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Comparison of experimental and numerical simulation results for the 5-10-5 MAX1 antenna

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Abstract

This paper compares numerical simulation results, from CST MWS®, with the experimental results published in [1] for the 5-10-5 MAX1 antenna configuration. This comparison is used to validate and establish the accuracy of the simulation software.

1 Introduction

Recent efforts have focused on using CST MWS®, a commercially available FITD software[1], for demonstrating the use of a Switched-Oscillator (SWO) as a photo-conductively switched antenna [2]. Since similar simulation models will continue to be used to describe, explain and optimize the SWO antenna design, it is essential to validate our numerical results. For this purpose, previously published experimental results for the 5-10-5 MAX1 (Hertzian dipole) antenna are used [1].

2 Determination of the input waveform for the 5-10-5 MAX1 antenna

One of the most important parameters in modelling any antenna is the shape and rise time of the input pulse. A simple Drude formalism in [1] was used to estimate the shape of the current pulse in the photo-conductive switch region. The rise time of this pulse was approximately 60 fs. Such a fast rise time is unsuitable for our simulations since it leads to an unreasonably large number of mesh cells (and hence a very long simulation time). Therefore, to compare our numerical results against the analytical model in [1], an input pulse with a slower rise must be used. A rise time of 0.5 ps was found to be appropriate. The task then is to determine an input pulse with a maximum rate of rise, t_{mr}, of 0.5 ps which matches the shape of the pulse in [1] (Fig. 4 a). In this note, the t_{mr} is used as the definition of the rise time [3].

The Drude response in [1] (equation (7)) evaluated to a double-exponential type function for the current in the photo-conductive region. For our simulations it is more convenient to approximate this input with a Reciprocal-of-the-Sum-of-two-Exponentials Excitation (RSEE), as the RSEE transitions more smoothly at higher frequencies [3].

The RSEE is defined here as

$$f(t) = \frac{\chi}{\exp[-\alpha(t-t_0)] + \exp[\beta(t-t_0)]}, \quad \alpha \geq 0, \quad \beta \geq 0, \tag{2.1}$$

which is almost identical to the defintion in [3], except for the χ parameter which is included to scale the peak amplitude of the function.

The t_{mr} of the above function is[2]

$$t_{\mathrm{mr}} = \left[\frac{df(t)}{dt}\right]^{-1} = -\frac{4}{(\beta-\alpha)\chi}. \tag{2.2}$$

Since we want a t_{mr} of 0.5 ps,

$$\alpha = \frac{8+\beta\chi}{\chi}. \tag{2.3}$$

t_0, χ and β are estimated by fitting the RSEE to the analytical input excitation in [1];

$$t_0 = 4.874 \text{ ps}, \tag{2.4}$$

$$\chi = 1.681, \tag{2.5}$$

$$\beta = 1.738 \text{ ps}^{-1}. \tag{2.6}$$

[1] http://www.cst.com/

[2] Note that this definition of t_{mr} is identical to that in [4] since $f_{\max} = 1.0$

The analytical excitation published in [1] and the RSEE are compared in Fig. 2.1. One observes the excellent agreement between the two curves. Note that fitting to the published data, i.e., the Drude model, implicitly takes into account the photo-conductive switch properties (carrier mobility, carrier lifetime etc.) which are otherwise difficult to accurately model in CST.

