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# Design and numerical simulation of switch and pressure vessel - part II

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**Abstract**

Simulation results for the pressure vessel surrounded by a dielectric sphere are presented. It is observed that the time spread is reduced. Rough calculations for predicting the effect of variation of the pressure vessel height and pressure vessel dielectric on the time of arrival of waves are also presented.

# 1 Introduction

As suggested in [1], a dielectric sphere is constructed which surrounds the pressure vessel (and switch). This is done to reduce the time spread observed in simulation results from the previous setup in [1]. Approximate analytical results are presented for predicting the effect of variation of $h_{pv}$ and $\epsilon_{r_{pv}}$ on the time spread.

# 2 Simulation

## 2.1 Setup

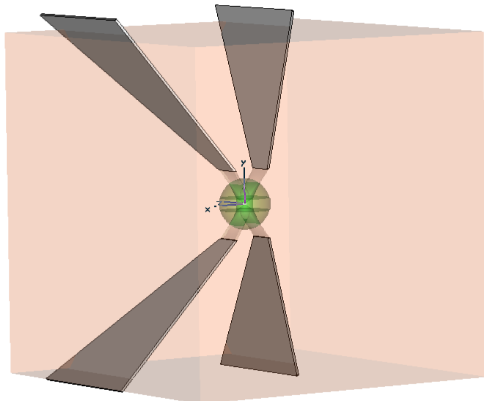
The simulation setup with a dielectric sphere surrounding the pressure vessel is shown in Fig. 2.1. The sphere is centered at the geometric center of the switch. Its radius ($r_s$) and dielectric constant ($\epsilon_{r_s}$) are the same as that of the pressure vessel i.e. $r_s = r_{pv}$ and $\epsilon_{r_{pv}}$. As in [1], the entire system is immersed in a dielectric which is the same as the last layer of the (conical) launching lens. Switch dimensions, probe orientations and other parameters are the identical to the simulation setup in [1] unless mentioned otherwise.

## 2.2 Results

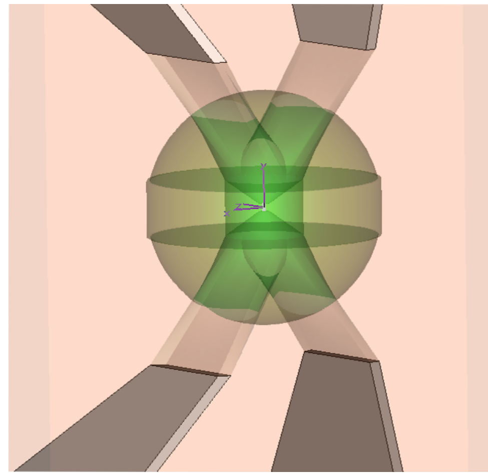
Simulation results for the setup in Fig. 2.1 are shown in Fig. 2.2. Each wave in Fig. 2.2(a) is normalized with respect to its minimum and plotted in Fig. 2.2(b). Figure 2.2(c) shows Fig. 2.2(b) in the timescale of interest. As can be observed from the normalized results in Fig. 2(c), the time spread has decreased from 20 ps for the setup in [1] to approximately 12 ps. Overall, the responses in Fig. 2(c) seem to be bunched much closer in the 0 ns−0.4 ns range compared to similar results in [1]. This is indeed a great improvement and perhaps practically acceptable. The dielectric sphere surrounding the pressure vessel certainly seems to have aided in reducing the time spread as predicted in the rough analytical approximations in [1].

