

ECE 5317/6351

Fall 2018

Project

Project update date: Dec. 4, 2018

INSTRUCTIONS

This project is due on Monday, Dec. 10, 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 "update date" on 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

An X-band air-filled rectangular waveguide is shown below. The waveguide extends to infinity in the $\pm z$ directions. A signal generator is attached to a feed probe at $z = 0$ with the polarity shown, along the centerline of the waveguide ($x = a/2$). The signal generator applies an input voltage signal that is described by

$$v_i(t) = E(t) \cos(\omega_0 t), \quad (1)$$

where the envelope of the signal is a pulse function that is described by

$$E(t) = \begin{cases} 1V, & 0 < t < t_0 \\ 0, & \text{otherwise.} \end{cases} \quad (2)$$

The duration of the pulse t_0 is described by an integer N giving the number of cycles of the carrier wave that are contained inside the pulse. That is,

$$t_0 = NT = \frac{N}{f_0} = 2\pi \frac{N}{\omega_0}, \quad (3)$$

where T is the period of the carrier wave. Note that the carrier frequency f_0 and the cycle duration parameter N are the two input parameters that completely describe the input waveform.

The input signal causes the TE₁₀ mode of the waveguide to have an electric field $\mathcal{E}_y(x, z, t)$ at $x = a/2$ (along the centerline) and $z = 0$ that is given by

$$\mathcal{E}_y(a/2, 0, t) = A_0 v_i(t). \quad (4)$$

The constant A_0 depends on the length of the probe exiting the waveguide, but this constant is not important here, and we can simply take $A_0 = 1$. Using the Fourier transform method, the electric field $\mathcal{E}_y(x, z, t)$ of the TE₁₀ mode at any point $z > 0$ along the centerline of the waveguide ($x = a/2$), which is taken as the output signal, is then given by

$$v_o(z, t) = \mathcal{E}_y(a/2, z, t) = A_0 \frac{1}{\pi} \operatorname{Re} \int_0^{\infty} \tilde{v}_i(\omega) e^{-jk_z z} e^{j\omega t} d\omega. \quad (5)$$

The wavenumber $k_z = \beta - j\alpha$ is the wavenumber of the TE₁₀ mode.

Above the cutoff frequency of the TE₁₀ mode, assume that the phase constant β is that of an ideal lossless waveguide and that the attenuation constant α is that due to conductor loss only, since the waveguide is air filled. Therefore, $\alpha = \alpha_c$ when we are above cutoff. Both the phase

and attenuation constants are frequency dependent. (Note that the formula for α_c was given in the class notes.)

Below the cutoff frequency of the TE_{10} mode, assume that the phase constant β is zero and that the attenuation constant α is that of an ideal lossless waveguide with perfectly conducting walls. That is, below cutoff the attenuation is only due to evanescence, and conductor loss can be neglected.

FORMULATION

Formulate the output signal $v_o(z, t) = \mathcal{E}_y(a/2, z, t)$ at a point $z > 0$, giving enough details to make the derivation complete. Note that the Fourier transform of the input voltage function $v_i(t)$ can be obtained in closed form, and you should do this as part of your analysis. Then implement the numerical calculation of the output signal using any software package that you prefer (e.g. Matlab, Mathcad, Mathematica, FORTRAN, etc.).

RESULTS

- 1) Plot the output voltage $v_o(z, t)$ versus t for $z = 1$ cm, 10 cm, 1 m, 10 m. Assume that $f_0 = 10$ GHz and $N = 10$.
- 2) Repeat part (1) for $f_0 = 5$ GHz.
- 3) Repeat part (1) for $z = 10$ m and $N = 1, 10, 100$.
- 4) From your results in part (1), numerically identify the phase and group velocities. (You may wish to repeat the calculation for other values of z than the ones indicated in part (1) to help

you determine accurately what the velocities are.) Compare with the theoretical numbers expected for an ideal lossless waveguide.

VALIDATION

If attenuation and dispersion are neglected, we have $k_z = k_0$. In this case the signal should propagate at the speed of light in free space 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! It is strongly recommended that you do this validation, as it will give you some confidence that your code is working correctly.

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.

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 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. The validation exercise should be very helpful to ensure that your results are accurate.

PARAMETERS OF THE WAVEGUIDE

$$a = 2.29 \text{ cm}$$

$$b = 1.02 \text{ cm}$$

$$\sigma = 3.0 \times 10^7 \text{ S/m}$$



