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# Photon Design Validation Report

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| **Name of Report** | A validation of the correctness of the mode volume calculator in OmniSim. |
| **Performance Date** | 2nd August 2010 |
| **Performed By** | Stephen Wong |
| **Product Name** | OmniSim / CrystalWave |
| **Product Version & Compile Date** | Version: 4.5.5 |
| **Main Reference** | |
| **External Files** | Modevolume-planestandingwave.prj |

# A validation of the correctness of the mode volume calculator in OmniSim

## 1. Report Summary

This test aims to confirm the validity of the mode volume calculator by measuring that of a standing wave established via a plain wave excitor in a simple device designed for this purpose. The theoretical result of the expected mode volume is 1.86 μm$^3$ which should be compared to the numerical result of 1.859 μm$^3$ from the mode volume calculator. There is an error of just under 0.054%.

### *1.1 Validation Test – Brief Description*

This test used a device where a standing wave is established via a plain wave excitor which sends a continuous electromagnetic (EM) wave towards the +z-direction. At three edges of the device in that same direction is a reflective wall at a precise distance from the excitor so that a standing wave can be formed. A box sensor with a width of exactly one wavelength of the excitation along the path of the EM wave within the medium is placed in this stationary wave in order to measure the mode volume. Because the excitation is a simple plain wave, one can easily calculate the expected mode volume and compared it with the numerical result.

### *1.2 Validation Test – Detailed Description*

The device is shown in Figure 1 and Figure 2. There is a plain wave excitor at z = 1.0 μm lying along the x-direction facing the positive z direction. The excitor is centred at the wavelength of 1.55 μm in a medium with a refractive index of 2.5. In the +z, +x and -x directions of the device are electric walls which facilitate the forming of a stationary standing wave of wavelength of 0.62 μm in the medium. A box sensor centred at (0.0, 0.5, 4.0) μm of dimensions (6.0, 1.0, 0.62) μm is placed to measure the mode volume of this standing wave according to the mathematical formula

$$V = \frac{\int \varepsilon(r)\mathrm{E}^2(r)d^3r}{(\varepsilon(r)\mathrm{E}^2(r))_{\max}}.$$

In this case the integral in the numerator is over the entire volume of the box sensor and the denominator is essentially twice the maximum energy density due to the E fields within the volume. After a certain time, a continuous standing wave is formed in the device as shown in Figure 3.