## 2.3 Discussion

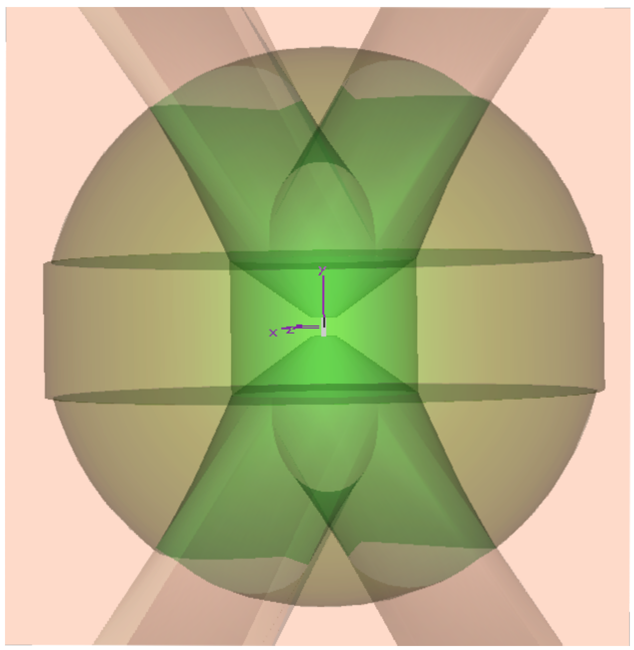
Results obtained from the dielectric sphere around the pressure vessel seem to narrow the time spread to values that may be practically tolerable. However, the most important point of concern is that the tolerance ($t_\delta \approx 10$ ps) placed on the switch system may have to be much stricter than that applied to the launching lens (see for e.g. [2] and [3]). This is because the tolerances of the switch (say, $t_{\delta_s}$) and launching lens (say, $t_{\delta_l}$) may be cumulative. If this is the case, then this may result in a total time spread much greater than the tolerance (i.e. $t_{\delta_s} + t_{\delta_l} > t_\delta \approx 10$ ps) outside the launching lens. Simulations with the entire launching lens and switch system are required to validate these speculations and if necessary impose much stricter tolerances on the switch system to obtain an overall time spread less than 10 ps outside the launching lens. It is also likely that the numerical problem of low resolution observed in the launching lens simulations is manifesting itself here (although probably not to such a large degree because of the smaller simulation space). Therefore, in the current simulations of the switch system, higher resolutions may result in an even smaller time spread.



(a) Simulation setup with switch and feed arms immersed in lens dielectric



(b) Zoomed in view of switch and feed arm system



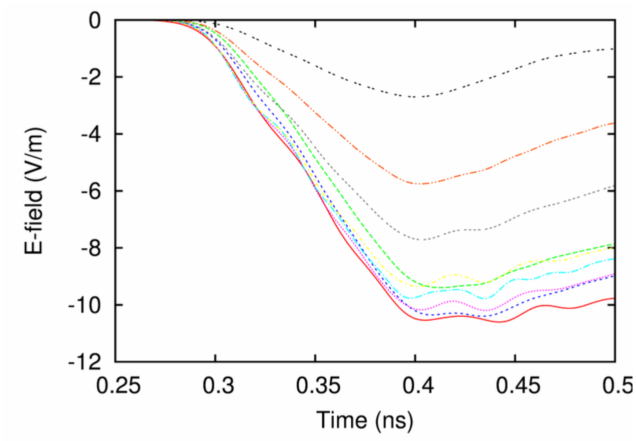
(c) Switch cones, hydrogen chamber, pressure vessel and feed arm connections

Figure 2.1: Simulation setup of switch and pressure vessel. Note that the entire system is immersed in a dielectric $\epsilon_{r_l} = 6.25$ [last layer of (conical) launching lens].

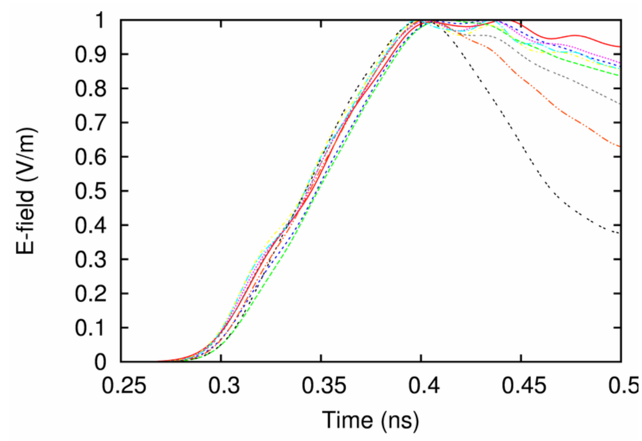
# 3 Effects of switch and pressure vessel parameter variations on time of arrival of fields

