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Numerical Calculation for the Focal Waveform of a Prolate-Spheroidal IRA with Different Types of Dielectric Lens

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Abstract

Three types of lens design procedure and the numerical focal waveform with this lens are discussed.

1 Introduction

This paper is an extension of [1,2,3]. Linear, exponentially and compensated incremental speed (CIS) increasing permittivity lens designs with CST-Microwave Studio are discussed. These lens are half sphere and we use shells to obtain the increase in permittivity.

1.1 Description of geometry

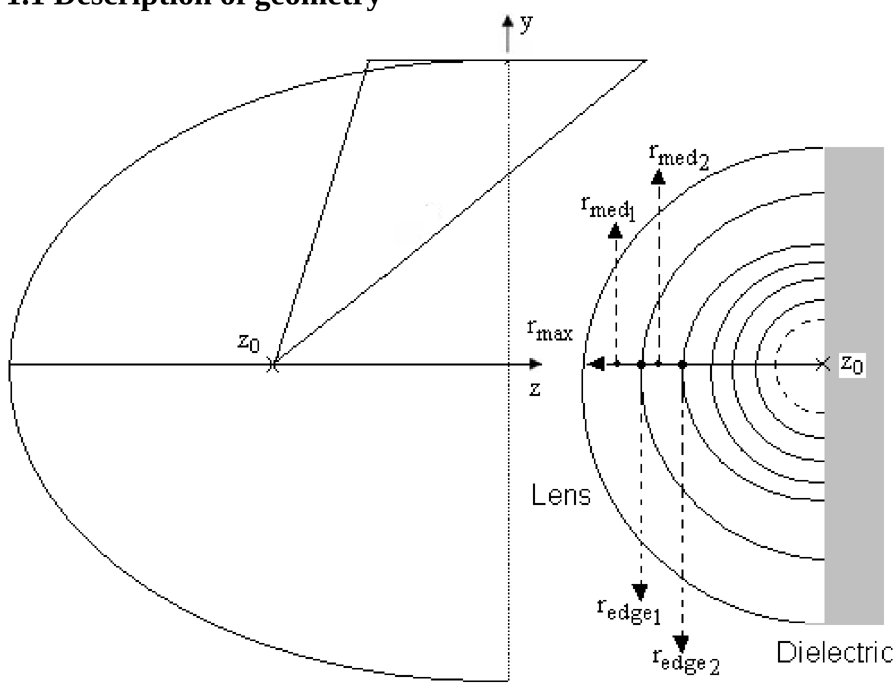

Figure 1.1 IRA Geometry

The focal point is $z_0 = 37.5$ cm and the other parameters of prolate-spheroidal IRA is defined in [2,3].The lens is a half sphere which has a radius of $r_{max} = 30$ cm . The risetime of the ramp-rising step incident wave is $t_\delta = 100\,\text{ps}$. We use 1 Volt differential source.

2. Design Considerations

Basic analytical calculations for the lens are defined in [4] .Dielectric material relative permittivities are

$$\varepsilon_r(r) = r/r_{max} + \varepsilon_{r\,max}\left(1 - r/r_{max}\right) \qquad \text{Linear}$$

$$\varepsilon_r(r) = e^{\ln(\varepsilon_{r_{max}})(1-\frac{r}{r_{max}})} \qquad \text{Expential} \qquad (2.1)$$

$$\varepsilon_r = \left((1-\varepsilon_{r\,max}^{-1/2})\frac{z}{z_{max}} + \varepsilon_{r\,max}^{-1/2}\right)^{-2} \qquad \text{CIS}$$

We are using shells to obtain the decrease.

Let us assume $\varepsilon_r(r_{med_1}) = 1$ and the thickness of the first shell is $\frac{ct_\delta/2}{\sqrt{\varepsilon_r(r_{med_1})}}$.The middle point of the first shell is $r_{med_1} = (r_{max} - r_{edge_1})/2$ and it can be found as

$$r_{max} - r_{med\,1} = \frac{ct_\delta/4}{\sqrt{\varepsilon_r(r_{med_1})}} \qquad (2.2)$$

One can find r_{edge_1} from r_{med_1} and if we substitute it in (2.1), $\varepsilon_r(r_{med_1})$ can be found. $\varepsilon_r(r_{med_1})$ can be substitute in (2.3) and r_{edge_1} can be found.