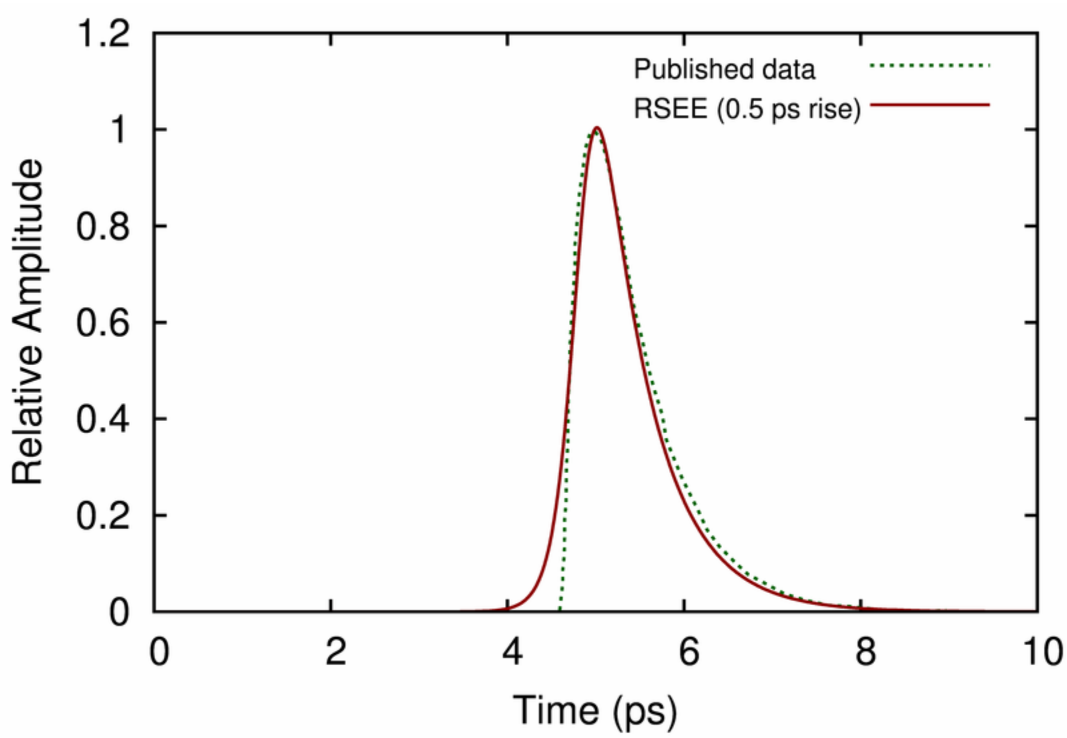


Figure 2.1: Comparison of the analytical excitation published in [1] and the RSEE with a t_{mr} of 0.5 ps

As mentioned in [1], the shape of the radiated pulse is identical to the derivative of the input excitation. The normalized derivative of the RSEE is shown in Fig. 2.2. The larger negative area, compared to Fig. 4b) in [1], is a consequence of using a slower rise (area must be conserved) [5].

The 5-10-5 MAX1 antenna is a broadband radiator and the experimental results in [1] are compared to the analytical approximations in the frequency domain. The normalized Fourier transform of Fig. 2.2, shown in Fig. 2.3, is therefore of more interest since a good agreement between our simulation results and Fig. 2.3 implies good agreement with published experimental data. Note that the FFT rolls of much quicker at higher frequencies, compared to Fig. 4c) in [1], again, due to the slower rise.