To recapitulate, the switch system dimensions from [1] are as follows

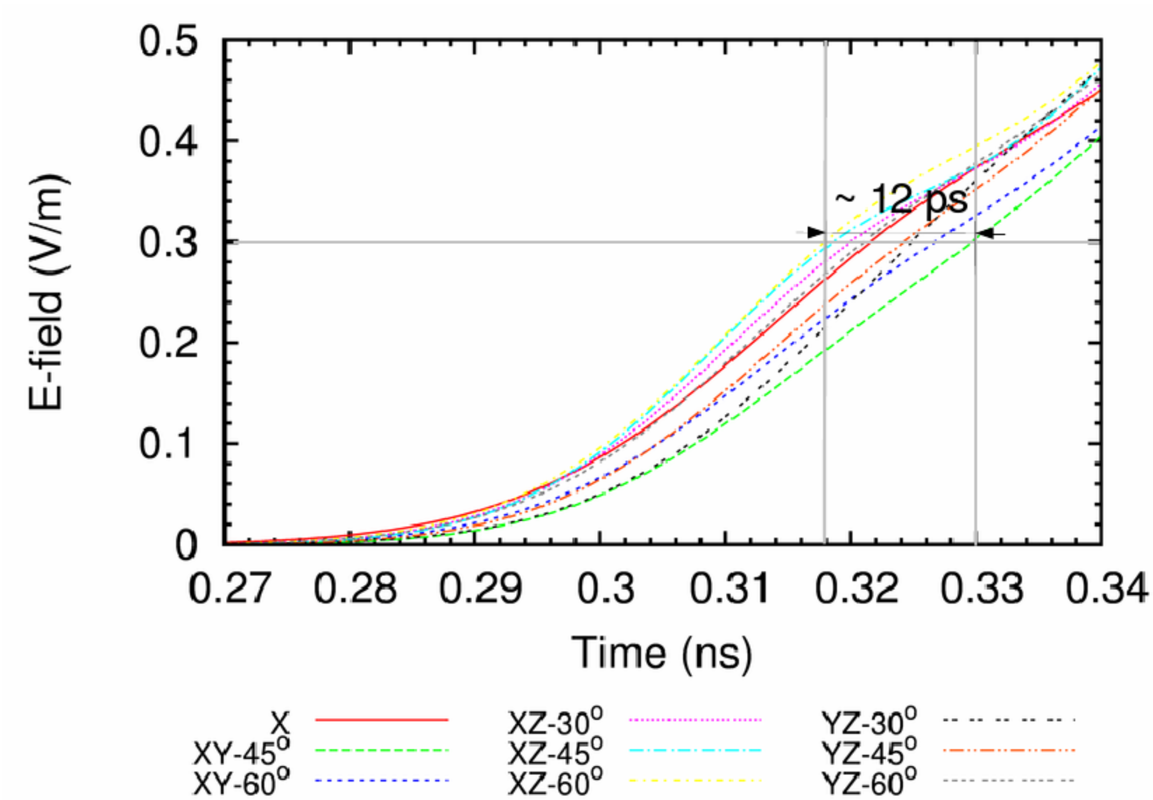
| | | |
|---|---|---|
| Pressure vessel height ($h_{pv} = 2h_{0_{pv}}$) | $=$ | 0.72 cm |
| Pressure vessel radius ($r_{pv}$) | $=$ | 1.5 cm |
| Pressure vessel dielectric ($\epsilon_{r_{pv}}$) | $=$ | 3.7 |
| Switch radius ($r_{sw}$) | $=$ | 0.5 cm |
| Switch gap ($h_{swgp}$) | $=$ | 0.5 mm |




(a) Simulation results for probe orientations in the three planes $xy, yz$ and $xz$.




(b) Results normalized with respect to the minimum of each of the wave in (a).




(c) "Zoomed in" plot of normalized results in (b) to present maximum difference between arrival times of various waves.

Figure 2.2: Simulation results and their normalized forms for the setup in Fig. 2.1. A maximum time difference of the order of 12 ps is observed in (c) which is much less than the time spread observed in the setup of Simulation-11. Note that the legend is the same for all plots.

First order approximations of variation of the pressure vessel height ($h_{0_{pv}} = h_{pv}/2$) and dielectric constant ($\epsilon_{r_{pv}}$) are presented in this section. Using the rough analysis here it is hoped that one can obtain enough insight to bypass the need for multiple simulations to predict the effect of variation of these parameters on the (numerical) results.

