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Switch Design for Launching a Spherical TEM Wave

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Abstract

This paper discusses different switch design procedures to obtain spherical launching waves for a prolate-spheroidal impulse radiating antenna (PSIRA or ΨRA). This switch will be located at the first focal point of the ΨRA.

1. Introduction

A uniform dielectric lens used to ensure the launching of an approximate spherical TEM wave onto the TEM feed arms of our prolate-spheroidal IRA is discussed in [1-4]. In this lens we have a spherical TEM wave centered on the switch center. However, outside the lens we have an approximate spherical TEM wave which is centered at the first focal point of the ΨRA.

This represents the range of interest of incoming-wave angles from the prolate-spheroidal IRA which has the dimensions as [5]

$$b = \Psi_0 = .5\,\text{m},\ a = .625\ \text{m}\ ,\ z_0 = .375\text{m}\ . \tag{1}$$

Where *a* and *b* are the radii and z_0 is the focal distance of the ΨRA.

The equal-time condition for a diverging spherical wave in a medium with permittivity $\varepsilon_r\varepsilon_0$ going into another diverging spherical wave in a second medium with ε_0 can be written as

$$\sqrt{\varepsilon_r}\,r_{1b} + r_2 - r_{2b} = \sqrt{\varepsilon_r}\,\ell_1 + r_2 - \ell_2 \tag{2}$$

r_2 is the radius of the spherical TEM wave centered at the focal point, r_{1b}, r_{2b} are the distances from launch and focal point to the lens boundary, respectively. z_b and Ψ_b are the z and Ψ values that correspond to this boundary point.

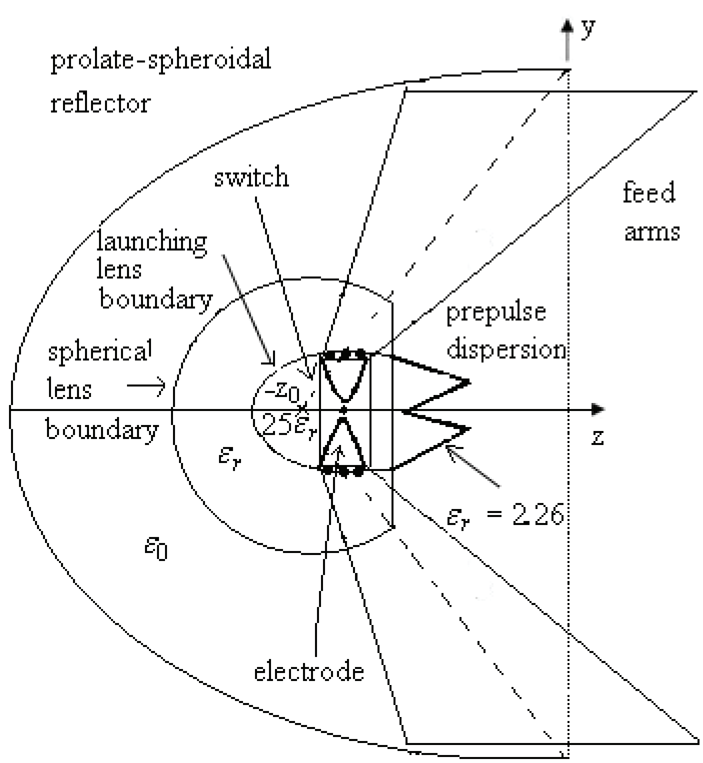

Figure 1. 60° Four-Arm ΨRA and launching lens geometry.

2. Switch Design

One can design the high-pressure vessel of the switch considering Brewster angle as in figure 2.

