EM Implosion Memos

Memo 31

August 2009

Design and numerical simulation of switch and pressure vessel - part I

Prashanth Kumar, Serhat Altunc, Carl E. Baum, Christos G. Christodoulou and Edl Schamiloglu
University of New Mexico
Department of Electrical and Computer Engineering
Albuquerque, NM 87131

Abstract

This paper presents the design and numerical simulation of a switch system (switch cones, pressure vessel and hydrogen chamber) as per dimensions provided by the ASR Corpooration. Possible cause for the time spread observed in the simulation results is explained.

1 Introduction

The switch is used to launch a spherical TEM wave from inside the launching lens as outlined in [1] and [2]. The basic components of the design are : 1) switch cones (metal), 2) gas (hydrogen) chamber and 3) pressure vessel (dielectric). These will collectively be referred to as the "switch system" in this paper. As a starting point, the dimensions of our switch system design are based on a typical model provided by the ASR Corporation [3]. The primary motivation behind the switch design is to avoid dielectric breakdown when sourced with voltages of 100 kV or more. The simulation procedure for the switch system is akin to that of the launching lens [4]. Time of arrival of various waves are measured on probes placed on a measurement sphere in the near field. Ideally, we desire a spherical TEM wave to originate from the geometric center of the switch (cones) i.e. all the waves should arrive simultaneously on the measurement sphere. Once a satisfactory design has been achieved, various parameters (for e.g. geometry and dielectric constant of the pressure vessel) of the switch system can be varied to optimize for a more practical design.

2 Dimensions of switch and pressure vessel

The dimensions of the switch gap, pressure vessel and high-pressure gas (typically hydrogen) chamber are based on a model provided by the ASR Corporation [3]. Figure 2.1 shows the various components of the switch system. The dimensions are tabulated in table 1. Note that the pressure vessel is a cylinder. The pressure vessel height is determined from the switch cone impedance as

Table 1: Dimensions of switch system

Component	Dimension/Value	
Pressure vessel height (h_{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

detailed in the next section. The dielectric constant inside the hydrogen chamber is $\epsilon_r \approx \epsilon_{r_0} = 1$.

As a first approximation, the switch system is considered to be immersed in a dielectric medium, $\epsilon_r = \epsilon_{r_l}$, corresponding to the last layer of the launching lens. For the conical design, $\epsilon_{r_l} = 6.25$ [5]. Ultimately, this surrounding dielectric will be divided into two regions. The first region corresponding to ϵ_{r_l} (toward the reflector) and the second region corresponding to a disperser medium to suppress unwanted waves propagating in the opposite direction.

3 Switch cone impedance calculations

It is desirable to match the impedance of the switch to that of the feed arms. Consider the switch geometry to be that of a cone. The problem is then equivalent to determining the half angle of

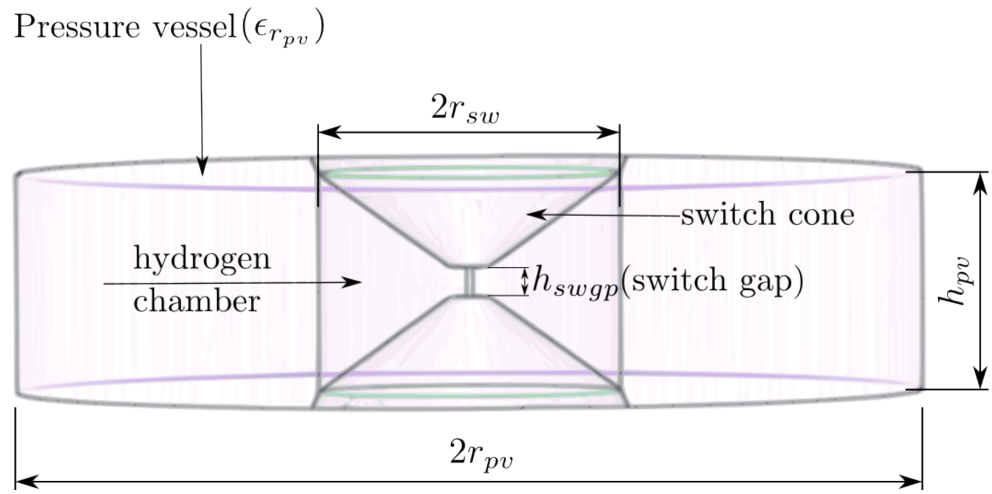


Figure 2.1: Switch and pressure vessel dimensions as per model provided by ASR Corporation

