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Lens Design for Incoming Spherical Wave

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Abstract

In this paper a lens design procedure is discussed to obtain better focusing for a prolate-spheroidal IRA for an incoming spherical wave from the reflector.

1 Introduction

This paper is an extension of [1] and the lens design considerations are based on [2]. N layers of an increasing dielectric lens, which have the same ratio of dielectric constants between adjacent layers, are considered for a prolate-spheroidal IRA. Instead of using a half-spherical lens, a new approach is proposed for incoming spherical waves to obtain better focusing for a prolate-spheroidal IRA.

2 Design Considerations

10 layers of increasing-dielectric-constant lens are used based on the calculations in [1]. We use the same ratio of dielectric constant between subsequent layers.

$$\varepsilon_{ratio} = \varepsilon_{r_{n+1}} / \varepsilon_{r_n} \ , \ \left(\varepsilon_{r_{n+1}} / \varepsilon_{r_n}\right)^N = \varepsilon_{ratio}^N = \varepsilon_{r\,max}$$
$$\varepsilon_{ratio} = \varepsilon_{r\,max}^{1/N} \tag{2.1}$$

We use N=10 layers and $\varepsilon_{r\,max} = 81$ for the worst case scenario for biological applications. We start from free space $\varepsilon_r = 1$ and our target dielectric is $\varepsilon_{r\,max} = 81$ and $\varepsilon_{ratio} = 1.55$ between subsequent layers.

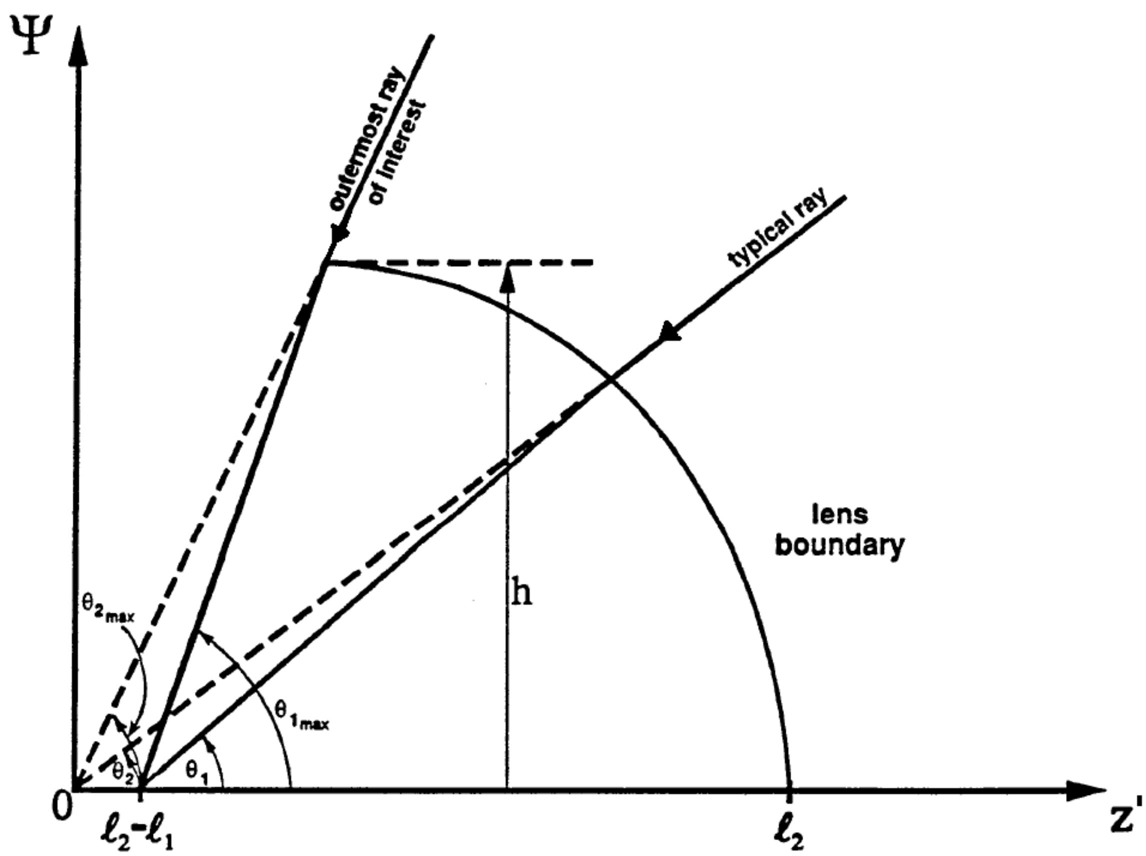

Figure 2.1 Lens for Incoming Spherical Wave [2]

$$\theta_{2\max} = \arctan(b/z_0)\ ,\ 0 \le \theta_2 \le \theta_{2\max} \tag{2.2}$$