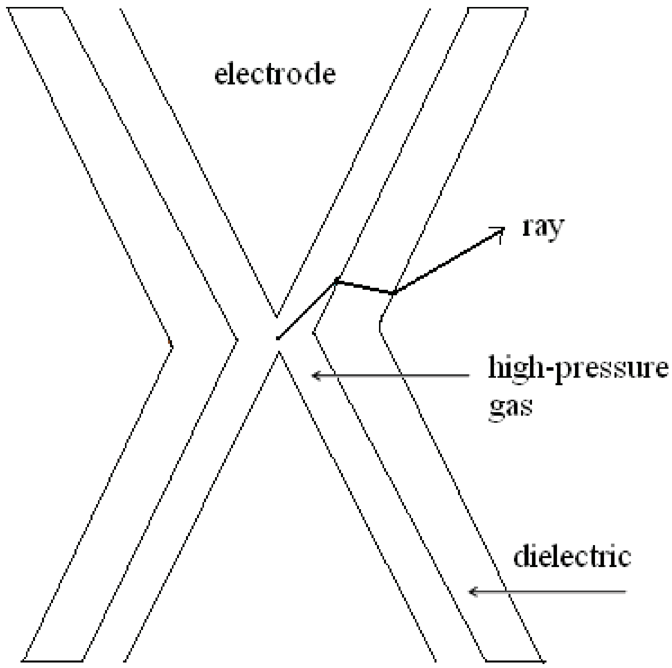

Figure 2. High-pressure gas switch with Brewster angle pressure vessel

Figure 3 presents the body-of-revolution switch into monocone(circular) geometry when we have a ground plane. The detailed calculations are presented in [6].

One can write the transit–time equalization condition for the outer two rays as follows

$$\ell_1\sqrt{\varepsilon_r} + r_1 - r_2 = \ell_2\sqrt{\varepsilon_r} \tag{3}$$

The impedance Z_c of the conical line is given by [6]

$$Z_c = \frac{1}{\sqrt{\varepsilon_r}}\frac{Z_0}{2\pi}\ln\left[\frac{\cot\left(\theta_0^{'}/2\right)}{\cot\left(\theta_1^{'}/2\right)}\right], \tag{4}$$

where $Z_0 \cong 377\,\Omega$ is the characteristic impedance of the free space. $\theta_0^{'}$ and $\theta_1^{'}$ are the angles shown in figure 3.