the switch cone. From [6], the pulse impedance of a circular cone antenna is given by

$$Z_a = \sqrt{\frac{\mu}{\epsilon}} \frac{1}{2\pi} \ln\left[\cot\left(\frac{\theta_0}{2}\right)\right] \tag{3.1}$$

where θ_0 is the half angle of the cone.

As mentioned previously, the switch system will be embedded in the last layer of the launching lens. We use $\epsilon_{r_l} = 6.25$, (for the conical launching lens design) in our designs and simulations [5]. For a four-arm setup (as considered in all our switch calculations) the impedance is 100 Ω. Therefore, it is required that the switch cone impedance be 100 Ω in ϵ_{r_l}. Hence, Z_a for the switch cone is $Z_a = 100/\sqrt{\epsilon_r} = 100/\sqrt{6.25} = 40\Omega$. The angle, θ_0, of the switch cone can be determined using equation (3.1) as $\theta_0 = 54.3323°$.

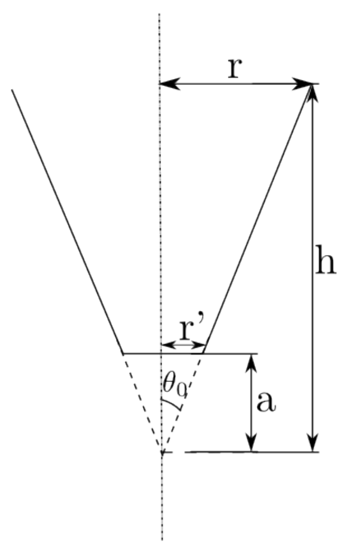


Figure 3.1: Calculations for angle and height of switch cone

In Fig. 3.1, $r = 0.5$ cm and $a = 0.5$ mm (a = switch gap) as per dimensions provided by the

ASR Corporation,. Therefore, $\tan\theta = r/h \Rightarrow h = r\cot\theta \approx 0.36$ cm. Also, $r' = a\tan\theta = 0.07$ cm. $h_{pv} = 2h$ in table 1.

3.1 Switch-feed-arm connection

Figure 3.2 shows the circular switch cone base extruded and lofted to connect to the flat face of the feed-arms.

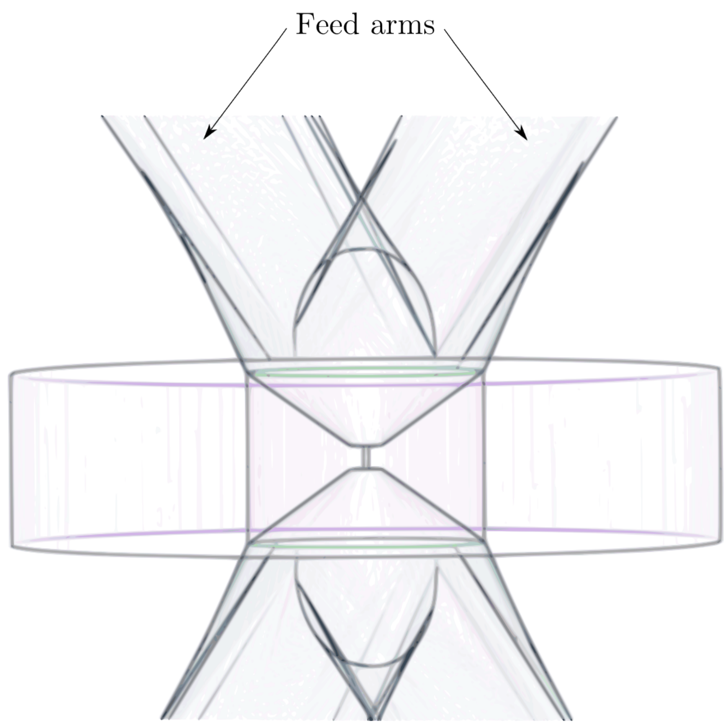


Figure 3.2: Extruded connection from switch base to feed arms

The calculations for switch cone impedance are approximate at best. This is because the details of the geometry of connection of the circular base of the switch cone to the flat face of the feed arms is not known exactly. Even if the details of such a connection were known, it would be a non-trivial task to analytically determine the impedances of these connections.