This represents the range of interest of angles incoming wave from the prolate-spheroidal IRA which has the dimensions as [3].

$$b = \Psi_0 = .5\,\text{m},\ a = .625\ \text{m}\ ,\ z_0 = .375\,\text{m} \tag{2.3}$$

From (2.2) and (2.3) for the first shell $\theta_{2\max} = 53.13^o$. Inside the lens the rays are changing their directions to the angle of θ_1 with respect to the z'-axis and $\theta_{1\max} \le \pi/2$ for geometrical design purposes. ℓ_1 and ℓ_2 are the distances on the z'-axis, h is the height of the lens. The normalized ℓ_1 and ℓ_2 parameters can be defined from (5.7) in [2] as

$$\frac{\ell_1}{h} = \frac{\sin(\theta_{1\max} - \theta_{2\max}) + \varepsilon_r^{1/2} \sin(\theta_{2\max}) - \sin(\theta_{1\max})}{(\varepsilon_r^{1/2} - 1)\sin(\theta_{1\max})\sin(\theta_{2\max})}$$

$$\frac{\ell_2}{h} = \frac{\varepsilon_r^{1/2}\left[\sin(\theta_{1\max} - \theta_{2\max}) + \sin(\theta_{2\max})\right] - \sin(\theta_{1\max})}{(\varepsilon_r^{1/2} - 1)\sin(\theta_{1\max})\sin(\theta_{2\max})} \tag{2.4}$$

To find θ_2 as a function of θ_1 a quadratic equation in either $\cos(\theta_2)$ or $\sin(\theta_2)$ can be solved from (5.8-5.10) in [2] as

$$\cos(\theta_2) = \frac{AB\sin^2(\theta_1) + \left|B\cos(\theta_1) - A\,\varepsilon_r^{1/2}\right|\sqrt{\left[B^2 - 2AB\varepsilon_r^{1/2}\cos(\theta_1) + A\varepsilon_r\right] - A^2\sin^2(\theta_1)}}{B^2 - 2AB\varepsilon_r^{1/2}\cos(\theta_1) + A\varepsilon_r}$$

$$\sin(\theta_2) = \frac{A(A\,\varepsilon_r^{1/2} - B\cos(\theta_1)) + |B|\sin(\theta_1)\sqrt{\left[B^2 - 2AB\varepsilon_r^{1/2}\cos(\theta_1) + A\varepsilon_r\right] - A^2\sin^2(\theta_1)}}{B^2 - 2AB\varepsilon_r^{1/2}\cos(\theta_1) + A\varepsilon_r} \tag{2.5}$$

$$A = (\ell_2/\ell_1) - 1\ ,\quad B = (\ell_2/\ell_1) - \varepsilon_r^{1/2}$$

A lens boundary curve can be defined by the coordinates of z' and Ψ as a function of θ_1 and θ_2 from (5.11) and (5.12) in [2].

$$\frac{z'}{h} = \frac{(\ell_2 - \ell_1)/h\tan(\theta_1)}{\tan(\theta_1) - \tan(\theta_2)}$$

$$\frac{\Psi}{h} = \frac{z}{h}\tan(\theta_2) = \frac{(\ell_2 - \ell_1)/h\tan(\theta_1)\tan(\theta_2)}{\tan(\theta_1) - \tan(\theta_2)} \tag{2.6}$$

This approach is just for the first shell, but we can expand it to the other shells. $\varepsilon_r = \varepsilon_{ratio} = 1.55$ and we will have different $\ell_1, \ell_2, \theta_{1\max}$ and $\theta_{2\max}$ for each layer.