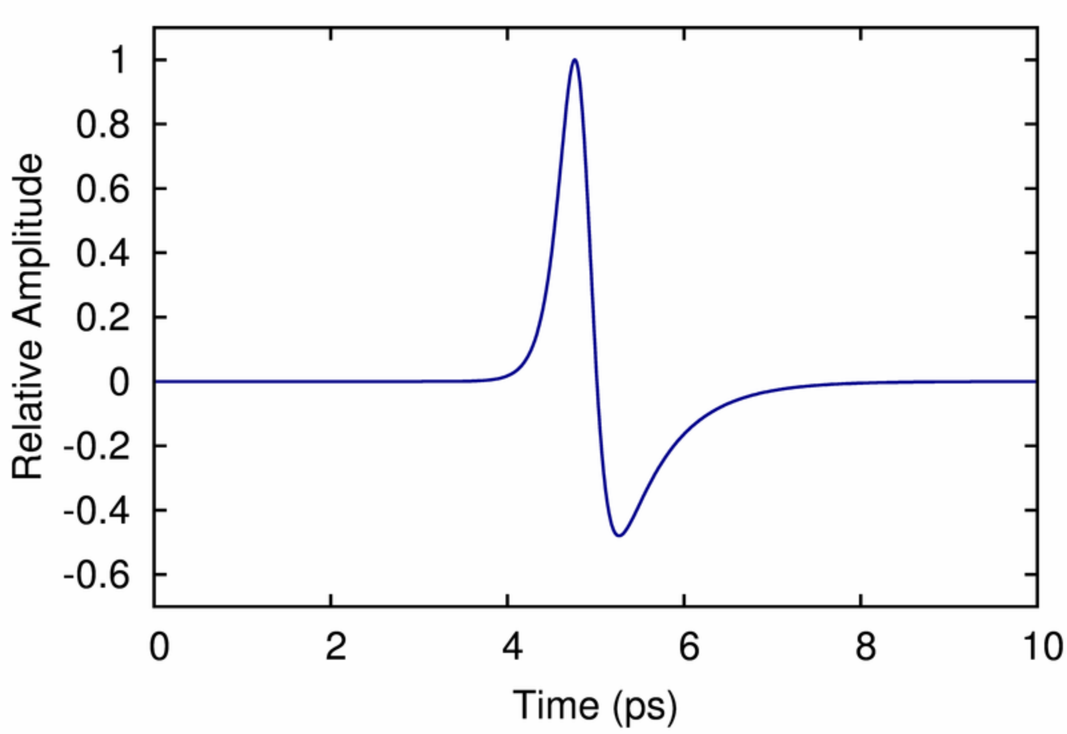


Figure 2.2: Shape of radiated pulse; derivative of the input excitation

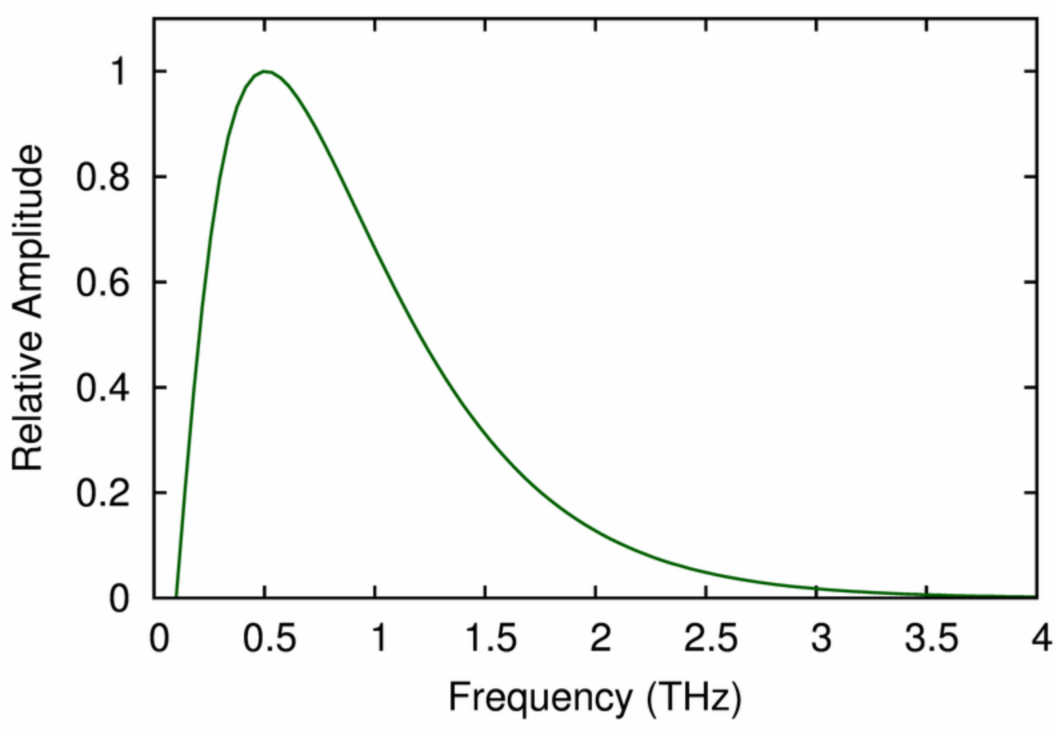


Figure 2.3: Frequency spectrum (Fourier Transform) of Fig. 2.2.

