

**ECE 5317/6351****Fall 2017****Project****INSTRUCTIONS**

This project is due on Monday, Dec. 11 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. Please make sure that your version of the project is the latest one that is on Blackboard by checking the date at the upper right of the first page. If any corrections need to be made, a revised version of the project will be posted on Blackboard and the date will be changed.

**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  $t_0 = 2.0 \times 10^{-10}$  [s].

**FORMULATION AND CALCULATION**

Formulate the transmission line voltage  $v(z,t)$  and current  $i(z,t)$  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 numerical calculation of the voltage and current using any software package

that you prefer (e.g. Matlab). Please use the CAD formulas given below for all of the microstrip line calculations.

## RESULTS

### A) Frequency-Domain

- 1) Plot the characteristic impedance (in  $\Omega$ ) versus frequency, from 0 to 50 GHz.
- 2) Plot the effective relative permittivity versus frequency, from 0 to 50 GHz.
- 3) Plot the conductor attenuation  $\alpha_c$ , the dielectric attenuation  $\alpha_d$ , and the total attenuation  $\alpha$  (all in np/m) versus frequency, from 0 to 50 GHz.

### B) Time-Domain

- 1) Plot the transmission-line voltage  $v(z,t)$  versus  $t$  for  $z = 1$  cm, 5 cm, 10 cm, and 20 cm.
- 2) Plot the transmission-line current  $i(z,t)$  versus  $t$  for  $z = 1$  cm, 5 cm, 10 cm, and 20 cm.
- 3) Repeat part (1) above assuming there is no dielectric or conductor loss.
- 4) Repeat part (1) above assuming there is no dielectric or conductor loss and there is no dispersion. This means that  $\epsilon_r^{eff}(f) = \epsilon_r^{eff}(0)$  (the effective relative permittivity is taken to be a constant value that does not depend on frequency).

**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

In part (4) of the Time-Domain results, the voltage pulse should propagate at the phase velocity  $v_p = c / \sqrt{\epsilon_r^{eff}(0)}$  without changing shape. Hence, you know what the correct results should be for this case. Make sure that your numerical solution gives you the correct results!

## **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 recommended 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](http://www.mathtype.com).

The Results section should provide the results that are required, and also provide a thorough discussion of the results. All plots should be done using software such as Matlab, etc., and should look professional.

A very 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 a good choice of scales and professional-looking axis 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  $\omega_{max}$  for the integration variable  $\omega$  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  $\omega$  as  $z$  increases. It might be helpful to break up the integral from zero to  $\omega_{max}$  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, even in the ideal case with no loss and no dispersion, because your numerical calculation has a finite integration limit. To read more about the Gibbs phenomenon, please visit [https://en.wikipedia.org/wiki/Gibbs\\_phenomenon](https://en.wikipedia.org/wiki/Gibbs_phenomenon).

## PARAMETERS OF MICROSTRIP LINE

$$\varepsilon_r = 10.2$$

$$\tan\delta = 0.0023 \text{ (loss tangent of substrate)}$$

$$h = 1.27 \text{ [mm]} \text{ (50 [mils])}$$

$$w = 1.325 \text{ [mm]}$$

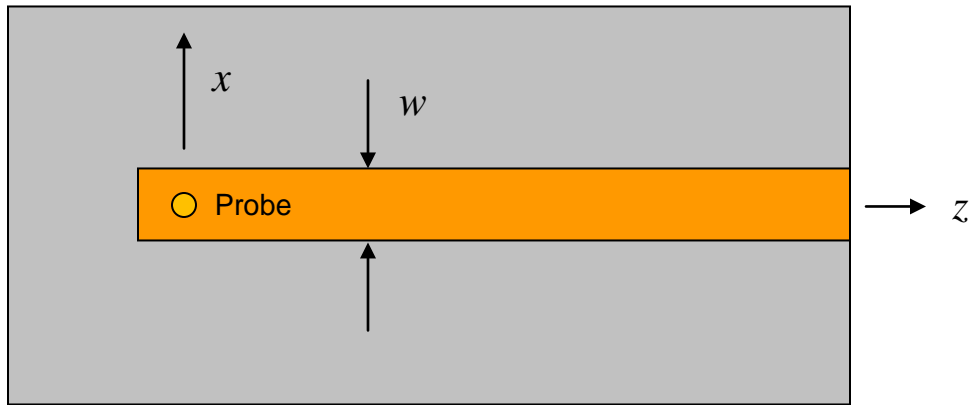
$$t = 0.0175 \text{ [mm]} \text{ (corresponding to 0.5 oz copper /ft}^2 \text{ for the copper cladding)}$$

