

Lecture V

Crosstalk for the ramp response using frequency-domain simulations in Ansoft HFSS

In this lecture, we continue to study the Finite-Difference Time-Domain (FDTD) method on staggered grid. We compare two solutions: one with the FDTD method from lecture #4 and another from Ansoft HFSS. We again study the coupling problem between two transmission lines.

1. Port definition in Ansoft HFSS

The port definition in Ansoft HFSS is shown in Fig. 1. All four ports are the lumped ports, with the 50Ω characteristic impedance.

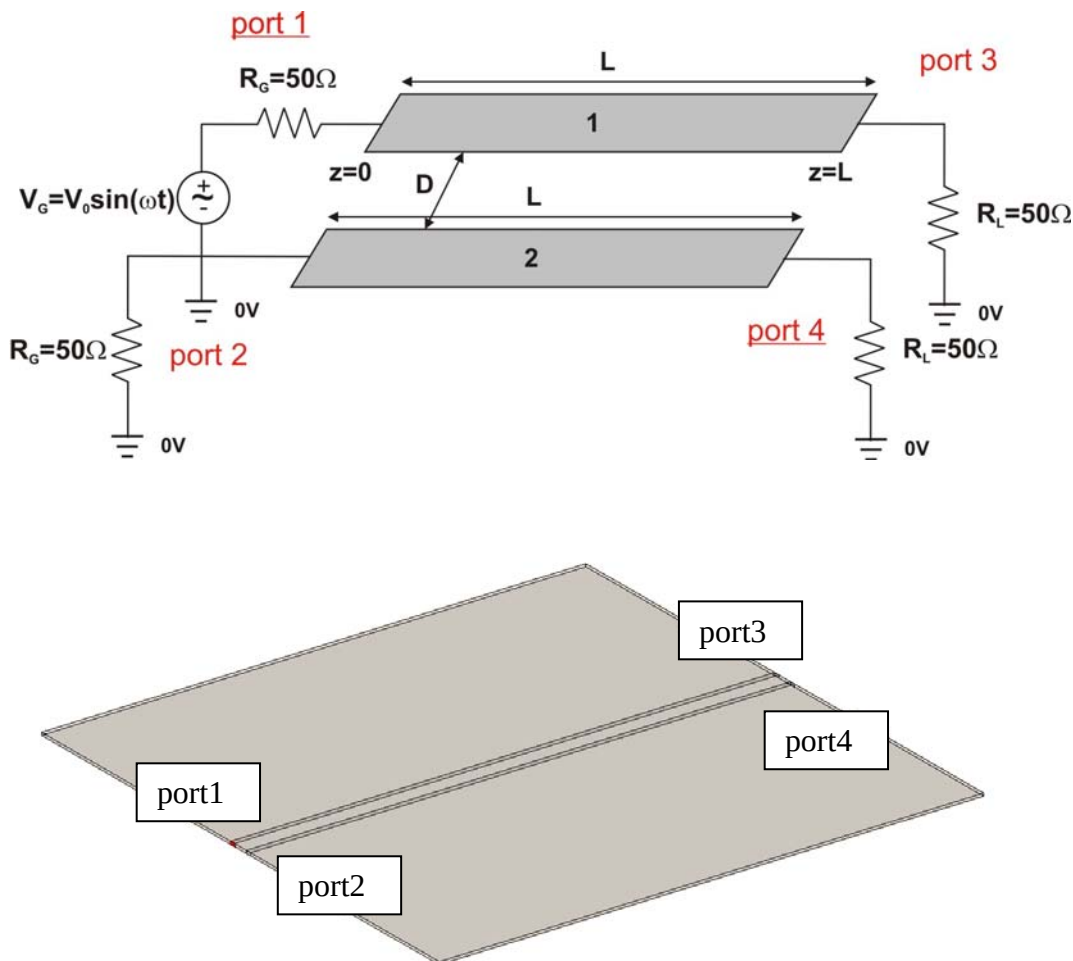


Fig. 1. Top - TL assembly for the FDTD simulations; bottom - the corresponding Ansoft HFSS project.

2. What could we do with the Ansoft HFSS frequency-domain solution?

In contrast to the FDTD solution, we cannot find line voltages and currents at every location in space, at least precisely. However, we can find them at the ports.