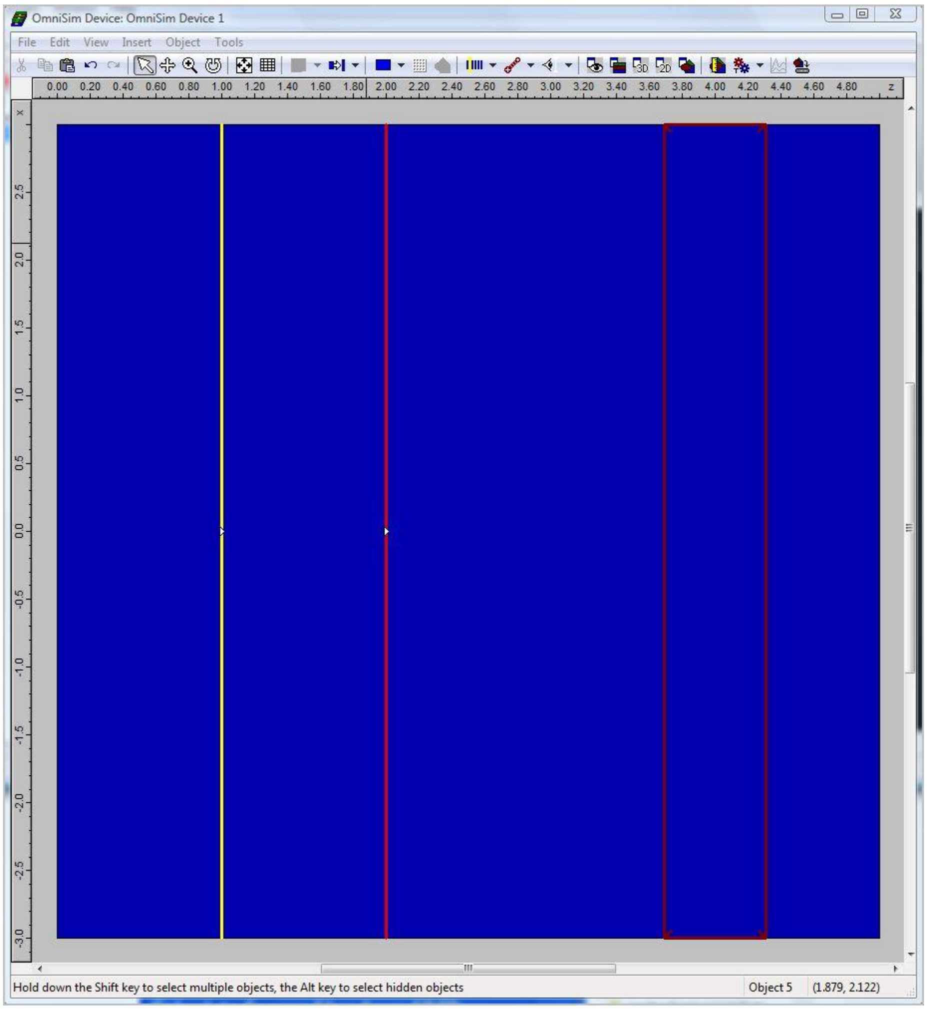


**Figure 1: A device with a plain wave excitor sending a continuous electromagnetic wave towards a reflective wall in the positive z direction.**