4 Simulation algorithm

The simulation algorithm is akin to the launching lens [4] and is as follows

1. Simulate the default setup in Fig. 2.1 (or Fig. 3.2). Examine time of arrival of waves on a (measurement) sphere in the near field to check if the source is emanating spherical waves.

2. If maximum time difference between various measurements is less than tolerance (10 ps in our case) then desired results have been achieved. Proceed to step 4.

3. If previous step is not true, examine cause of discrepancy and add/subtract dielectric in regions around switch where waves arrive too early or too late i.e. "tweak" dielectric surrounding switch.

4. Examine responses by varying parameters of the switch, h_{pv}, $\epsilon_{r_{pv}}$ and h_{swgp} i.e. optimize the dimensions to maximize amplitude and minimize difference in arrival times of waves.

5 Simulation

5.1 Setup

The simulation setup of the switch system (switch, pressure vessel, hydrogen chamber and feed arm connections) is shown in Fig. 5.1. The entire switch system is immersed in a dielectric that corresponds to the last layer of the non-uniform, conical launching lens design (ϵ_r =6.25). To first order, the results obtained here will be applicable in the spatial region of interest.

Figure 5.2 shows the orientations of various probes placed around the switch system. Probes were placed 30° apart on each of the planes (xy, xz and yz) on a sphere of radius 4 cm centered at the geometric center of the switch (cones). Arrival times of various waves are measured on these probes to ensure that the maximum time difference between any two waves is less than the acceptable tolerance of 10 ps.

5.2 Important CST/Simulation Parameters

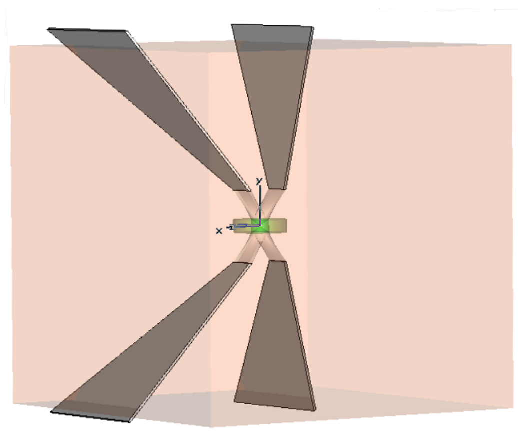
Domain	Time domain
Input	Ramp rising with 100 ps rise time
Excitation voltage	1 V
Frequency range	0−10 GHz
Lines per wavelength (LPW)	15
Simulation space (size of dielectric cube of $\epsilon_{r_l} = 6.25$)	10 cm

5.3 Results

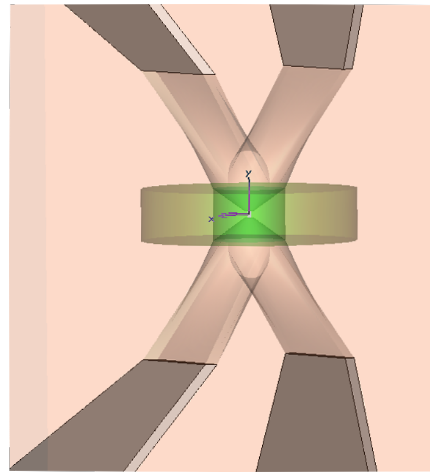
Simulation results for the setup in Fig. 5.1 and probe orientations in Fig. 5.2 are shown in Fig. 5.3. Each wave in Fig. 5.3(a) is normalized with respect to its minimum and plotted in Fig. 5.3(b). Figure 5.3(c) shows Fig. 5.3(b) in the timescale of interest. As can be observed, the maximum time difference between the responses (time spread) is approximately 20 ps.

