ECE 5317/6351

Fall 2011

Project

INSTRUCTIONS

This project is due on the last day of class. Please work individually on the project, and do not discuss it with anyone other than the instructor.

PROBLEM DESCRIPTION

A microstrip line is shown below. The line extends to infinity in the z direction. A signal generator is attached at $z = 0$ with the polarity shown. The signal generator applies a voltage signal that is

$$v_s\left(t\right) = \begin{cases} 1V, & 0 < t < t_0 \\ 0, & \text{otherwise} \end{cases}$$

where $t_0 = 10^{-10}$ [s].

FORMULATION AND CALCULATION

Formulate the transmission line voltage $v(z, t)$ at a point $z > 0$, giving enough details to make the derivation complete. However, you do not need to re-derive anything in your write-up that is already derived in the class notes. Note that the Fourier transform of the input voltage function can be obtained in closed form, and you should do this as part of your analysis. Then implement the calculation of the voltage and current using any software package that you prefer. Please use the CAD formulas given below for the microstrip line calculations.

RESULTS

A) Frequency-Domain

1. Plot the characteristic impedance (in Ω) versus frequency, from 0 to 100 GHz.

2. Plot the effective relative permittivity versus frequency, from 0 to 100 GHz.

3. Plot the conductor attenuation α_c, the dielectric attenuation α_d, and the total attenuation α (all in np/m) versus frequency, from 0 to 100 GHz.

B) Time-Domain

1. Plot (on the same graph if possible) the transmission-line voltage v (z, t) versus t for $z = 1$ cm, 2 cm, 4 cm, 8 cm, and 16 cm.

2. Repeat part (1) above assuming there is no dielectric or conductor loss.

3. Repeat part (1) above assuming there is no dielectric or conductor loss and there is no dispersion, so that the characteristic impedance and the effective permittivity are independent of frequency, and are taken equal to their respective values at zero frequency.

Validation

It is strongly recommended that you validate your numerical integration by first calculating the pulse propagation for a lossless line ($\alpha_c = \alpha_d = 0$) with no dispersion ($\varepsilon_r^{eff}(f) = \varepsilon_r^{eff}(0)$ and $Z_0(f) = Z_0(0)$). In this case, the voltage and current pulses should propagate at the phase velocity $v_p = c / \sqrt{\varepsilon_r^{eff}(0)}$ without changing shape. Hence, you know what the correct result should be.

FORMAT GUIDELINES

Your project should consist of a write-up that contains an Abstract, an Introduction section, a Formulation section, a Results section, and a Conclusions Section. You may also include a References section and an Appendix, if appropriate. The project should be done on a word processor.

The Results section should provide the results that are required, and also provide a thorough discussion of the results.

A significant part of your grade will depend on the accuracy of your results, so you are encouraged to do as much numerical checking as possible to have confidence in your results.

A significant part of your grade will also depend on the thoroughness of your discussion and your interpretation of the results.

You will also be graded on the neatness and quality of your write-up, and the quality of your results. Please use good scales and labeling when you plot your results and make sure that your plots are easy to read and look nice.

NUMERICAL ISSUES

Numerical experimentation will probably be required to make sure that you have a sufficient limit of integration in ω for the inverse Fourier transform integral, and that you have a sufficient sample density when you compute the integral. You may wish to plot the integrand to help you with this. Note that the integration may require a finer sample density as the distance z increases, since the integrand will oscillate faster as a function of ω as z increases.

