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# Suggestions to improve the efficacy of the uniform launching lens design

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**Abstract**

Construction of graded dielectric spheres of increasing radius, centered on the switch, are suggested to better match a launched wave into the high dielectric medium of the uniform launching lens. Transmission coefficients are calculated to assess the improvements using this method.

# 1 Introduction

One of the major drawbacks of the uniform launching lens design [1] is matching the launched wave into the high dielectric medium of the lens. The wave is launched from the switch system [2, 3] with $\epsilon_r \approx 4$ into the lens where $\epsilon_r \geq 25$.

The uniform launching lens design is based on the fact that, inside the uniform launching lens, spherical TEM waves are centered at the switch center. Outside the lens, the waves are centered at the first focal point. It is important to note that the lens boundary curve remains unchanged when designed from any spherical wavefront inside the lens, with a virtual focus at the switch center. Using this fact, the notion of surrounding the pressure vessel with a dielectric sphere (as described in [3]) can be extended to better match the launched wave into the uniform lens medium. This can be done using graded dielectric spheres (of increasing radius) centered on the geometric center of the switch. Doing so would reduce reflections and consequently increase the net transmission coefficient of the launched wave.

# 2 Determination of $\epsilon_r$'s and $d$'s for graded dielectric spheres centered at the switch

Figure 2.1 shows the uniform launching lens and graded dielectric spheres of increasing radius centered on the switch system. $d_1, d_2, d_3, ..., d_n$ represent the thicknesses of the various "shells" and $\epsilon_{r_1}, \epsilon_{r_2}, ..., \epsilon_{r_n}$ the corresponding relative dielectric constants. This design should result in an increase in the net transmission coefficient of a wave launched from the switch as the wave is now better matched to the lens medium.

The concepts for a spherical graded lens design developed for the focusing lens [4] can be applied to the current case with the modification that the parameter $\nu$ (which represents the number of spatial pulse widths in a layer) is no longer relevant here as the waves launched from the switch are guided by the feed arms (Fig. 2.1). Note also, that the design of the focusing lens is log-periodic, i.e., $d_n\sqrt{\epsilon_{r_n}}$ = constant without any constraint on the geometry/shape of the lens. Therefore, for the current case in Fig. 2.1 one may as well consider a planar geometry to determine the various $d$'s and $\epsilon_r$'s.

Let $N$ be the number of layers around the switch. In Fig. 2.1 the following conditions are imposed :

1. $d_1 = r_{pv}$ = radius of pressure vessel,
2. $\epsilon_{r_1} = \epsilon_{r_{pv}}$ = dielectric constant of pressure vessel,
3. $\sum_{n=1}^{N} d_n < d_l$ = dimension of uniform launching lens in $z$ direction.

The first two conditions fix the electrical distance, $d_1\sqrt{\epsilon_{r_1}} = r_{pv}\sqrt{\epsilon_{r_{pv}}}$ = constant. The third condition limits the maximum number of layers.

