ECE 6340

Fall 2025

Project

Date of last update: Oct. 20, 2025

Instructions

This project is due on Monday, Dec. 8, at 5:00 p.m. (Please submit it by slipping a hard copy under the instructor's door by the deadline.) Please work individually on the project, and do not discuss it with anyone other than the instructor. To do otherwise will be considered a violation of the UH Academic Honesty Policy.

Problem Description

A microstrip line is shown below. The line has a characteristic impedance $Z_0(f)$ that is frequency dependent, but the line is designed so that the characteristic impedance is 50 [Ω] at low frequency, i.e., $Z_0(0)$= 50 [Ω]. The line starts at z = 0 and is semi-infinite. A signal generator is attached at z = 0 with the polarity shown. The signal generator applies a voltage pulse that is described by

$$v_{\text{in}}(t) = \begin{cases} 1.0\ [\text{V}], & 0 < t < T \\ 0, & \text{otherwise} \end{cases}$$

where $T = 1.0\times10^{-10}$ [s].

Formulation and Calculation

Formulate the transmission line voltage $v_{\text{out}}(z,t)$. Do this by first solving for the Fourier transform of the output voltage at any point z on the line. Give 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. Then implement the calculation of the output voltage using any software package that you prefer to do the inverse Fourier transform integral (i.e., the integral in ω). Your results should be in the following form:

$$v_{\text{out}}(z,t) = \frac{1}{\pi}\text{Re}\int_0^{\infty} \tilde{v}_{\text{out}}(z,\omega)\, e^{j\omega t}\, d\omega \tag{1}$$

with

$$\tilde{v}_{\text{out}}(z,\omega) = \tilde{v}_{\text{in}}(\omega)\, H\left(z,\omega\right), \tag{2}$$

where $H\left(z,\omega\right) = e^{-\gamma(\omega)z}$ is the transfer function that gives the frequency-domain (i.e., phasor) voltage output at z due to an input voltage phasor of $V_{\text{in}} = 1.0$ at z = 0, and $\gamma\left(\omega\right) = \alpha\left(\omega\right) + j\beta\left(\omega\right)$.

Results

A) Frequency-Domain

1. Plot the characteristic impedance of the microstrip line 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 (where $\alpha = \alpha_c + \alpha_d$) versus frequency from 0 to 100 GHz.

Use the CAD formulas given towards the end of the document to make these plots.

B) Time-Domain

1) Plot the transmission-line voltage $v_{\text{out}}\left(z,t\right)$ versus t for the following distances down the line: z = 0.0 [cm], z = 1.0 [cm], z = 2.0 [cm], z = 4.0 [cm], z = 8.0 [cm], z = 16.0 [cm].

2) Repeat the above results in part (1) assuming that the line is an ideal lossless TEM_z transmission line. This means that it is lossless ($\alpha = 0$) and that there is no dispersion, so that the effective permittivity does not vary with frequency, and is taken to be the value at zero

frequency. Note: From the class notes, we know what to expect for signal propagation on an ideal lossless and dispersionless transmission line, so the results from part (2) will serve as a good validation of your code.

3) Repeat part (1) assuming that $\gamma(\omega)$ now corresponds to a lossless air-filled standard X-band rectangular waveguide carrying the TE_{10} mode, where the waveguide has dimensions a = 2.2225 [cm] and b = 1.0319 [cm]. Note that below the cutoff frequency (6.7445 GHz) we have only α, and above the cutoff frequency we have only β. For the TE_{10} mode we have

$$\gamma = jk_z ,$$

where

$$k_z = \beta = \sqrt{k_0^2 - \left(\frac{\pi}{a}\right)^2}, \quad f \geq f_c$$

$$k_z = -j\alpha = -j\sqrt{\left(\frac{\pi}{a}\right)^2 - k_0^2}, \quad f \leq f_c .$$

Format Guidelines

The project should be written on a word processor and have the following sections:

- ◊ Title page
- ◊ A brief Abstract
- ◊ A brief Introduction section
- ◊ An Analysis section
- ◊ A Results section
- ◊ A Conclusion section
- ◊ A Reference section (if any references are cited)

