

FDTD Circuit Design and Validation

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Eric J. Lundquist

Introduction

This report discusses the use of the FDTD method in order to simulate the behavior of an electrical signal along a line, incorporating the RLGC (resistance, inductance, conductance, and capacitance) parameters of the line. A 1D FDTD code was developed in order to simulate the propagation of a signal through a line of which the RLGC parameters could be adjusted at any point in the line.

Filter Design

This was accomplished by generating RLGC vectors which could be programmed to certain desired features of the line. In order to test the accuracy of the code, a low-pass filter was also designed and programmed, according to the following design:

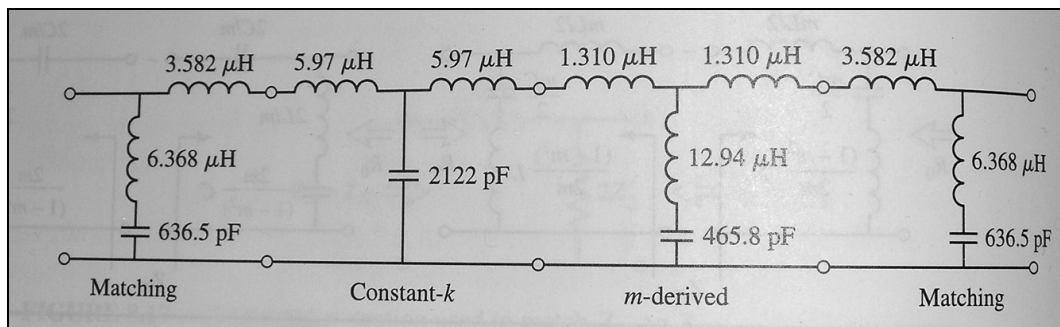


Figure 1: Low-pass composite filter.¹

The code was adapted in order to program the filter design as a traditional RLGC element. This was necessary in order to combine the inductors and capacitors which are connected in series in both the matching sections and the *m*-derived section of the filter. The derivation took place as follows:

$$j\omega L + \frac{1}{j\omega C} = \frac{j^2\omega^2}{j\omega} L + \frac{1/C}{j\omega}$$
$$= \frac{1/C - L\omega^2}{j\omega}$$

$$\frac{1}{j\omega C^c} = \frac{1/C - L\omega^2}{j\omega}$$

$$C^c = \frac{1}{1/C - L\omega^2}$$

$$C^c = \frac{C}{1 - LC\omega^2} \quad (1)$$

Where C^c is the equivalent combined capacitive impedance of the LC filter sections. Additionally, note that this value is indeed frequency-dependent.

Filter Validation

The signal propagated through the 2 MHz low-pass filter became somewhat attenuated at frequencies below 2 MHz, but extremely attenuated at 2 MHz and above. Results from the reflected signal are shown later. In this case, the load is matched and thus the signal is rather low in magnitude.

The FDTD step size was adjusted to accommodate the smallest inductance value of the filter design. Both the simulated and expected frequency response of the filter matched closely, as shown below:

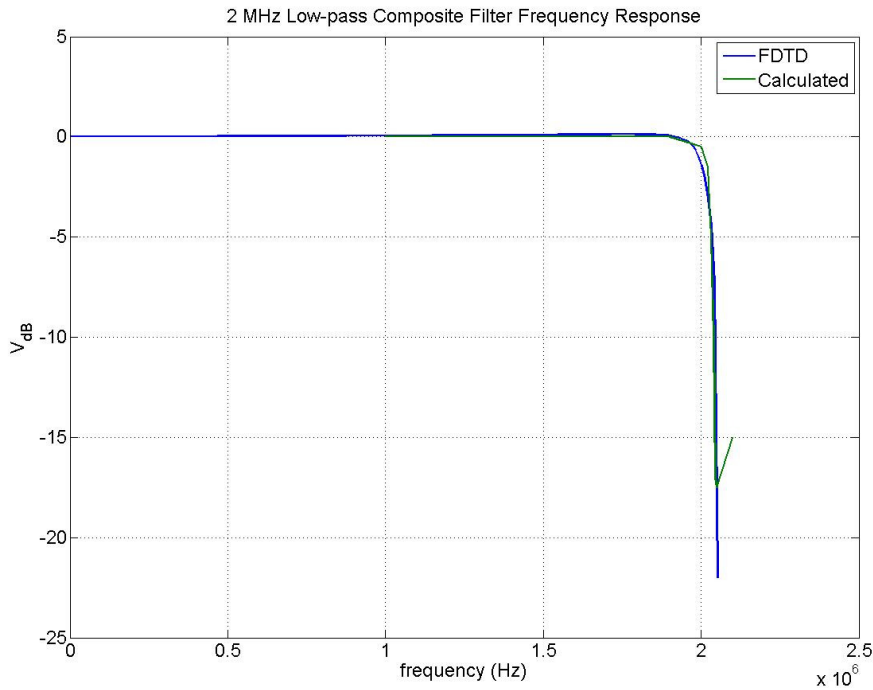


Figure 2: Frequency Response of 2 MHz Low-pass Composite Filter

Reflection Coefficient Validation

Finally, the code was verified by measuring the reflection coefficient and comparing the simulated results to those of the analytic equations. The reflection coefficient was measured as follows:

$$\Gamma_{analytic} = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (2)$$

$$\Gamma_{simulated} = \frac{|V_{reflected}|}{|V_{source}|} \quad (3)$$

The reflections were measured by first running the code for a longer length of line, and the re-running the simulation for a shorter length and allowing the signal to reflect from the load. Thus, the original signal could be subtracted from the second signal in order to attain the reflected signal. The amplitude of the reflections were obtained in this manner.

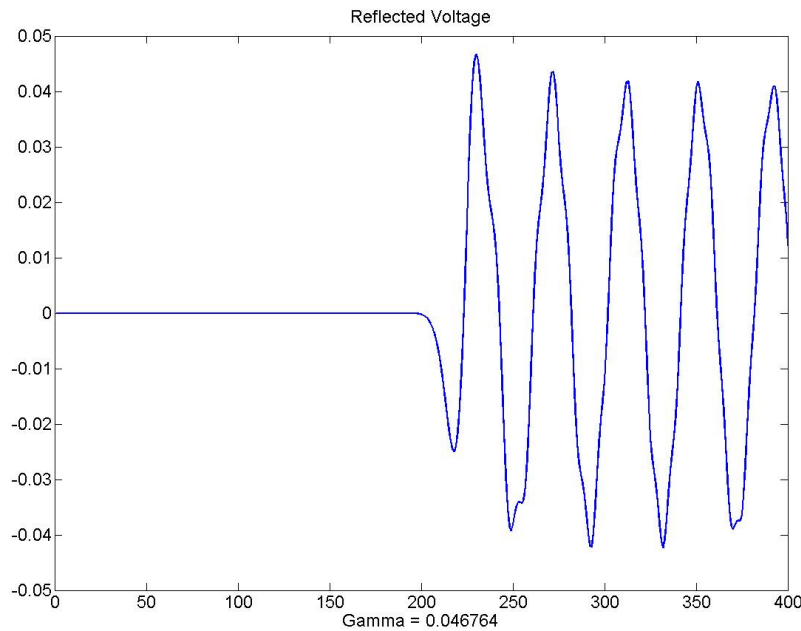


Figure 3: Reflected signal from matched load ($Z_L=Z_0$).

A comparison of the simulated and analytically computed reflection coefficients is shown below in **Table 1**.

Table 1: Simulated and Analytically Calculated Reflection Coefficients

Z_L (in terms of Z_0)	Γ (Simulated)	Γ (Analytic)
0.25	-0.6	-0.6
0.3	-0.5381	-0.5385
0.5	-0.3315	-0.3333
0.75	-0.1405	-0.1429
1.0	0.0361	0
1.5	0.1981	0.2000
2.0	0.3330	0.3333
3.0	0.5020	0.5000
4.0	0.6031	0.6000

It was concluded that the FDTD method was effective in the simulation the signal behavior along a line which incorporates the RLGC parameters of the line. A small simulation error of approximately 0.0125 (unitless) was found in the reflection coefficient.