6 Cause of time spread in simulation results

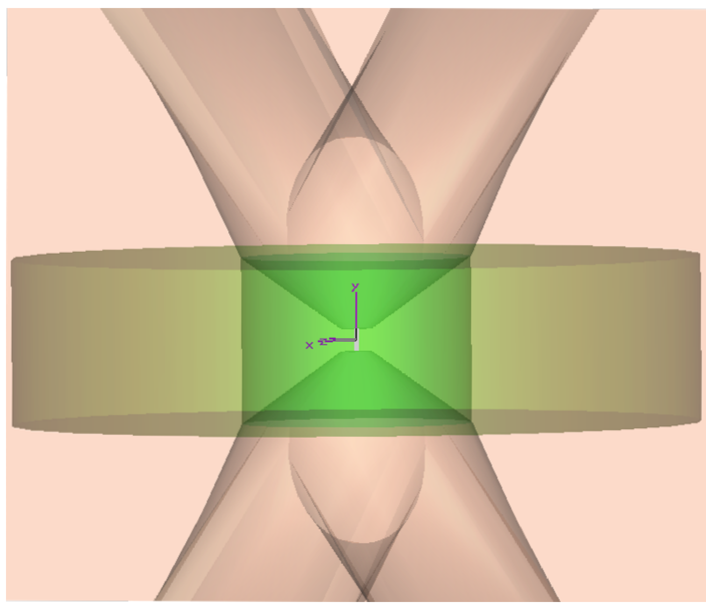
Clearly, the time spread of 20 ps observed in Fig. 5.3(c) is beyond our range of tolerance (10 ps). The lack of rotational symmetry in all three planes in the switch system design leads to different arrival times of waves travelling along different paths. For example, consider the rays arriving at points a and b on the measurement sphere as shown in Fig. 6.1.



(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 5.1: 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].

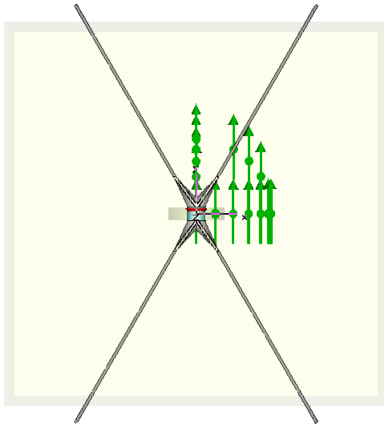
The arrival time of a ray arriving at point a on the sphere can be calculated as

$$
\begin{aligned}
ct_a &= \sqrt{\epsilon_{r0}}r_{sw} + (r_{pv} - r_{sw})\sqrt{\epsilon_{r_{pv}}} + (R - r_{pv})\sqrt{\epsilon_{r_l}} && (6.1)\\
&= r_{sw} + (r_{pv} - r_{sw})\sqrt{\epsilon_{r_{pv}}} + (R - r_{pv})\sqrt{\epsilon_{r_l}} && (6.2)
\end{aligned}
$$

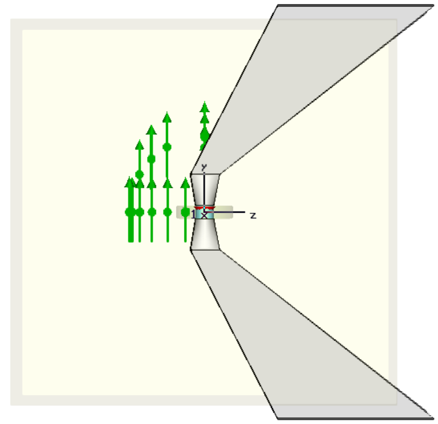
where $\sqrt{\epsilon_{r_l}}$ is the dielectric constant of the last layer of the launching lens surrounding the switch system.

Similarly, the arrival time of a ray arriving at point b on the sphere can be calculated as

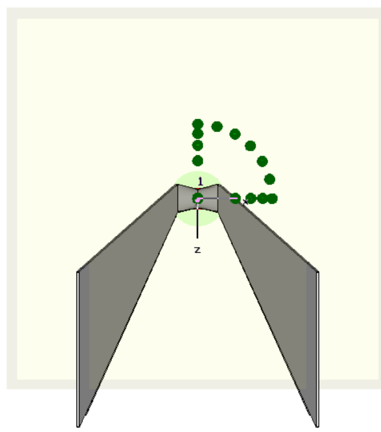
$$
ct_b \approx \sqrt{\epsilon_{r0}}h_{0_{pv}} + (R - h_{0_{pv}})\sqrt{\epsilon_{r_l}} \qquad (6.3)
$$



(a) Probe orientations for setup in the xy plane.