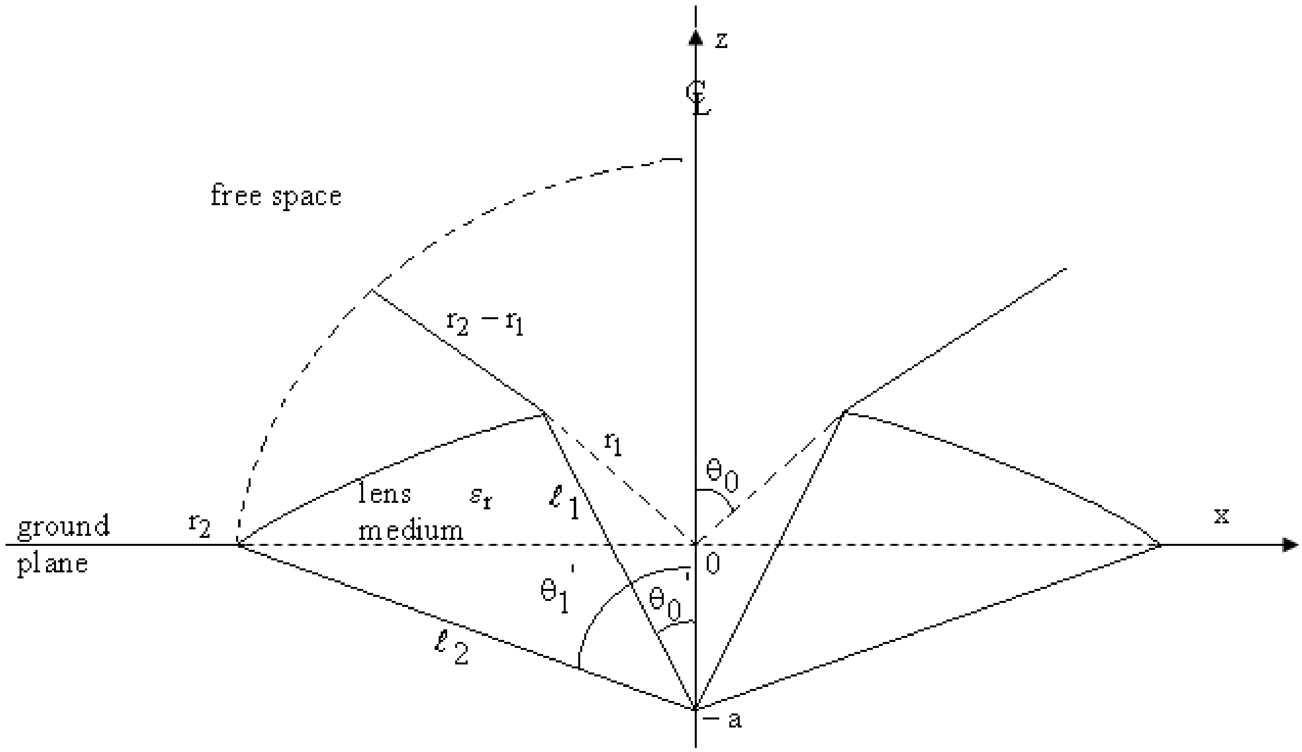

Figure 3. Body-of-revolution switch into monocone(circular) geometry

Figure 4 is devoted to the body-of-revolution switch and lens geometry. The impedance Z_{ca} of the cone in the free space for 60^o Four-Arm ΨRA is $Z_{ca} = 200\,\Omega$ [5]. We are narrowing the cone at the switch point to increase the cone impedance such a way that it will compensate the decrease in the Z_c due to the relative dielectric constant $\varepsilon_{r\,ll}$ of the launching lens. Boundary shapes should be calculated to equalize the transit times. The relative dielectric constant $\varepsilon_{r\,\ell\ell}$ of the spherical lens is $\varepsilon_{r\,\ell\ell} = 1$. We will be using SF_6 for spherical lens as discussed in [1].

The relative dielectric constant $\varepsilon_{r\,sw}$ of the switch can be

$$\begin{aligned} &1.\ \text{gas } \varepsilon_{r\,sw} = 1, \quad Z_{sw} = Z_{ca}, \\ &2.\ \text{plastic } \varepsilon_{r\,sw} > 1. \end{aligned} \tag{5}$$

Figure 5 shows the switch and launching lens geometry. We are trying to match the switch characteristic impedance Z_{csw} of the cone in the switch to the characteristic impedance $Z_{c\ell}$ of the cone in the lens. We should also investigate, if we can make $\varepsilon_{r\,p} = \varepsilon_{r\,\ell\ell}$.