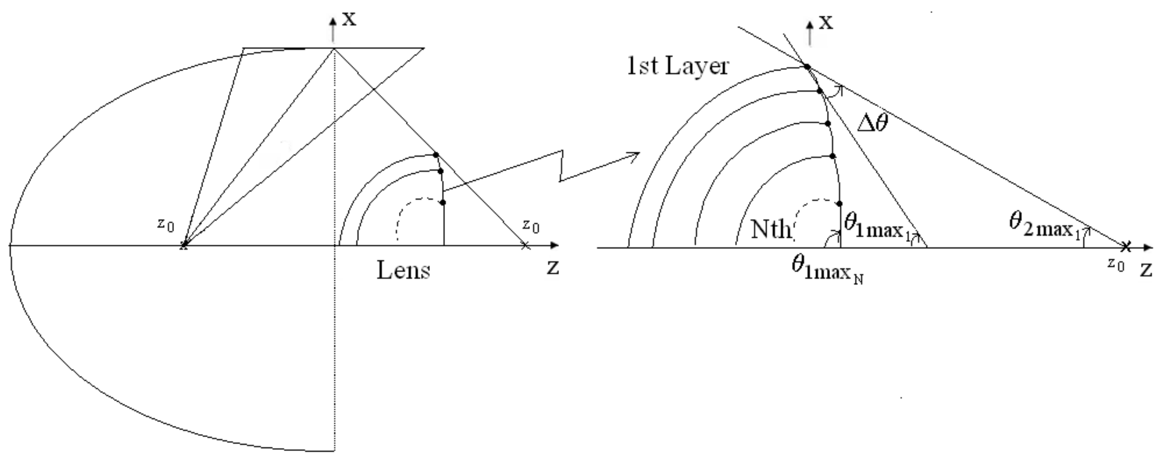

Figure 2.2 IRA and Lens Geometry

We can define a new coordinate system which is centered at $z = z_0$. We will call this system z' and it can be defined as

$$z'/h = -(z - z_0)/h \tag{2.7}$$

The IRA and lens geometry is presented in Fig. 2.2 and the $\theta_{1\max}$ and $\theta_{2\max}$ can be calculated as follows

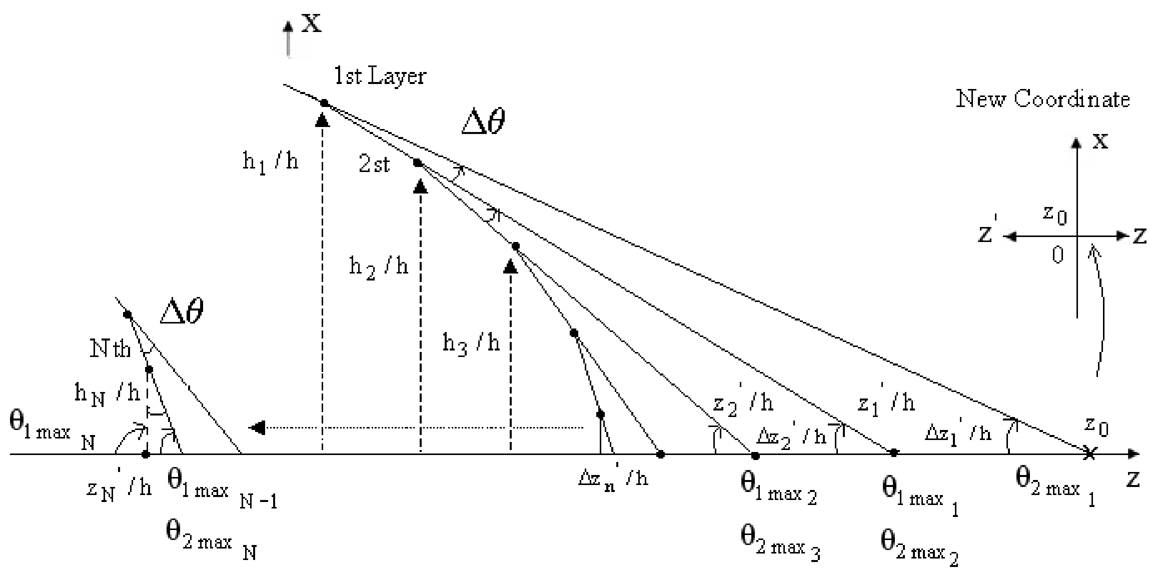

Figure 2.3 $\theta_{1\max}$ and $\theta_{2\max}$ Values

We use N=10 layers and $\Delta\theta$ is the change in the angle as one goes from one to the next. This is constant, and it is

$$\Delta\theta = (\theta_{1\max_N} - \theta_{2\max_1})/N \tag{2.8}$$

We design the lens for two different $\theta_{1\max_{10}}$ angles.

$$\theta_{1\max 10} = \begin{cases} 90^{o}\ (\pi/2) \\ 85^{o} \end{cases} \tag{2.9}$$

For the $\pi/2$ case $\Delta\theta = 3.7^{o}$ and for the 85^{o} case $\Delta\theta = 3.2^{o}$.