3 Numerical simulations

3.1 Setup

3.1.1 Structure visualization

The perspective, top and side views of the 5-10-5 MAX1 antenna on silicon and sapphire substrates are shown in Fig. 3.1 and Fig. 3.2. The dimensions of the antenna, substrate thicknesses and the silicon lens given in [1] lead to an unreasonably large number of mesh cells in the simulation domain (a problem with such large dimensions cannot be handled by our existing computing resources). Therefore, a subset of the original problem is solved, with the following modifications,

1. The length of transmission lines is reduced to 1.5 mm on either side of antenna, Fig. 3.2, instead of 1 cm as used in [1].

2. Since we are only interested in comparing the temporal and spectral properties of the electric field, and *not* its absolute amplitude, the silicon lens is omitted.

3. The substrate dimensions are chosen arbitrarily so as to extend beyond the transmission lines on either side. The thickness of the substrates is kept as small as possible to limit the number of mesh cells, and avoid reflections from the sapphire-air interface which would significantly affect the radiated waveform. As shown in Fig. 3.2(b), the antenna is on a 0.5 μm thick silicon substrate. A 200 μm thick sapphire substrate extends below the silicon substrate. While the antenna is assumed to be aluminum (lossy), the silicon and sapphire are assumed to be lossless.

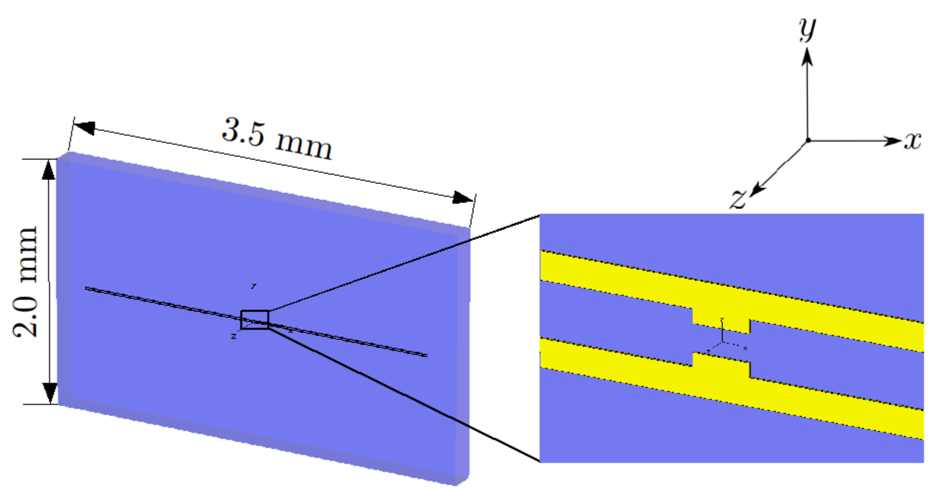
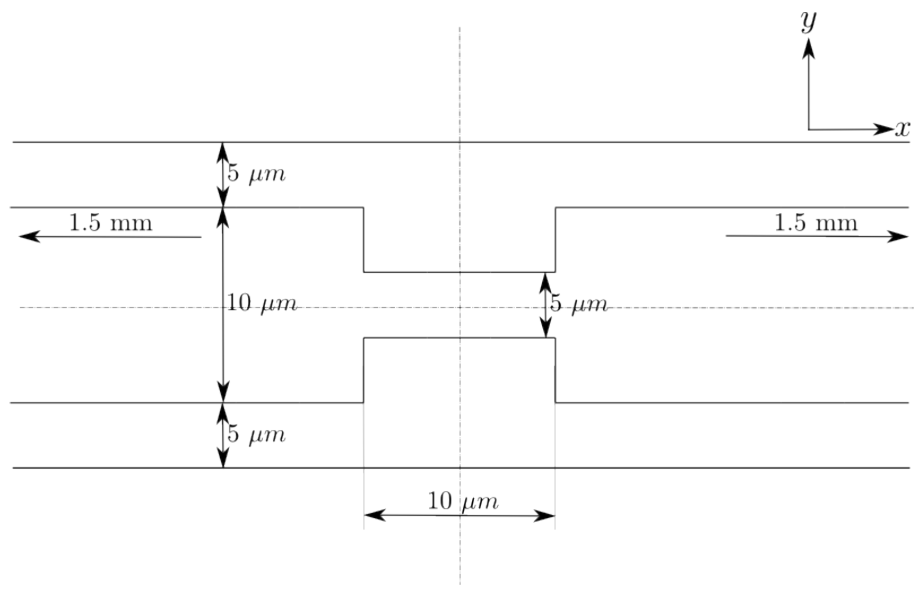
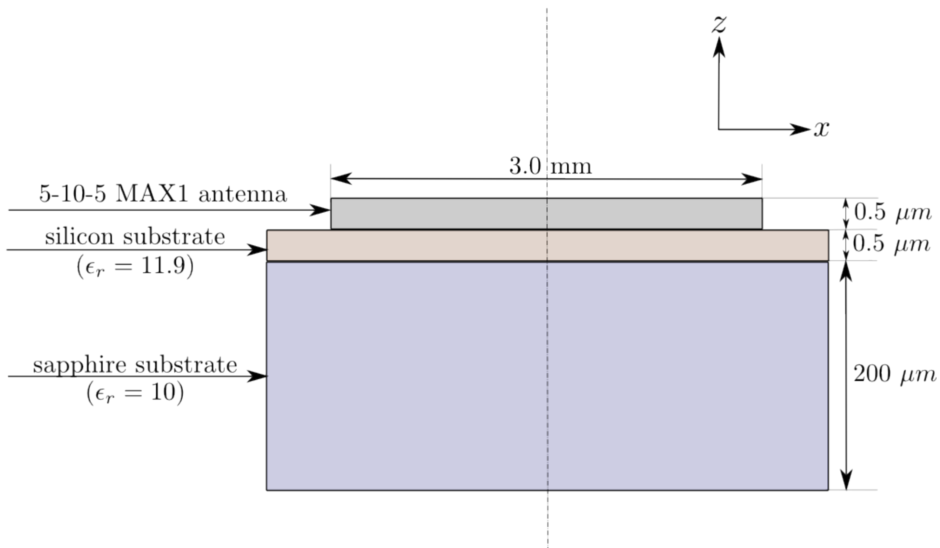


Figure 3.1: Perspective view.



(a) Top view.



(b) Side view (not to scale).

Figure 3.2: Perspective, top and side views of the 5-10-5 MAX1 antenna simulation setup.

3.1.2 Probe placements

Since we are interested in the radiation through the silicon and sapphire substrates, far-field electric-field probes were placed at 1 cm from the origin, along the $-z$-axis, oriented in the x, y and z directions, as shown in Fig. 3.3.

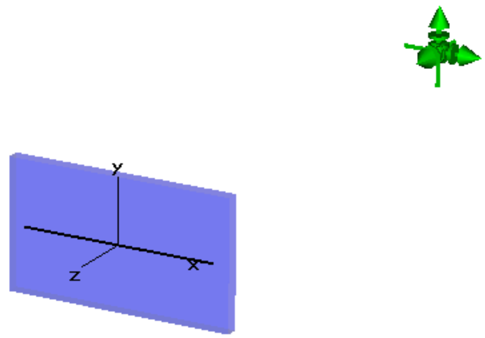


Figure 3.3: Orientations and placements of electric field probes.