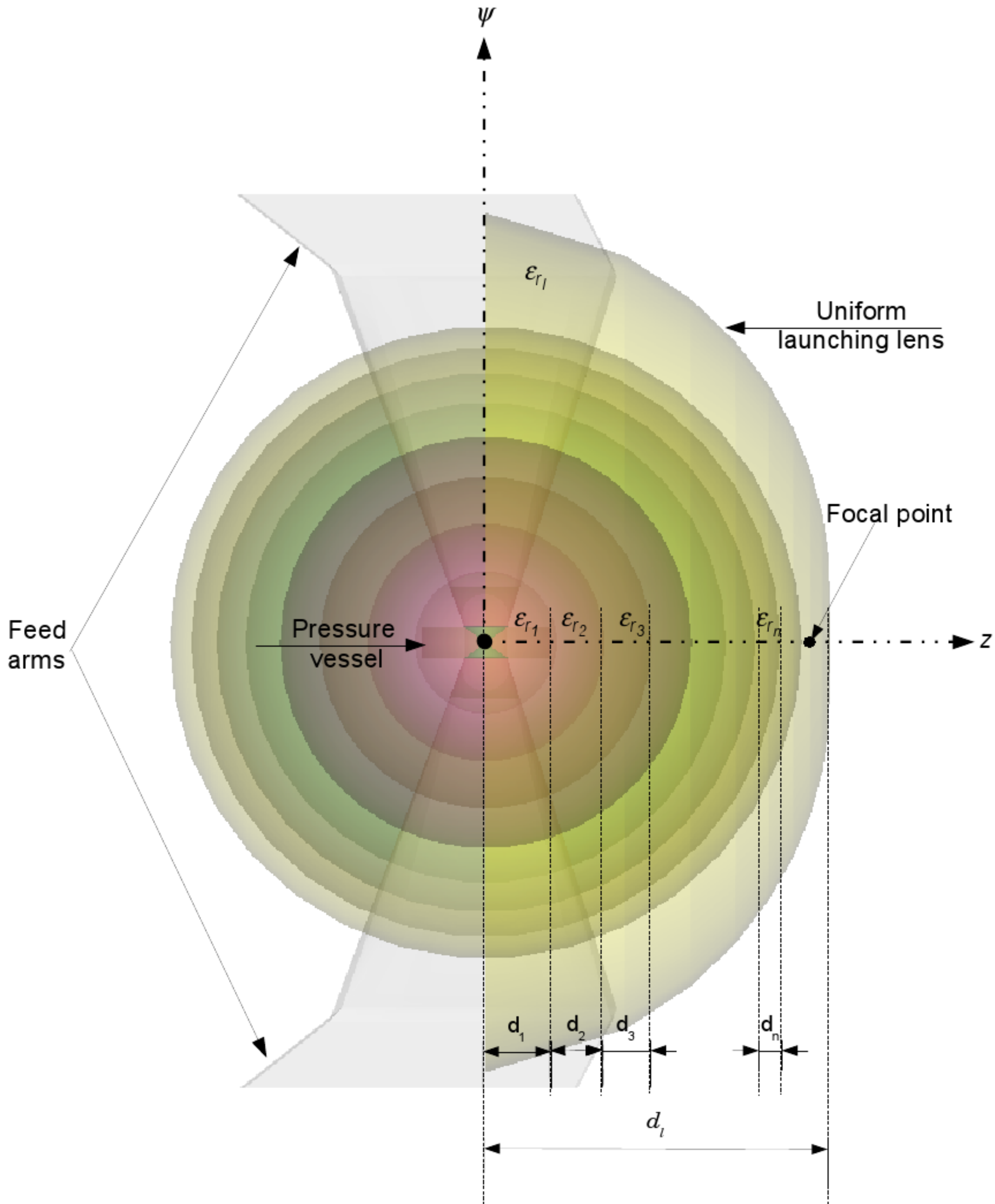


Figure 2.1: Graded dielectric spheres placed around switch system to better match a launched wave into the high dielectric of the uniform launching lens. Note that $d_{n+1}\sqrt{\epsilon_{r_{n+1}}} = d_n\sqrt{\epsilon_{r_n}}$ and $\epsilon_{r_n} < \epsilon_{r_{n+1}} \leq \epsilon_{r_l}$, where $\epsilon_{r_l}$ = dielectric medium of uniform launching lens.

For the electrical distances to be the same

$$d_1\sqrt{\epsilon_{r_1}} = d_2\sqrt{\epsilon_{r_2}} = ... = d_n\sqrt{\epsilon_{r_n}}. \tag{2.1}$$

For a log-periodic lens design we have the important condition

$$\frac{\epsilon_{r_{n+1}}}{\epsilon_{r_n}} = \text{constant} = \xi(\text{say}) = \left(\frac{\epsilon_{r_{\max}}}{\epsilon_{r_{\min}}}\right)^{1/N}. \tag{2.2}$$

In our case, we have $\epsilon_{r_{\min}} = \epsilon_{r_1} = \epsilon_{r_{pv}}$ and $\epsilon_{r_{\max}} = \epsilon_{r_N} = \epsilon_{r_l}$, hence

$$\xi = \left(\frac{\epsilon_{r_l}}{\epsilon_{r_{pv}}}\right)^{1/N}. \tag{2.3}$$

Using the above identities, equation (2.1) can be simplified as

$$\begin{aligned}
d_1\sqrt{\epsilon_{r_1}} = d_2\sqrt{\epsilon_{r_2}} \quad &\Rightarrow \quad d_2 = d_1\sqrt{\frac{\epsilon_{r_1}}{\epsilon_{r_2}}} = \frac{d_1}{\sqrt{\xi}} \\
d_2\sqrt{\epsilon_{r_2}} = d_3\sqrt{\epsilon_{r_3}} \quad &\Rightarrow \quad d_3 = d_2\sqrt{\frac{\epsilon_{r_2}}{\epsilon_{r_3}}} = \frac{d_1}{(\sqrt{\xi})^2} \\
&\vdots \\
d_n \quad &= \quad \frac{d_1}{(\sqrt{\xi})^{n-1}} = d_1\xi^{(1-n)/2}, \quad n \geq 2.
\end{aligned} \tag{2.4}$$

The corresponding dielectric constant for the $n^{\text{th}}$ layer is $\epsilon_{r_n} = \epsilon_{r_{\min}}\,\xi^n$.