$$r_{max} - r_{edge\,1} = \frac{ct_\delta/2}{\sqrt{\varepsilon_r(r_{med1})}} \qquad (2.3)$$

Then we can find $r_{med\,2}$ from (2.4)

$$r_{edge_1} - r_{med_2} = \frac{ct_\delta/4}{\sqrt{\varepsilon_r(r_{med_1})}} \qquad (2.4)$$

If we substitute r_{med_2} in (2.1) $\varepsilon_r(r_{med_2})$ can be found. One can substitute $\varepsilon_r(r_{med_2})$ in

$$r_{edge_1} - r_{edge_2} = \frac{ct_\delta/2}{\sqrt{\varepsilon_r(r_{med_2})}} \qquad (2.4)$$

r_{edge_2} can be found from (2.4).

This iterative technique can be applied to the n_{th} shell so all the radiuses and permittivities can be found consequently. These values can be limited with $\varepsilon_{r\,max}$ and r_{max}. The worst case scenario is when $\varepsilon_{r\,max} = 81$ is the relative permittivity of water.

3. Numerical Results

The parameters for our numerical results are

$$t_\delta = 100 \text{ ns},\ r_{max} = 30 \text{ cm},\ \varepsilon_r(r_{max}) = 30 \qquad (3.1)$$

The prolate-spheroidal IRA parameters are defined in [3]

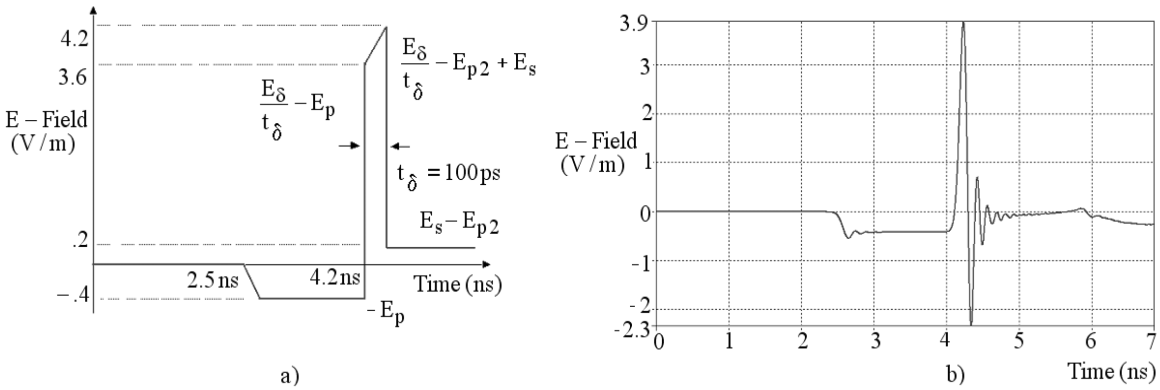

Figure 3.1 Focal Waveforms a)Analytical b)Numerical at 5 GHz and LPW=8 [5]

Analytical and numerical waveforms without Lens are presented in fig. 3.1.

