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Diagnostics : Identifying the cause of 100 ps time dispersion in simulation results of non-uniform launching lens designs

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Abstract

The 100 ps time dispersion obtained in all our previous simulation results is a cause of concern. This paper presents simulation results for two cases : 1) Uniform launching lens and 2) Switch and feed arm (without lens), in an attempt to diagnose the cause for observed discrepancies. These cases have been chosen as analytical results are known exactly and hence would easily help identify any errors.

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1   Introduction

The constant 100 ps time difference observed in all the previous simulation results (planar, [1] and conical, [2]) is a cause of concern. We suspect that this may be due to inherent numerical inconsistencies arising due to the parameters intialized in CST. This suspicion is easily verified by analyzing simulations for which analytical results are previously known. Two such cases are considered in this paper:

1. Unifrom launching lens as described in [3]

2. Feed arm and switch without lens; electrical center of switch at the origin

Any discrepancies which would arise in the above two cases would shed some light on the discrepancies of the planar and conical simulation results.

The simulation setup and CST parameters are identical to the planar case as described in [1], unless mentioned otherwise.

2   Simulation results for uniform lens ($\epsilon_r = 36$)

The front and perspective views of the uniform lens are shown in Fig. 2.1. The lens curve was obtained as per the "numerical" solutions to equations in [3] for $\epsilon_r = 36$.

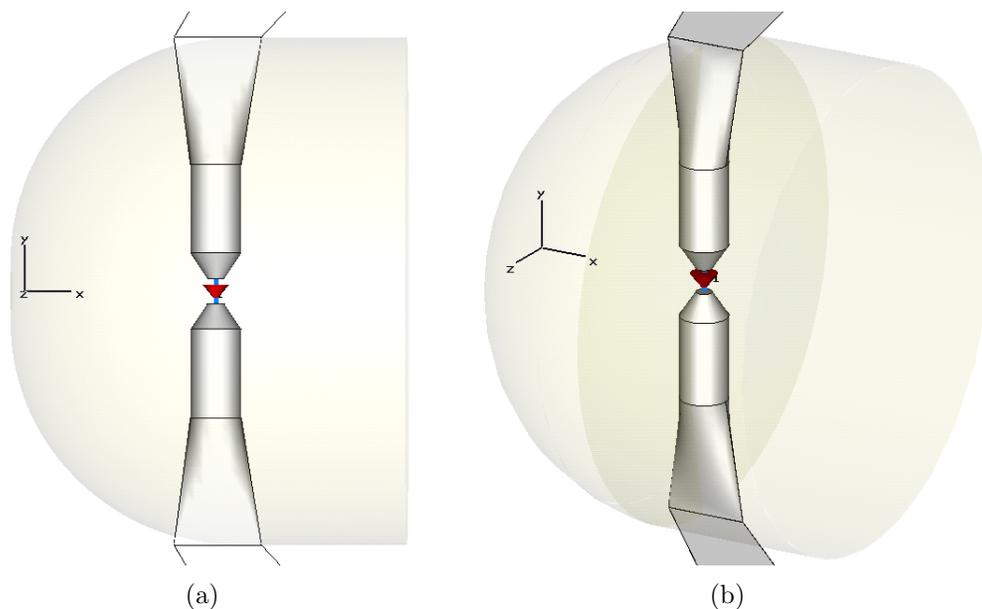(a)   (b)

Figure 2.1: Front and perspective views of uniform lens design

Results obtained for the current setup are shown in Fig 2.2. Analytical results for the uniform lens are known for all time. Simulation of the uniform lens case should thus yield results where responses from all the probes overlap each other in time i.e. zero time difference between various responses. However, Fig. 2.2 shows otherwise, specifically, a 100 ps time difference between the 0° and 127° responses.