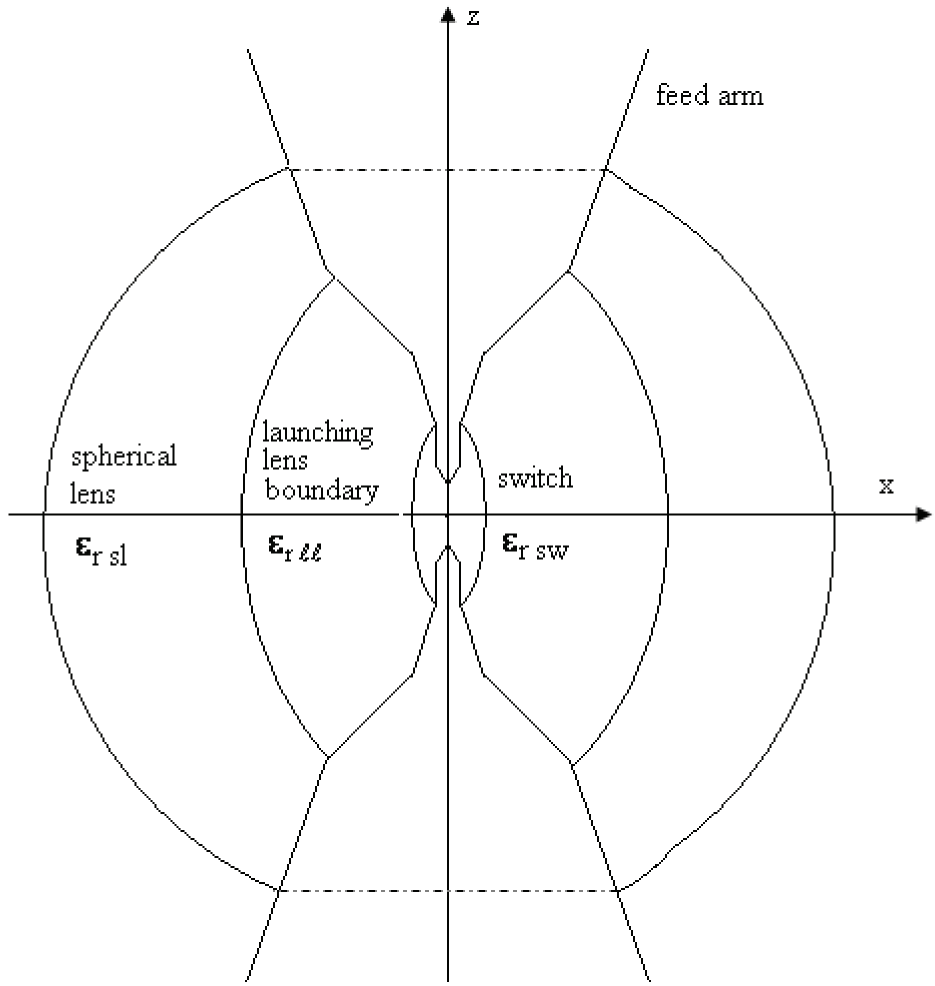

Figure 4. Body-of-revolution switch and lens geometry

By assuming low $Z_{c\ell}$ on the reflector side vs. higher $Z_{c\ell}$ on the other side, we can calculate the Z_{csw} or Y_{csw} (admittance) as shown in figure 6.

$$Y_{csw} = Y_{eff} = \frac{1}{2}\left[Y_{c\,back} + Y_{c\,front}\right] \tag{6}$$

We may use the relative dielectric constants of $\varepsilon_{r\,front} = 25$ and $\varepsilon_{r\,back} = 2.25\,(\text{oil})$ for the launching lens. Therefore, we can calculate the admittance Y_{csw} of the cone in the switch by substituting the relative dielectric constant values in (6)

$$Y_{csw} = \frac{1}{2}\left[0.3Y_{c\,front} + Y_{c\,front}\right] = .65Y_{c\,front} \tag{7}$$

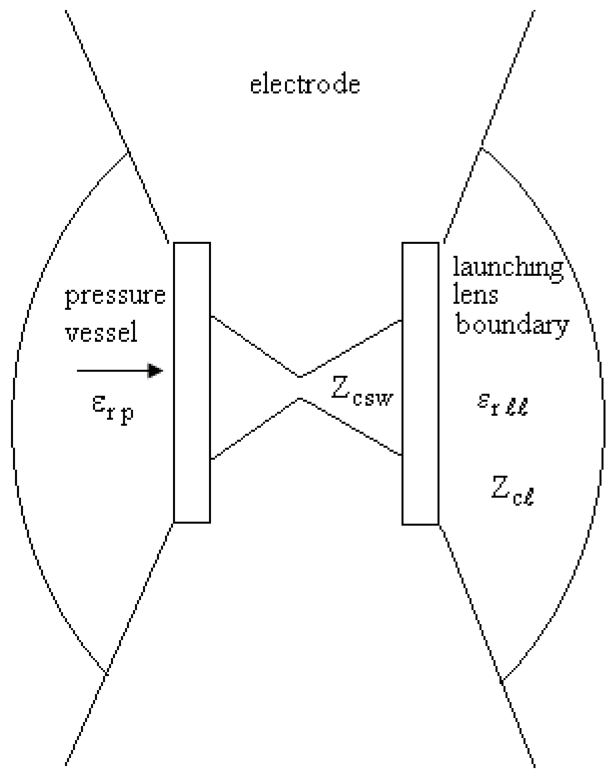

Figure 5. Switch and launching lens geometry

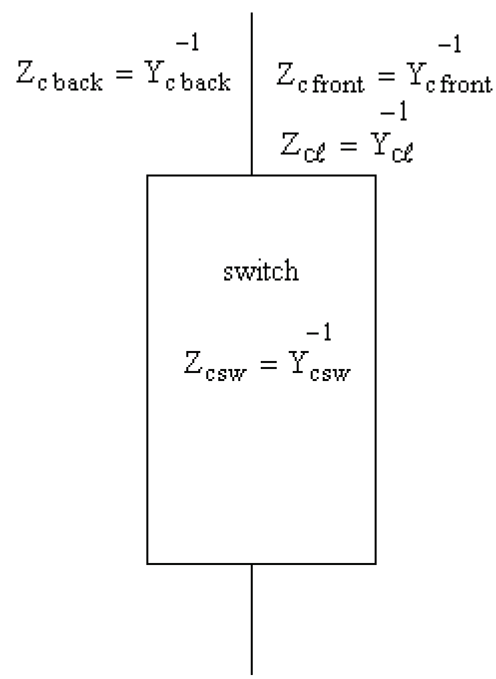

Figure 6. Switch admittances

One can write the admittances proportional to the ε_r values

$$Y_{cf} \propto \sqrt{\varepsilon_{r\ell}} = 5,\ Y_{csw} \propto 0.65 Y_{cf} = 3.25 \tag{8}$$

Hence, we need $Y_{csw} \cong Y_{c\ell}$ so the angle at the switch needs to be made small to match the impedances and remove the inductance of the volume around the switch. Note that the wave is being launched into a region with boundaries approximately characterized as shown in figure 7.