3.1.3 Important CST/Simulation Parameters

Domain	Time
Excitation	Discrete
Input	RSEE with a t_{mr} of 0.5 ps (see Sec. 2)
Peak excitation current	1 A
Frequency range	0−3 THz
LPW	10

3.2 Results

The normalized analytical and numerical simulations results for the electric field (E_y), in the time domain, are compared in Fig. 4.1. One observes the excellent agreement between the two curves. Corresponding results in the frequency domain are compared in Fig. 4.2 (Fourier transform of the curves in Fig. 4.1). Again, one notes the good agreement between the two curves. The peak frequency, 0.5 THz, in the simulation results differs only by ≈0.1 THz from that predicted analytically. The experimental frequency domain response in [1] was also found to agree very well with the predicted analytical response. This implies an excellent agreement between the simulation and experimental results.

4 Conclusions

The 5-10-5 MAX1 antenna configuration in [1] has been numerically simulated in CST. Excellent agreement is found between the numerical simulation, analytical, and experimental results. Hence CST MWS®can be used to reliably and accurately model, describe, and optimize future SWO antenna designs.

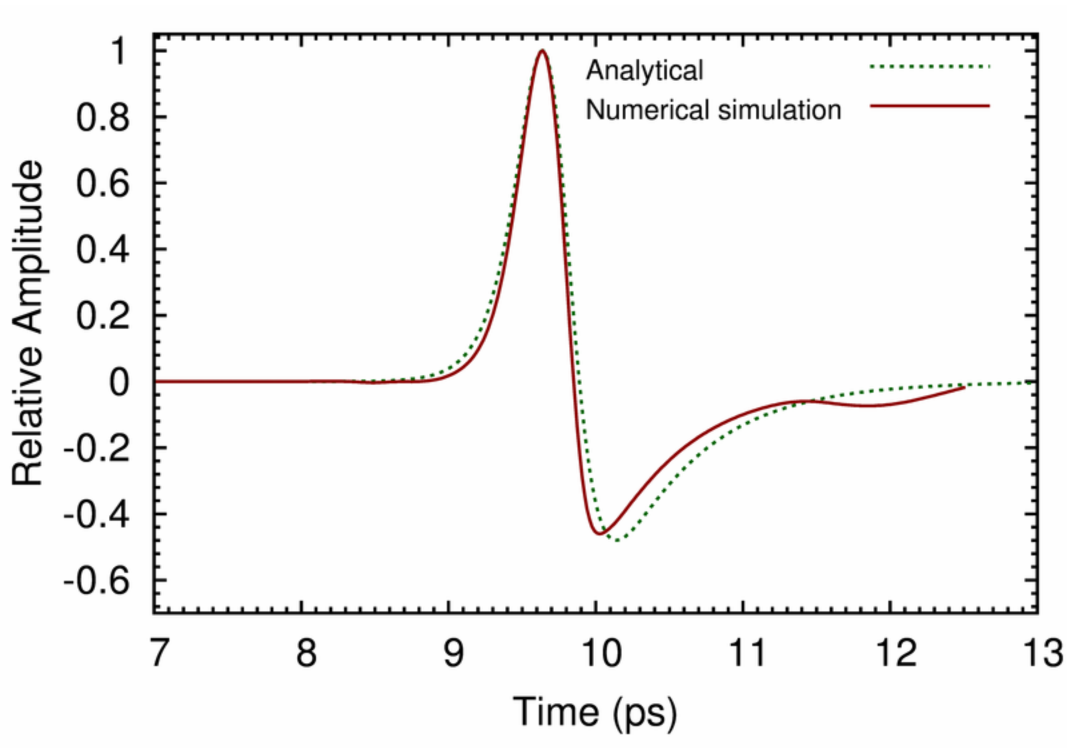


Figure 4.1: Comparison of the normalized analytical and numerical simulations results for the electric field (E_y).