The cause for the observed time difference is suspected to be due to numerical dispersion and can be easily verified by doing a simulation with the switch and feed arm (without lens) at the origin. Nevertheless, the current simulation sheds some light on previous simulations. The dispersion in previous simulations is most likely due to the same factors causing dispersion for the current uniform case. Therefore, there is a probability that previous simulation results, specially the case of the conical lens where the results are known (semi-)analytically, would yield much smaller time differences in practical, experimental scenarios.
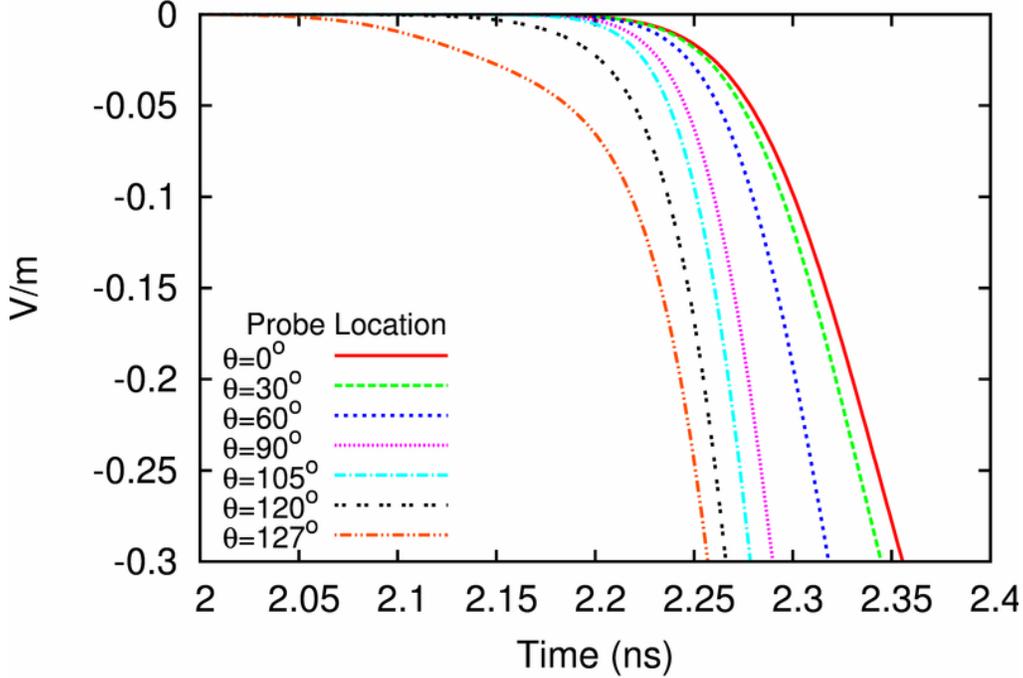

Figure 2.2: Results at various angles in the $x - z$ plane for probe setup.

3   Simulation results for switch and feed arm without lens

The front and perspective views of the switch-feed-arm (no lens) case are shown in Fig. 3.1. The electrical center of the switch is at the origin. The setup is extremely simple as it consists of purely PEC components and the geometry is not complicated. The switch at the origin of the coordinate system should produce results with the lens setup in [1] and [2] (as in these simulations the lens is designed so that the waves appear to originate from the origin/focal point).

Results for the setup are shown in Fig. 3.2 and Fig. 3.3. Results on the nanosecond scale shown in Fig. 3.2 are as expected, i.e. responses from all probes overlap each other. However, our lens designs focus on the picosecond scale. Fig. 3.3 shows Fig. 3.2 zoomed in to the picosecond scale. Notice the large dispersion of the order of 30 ps. There seems to be an obvious numerical error in the computational process for the given parameters. In the presence of a dielectric, such errors might propogate resulting in even larger errors. This may be what is observed in previous simulations with the lens.
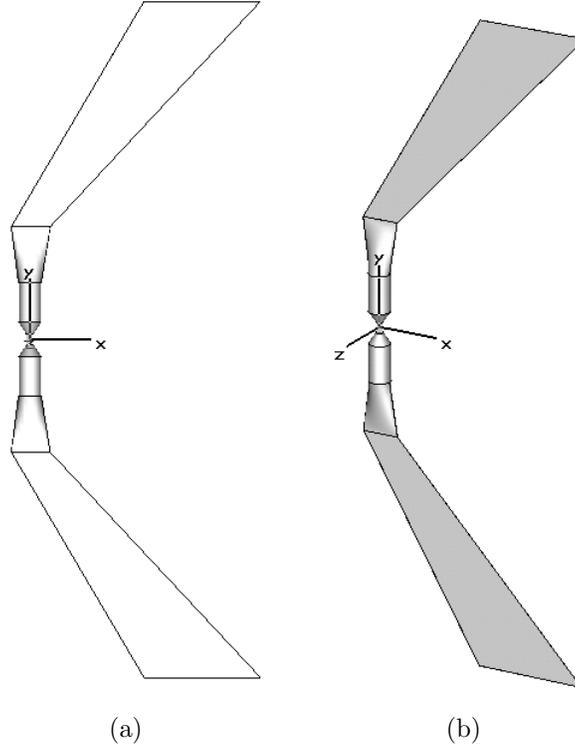
Figure 3.1: Front and perspective views of feed arm and switch with source point at origin