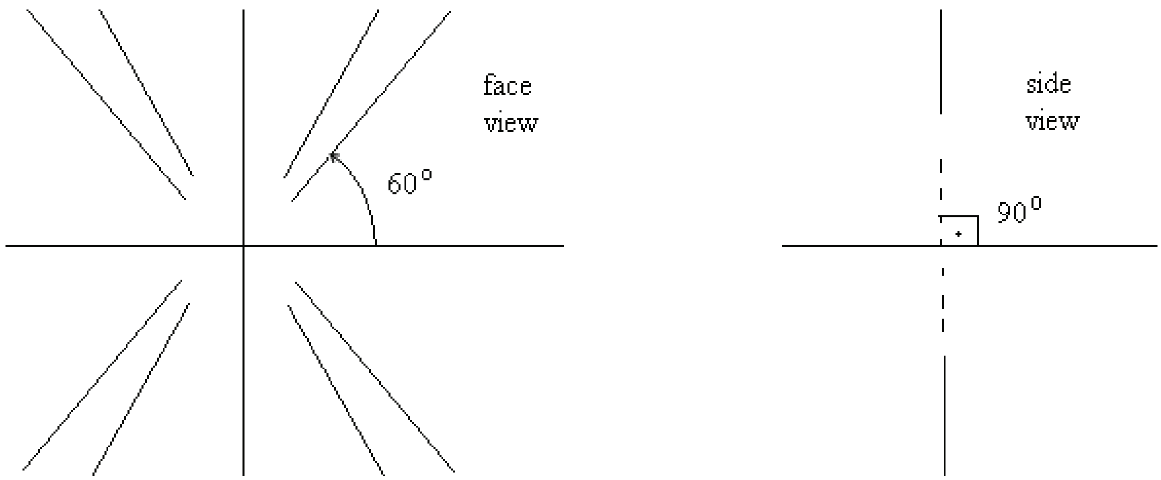

Figure 7. Face and side view of the feed arms

One can write the switch volume inductance as

$$L = t_r Z_c . \tag{9}$$

If we have a 1 cm gap between electrodes, the rise time is $t_r = 33\,\text{ps}$ and $Z_c = 200\,\Omega$ is the cone impedance in the free space. We would like to remove this inductance. In our case we will be using the maximum rise of time $t_{mr} = 30\,\text{ps}$ as discussed in [5]. Assuming we are driving $Z_c = 200\,\Omega$ antenna and $\varepsilon_{r\ell} = 25$, one can find the impedance of the switch from (7)

$$Z_{csw} = \frac{200\,\Omega}{\sqrt{\varepsilon_{r\ell}} * .65} = 67\,\Omega . \tag{10}$$

We can calculate the cone angle θ_c as seen from figure 8 by using (10) [7]

$$Z_{csw} = Z_0 \frac{1}{2\pi} \ln\left(\cot\left(\frac{\theta_c}{2} \right) \right) \tag{11}$$

However, in our case we have two cones in series. Hence, the characteristic impedance is

$$Z_{csw} = 2 * Z_0 \frac{1}{2\pi} \ln\left(\cot\left(\frac{\theta_c}{2}\right)\right) = Z_0 \frac{1}{\pi} \ln\left(\cot\left(\frac{\theta_c}{2}\right)\right) \tag{11}$$

From (11) cone angle is $\theta_c = 60^o$.

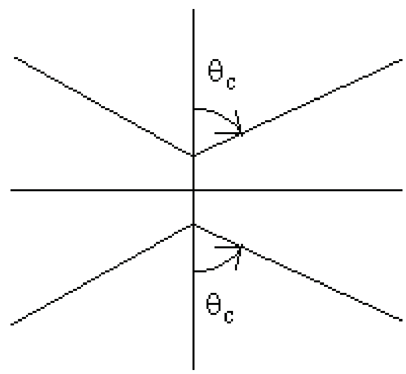

Figure 8. Cone angle θ_c

We can also make the switch asymmetric to deliver the field in the front or reflector direction. Figure 9 shows this asymmetric switch geometry.