MICROSTRIP GEOMETRY

TOP VIEW

END VIEW

SIDE VIEW
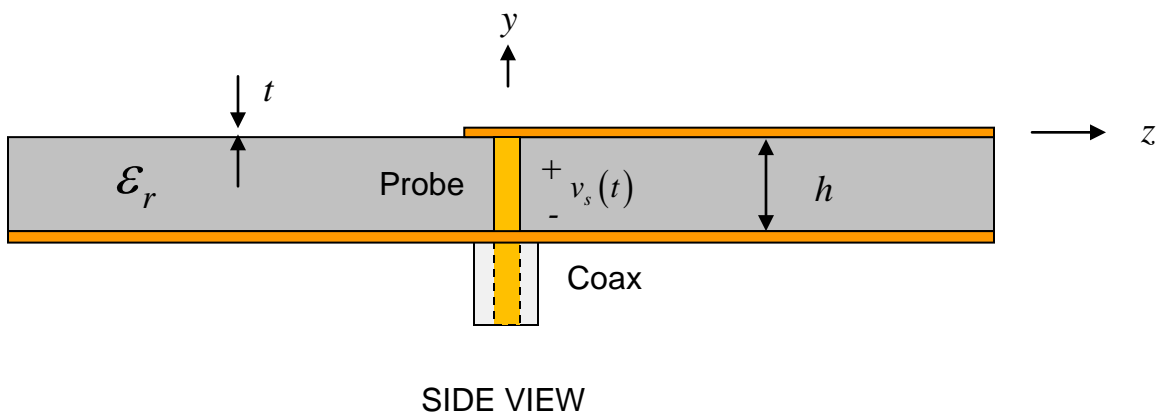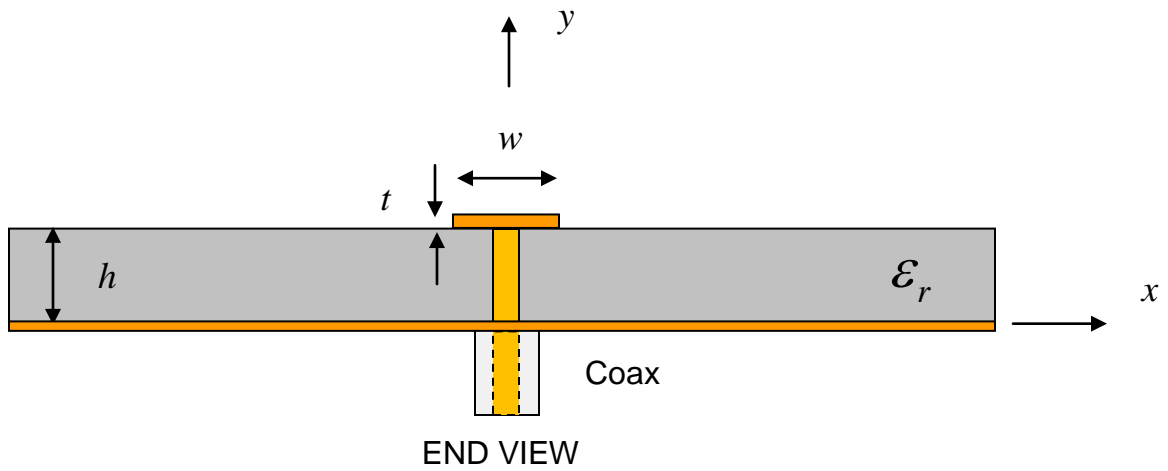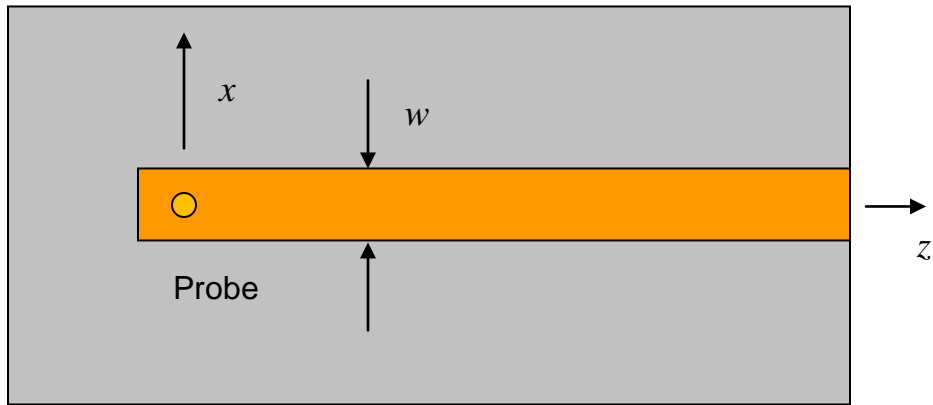
PARAMETERS OF MICROSTRIP LINE:

$\varepsilon_r = 2.2$

$\tan \delta = 0.001$ (loss tangent of substrate)

$h = 1.524$ [mm] (60 [mils])

$w = 50$ [mils]

$t = 0.0175$ [mm] (corresponding to 0.5 oz copper /ft^2 for the copper cladding)

$\sigma = 3.0 \times 10^7$ [S/m] (for copper conductors)

Note: ε_r is the above table denotes ε_r' (the real part of the complex effective permittivity). Hence, $\varepsilon_{rc} = \varepsilon_{rc}' - j\varepsilon_{rc}'' = \varepsilon_r \left(1 - j(\tan \delta)\right)$.

APPROXIMATE CAD DESIGN FORMULAS

Note: In these formulas, ε_r is the real part of the complex effective permittivity. That is, ε_r denotes $\varepsilon_r{}'$.