## 3.1 Effect of variation of height of pressure vessel

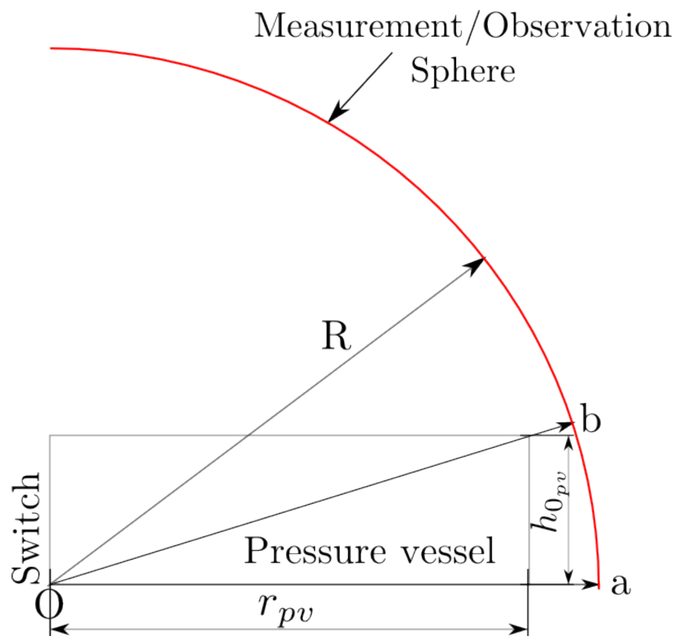



Figure 3.1: Simplified time calculations for "default" switch case without pressurized hydrogen chamber.

The dielectric sphere surrounds the cylindrical pressure vessel with radius $r_{pv}$. Therefore, the two rays with maximum time difference are those arriving at points $a$ and $b$ on the measurement sphere as shown in Fig. 3.1. An increase in $h_{0_{pv}}$ (or equivalently, $h_{swgp}$) will most affect the time of arrival of these rays. An estimate of the time difference between the arrival times of the two rays can be easily obtained. Note that the hydrogen chamber is neglected in these calculations but this should not affect the results too much. The labeling conventions in [1] for the switch configuration are used.

Time of arrival of a ray from $O$ (geometric center of switch system) to point $a$ on measurement/observation sphere is

$$ct_a = r_{pv}\sqrt{\epsilon_{r_{pv}}} + (R - r_{pv})\sqrt{\epsilon_{r_l}} \tag{3.1}$$

Time of arrival of a ray from $O$ (geometric center of switch system) to point $b$ on measurement/observation sphere is

$$ct_b = \left(\sqrt{r_{pv}^2 + h_{0_{pv}}^2}\right)\sqrt{\epsilon_{r_{pv}}} + \left[R - \left(\sqrt{r_{pv}^2 + h_{0_{pv}}^2}\right)\right]\sqrt{\epsilon_{r_l}} \tag{3.2}$$

Time difference between the two rays is

$$
\begin{aligned}
ct_\delta = c|t_b - t_a| &= \left| \left( \left( \sqrt{r_{pv}^2 + h_{0_{pv}}^2} \right) \sqrt{\epsilon_{r_{pv}}} + \left[ R - \left( \sqrt{r_{pv}^2 + h_{0_{pv}}^2} \right) \right] \sqrt{\epsilon_{r_l}} \right) - \left( r_{pv}\sqrt{\epsilon_{r_{pv}}} + (R - r_{pv})\sqrt{\epsilon_{r_l}} \right) \right| \\
&= \left| \sqrt{\epsilon_{r_{pv}}} \left( \sqrt{r_{pv}^2 + h_{0_{pv}}^2} - r_{pv} \right) + \sqrt{\epsilon_{r_l}} \left( r_{pv} - \sqrt{r_{pv}^2 + h_{0_{pv}}^2} \right) \right| \qquad (3.3) \\
&= \left| \left( \sqrt{\epsilon_{r_{pv}}} - \sqrt{\epsilon_{r_l}} \right) \left( \sqrt{r_{pv}^2 + h_{0_{pv}}^2} - r_{pv} \right) \right| \qquad (3.4)
\end{aligned}
$$