Attenuation Validation

Another program was designed in order to validate the attenuation of the line. Using parameters from both measured lines and lossless lines, attenuation vs. distance was measured in FDTD by storing the maximum amplitudes of the waves as they propagated along the line. All the simulations were run at 1 MHz.

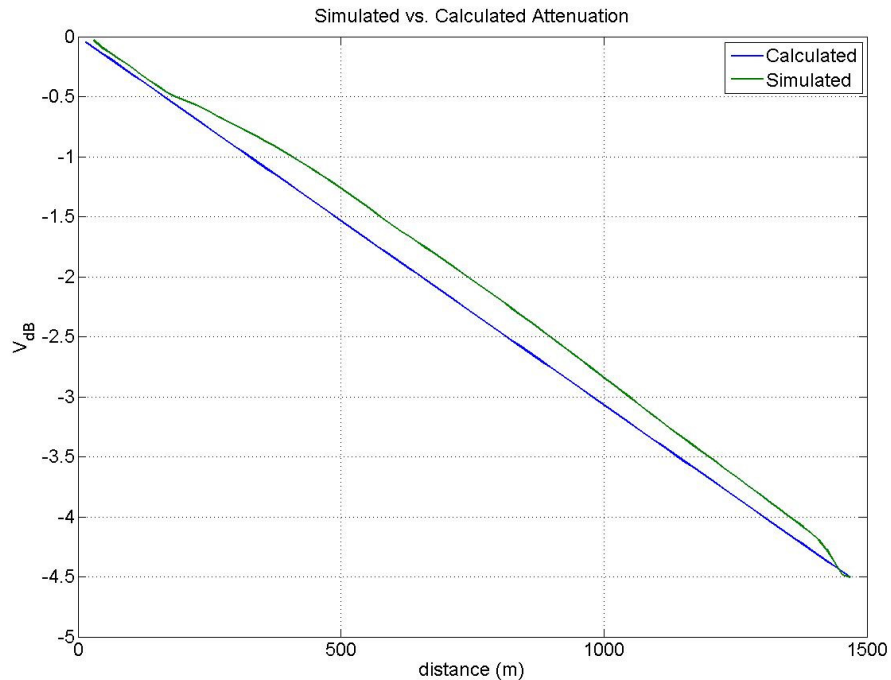


Figure 4: Simulated vs. Calculated Attenuation for RG58 Coax Parameters

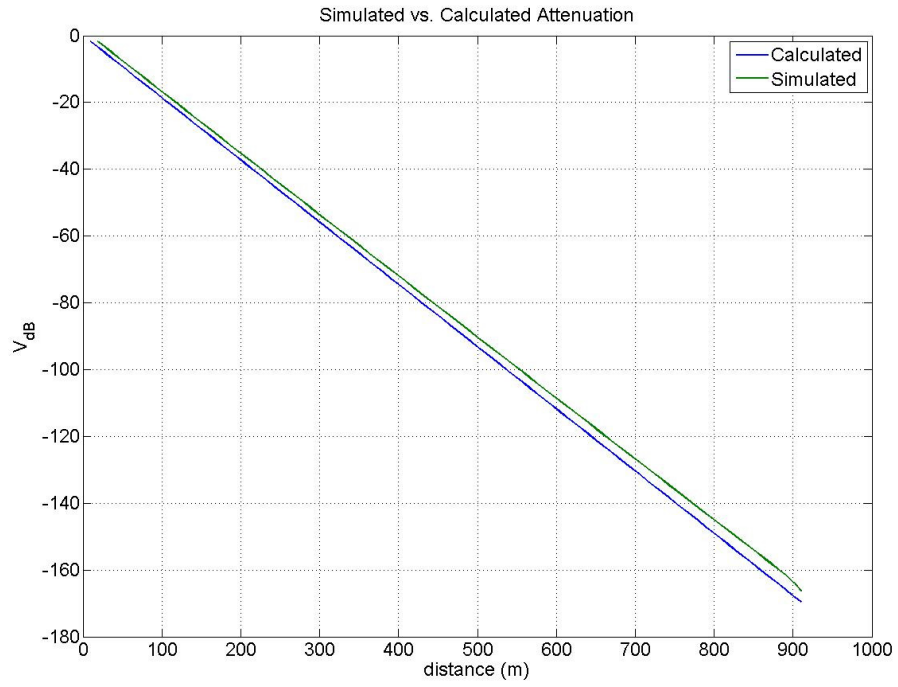


Figure 5: Simulated vs. Calculated Attenuation for Measured ECE 3300 Wire Parameters

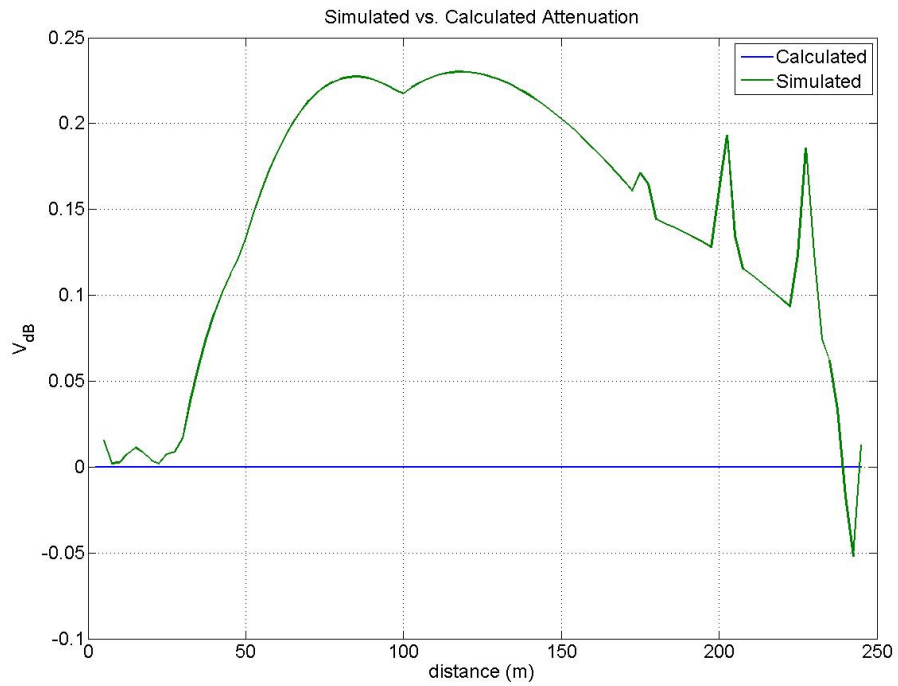


Figure 6: Simulated vs. Calculated Attenuation for Lossless Line Parameters

The simulated and calculated responses appeared to match very well. It may be noted that the simulation attenuation actually displayed less attenuation than the calculated responses. It was postulated that this may have been due to reflection from the boundaries, but even when the simulation was stopped before the wave reached the boundary, the values looked nearly identical. Thus, there is a tiny difference of about 0.1-0.2 dB between the simulation and the calculated response. This is in agreement with the lossless line simulation, which showed a 0.1-0.25 dB attenuation where 0 was the expected value.

Conclusion

The FDTD method was shown to be highly effective in the simulation the signal behavior along a line which incorporates the RLGC parameters of the line. Both the simulated and expected frequency response of the low-pass filter matched closely, although improvements to the FDTD step size were necessary and further adjustments are necessary if higher frequencies are to be tested. A small simulation error of approximately 0.0125 (unitless) was found in the reflection coefficient. Furthermore, there was a tiny difference of about 0.1-0.2 dB between the simulation and the calculated responses of line attenuation. This is in agreement with the lossless line simulation, which showed a 0.1-0.25 dB attenuation where 0 was the expected value.

NOTES

¹ Pozar, David M., *Microwave Engineering* (John Wiley and Sons: Danvers, Massachusetts [2005]), p. 389.