(b) Probe orientations for setup in the yz plane.



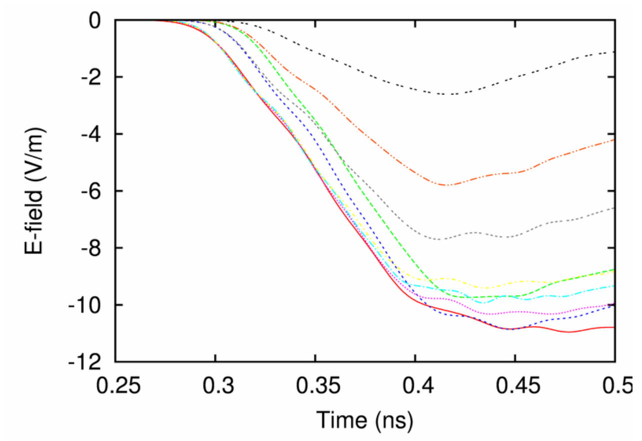
(c) Probe orientations for setup in the xz plane.

Figure 5.2: Orientation of probes placed to measure time of arrival of various waves for the switch system. Probes are placed 30° in each of the planes (xy, xz and yz) along a sphere of radius 4 cm centered at the geometric center of the switch system.

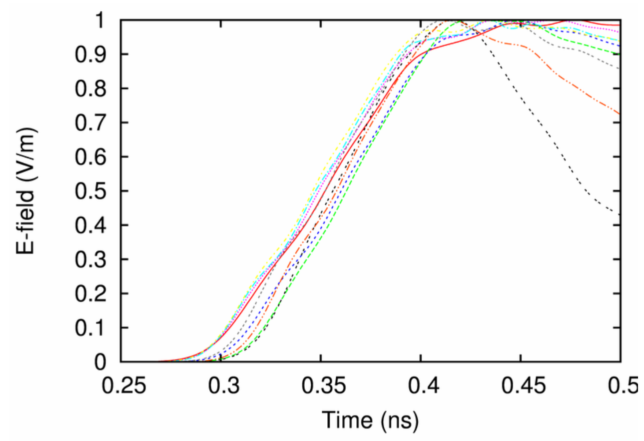
where $h_{pv} = 2h_{0_{pv}}$. The time difference, $t_\delta = |t_a - t_b|$, is

$$\begin{aligned} ct_\delta &= c|t_a - t_b| = |[r_{sw} + (r_{pv} - r_{sw})\sqrt{\epsilon_{r_{pv}}} + (R - r_{pv})\sqrt{\epsilon_{r_l}}] - [h_{0_{pv}} + (R - h_{0_{pv}})\sqrt{\epsilon_{r_l}}]| \\ &= |r_{sw} + (r_{pv} - r_{sw})\sqrt{\epsilon_{r_{pv}}} - r_{pv}\sqrt{\epsilon_{r_l}} - h_{0_{pv}} + h_{0_{pv}}\sqrt{\epsilon_{r_l}}| \end{aligned} \tag{6.4}$$