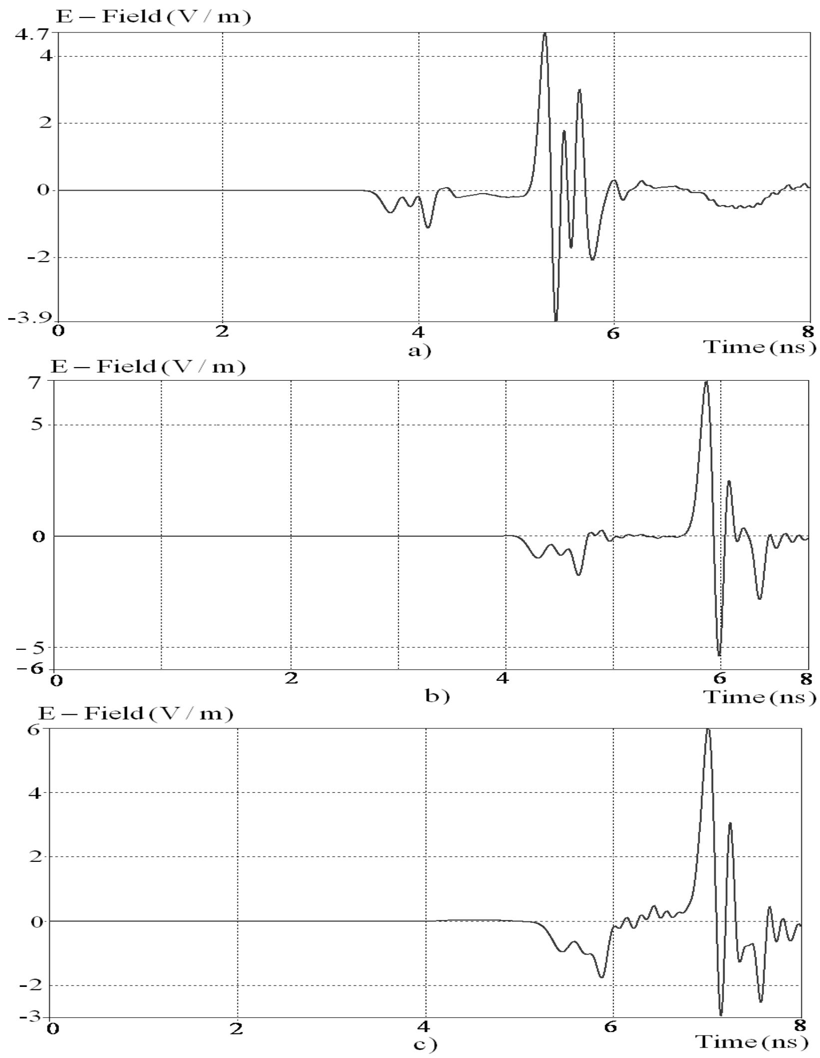

Figure 3.2 Numerical Focal Waveforms at a)CIS b)Exponential c)Linear for LPW=8

Time(ns)	CIS	Exp	Lin
Lens	2.1	2.63	3.8
Prepulse	3.6	4.13	5.3
Impluse	5.2	5.8	6.9

Table 1. Propagation Time in lens and Arrival Time

One can see from Fig. 3.2 that we have better results for higher frequencies than we had before [5]. The prepulse term is dispersed because of the lens. We designed the lens for just impulse term. Propagation time in lens and arrival time values can be calculated from (3.6),(4.11) and (5.5) in [4].

Analytically we expect an approximation for the net transmission improvement as defined in [1 (5.4)]

$$F_0 T = \varepsilon_{r_{max}}^{1/2} \varepsilon_{r_{max}}^{-1/4} = \varepsilon_{r_{max}}^{1/4} \qquad (3.2)$$

Where F_0, T are the enhancement and transmission factors [1]. We should have a $\sqrt[4]{30} = 2.34$ transmission improvement. So from fig. 3.1 we should have a peak around 9.1 V/m which is the multiplication of the peak without lens and transmission improvement. We can see from Fig. 3.2 b) we have an impulse amplitude around 6 V/m. First of all (3.2) is just an approximation. The field is not a plane wave and then we are having numerical errors. Furhermore these equations are approximations. So we are not obtaining the analytical results. We really need more accurate computer results.

4.Conclusion

Numerical focal waveforms of a prolate-spheroidal IRA with three types of increasing dielectric lens are calculated. We are using high permittivity material and the dimensions of the geometry are big .We are having errors because of approximations and numerical errors. In general we are obtaining reasonable prepulse,one can see from fig. 3.2 that the prepulse is actullay reduced by the lens. The impulse is getting closer to the real values but the postpulse is inconsistent with real values. For experiment and simulation we might fill the whole geometry with water ($\varepsilon_r = 81$) but this leads to other problems. So we expect to obtain better focusing.

References

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2. C. E. Baum, "Focal Waveform of a Prolate-Spheroidal IRA", Sensor and Simulation Note 509, February 2006.
3. S. Altunc and C. E. Baum, "Extension of the Analytic Results for the Focal Waveform of a Two-Arm Prolate-Spheroidal Impulse-Radiating Antenna (IRA)", Sensor and Simulation Note 518, Nov 2006.
4. S. Altunc and C. E. Baum, "Lens Design for a Prolate-Spheroidal IRA", EM Implosion Memos, Memo 9, January 2007.
5. S. Altunc and C. E. Baum, "Comparison of Analytical and Numerical Results for a Prolate-SpheroidalImpulse-Radiating Antenna (IRA)", Sensor and Simulation Note 519, Nov 2006.