As an example, consider the case where $\epsilon_r = 36$ and $h = 10$ cm for the uniform launching lens [1]. For these values, $d_l = 8.0$ cm. Further, let $r_{pv} = 1.5$ cm and $\epsilon_{r_{pv}} \approx 4$ as in [3]. Table 1 summarizes the $d$'s and $\epsilon_r$'s for these parameters. The $\sum d_n$ column is the distance of the $n^{\text{th}}$ layer from the switch center. Note that for these parameters the maximum number of layers is 8.

Table 1: $d$'s (in cm) and $\epsilon_r$'s for various layers for uniform launching lens with $\epsilon_{r_l} = 36$

| $n$ | $d_n$ (cm) | $\sum d_n$ (cm) | $\epsilon_{r_n}$ | $d_n\sqrt{\epsilon_{r_n}}$ (cm) |
|---|---|---|---|---|
| 1 | 1.5 | 1.5 | 4. | 3. |
| 2 | 1.28213 | 2.78213 | 5.47495 | 3. |
| 3 | 1.0959 | 3.87803 | 7.49378 | 3. |
| 4 | 0.936722 | 4.81475 | 10.257 | 3. |
| 5 | 0.800664 | 5.61541 | 14.0392 | 3. |
| 6 | 0.684369 | 6.29978 | 19.2159 | 3. |
| 7 | 0.584965 | 6.88475 | 26.3016 | 3. |
| 8 | 0.5 | 7.38475 | 36. | 3. |

## 3 Calculation of transmission coefficents

The effectiveness of the graded spheres in the above design can by determined by comparing the percentage gain in the transmission coefficients with and without the graded spheres.

### 3.1 Transmission coefficients without graded spheres around switch center

Consider the original switch system design with only the uniform launching lens (without the graded spheres), i.e., the wave is launched from the switch center into the pressure vessel, $\epsilon_{r_{pv}}$, travels through the lens, $\epsilon_{r_l}$, into air, $\epsilon_{r_0}$. The transmission coefficient for a wave travelling from the pressure vessel into the lens is

$$T_{\text{pv-lens}} = \frac{2\epsilon_{r_l}^{-1/2}}{\epsilon_{r_{pv}}^{-1/2} + \epsilon_{r_l}^{-1/2}} = \frac{2(1/6)}{1/6 + 1/2} = 0.5. \tag{3.1}$$

The transmission coefficient for a wave travelling from the pressure vessel (through the lens) to air is

$$T_{\text{pv-lens-air}} = \left( \frac{2\epsilon_{r_l}^{-1/2}}{\epsilon_{r_{pv}}^{-1/2} + \epsilon_{r_l}^{-1/2}} \right) \left( \frac{2\epsilon_{r_0}^{-1/2}}{\epsilon_{r_l}^{-1/2} + \epsilon_{r_0}^{-1/2}} \right) = (1/2)(12/7) = 0.857. \tag{3.2}$$

### 3.2 Transmission coefficients with graded spheres around switch center

Now consider graded dielectric spheres placed around the switch center as shown in Fig. 2.1. The transmission coefficient between the $n^{\text{th}}$ and $n+1^{\text{th}}$ layer is

$$T_{\text{n,n+1}} = \frac{2\epsilon_{r_{n+1}}^{-1/2}}{\epsilon_{r_{n+1}}^{-1/2} + \epsilon_{r_n}^{-1/2}} = \frac{2}{1+\sqrt{\xi}}. \tag{3.3}$$

For $N$ layers ($N = 8$ in our example) the transmission coefficient for a wave travelling from the switch center into the uniform launching lens medium is

$$T_{\text{pv-gs-lens}} = \left( \frac{2}{1+\sqrt{\xi}} \right)^N = 0.567 \quad (\text{for N} = 8). \tag{3.4}$$

The transmission coefficient for a wave travelling from the pressure vessel (through the graded dielectric spheres) to air is

$$T_{\text{pv-gs-lens-air}} = \left( \frac{2}{1+\sqrt{\xi}} \right)^N \left( \frac{2\epsilon_{r_0}^{-1/2}}{\epsilon_{r_l}^{-1/2} + \epsilon_{r_0}^{-1/2}} \right) = 0.567(12/7) = 0.972. \tag{3.5}$$

The percentage increase between $T_{\text{pv-lens}}$ and $T_{\text{pv-gs-lens}}$ is $(T_{\text{pv-gs-lens}} - T_{\text{pv-lens}})100 = 6.657\%$. Similarly, the percentage increase between $T_{\text{pv-lens-air}}$ and $T_{\text{pv-gs-lens-air}}$ is $(T_{\text{pv-gs-lens-air}} - T_{\text{pv-lens-air}})100 = 11.413\%$. Therefore, a mere 10 % increase is obtained with the graded spheres around the switch. A lot of work for such a small increase!