A plot of $t_\delta$ versus $h_{0_{pv}}$ is shown in Fig. 3.2. As expected, the time difference between the two rays increases as $h_{0_{pv}}$ is increased. The variation is non-linear. Beyond $h_{0_{pv}} \approx 1.3$ cm (i.e. $h_{pv} \approx 2.6$ cm), $t_\delta \approx 10$ ps. There is therefore a comprimise to be made: increasing the height of the pressure vessel allows for greater gas pressure and hence higher discharge voltages. This is desirable. However, increasing the height of the pressure vessel also increases the time difference $t_\delta$ as seen in the Fig. 3.2. Practically, it is necessary to give preference to $t_\delta$, as propagation through the dielectric of the launching lens may increase the time difference even further. It must be ensured that the maximum time difference between all rays arriving on a measurement sphere outside the launching lens does not exceed the tolerance of 10 ps.

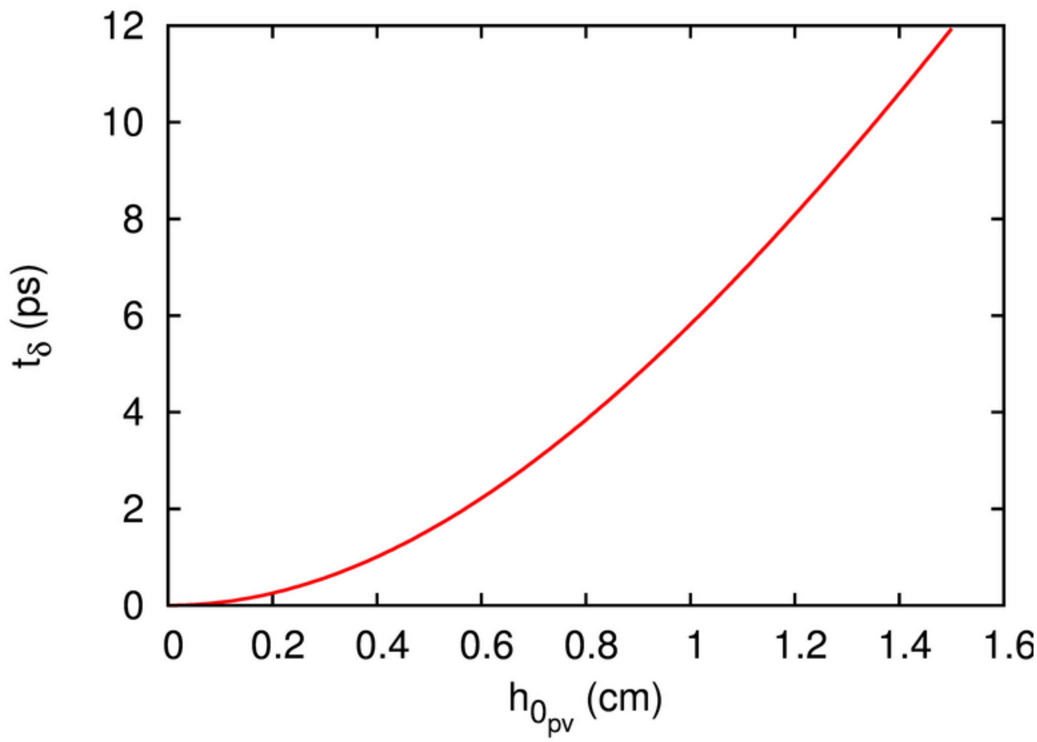



Figure 3.2: Plot of $t_\delta$ vs. height of pressure vessel $h_{0_{pv}}$.

## 3.2 Determination of optimum dielectric constant of pressure vessel

Although it is difficult to change the physical dimensions of the switch cone itself (since they are manufactured by the ASR [1]), it is relatively easy to change the dielectric constant of the pressure vessel surrounding the switch. Therefore, it is worthwhile to determine the optimum dielectric constant which would maximize power transfer to the surrounding lens.

The dielectric sphere surrounding the pressure vessel enables one to consider a transmission line equivalent of the problem (lossless and dispersionless model assumed). The hydrogen chamber, pressure vessel and lens dielectric can be approximated as three concentric spheres of increasing dielectric constant. Figure 3.2 shows such a transmission line model of the switch system where the impedances are : $Z_0$ = hydrogen chamber, $Z_{pv}$ = pressure vessel and $Z_l$ = dielectric of last layer of launching lens surrounding the pressure vessel. In this model, it is possible to calculate the optimum (desirable) dielectric constant of the pressure vessel by maximizing the net transmission coefficient of the system.