$\Delta z_n^{'}/h$ is the normalized distance between each layer-beginning point on the $z^{'}$-axis.

$\Delta z_n^{'}/h$ is the sum of the n distances on the $z^{'}$-axis.

3 Concluding Remarks

We design a lens for incoming spherical waves to obtain better focusing for a prolate-spheroidal IRA. This design is based on the same procedure as in [2]. But in this design just one layer was used. So we extended this design to N=10 layers. In this case we have different ℓ_1/h, ℓ_2/h, $\theta_{1\max}$, $\theta_{2\max}$, h_n/h, $z_n^{'}/h$. So we calculate these values for the first layer. Then we correct the values for the other layers.

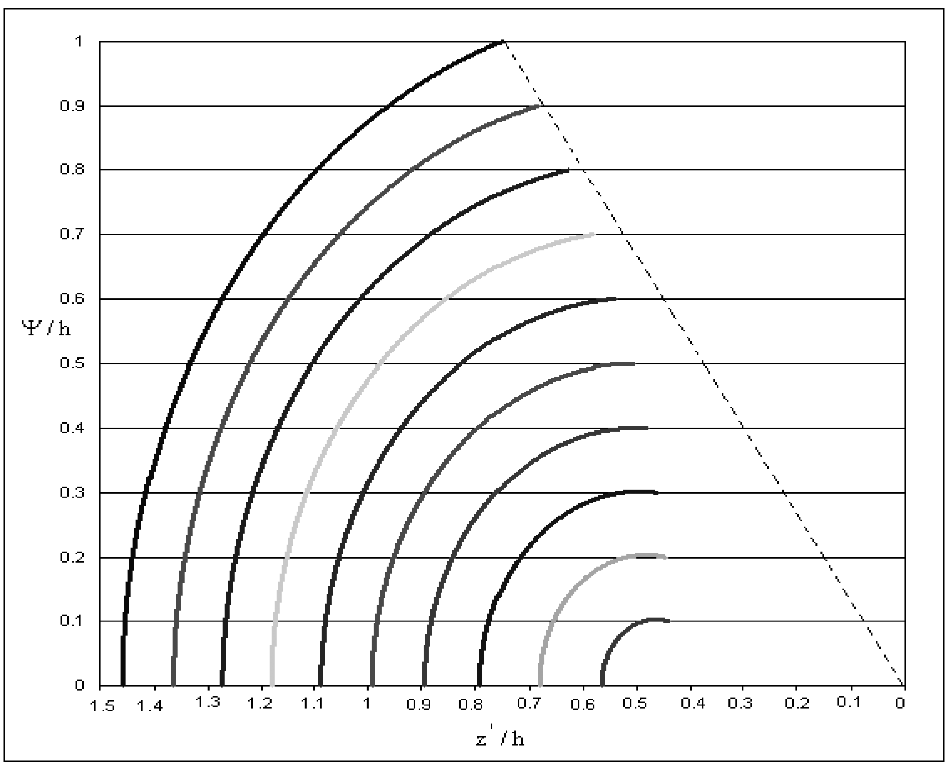

Figure 3.1 Ψ/h vs $z^{'}/h$ for $\theta_{1\max_{10}} = \pi/2$

Layer	h_n / h	$\Delta z_n' / h$	z_n' / h	θ_{1max}	θ_{2max}
1	1.0	0.096	0.000	0.992	0.927
2	0.9	0.079	0.096	1.056	0.992
3	0.8	0.066	0.175	1.120	1.056
4	0.7	0.054	0.241	1.185	1.120
5	0.6	0.044	0.295	1.249	1.185
6	0.5	0.035	0.339	1.313	1.249
7	0.4	0.027	0.374	1.378	1.313
8	0.3	0.020	0.401	1.442	1.378
9	0.2	0.013	0.421	1.506	1.442
10	0.1	0.006	0.434	1.571	1.506

Table 3.1 h_n / h, $\Delta z_n' / h$, z_n' / h , θ_{1max} , θ_{2max} values for $\theta_{1max_{10}} = \pi / 2$

First we calculate the Ψ / h and z' / h values for the first layer then for the second layer we calculate Ψ / h and z' / h we correct them by dividing $h_{corrected}$ value then we add the corrected values z_n' / h value.