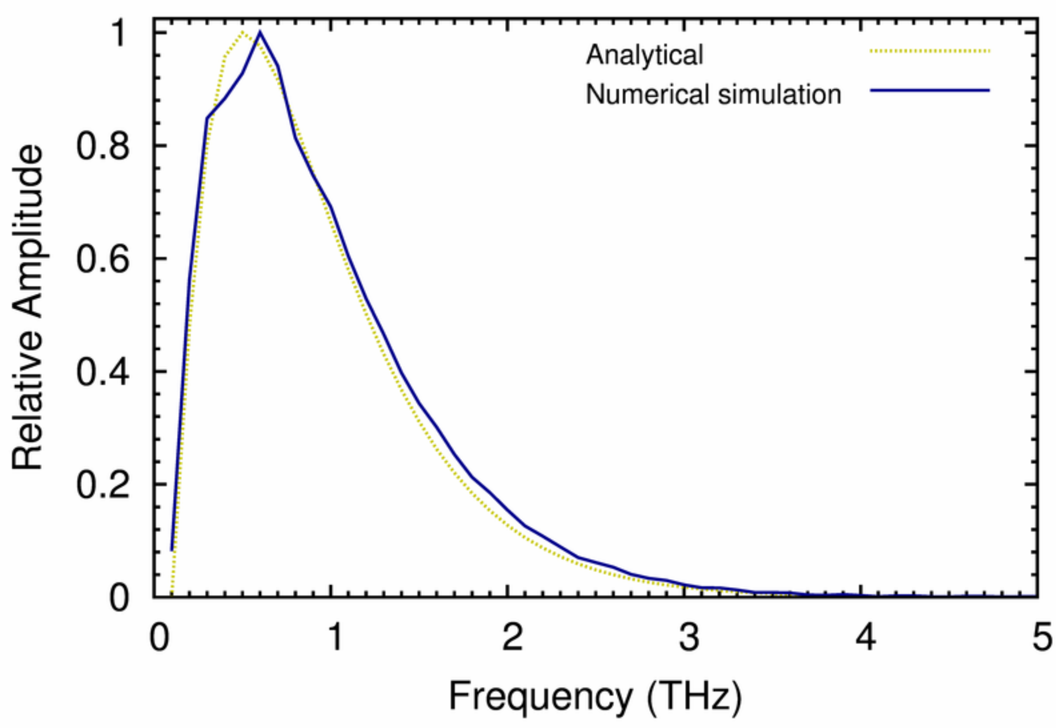


Figure 4.2: Comparison of the normalized analytical and numerical simulations results for the electric field (E_y) in the frequency domain (FFT of Fig. 4.1).

References

[1] D. R. Grischkowsky and N. Katzenellenbogen, *Femtosecond Pulses of THz Radiation: Physics and Applications*, vol. 9, pp. 9–14. Washington, DC: OSA Proceedings on Picosecond Electronics and Optoelectronics, Optical Society of America, 1991.

[2] Prashanth Kumar, Carl E. Baum, Serhat Altunc, Christos G. Christodoulou and Edl Schamiloglu, "Switched oscillator as an antenna," *Terahertz Memo 1*, Sept. 2009.

[3] C. E. Baum, "Some Considerations Concerning Analytic EMP Criteria Waveforms," *Theoretical Note 285*, October 1976.

[4] S. Altunc, *Focal Waveform of a Prolate-Spheroidal Impulse Radiating Antenna (IRA)*. PhD thesis, University of New Mexico, December 2007.

[5] C. E. Baum, "Some Limiting Low-Frequency Characteristics of a Pulse-Radiating Antenna," *Sensor and Simulation Note 65*, October 1968.