The transmission coeffcient, $T_1$, of a wave travelling from the hydrogen chamber to the pressure vessel is

$$T_1 = \frac{2Z_{pv}}{Z_0 + Z_{pv}} = \frac{2\epsilon_{r_{pv}}^{-1/2}}{\epsilon_{r_0}^{-1/2} + \epsilon_{r_{pv}}^{-1/2}} \tag{3.5}$$

since $Z \propto \epsilon_r^{-1/2}$. Similarly, the transmission coefficient, $T_2$, from the pressure vessel to the lens dielectric is

$$T_2 = \frac{2Z_l}{Z_{pv} + Z_l} = \frac{2\epsilon_{r_l}^{-1/2}}{\epsilon_{r_{pv}}^{-1/2} + \epsilon_{r_l}^{-1/2}} \tag{3.6}$$

Therefore, the net/total transmission coefficent can be written as

$$T_{\text{total}} = T_1 T_2 = \left(\frac{2\epsilon_{r_{pv}}^{-1/2}}{\epsilon_{r_0}^{-1/2} + \epsilon_{r_{pv}}^{-1/2}}\right)\left(\frac{2\epsilon_{r_l}^{-1/2}}{\epsilon_{r_{pv}}^{-1/2} + \epsilon_{r_l}^{-1/2}}\right) = \left(\frac{2\epsilon_{r_{pv}}^{-1/2}}{\epsilon_{r_0}^{-1/2} + \epsilon_{r_{pv}}^{-1/2}}\right)\left(\frac{2\epsilon_{r_l}^{-1/2}}{\epsilon_{r_{pv}}^{-1/2} + \epsilon_{r_l}^{-1/2}}\right) \tag{3.7}$$

Since $\epsilon_{r_0} = 1$ and $\epsilon_{r_l} = 6.25$ (for the conical lens design), the optimum value of $\epsilon_{r_{pv}}$ can be calculated as

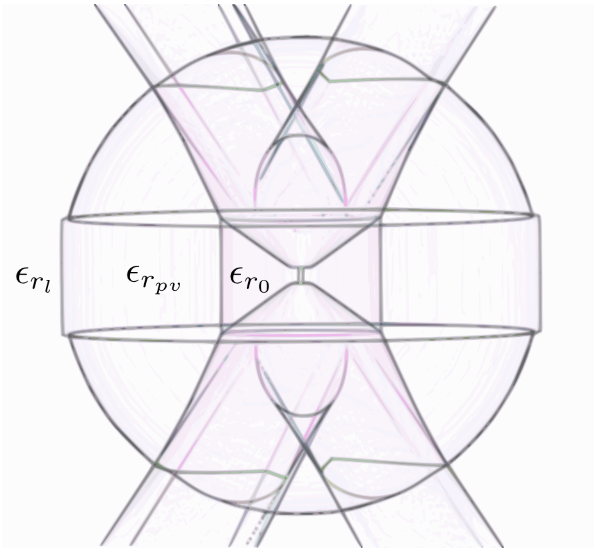
$$\frac{dT_{\text{total}}}{d\epsilon_{r_{pv}}} = 0 \Rightarrow \epsilon_{r_{pv}} = 2.5 \tag{3.8}$$

A plot of the transmission coefficent is shown in Fig. 3.4. As can be seen there is not much difference in $T_{\text{total}}$ for $\epsilon_{r_{pv}} > 2.5$. For example, $T_{\text{total}}(\epsilon_{r_{pv}} = 2.5) - T_{\text{total}}(\epsilon_{r_{pv}} = 3.7) = 0.005$ which is practically insignificant. So the only criteria for the dielectric constant of the pressure vessel (and surrounding dielectric sphere) is that $\epsilon_{r_{pv}} \geq 2.5$. Hence the value of $\epsilon_{r_{pv}} = 3.7$ adopted so far does not lead to much power losses.

