width. For a 50 Ω, 8 mil wide microstrip line with a $\varepsilon_r = 4.5$ substrate material, determine whether the extra capacitance introduced by the right-angle bend is about 0.01 pF. Compare this excess capacitance to the inherent capacitance of the line without a bend. How does this capacitance affect the time delay? Estimate the extra capacitance introduced by the right-corner bend if the trace width is 100 mil. [Johnson, '93]

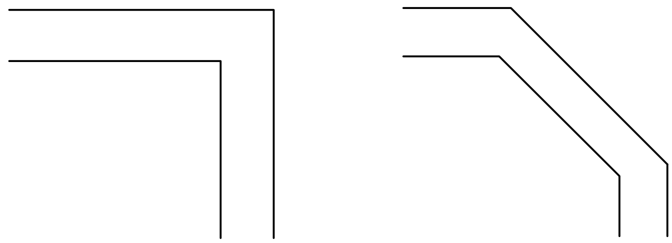

Figure 1

13.52 Determine the reflection and transmission coefficients for a transmission line of impedance Z_o connected to a load consisting of inductor L that is connected in series to a parallel RC circuit. Using reasonable values for the elements, determine the effect of L and C on a transient 74AS00 TTL signal. Can the L improve the system performance?

13.53 Rather than perfectly matching a transmission line to its load, one source recommends that the actual matching resistance be slightly greater than that for a perfectly matched situation. This source states that this slightly larger resistance introduces additional low-pass filtering or rounding of quickly changing signals, which reduces high-frequency emissions. In addition, it is claimed that the peak current is reduced. Determine the validity of these statements.