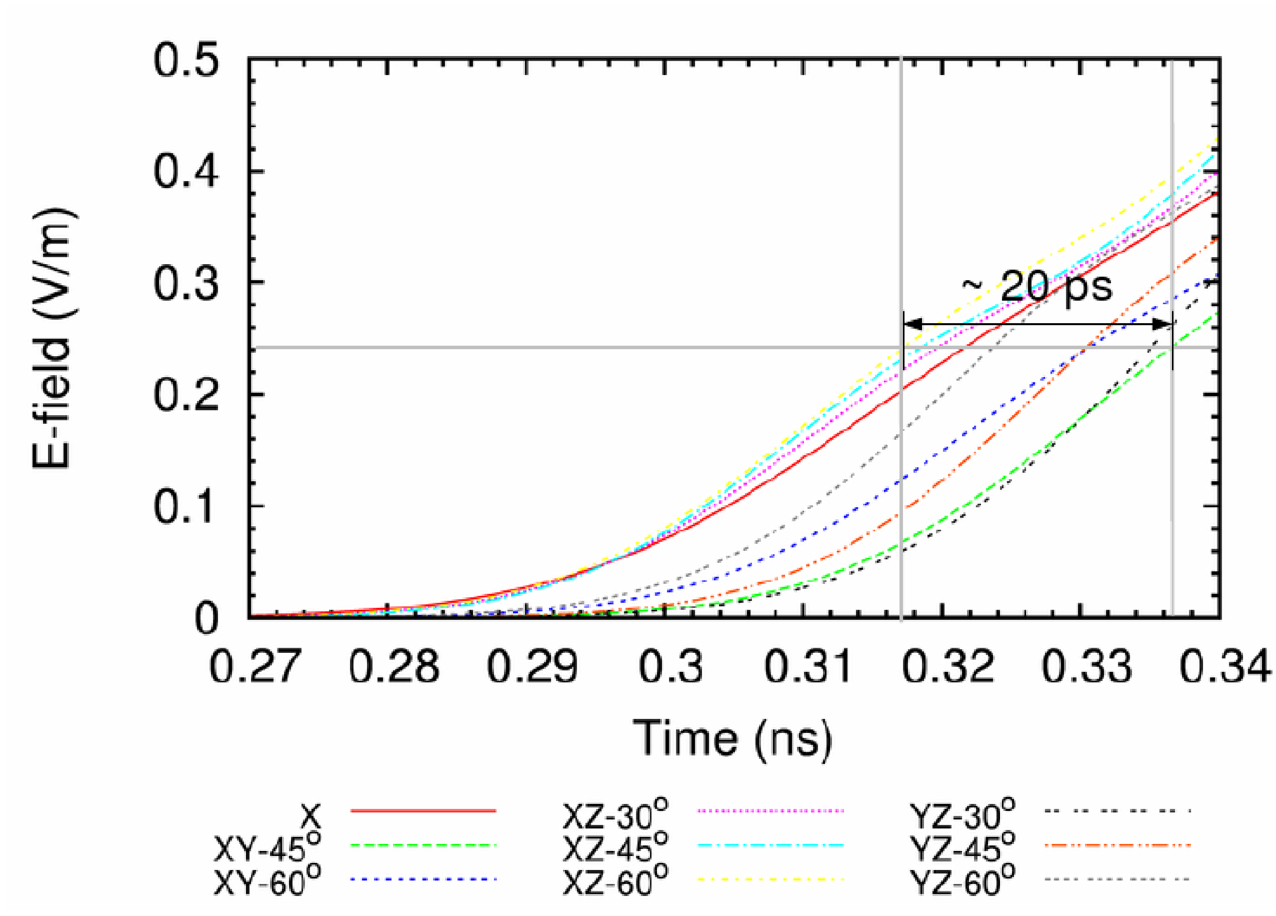
For the dimensions in table 1 : $t_\delta \approx 26.2$ ps which is of the same order as observed in the simulation results in Fig. 5.3(c). A simple way to compensate for the late arrival of the slow rays, b, is to surround the pressure vessel by a sphere of the same dielectric ($\epsilon_{r_{pv}}$) and radius (r_{pv}). This would ensure that all rays arrive simultaneously on the measurement sphere as these rays would have travelled approximately the same electrical distance. Such a configuration is shown in Fig. 6.2.



(a) Simulation results for probe orientations in Fig. 5.2.



(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 5.3: Simulation results and their normalized forms are presented in plots above. A maximum time difference of the order of 20 ps is observed in (c). Note that the legend is the same for all plots.