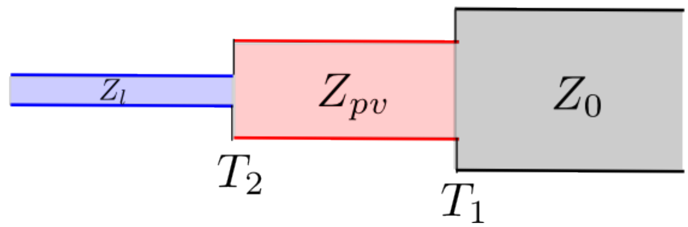
## 4 Conclusion

Simulation results with a dielectric sphere surrounding the pressure vessel have been presented. It is observed that the time spread is reduced by almost 50% compared to similar results in [1]. However, the tolerance times on the switch may have to be reduced.

Approximate calculations for predicting the variation of $h_{pv}$ indicate that a small $h_{pv}(< 2.6)$ cm is desirable to keep the time spread to a minimum. Optimization of $\epsilon_{r_{pv}}$ based on a transmission line model show that there is little variation in transmitted power for $\epsilon_{r_{pv}} \geq 2.5$.




(a) Dielectric constants of switch and pressure vessel system with surrounding dielectric sphere




(b) Transmission line model

Figure 3.3: Transmission line model of dielectric constants in switch and pressure vessel system to calculate optimum value of dielectric constant of pressure vessel by maximizing transmission coefficient of wave in system.

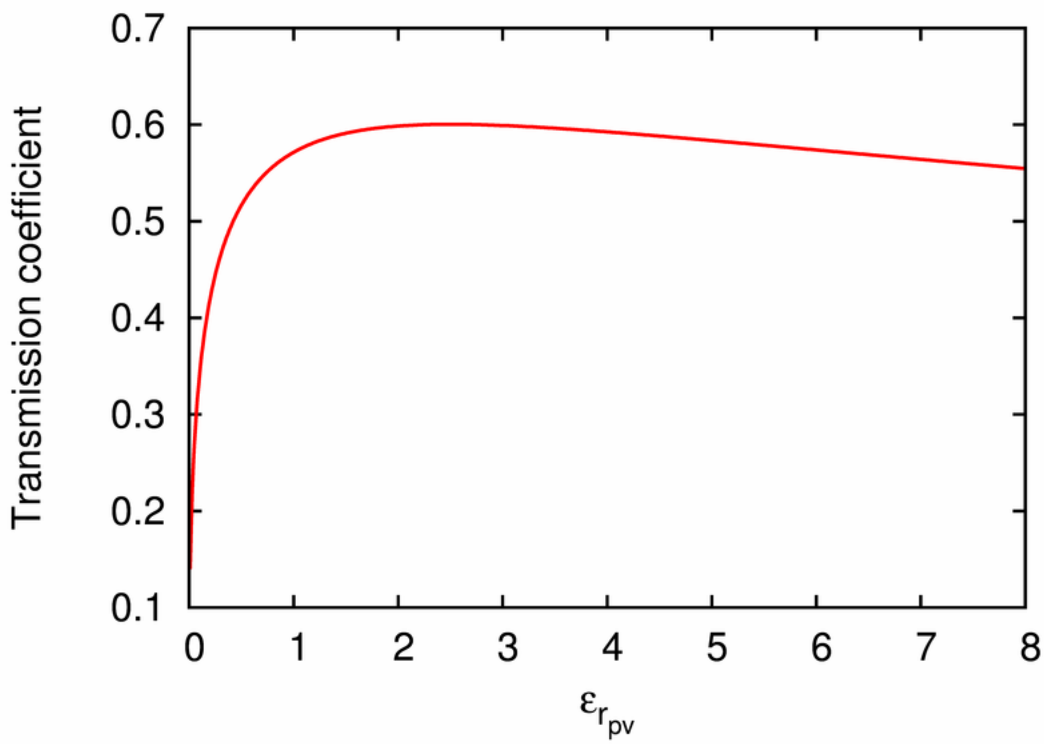



Figure 3.4: Plot of transmission coefficient vs. dielectric constant of pressure vessel.

# References


[1] 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.

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

[3] Prashanth Kumar, Carl E. Baum, Serhat Altunc, Christos G. Christodoulou and Edl Schamiloglu , "Simulation results for 6-layer and 7-layer conical non-uniform launching lens." EM Implosion Memo 29, June 2009.