Phase Constant

$$\beta = k_0 \sqrt{\varepsilon_r^{eff}(f)}$$

where the "effective relative permittivity" is

$$\varepsilon_r^{eff}(f) = \left(\sqrt{\varepsilon_r^{eff}(0)} + \frac{\sqrt{\varepsilon_r} - \sqrt{\varepsilon_r^{eff}(0)}}{1 + 4F^{-1.5}} \right)^2$$

$$\varepsilon_r^{eff}(0) = \frac{\varepsilon_r + 1}{2} + \left(\frac{\varepsilon_r - 1}{2} \right) \left(\frac{1}{\sqrt{1 + 12(h/w)}} \right) - \left(\frac{\varepsilon_r - 1}{4.6} \right) \left(\frac{t/h}{\sqrt{w/h}} \right) \qquad (w/h \geq 1)$$

$$F = 4 \left(\frac{h}{\lambda_0} \right) \sqrt{\varepsilon_r - 1} \left(0.5 + \left(1 + 0.868 \ln \left(1 + \frac{w}{h} \right) \right)^2 \right)$$

Characteristic Impedance

$$Z_0(f) = Z_0(0) \left(\frac{\varepsilon_r^{eff}(f) - 1}{\varepsilon_r^{eff}(0) - 1} \right) \sqrt{\frac{\varepsilon_r^{eff}(0)}{\varepsilon_r^{eff}(f)}}$$

where

$$Z_0(0) = \frac{120\pi}{\sqrt{\varepsilon_r^{eff}(0)} \left[(w'/h) + 1.393 + 0.667 \ln \left((w'/h) + 1.444 \right) \right]} \qquad (w/h \geq 1)$$

$$w' = w + \frac{t}{\pi} \left(1 + \ln \left(\frac{2h}{t} \right) \right) \qquad \left(w/h \geq \frac{1}{2\pi} \right)$$

Conductor Loss

Note: In these formulas, Z_0 means $Z_0(f)$.

$\dfrac{w}{h} \le \dfrac{1}{2\pi}$:

$$\alpha_c = \left(\dfrac{R_s}{hZ_0} \right)\left(\dfrac{1}{2\pi} \right)\left[1 - \left(\dfrac{w'}{4h} \right)^2 \right]\left[1 + \dfrac{h}{w'} + \dfrac{h}{\pi w'}\left(\ln\left(\dfrac{4\pi w}{t} \right) + \dfrac{t}{w} \right) \right]$$

$\dfrac{1}{2\pi} < \dfrac{w}{h} \le 2$:

$$\alpha_c = \left(\dfrac{R_s}{hZ_0} \right)\left(\dfrac{1}{2\pi} \right)\left[1 - \left(\dfrac{w'}{4h} \right)^2 \right]\left[1 + \dfrac{h}{w'} + \dfrac{h}{\pi w'}\left(\ln\left(\dfrac{2h}{t} \right) - \dfrac{t}{h} \right) \right]$$

$\dfrac{w}{h} \ge 2$:

$$\alpha_c = \left(\dfrac{R_s}{hZ_0} \right)\left[\dfrac{w'}{h} + \dfrac{2}{\pi}\ln\left(2\pi e\left(\dfrac{w'}{2h} + 0.94 \right) \right) \right]^{-2}\left[\dfrac{w'}{h} + \dfrac{w'/(\pi h)}{\dfrac{w'}{2h} + 0.94} \right]\left[1 + \dfrac{h}{w'} + \dfrac{h}{\pi w'}\left(\ln\left(\dfrac{2h}{t} \right) - \dfrac{t}{h} \right) \right]$$

where

$$R_s = \dfrac{1}{\sigma \delta}$$

$\delta = \sqrt{\dfrac{2}{\omega \mu_0 \sigma}}$ (This is the skin depth, assuming the metal is nonmagnetic).

Dielectric Loss

$$\alpha_d = q\, k_0 \sqrt{\varepsilon_r} \left(\frac{\tan \delta}{2} \right)$$

where the "filling factor" q is

$$q = \sqrt{\frac{\varepsilon_r}{\varepsilon_r^{eff}}} \left(\frac{\varepsilon_r^{eff} - 1}{\varepsilon_r - 1} \right).$$

REFERENCES

L. G. Maloratsky, Passive RF and Microwave Integrated Circuits, Elsevier, 2004.

I. Bahl and P. Bhartia, Microwave Solid State Circuit Design, Wiley, 2003.

R.A. Pucel, D. J. Masse, and C. P. Hartwig, "Losses in Microstrip," *IEEE Trans. Microwave Theory and Techniques*, pp. 342-350, June 1968.

R.A. Pucel, D. J. Masse, and C. P. Hartwig, "Corrections to 'Losses in Microstrip'," *IEEE Trans. Microwave Theory and Techniques*, Dec. 1968, p. 1064.