3.1 Probable cause : Assumptions in frequency of input waveform

The input waveform used in all our simulations is a ramp rising step function, rising from 0 V to 1 V in 100 ps and then staying at 1 V thereafter. CST MWS requires the specification of a frequency range within which the results from all the probes will be calculated/filtered. Our initial assumption was to set a frequency range from 0 GHz − 10 GHz as 10 GHz corresponds to 100 ps. However, this frequency range specification may not be entirely accurate. Consider the following : at 10 ps the frequency corresponding to the ramp rising function is 100 GHz, at 50 ps it is 20 GHz and at 100 ps it is 10 GHz. Therefore a natural query that may arise would be : what is the response of the probes at 10 ps or 50 ps when the maximum frequency of observation is 10 GHz? This frequency limitation may be a likely cause, but it does not explain why there is the observed dispersion between probes at various angles on the same plane (and on the same measurement sphere). The most obvious method to verify the frequency limitation is to increase the frequency of our simulations to 100 GHz, but due to our limited resources and computational power this is not possible.

However, it *is* possible to verify the frequency limitation in an alternate and much simpler scenario where increasing the frequency would still be within our computational power. For this we used a built-in example from CST of a simple dipole centered on the origin and simulated the case with our ramp rising input signal as in all our previous simulations. Indeed on the picosecond time scale we observed dispersion albeit less in this case − of the order of approximately 15 ps. When the frequency was increased to 25 GHz and the mesh size refined to 40 LPW (10 GHz and 10 LPW were used in all previous simulations) a dispersion of less than 3 ps was observed.
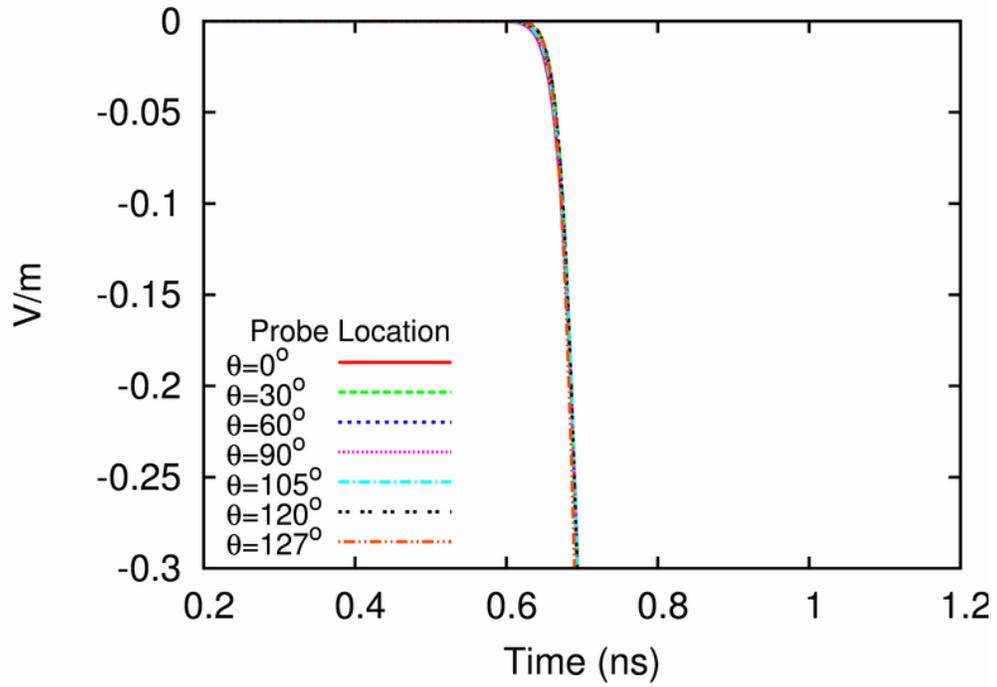
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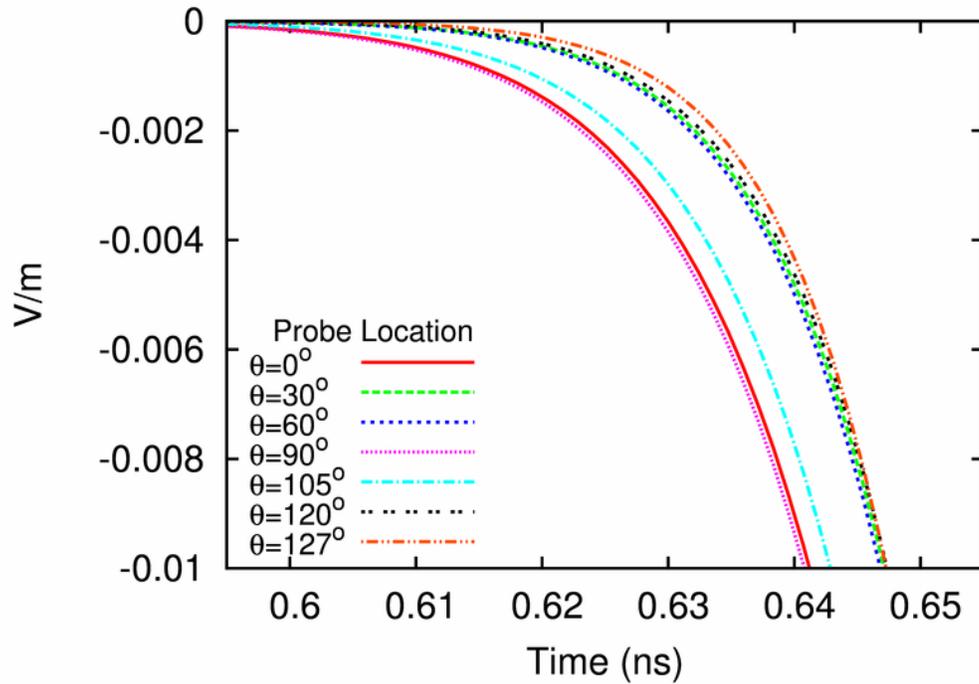Figure 3.2: Results at various angles in the $x - z$ plane for probe setup.