In particular, the element S_{41} of the four-port scattering matrix $\hat{S}$ of the size 4×4 determines the frequency-domain transfer function between ports 1 and 4 - see Fig. 2 that follows.

$$H(\omega) = S_{41}(\omega) = \frac{V_4^-}{V_1^+} = \frac{V_4^-(\omega)}{V_1^+(\omega)} \quad (1)$$

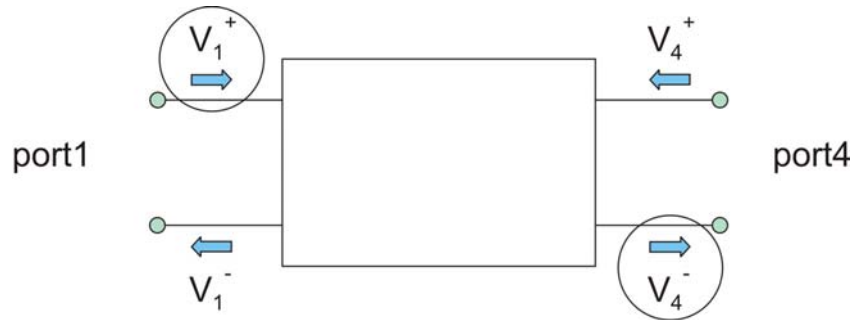


Fig. 2. Transfer function between two ports (ports 1 and 4 in Fig. 1) found using the scattering matrix.

1. Analytical model for the ramp response

The direct feeding of the finite ramp response (Fig. 3 - top) into Fourier transform pair may cause large errors, due to singular behavior of the frequency-domain representation. A simple analytical formula for the Fourier transform of a finite ramp $f(t)$ shown in Fig. 3 should be used instead.

In terms of notations of Fig. 3,

$$f(t) = u(t) - r(t) \quad (2)$$

where $u(t)$ is the step response and

$$r(t) = \frac{a}{\tau}(\tau - t), \quad 0 < t < \tau, \quad r(t) = 0, \quad \text{otherwise} \quad (3)$$

is a finite triangle function. One has (see, for example, [1])

$$U(\omega) = a\pi\delta(\omega) + \frac{a}{j\omega} \quad (4)$$

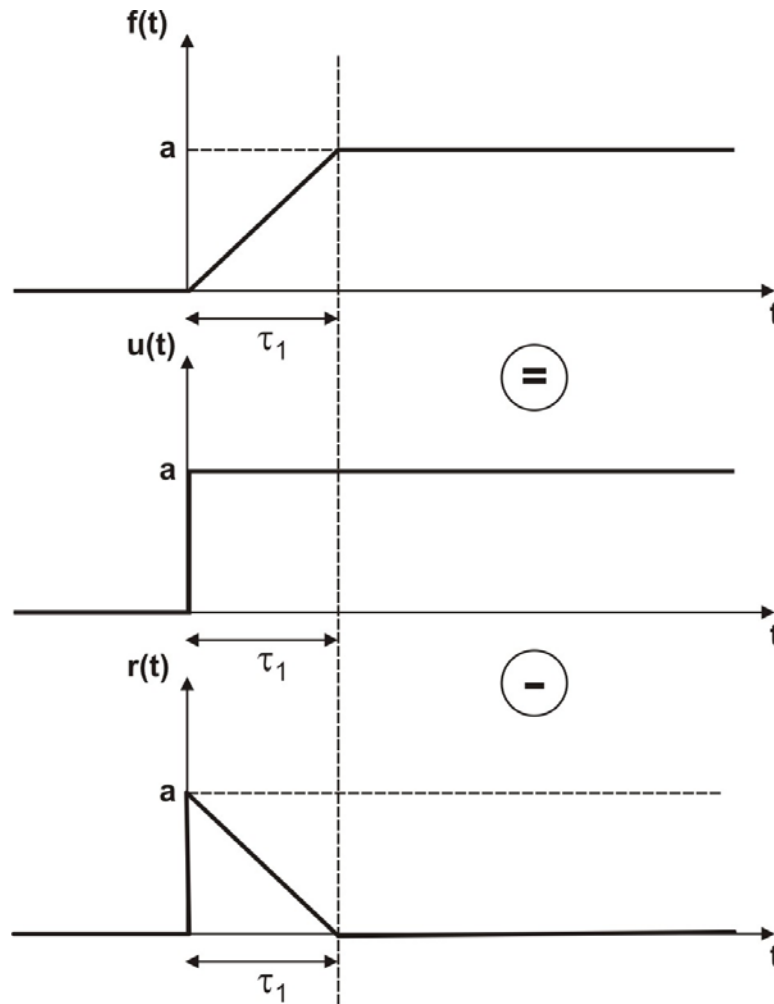


Fig. 3. Finite ramp response decomposition.