# 4 Discussion

As in Fig. 4.1 one may be tempted to further increase the transmission coefficient by placing dielectric spheres (of increasing radius) *outside* the launching lens centered at the focal point. Exactly the same calculations for determining the $d$'s and $\epsilon_r$'s used in the previous sections can be applied. However, as shown in Fig. 4.1, this would result in concentric spheres of varying dielectric interesecting the uniform launching lens boundary. The launching lens boundary will therefore no longer be surrounded by a uniform medium, but would rather be surrounded by different dielectric constants corresponding to those of the concentric spheres of increasing radius centered at the first focal point. The major drawback of this argument is that the launching lens is designed for a wave propagating into air and not the kind of medium (with multiple $\epsilon_r$s) as described above. One possible way around this is to start placing the concentric spheres at a radius $> h$. But this would further complicate the design.

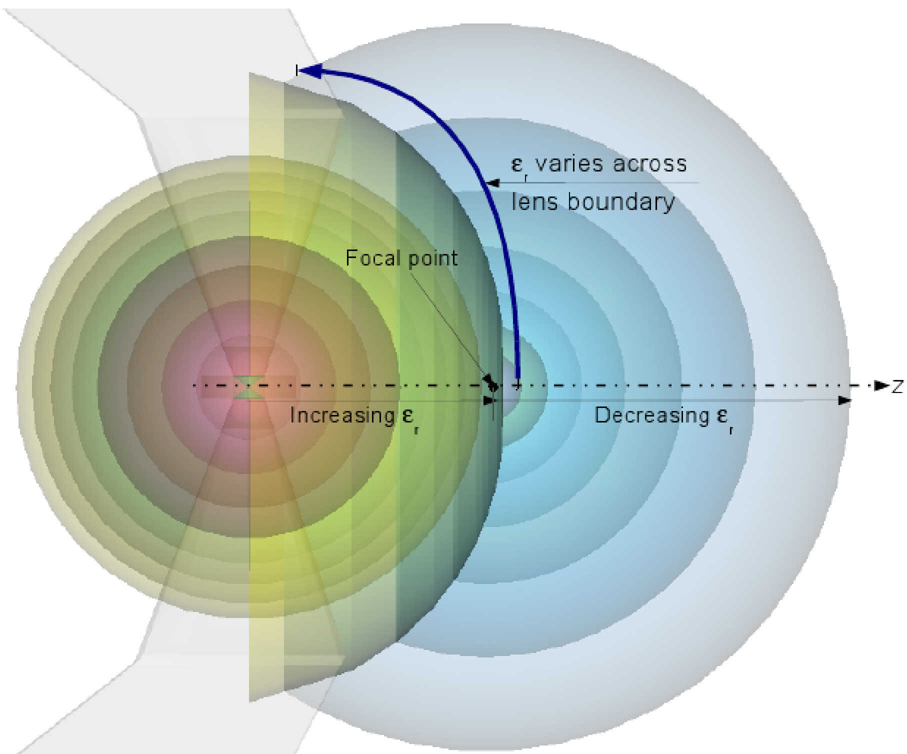


Figure 4.1: Additional graded dielectric spheres placed around the first focal point in an attempt to further increase the net transmission coefficient to air.

# 5 Conclusion

A method to increase the efficacy of the uniform launching lens has been suggested. This method involves the construction of log-periodic ($d\sqrt{\epsilon_r}$ = constant), graded dielectric spheres of increasing radius, centered at the switch system. This suggestion comes from the need to better match a launched wave into the high dielectric of the uniform launching lens. Transmission coefficient calculations, however, tend to indicate that the suggested method results in a mere 10% increase in the net transmission coefficient of a wave travelling from the switch (through the lens) into air. This technique is therefore not very efficient and too cumbersome to be practically viable.

## References


[1] Serhat Altunc, Carl E. Baum, Christos G. Christodoulou and Edl Schamiloglu, "Analytical Calculations of a Lens for Launching a Spherical TEM Wave." Sensor and Simulation Note 534, Oct. 2008.

[2] Prashanth Kumar, Carl E. Baum, Serhat Altunc, Christos G. Christodoulou and Edl Schamiloglu , "Design and numerical simulation of switch and pressure vessel setup - part I." EM Implosion Memo 31, Aug. 2009.

[3] Prashanth Kumar, Carl E. Baum, Serhat Altunc, Christos G. Christodoulou and Edl Schamiloglu , "Design and numerical simulation of switch and pressure vessel setup - part II." EM Implosion Memo 31, Aug. 2009.

[4] Serhat Altunc, Carl E. Baum, C. Jerald Buchenauer, Christos G. Christodoulou and Edl Schamiloglu, "Design of a Special Dielectric Lens for Concentrating a Subnanosecond Electromagnetic Pulse on a Biological Target." Accepted in IEEE Transactions on Dielectrics and Electrical Insulation.