Figure 3.3: Results at various angles in the $x - z$ plane for probe setup.

Increasing the frequency and refining the mesh size amounts to lowering the time-step used in numerical calculations. The preliminary results from this simple case of an electrical dipole lead us to suspect that we may need to resolve our mesh to much finer resolutions to correct for errors in our time-domain, which corresponds to the order of picoseconds. If working in the nanosecond time scale, errors obtained from CST are quite acceptable. However, in our case, where time differences greater than 10 ps are not tolerable, the higher frequencies in the input signal must be resolved so our calculations can be made with greater accuracy. We suspect that this inability to resolve the timings at the picosecond scale lead to even larger errors in the presence of the dielectric.

4 Amplification in electric field with lens

It is interesting to note that there is an amplification in the electric field response in the presence of a dielectric lens when compared to the feed arm only case. This is to be expected since the energy capacity of a dielectric is much higher than air. Fig. 4.1 compares the responses for a probe at $0°$ for the non-uniform (planar), uniform and feed arm only case. Results of the feed arm only case are without the switch and the setup is shown in Fig. 4.2 (excitation gap is 4 mm). The non-uniform case corresponds to a 3-layer planar design with $d_1 = d_2 = d_3 = 10/3$ cm, and $\epsilon_{r_1} = 1.5$, $\epsilon_{r_2} = 1.75$, $\epsilon_{r_3} = 7.69$ (this 3-layer design was one of our initial test cases and hence the values of the dielectric constants and corresponding distances have not been calculated from equations in [1]).