ε_{rp} is the relative dielectric constant of the pressure vessel and it is

$$2.25(\text{oil}) \le \varepsilon_{rp} \le 5 \tag{12}$$

The dielectric constant of the lens and the cone impedance in the launching lens are

$\varepsilon_{r\ell} = 25,$

$Z_{c\ell} = 2Z_c / \sqrt{\varepsilon_{r\ell}} = 80\,\Omega.$

We may use oil which has a dielectric constant of $\varepsilon_{rback} = 2.25$ for the back side. Therefore, the dielectric constant of the back side and the cone impedance in the back are

$$\begin{aligned} &\varepsilon_{rb} = 2.25, \\ &Z_{cb} = 2Z_c / \sqrt{\varepsilon_{rb}} = 266\Omega. \end{aligned} \tag{13}$$

One can find the cone impedance in the switch by using two parallel impedances

$$Z_{csw} = \frac{1}{1/Z_{cb} + 1/Z_{c\ell}} \cong 62\,\Omega \tag{14}$$

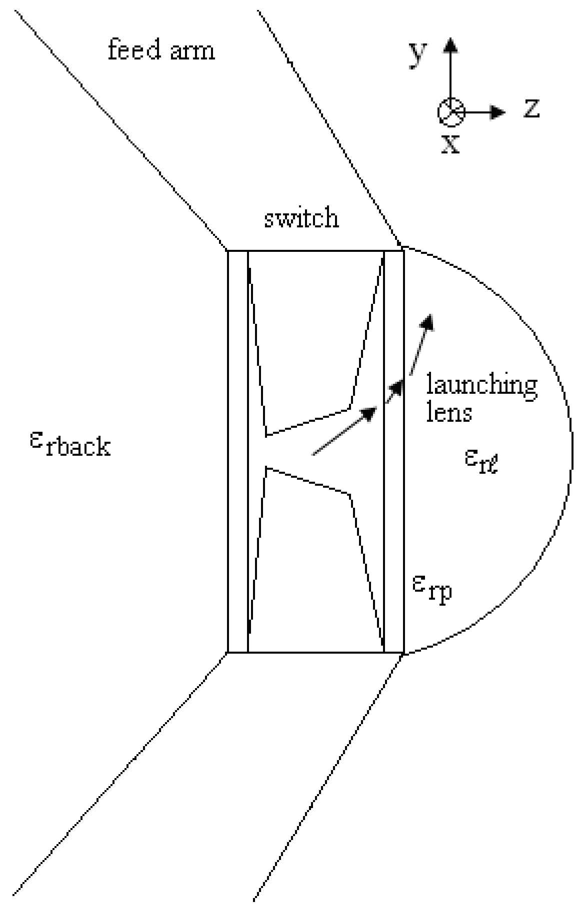

Figure 9. Asymmetric switch geometry.

Figure 10 presents symmetric vs. asymmetric switch design for $\varepsilon_{r\ell} = 25$ which should be investigated numerically.

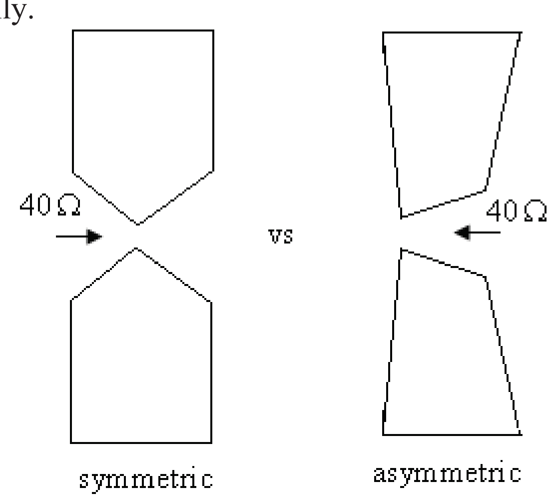

Figure 10. Symmetric vs. asymmetric switch design for $\varepsilon_{r\ell} = 25$

3. Conclusion and Future Work

We have presented different switch design procedures to obtain spherical launching waves for a ΨRA which will be located at the first focal point of the ΨRA. This lens will be used to ensure the launching of an approximate spherical TEM centered at the first focal point of the ΨRA. However, more detailed numerical simulations should be done to obtain a more sophisticated lens for better launching.

