ECE 5317/6351

Fall 2026

Project

Project update date: 10/21/2026

INSTRUCTIONS

This project is due on Monday, Dec. 7, 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 Canvas by checking the "project update date" above on this page. If any corrections need to be made, a revised version of the project will be posted on Canvas and the date will be changed.

PROBLEM DESCRIPTION

The purpose of this project is to look at signal distortion on a microstrip line and construct an "eye diagram" for this system. A signal generator is attached at $z = 0$ with the polarity shown in the figures below. The signal generator applies a voltage signal to a semi-infinite line that is given by

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

where $t_0 = 1.0 \times 10^{-10}$ [s].

FORMULATION AND CALCULATION

Formulate the transmission line voltage $v(t,z)$ at a point $z > 0$, giving enough details to make the derivation complete, based on the transfer function for the line. 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 $v(t,z)$ using any software package that you prefer (e.g., MATLAB). Please use the CAD formulas given below for all of the microstrip line calculations (to get $\alpha(\omega)$ and $\beta(\omega)$ and hence the transfer function $H(\omega)$).

RESULTS

A) Frequency-Domain

1) Plot the characteristic impedance vs. frequency for the microstrip line. Ignore loss for this calculation (the characteristic impedance will therefore be a real number). Plot from 0 to 100 GHz.

2) 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, for the microstrip line.

B) Time-Domain

1) Plot the transmission-line voltage $v(t,z)$ versus t for z = 1 cm, 5 cm, 10 cm, 20 cm, and 40 cm. Account for all loss (dielectric and conductor).

2) Repeat the above plots assuming there is no dielectric or conductor loss (please see the note below).

C) Eye Diagram

Make an eye diagram for this pulse shape, assuming three consecutive rectangular pulses for the input signal, which can each have a value or 0 or 1 for the amplitude (i.e., a three-bit sequence). The three bits of the input signal occupy the time regions $-t_0 \le t \le 0$, $0 \le t \le t_0$, and $t_0 \le t \le 2t_0$. Assume that we are looking at the output at a distance of z = 10 cm. Plot your result for $-t_0 \le t' \le 2t_0$, where $t' \equiv t - (l/c)\sqrt{\varepsilon_r^{\text{eff}}(0)}$.

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

If we remove all loss from the microstrip line and we also assume that the effective permittivity is a constant (not a function of frequency) and is chosen to be the zero-frequency value, the voltage pulse should propagate at the phase velocity $v_p = c / \sqrt{\varepsilon_r^{\text{eff}}(0)}$ without changing shape or losing amplitude. Hence, you know what the correct results should be for this case. Make sure that your numerical solution gives you the correct results! (Your results will exhibit the Gibbs phenomenon, however; please see the note below in the discussion of numerical issues.) For even extra validation, you can try getting the results for the case of the pulse propagating on the microstrip line that is shown in the class notes.

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.)

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 ω in the numerical calculation of the inverse Fourier transform integral. You may also need to experiment to make sure 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 $\omega_{\max}$ 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.

PARAMETERS OF MICROSTRIP LINE

$\varepsilon_r = 2.2$

$\tan\delta = 0.0009$ (loss tangent of substrate)

h = 1.575 [mm] (62 [mils])

w = 4.86 [mm]

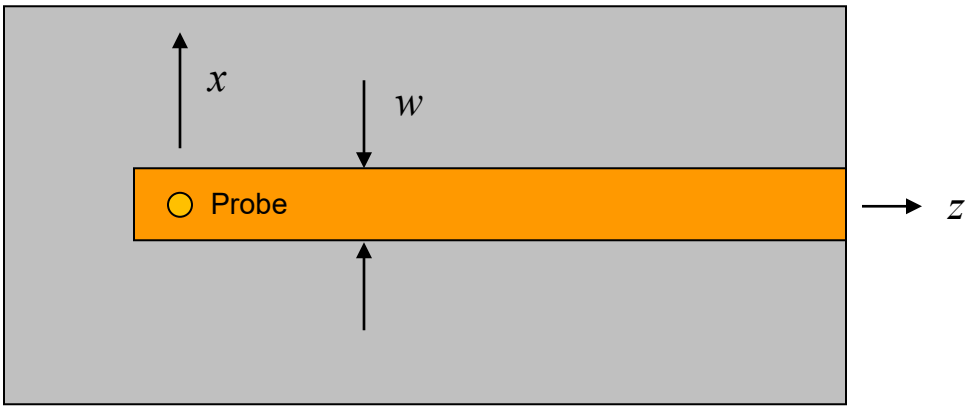
t = 0.0175 [mm] (corresponding to 0.5 oz copper /ft^2 for the copper cladding)