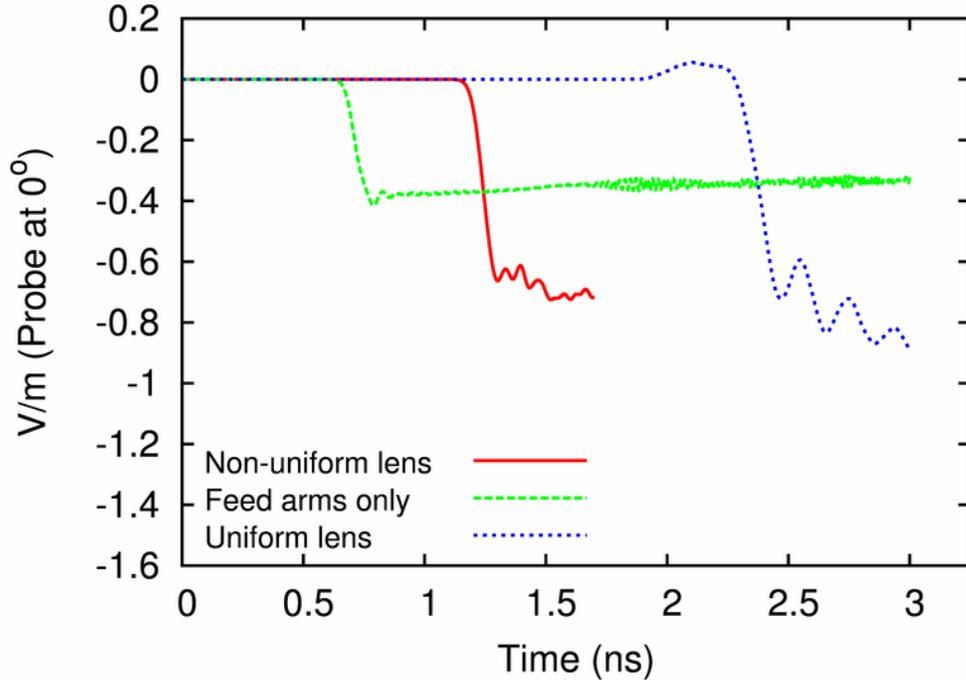

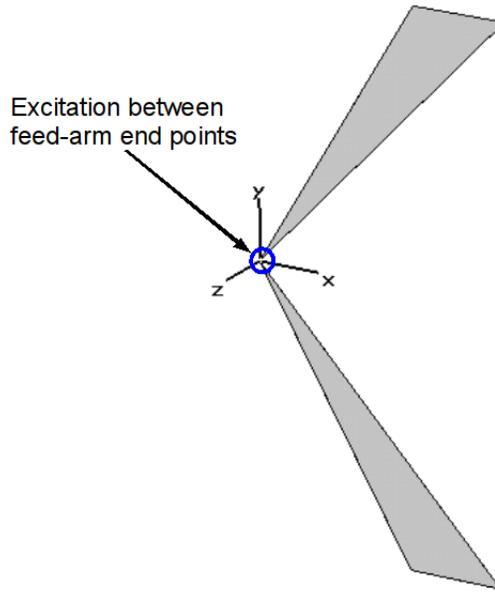Figure 4.1: Comparison of results for uniform dielectric lens case with non-uniform and feed-arms only cases

Figure 4.2: Simulation setup with feed arms only and excited at the origin, excitation gap at origin is 4 mm

5 Conclusions

The most likely cause for the 100 ps time difference in almost all simulations with the dielectric lens has been identified − lack of numerical resolution in the software used. The order of the errors produced by the software are too great for our design constraints in the time domain of our interest. In order to reduce errors, much finer resolutions are required, which are equivalent to increasing the frequency range of inspection to the order of 100 GHz so that earlier times in the input ramp rising step can be resolved. Initial verification of increasing the mesh resolution with a simple dipole seem to indicate that this may indeed be the case.

References

[1] Prashanth Kumar, Serhat Altunc, Carl E. Baum, Christos G. Christodoulou, Edl Schamiloglu, "Simulation results for 3-layer and 6-layer planar non-uniform launching lens." EM Implosion Memo 27, June 2009.

[2] Prashanth Kumar, Serhat Altunc, Carl E. Baum, Christos G. Christodoulou, Edl Schamiloglu, "Simulation results for 6-layer and 7-layer conical non-uniform launching lens." EM Implosion Memo 28, June 2009.

[3] Serhat Altunc, Carl E. Baum, Christos G. Christodoulou, Edl Schamiloglu, "Analytical Calculations of a Lens for Launching a Spherical TEM Wave." Sensor and Simulation Notes, Oct. 2008.