As discussed in [1-5], we have designed an isotropic launching lens. However, this results $\varepsilon_{r\ell} = 25$ which has some disadvantages because of the high dielectric constant values. We may design a nonuniform launching lens to lower the $\varepsilon_{r\ell}$ value. Figure 11 and 12 present two different types of nonuniform lens.

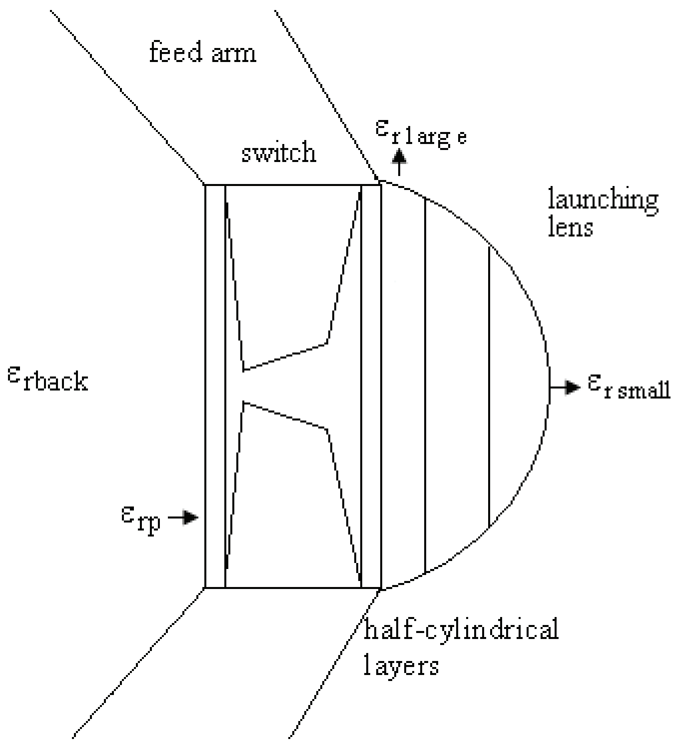

Figure 11. Nonuniform launching lens with increasing ε_r subsequent half-cylindrical layers.

With these two nonuniform designs we may lower the ε_r values as

$$\varepsilon_r = \frac{\varepsilon_{r\,large}}{\varepsilon_{r\,small}} \leq 10 \tag{15}$$

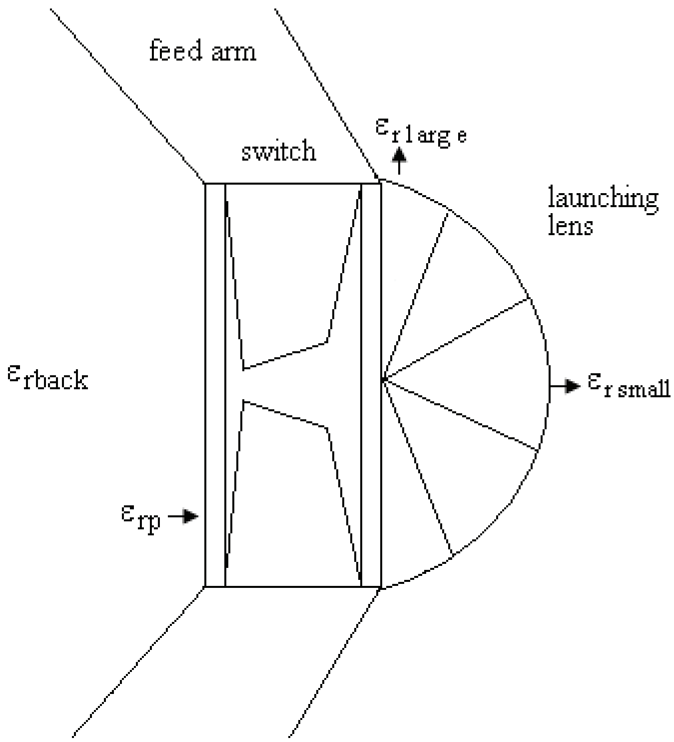

Figure 12. Nonuniform launching lens with increasing ε_r values as a function of θ.

These designs may help us to reduce the dielectric constant $\varepsilon_{r\ell}$ of the lens. Numerical simulations will provide more detailed information about these designs.

References

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