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

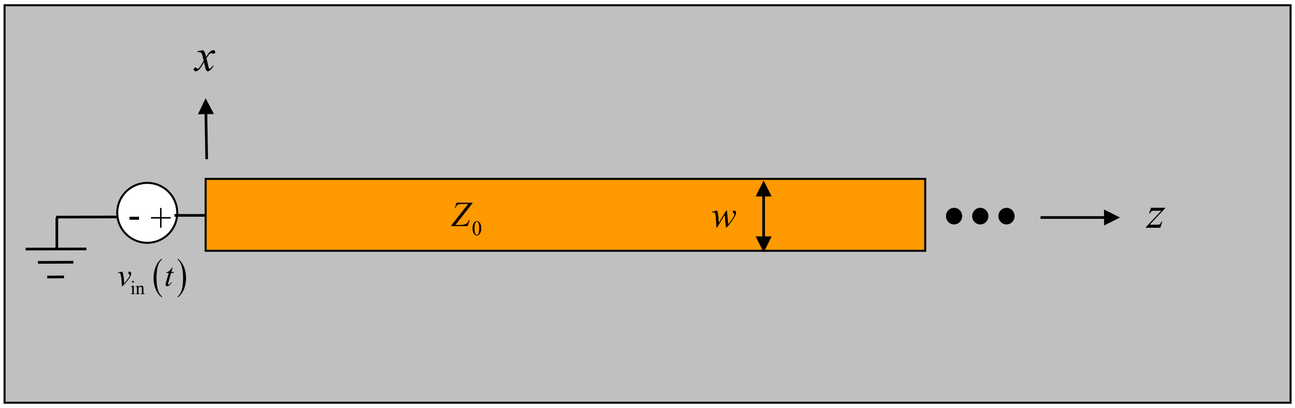
Your grade will also depend on your discussion and your interpretation of the results.

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 so that the plots are easy to read and look professional. It is strongly recommended to use MathType for your equations. You may use this project description as a template for the format if you wish.

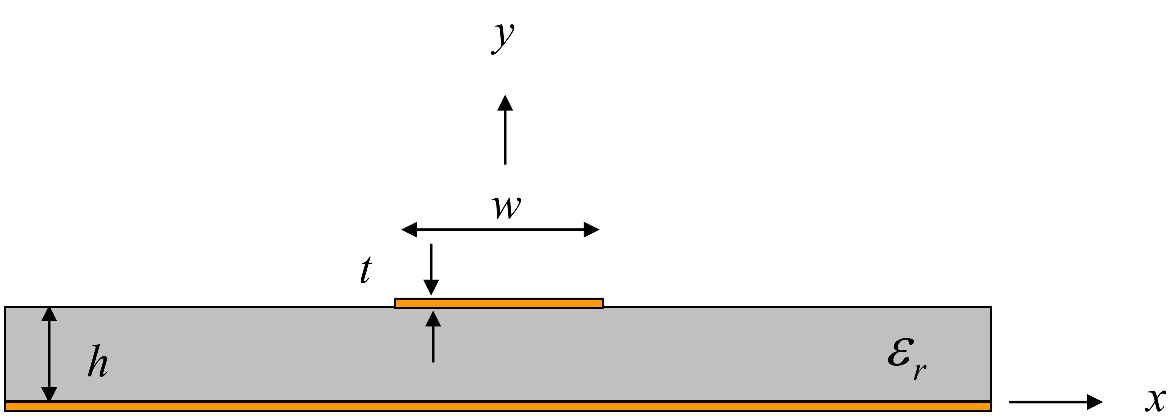
Numerical Issues

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 also that you have a sufficient sample density when you compute the integral (assuming that you program the integration yourself). You may wish to plot the function $\tilde{v}_{\text{out}}(\omega)$ to help you with this.

Microstrip Geometry



TOP VIEW



END VIEW

Parameters of Microstrip Line

$\varepsilon_r = 2.2$

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

h = 1.524 [mm] (60 mils)

w = 4.85 [mm] (This should correspond to Z_0 = 50 [Ω] at low frequency.)

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

σ = 3.0 × 10^7 [S/m] (This value is for copper conductors, allowing for surface roughness.)

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

MICROSTRIP FORMULAS

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

Phase Constant

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

where the "effective relative permittivity" is

$$\varepsilon_r^{\text{eff}}\left(f\right) = \left(\sqrt{\varepsilon_r^{\text{eff}}(0)} + \frac{\sqrt{\varepsilon_r} - \sqrt{\varepsilon_r^{\text{eff}}(0)}}{1+4/F^{3/2}}\right)^2$$

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

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

Characteristic Impedance

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

where

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

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

Conductor Loss

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

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

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

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

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

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

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

where

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

$R_s = \frac{1}{\sigma\delta}$ (This is the surface resistance of the metal.)

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

$e = 2.718281828$ (This is the usual mathematical symbol e.)

Dielectric Loss

$$\alpha_d = q\,k_0 \left(\frac{\tan\delta}{2}\right)\left(\frac{\varepsilon_r}{\sqrt{\varepsilon_r^{\text{eff}}(0)}}\right)$$

where the "filling factor" q is

$$q = \frac{\varepsilon_r^{\text{eff}}(0) - 1}{\varepsilon_r - 1}.$$

Total Loss

$$\alpha = \alpha_c + \alpha_d$$

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.