ECE 5317/6351

Fall 2015

Project

INSTRUCTIONS

This project is due on Monday, Dec. 14 at 5:00 p.m. (Please submit your project by slipping it under the instructor's door.) 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

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

where $t_0 = 0.5 \times 10^{-10}$ [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 the transmission-line voltage v (z, t) versus t for $z = 1$ cm, 20 cm, and 100 cm.

2) Plot the transmission-line current i (z, t) versus t for $z = 1$ cm, 20 cm, and 100 cm.

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

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

Note: To remove the dielectric loss, set the loss tangent of the dielectric to be zero. To remove the conductor loss, set the conductivity of the metal to be high enough so that the metal behaves essentially as a perfect conductor.

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, so that $\varepsilon_r^{eff}(f) = \varepsilon_r^{eff}(0)$ and $Z_0(f) = Z_0(0)$. In this case, the voltage and current pulses should both 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 for this case.

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, with the equations done in the word processor. You may use any word processor that you wish. However, it is recommend that you write the report using Microsoft Word along with MathType to do the equations. (This is how this project document was written.) For a free 30-day trial version of MathType, please visit www.mathtype.com.

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.

Also important is 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 (including grammar, format, and appearance), 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 ω_{max} for the integration variable ω in the inverse Fourier transform integral, and that you have a sufficient sample density (number of integration points) when you compute the integral. You may wish to plot the integrand to help you with this. Note that the numerical 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. It might be helpful to break up the integral from zero to ω_{max} into several sub-intervals.

Also, be aware that you will encounter what is known as the "Gibbs' phenomenon" since the input pulse has sharp edges. This means that there will be "ringing" near the edges of the pulse in

the ideal case with no loss and no dispersion, because of your numerical calculation that has a finite integration limit. To read more about the Gibbs' phenomenon, please visit https://en.wikipedia.org/wiki/Gibbs_phenomenon.

PARAMETERS OF MICROSTRIP LINE:

$\varepsilon_r = 2.33$

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

$h = 0.787$ [mm] (31 [mils])

$w = 2.35$ [mm]

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

$\sigma = 3.0 \times 10^7$ [S/m] (for both of the copper conductors, the strip and the ground plane)

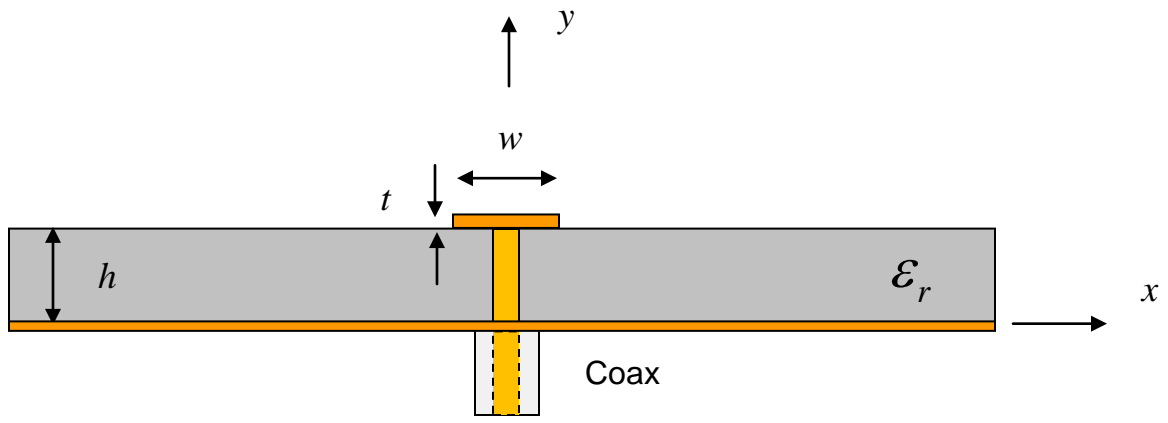Note: ε_r is the above table denotes ε'_r (the real part of the complex effective permittivity). Hence, $\varepsilon_{rc} = \varepsilon'_{rc} - j\varepsilon''_{rc} = \varepsilon_r \left(1 - j(\tan \delta)\right)$.
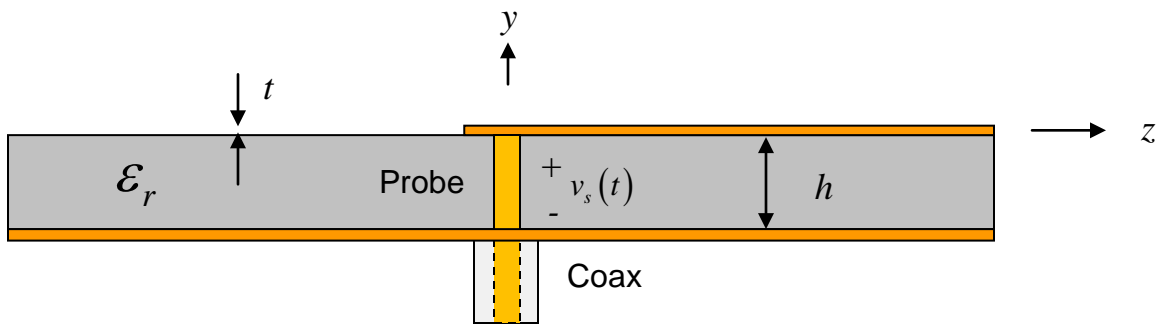
MICROSTRIP GEOMETRY
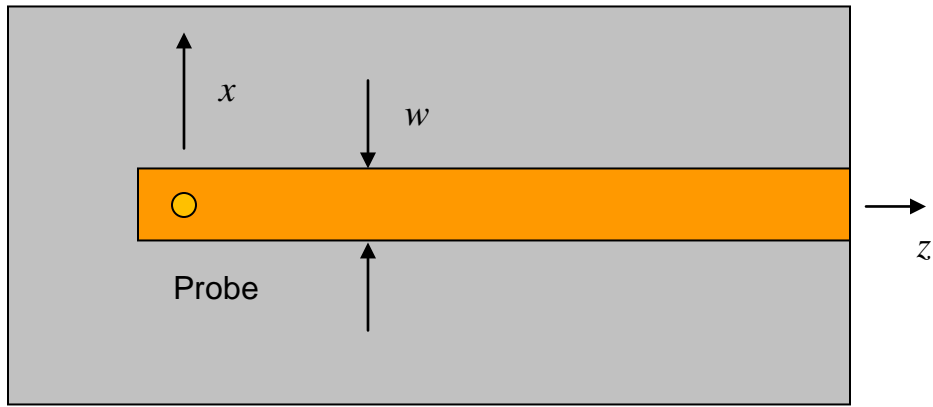
TOP VIEW

END VIEW

SIDE VIEW

APPROXIMATE CAD DESIGN FORMULAS

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

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 $Z_0(f)$.

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

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

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

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

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

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

where

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

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

Note: In the term $2\pi e$ in the above formula, e is Euler's constant, $e = 2.718281828$.

Dielectric Loss

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

where the "filling factor" q is

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

and

$$\varepsilon_r^{eff} = \varepsilon_r^{eff}\left(f \right).$$

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.