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

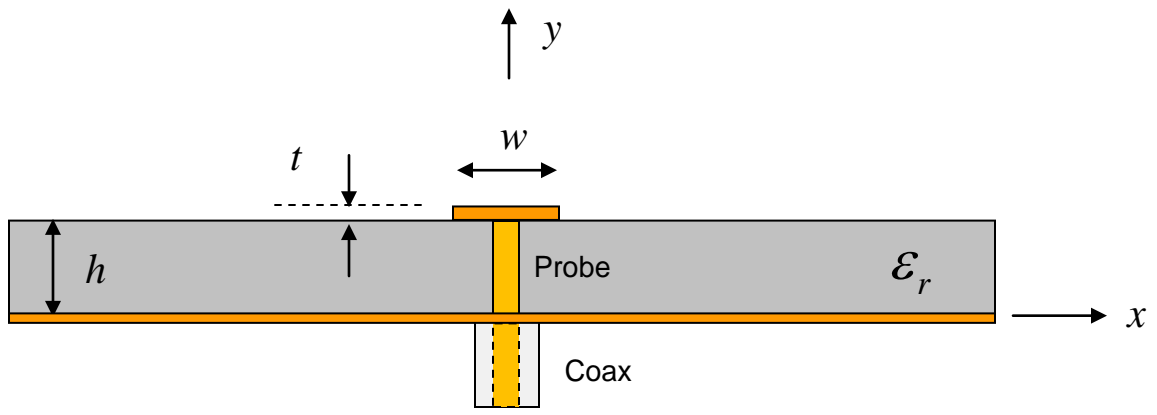
**Note:** This substrate corresponds to Rogers 6010 material.

**Note:** The characteristic impedance should be 50 [ $\Omega$ ] at 10 GHz (according to TXLINE).

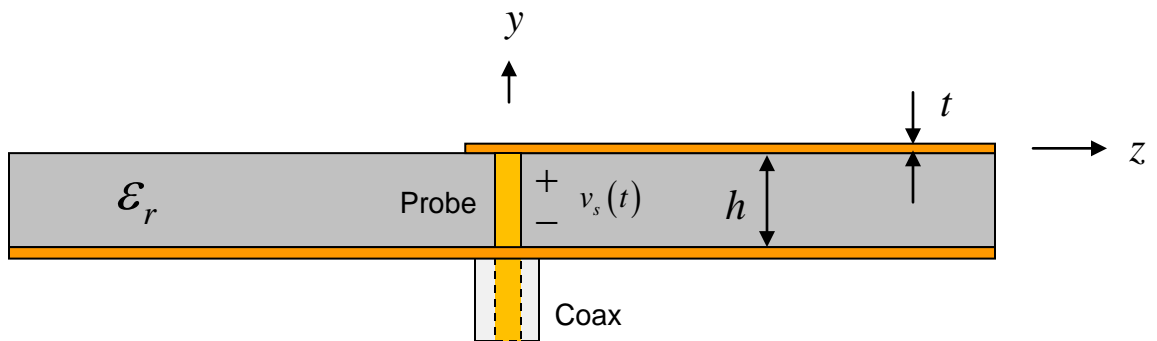
# MICROSTRIP GEOMETRY



TOP VIEW



END VIEW



SIDE VIEW

## APPROXIMATE CAD DESIGN FORMULAS

**Note:** In these formulas,  $\epsilon_r$  is the real part of the complex effective permittivity.

### Phase Constant

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

where the “effective relative permittivity” is

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

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

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

### Characteristic Impedance

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

where

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

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

## Conductor Loss

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

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

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

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

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

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

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

where

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

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

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

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

## Dielectric Loss

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

where the “filling factor”  $q$  is

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

## 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.