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

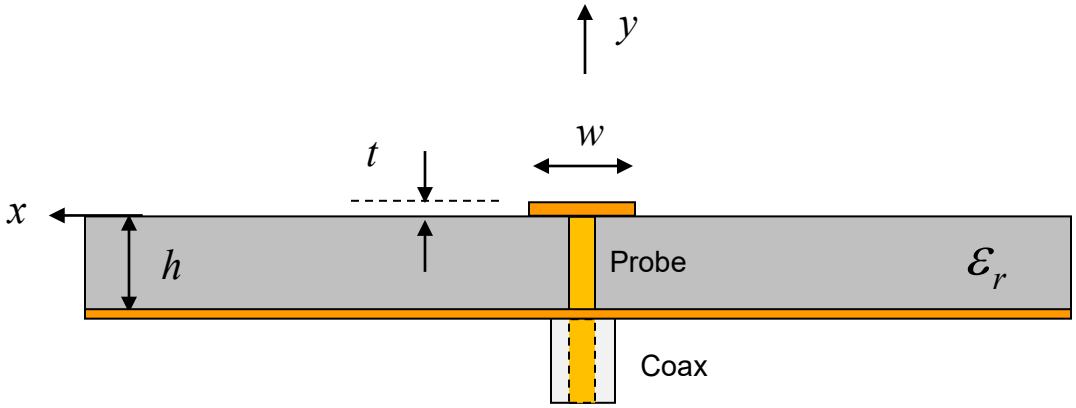
Note: This substrate corresponds to Rogers 5880 material.
(https://www.rogerscorp.com/advanced-electronics-solutions/rt-duroid-laminates/rt-duroid-5880-laminates)

Note: The characteristic impedance should be 50 [Ω] at 0.01 GHz (according to TXLINE).

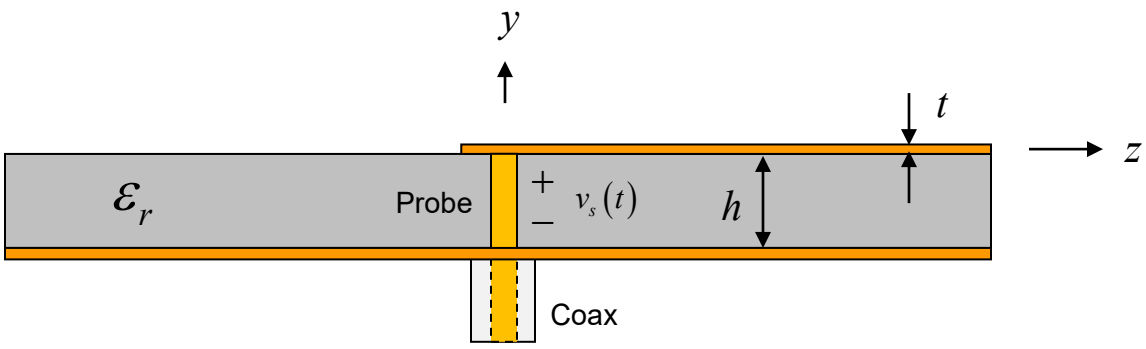
MICROSTRIP GEOMETRY



TOP VIEW



END VIEW



SIDE VIEW

APPROXIMATE CAD DESIGN FORMULAS FOR MICROSTRIP

Note: In these formulas, ε_r is the real part of the complex relative permittivity.

Phase Constant

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

where the "effective relative permittivity" is

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

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

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

Characteristic Impedance

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

where

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

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

Conductor Attenuation

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

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

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

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

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

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

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

where

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

$\delta = \sqrt{\frac{2}{\omega\mu_0\sigma}}$ (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 last α_c formula, e is the number e (sometimes called "Euler's number"), $e = 2.718281828$.

Dielectric Attenuation

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

where the "filling factor" q is

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

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.