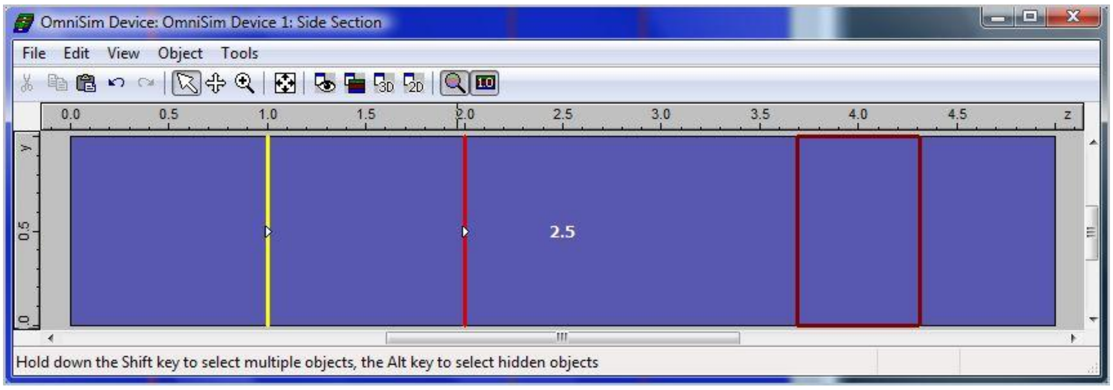


**Figure 2: A side view of the device also showing the refractive index of the medium.**

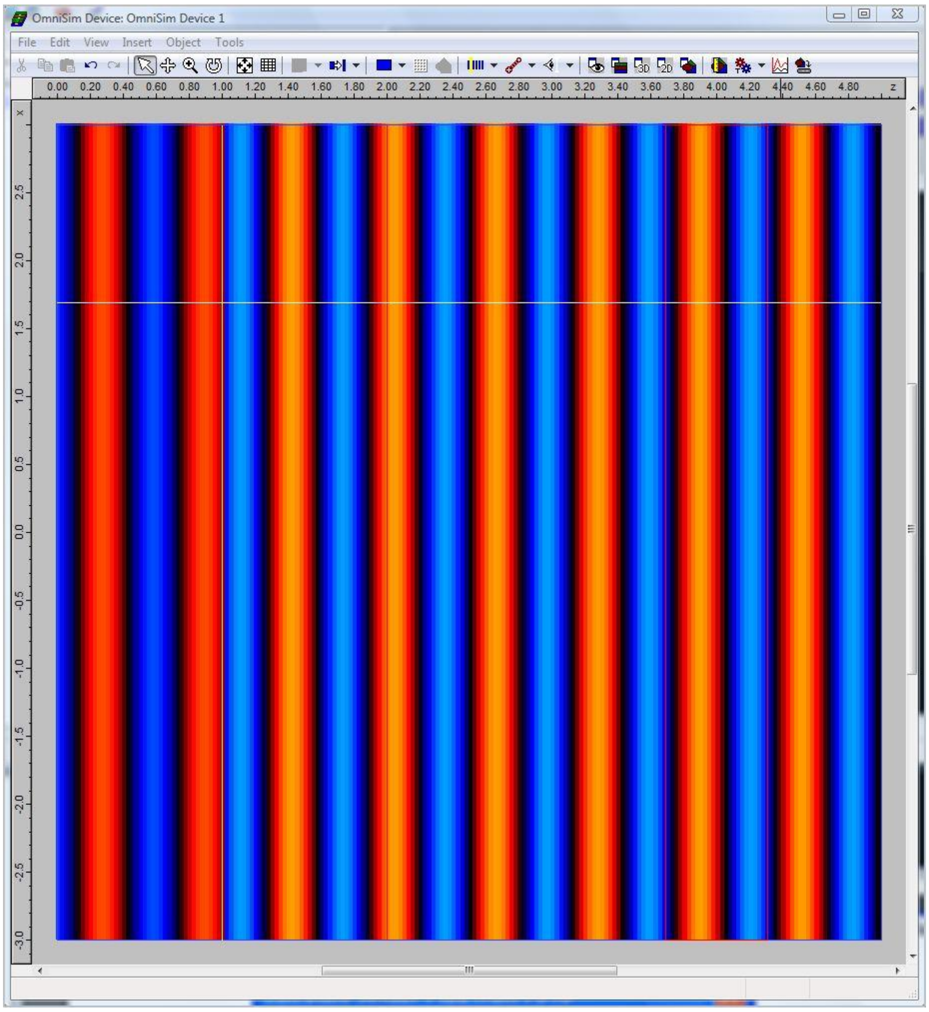


**Figure 3: A continuous standing wave is formed in the device thanks to the reflective walls in +z, +x and -x directions.**

### *1.3 Results*

Using a grid size of 0.05 μm, the FDTD calculation was run for 4096 time steps. The results from the mode volume calculator are shown in

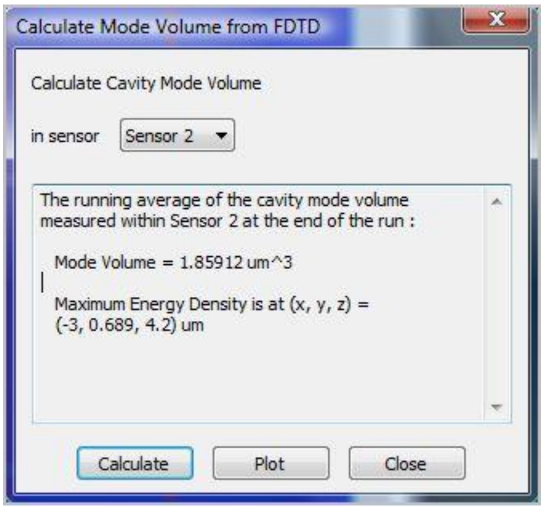


**Figure 4: Results from the Mode Volume Calculator.**

The calculator produced a result of 1.859 μm$^3$. One can plot the mode volume versus time in Figure 5 to see that this has stabilised.

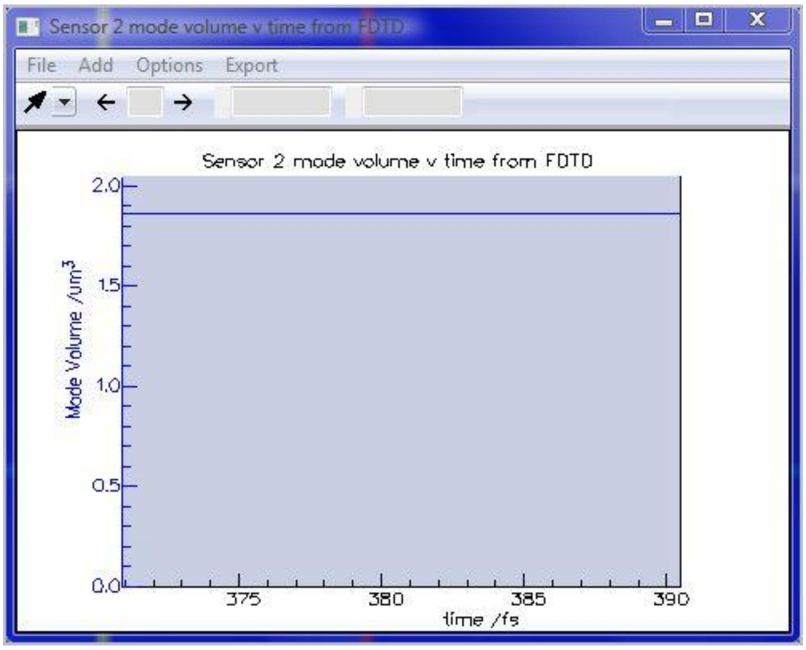


**Figure 5: The variation of the mode volume with time.**

This should be compared with the expected theoretical result. For a plain wave propagating towards the +z direction, one can write the electric field as

$$\mathrm{E}(r) = \mathrm{Re}(A\exp(-i(\omega t - kz + \phi)))$$

where $A$ is the amplitude. From the formula above

$$V = \int \cos^2(\omega t - kz + \phi)dzdxdy = S_x S_y \int \cos^2(\omega t - kz + \phi)dz = \frac{1}{2} S_x S_y S_z \, .$$

Here $S_i$ , $i$ =x, y, z are the dimensions of the box sensor. So one has

$$V = 0.5 * 6.0 * 1.0 * 0.62 = 1.86 \ \mu\mathrm{m}^3.$$

The agreement with the result from the calculator is excellent.