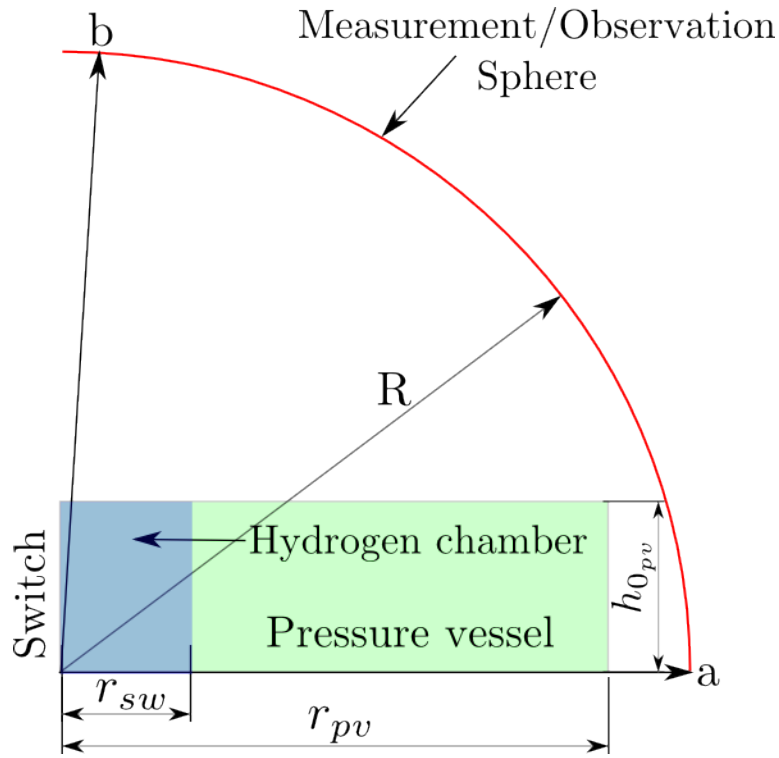


Figure 6.1: Diagram showing fast (a) and slow (b) rays in the switch system design leading to different time of arrivals of these rays on the measurement sphere.

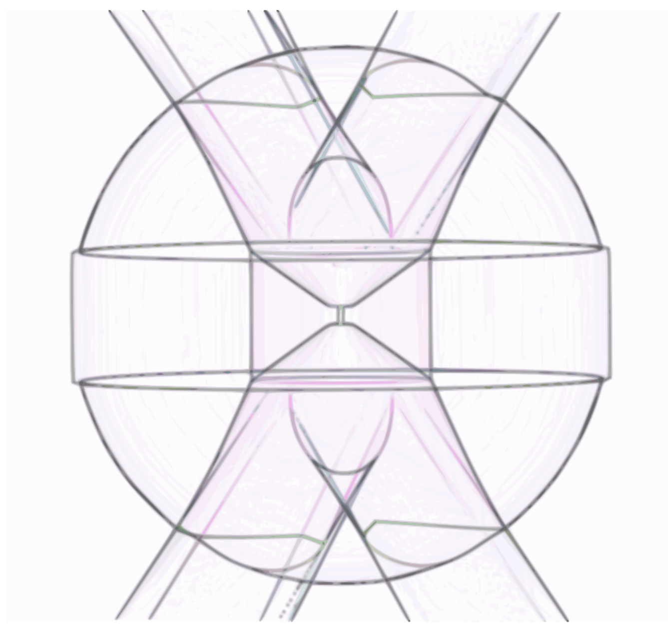


Figure 6.2: Pressure vessel (and switch) surrounded by a sphere of radius r_{pv} and dielectric constant $\epsilon_{r_{pv}}$.

References

[1] 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.

[2] 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.

[3] ASR, "Personal Communication - Michael C. Skipper." ASR Corporation, 7817 Bursera NW, Albuquerque, NM 87120, July 2009. info@asrcorporation.com.

[4] Prashanth Kumar, Carl E. Baum, Serhat Altunc, Christos G. Christodoulou and Edl Schamiloglu , "Analytical considerations for curve defining boundary of a non-uniform launching lens." EM Implosion Memo 26, June 2009.

[5] Prashanth Kumar, Carl E. Baum, Serhat Altunc, Christos G. Christodoulou and Edl Schamiloglu , "Derivation of the dielectric constant as a function of angle for designing a conical non-uniform launching lens." EM Implosion Memo 28, June 2009.

[6] C. E. Baum, "A Circular Conical Antenna Simulator." Sensor and Simulation Note 36, Mar. 1967. Air Force Weapons Laboratory.