Simultaneously,

$$\begin{aligned}
 R(\omega) &= \int_{-\infty}^{+\infty} r(t) \exp(-j\omega t) dt = a \int_0^{\tau} \exp(-j\omega t) dt - \frac{a}{\tau} \int_0^{\tau} t \exp(-j\omega t) dt \\
 &= \frac{a}{j\omega} - \frac{a}{\omega^2 \tau} (\exp(-j\omega \tau) - 1)
 \end{aligned} \tag{5}$$

Therefore,

$$F(\omega) = U(\omega) - R(\omega) = a\pi\delta(\omega) + \frac{a}{\omega^2 \tau} (\exp(-j\omega \tau) - 1) \tag{6}$$

2. Port coupling estimation from frequency data

A harmonic voltage $V_4^-(\omega)$ excited at one port (port 4) by a harmonic voltage, $V_1^+(\omega)$, applied to port 1 at any frequency ω is given by

$$V_4^-(\omega) = S_{41}(\omega)V_1^+(\omega) \quad (7)$$

The scattering coefficient $S_{41}(\omega)$ is thus the system transfer function in the frequency domain. The coupling system is linear and time-invariant; Eq. (7) therefore yields (inverse Fourier transform)

$$v_4(t) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} V_4^-(\omega) \exp(j\omega t) d\omega = \frac{1}{2\pi} \int_{-\infty}^{+\infty} S_{41}(\omega) V_1^+(\omega) \exp(j\omega t) d\omega \quad (8)$$

for the coupled voltage, $v_4(t)$. The voltage $V_1^+(\omega)$ is the Fourier transform of the finite ramp response. It is obtained from Eq. (6) simply by replacing a constant a with the step voltage magnitude V_0 , i.e.

$$V_1^+(\omega) = V_0 \pi \delta(\omega) + \frac{V_0}{\omega^2 \tau} (\exp(-j\omega\tau) - 1) \quad (9)$$

Substitution into Eq. (8) yields the final result

$$v_4(t) = \frac{V_0}{2} S_{41}(0) + \frac{V_0}{2\pi\tau} \int_{-\infty}^{+\infty} \frac{S_{41}(\omega)}{\omega^2} (\exp(-j\omega\tau) - 1) \exp(j\omega t) d\omega \quad (10)$$

3. Necessary conditions for a frequency-domain solver

Once the scattering parameter $S_{41}(\omega)$ is calculated over a wide (ideally infinite) range of frequencies

$$0 \leq f < f_0 \quad (11)$$

the voltage $v_4(t)$ can be obtained from Eq. (10) for a finite ramp excitation voltage $v_1(t)$ of any duration τ . Indeed, one has to consider frequencies in the upper band:

$$f_0 \gg \frac{1}{\tau} \quad (12)$$

in order to obtain a sufficient accuracy.

The sampling frequency step in the inverse Fourier transform in Eq. (10) also needs to be chosen small enough. If T is the maximum absolute value of time t in Eq. (10), the argument of the exponential function in integral (10) varies at most by

$$2\pi\Delta f * N * T \quad (13)$$

over its period. Here, N is the number of frequency steps Δf over the integration period. Assuming that N is given (at least 6 integration points over the period) and equating expression (12) to 2π , we obtain a condition for the minimum acceptable frequency step for the Ansoft HFSS frequency sweep:

$$\Delta f \leq \frac{1}{N * T} \quad (14)$$

5. MATLAB implementation

A MATLAB script `wrapper.m` performs the following operations:

1. It imports the $S_{41}(\omega)$ data from an Ansoft project in a *.tab format and plots the data (Fig.1). Example of the appropriate format:

Freq, GHz	Re($S_{41}(f)$)	Im($S_{41}(f)$)
1	0.0835841020637039	-0.0565791360471161
1.1	0.0842064682765277	-0.0697615437355909
1.2	0.0828677905397408	-0.0841402369127413
1.3	0.0791894869362952	-0.0993294615328412
1.4	0.0728893208138522	-0.114835424657943
1.5	0.0638158968680643	-0.130088070264065
1.6	0.0519694609224373	-0.144485673892939
1.7	0.0375038176984169	-0.157445060792047

2. Then, it calculated the coupled voltage $v_4(t)$ with the transfer function $S_{41}(\omega) = 1$, i.e. checks the correctness of the frequency data (maximum frequency, sampling frequency interval) used. The output voltage in this case must be (approximately) equal to the initial finite voltage ramp.

3. It continues the spectrum of $S_{41}(\omega)$ all the way to DC (if Ansoft HFSS does not go to DC) and sets $S_{41}(\omega = 0) = 0$.

4. Finally, it calculates the coupled voltage $v_4(t)$ using the imported Ansoft HFSS data on $S_{41}(\omega)$. The applied voltage amplitude V_0 in Eq. (9) is exactly 1V.

Example 1. The parameters of two (approximately $50\ \Omega$ each) coupled microstrip lines on 62 mil FR4 with $\epsilon_r = 4.4$ are as follows:

- the line length is 300.0 mm;
- the line width is exactly 3mm;
- gap between lines is 9.0 mm.

Obtain the solution for the coupled voltage at port 4 in MATLAB using the FDTD method from lecture#4. The bit form is given by

the ramp rise time $\tau_1 = 62.5\text{ps}$;

the flat top width $\tau_2 = 500\text{ps}$.

Solution:

We use the MATLAB scripts `mt_l_04.m` from lecture#4. We modify this script by plotting the output voltage at port 4 (at the end of the second transmission line).

The modification reads (except for plotting):

```
VoltagePort4(n)= Vnext(2, end);
```

A third plot is also included - the terminal voltage as a function of time. The resulting script is named `mt_l_05.m`. Its output (for 1 V excitation - important) is shown in Fig. 4. The excitation of 1 V must be used to be consistent with the Ansoft HFSS data and the script `wrapper.m`.