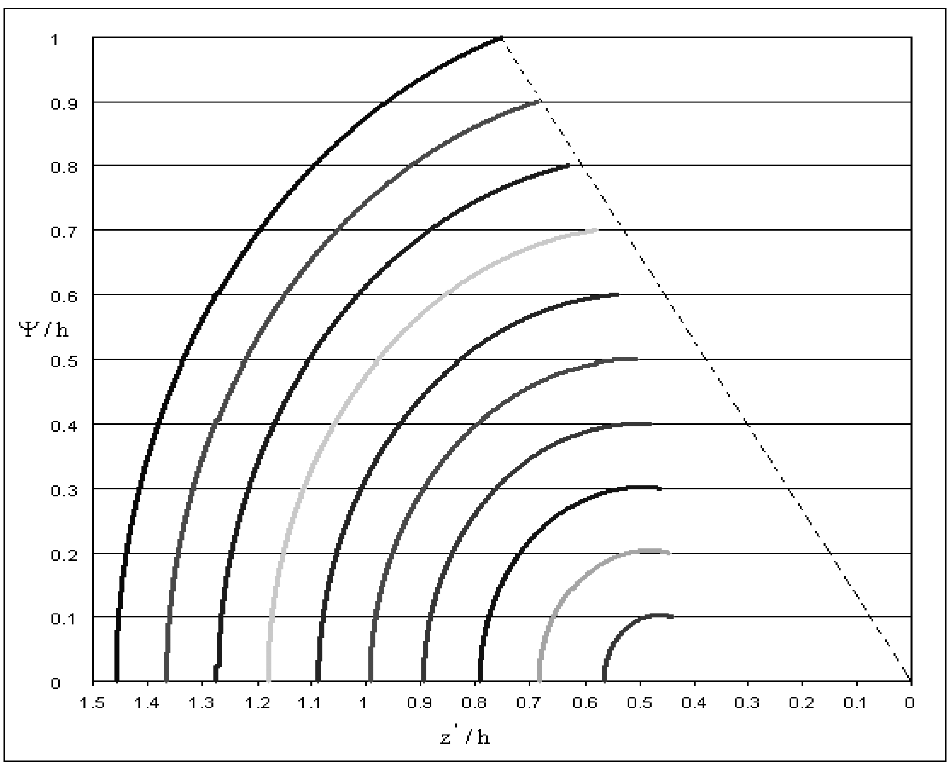

Figure 3.2 Ψ / h and z' / h for $\theta_{1max_{10}} = 85^o$

Layer	h_n/h	$\Delta z_n'/h$	z_n'/h	θ_{1max}	θ_{2max}
1	1.0	0.096	0.000	0.992	0.927
2	0.9	0.079	0.096	1.056	0.992
3	0.8	0.066	0.175	1.120	1.056
4	0.7	0.054	0.241	1.185	1.120
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Table 3.1 h_n/h, $\Delta z_n'/h$, z_n'/h , θ_{1max} , θ_{2max} values for $\theta_{1max_{10}} = 85^o$

As one can see from Fig 3.1 and Fig. 3.2 , for $\theta_{1max_{10}} = \pi/2$ case we obtain better focusing but for $\theta_{1max_{10}} = 85^o$ case we can easily focus to the dielectric target regarding geometry.

We call h the radius of the shell , it is a universal normalization parameter. But this calculation is not determining h, because it is an optical calculation (infinite frequency). To determine how large h should be is a difficult problem. Clearly h must be much larger than the focus pulse width, and the rise-time of the incoming wave, and it should be smaller than the radius of the reflector.

$$ct_\delta = 3\,\text{cm} << h < b = 50 \text{ cm} \qquad (3.1)$$

References

1. S. Altunc and C. E. Baum, “Calculating the Optimum Number of Layers for a Lens”, EM Implosion Memos, Memo 13, Feb 2007.
2. C. E. Baum , J. J. Sadler and A. P. Stone “A Uniform Dilectric Lens for Launching a Spherical Wave into a Paraboidal Reflector”, SSN 360, July 1993.
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.