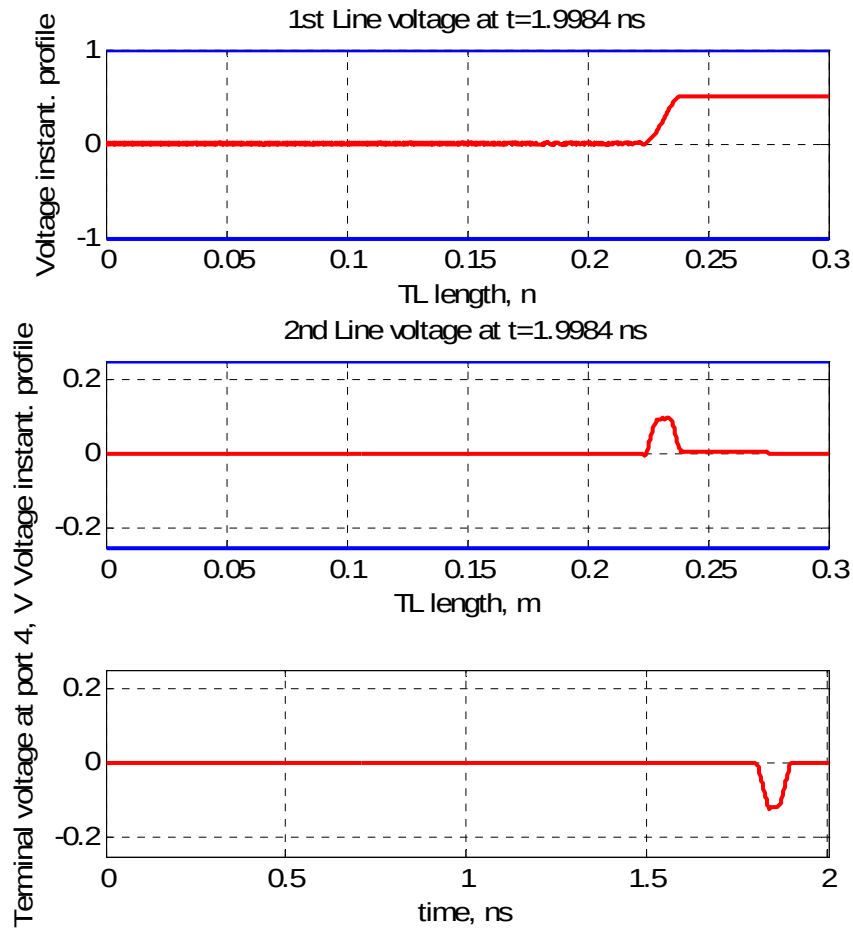


Fig. 4. The resulting voltage form at port 4 as a function of time (the end of the second transmission line) obtained with the FDTD - the bottom plot. Two top plots show the related line voltages at the same time moment.

6. Ansoft part

1. Review various Ansoft projects
2. Check the mesh in Ansoft
3. Discuss how to plot time-domain data in Ansoft (try!)
4. How to export the data (real/imag, delete header, etc.)
5. Start comparison

Show the best comparison result - see Fig. 5 that follows.

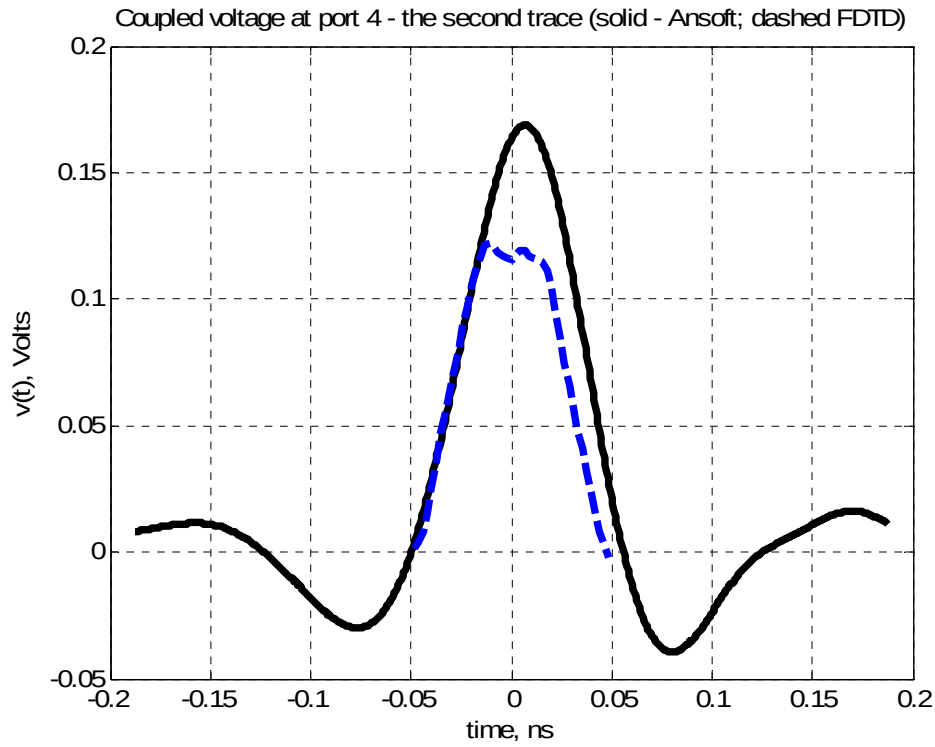


Fig. 5. The best agreement achieved between Ansoft and FDTD so far.

References

1. J. D. Gibson, *Digital and Analog Communications*, Prentice Hall, Upper Saddle River, NJ, 1993.

HW#5 exercise

This exercise is based on the Ansoft codes and the MATLAB codes to this lecture.

Its goal is pretty simple: generate the analog of Fig. 5 when the gap between two TLs is decreased to 4.2 mm. All other parameters remain the same.

You need to run the corresponding MATLAB/Ansoft simulations to accomplish the task. Include their description into your HW report. You might also want to list the Ansoft execution times (per frequency step) necessary to solve this task.

By comparing the two solutions we could finally prove if the method given in this lecture is correct (no factor of 2 or something else is missing...) and could be used by everyone.
