

## Resonant Frequencies in Rectangular Waveguide Cavity

Determining a resonant frequency of a cavity is a frequent task in analyzing various microwave systems. Often, due to the shape and interior structure of the cavity, it is not possible to perform direct resonant frequency calculations by simply applying analytical formulas derived from electromagnetic (EM) theory. In these cases, direct calculations are replaced by numerical simulation of a cavity model using appropriate 3D EM simulation software.

Modelling and simulation of the cavities will be presented in this application note. It will be shown how the resonant frequencies of rectangular waveguide cavity resonator can be determined using WIPL-D Pro CAD, a full wave 3D EM Method-of-Moments based (MoM) solver. Also, it will be shown that WIPL-D Pro CAD can be used as an **accurate and easy to use software tool**. Resonant frequencies will be calculated with **very high precision**. This will be verified by comparing WIPL-D results with results obtained using EM theory.

### Rectangular Waveguide Cavity Resonator

Rectangular waveguide cavity resonator was modeled using a simple metallic cuboid - a WIPL-D Pro CAD built-in primitive (Figure 1). In the particular case of waveguide cavity, the losses are taken into account through the skin effect occurring when the resonator walls are made from metal with a conductivity value of  $\sigma = 19 \text{ MS/m}$ . The interior of the resonator is vacuum.

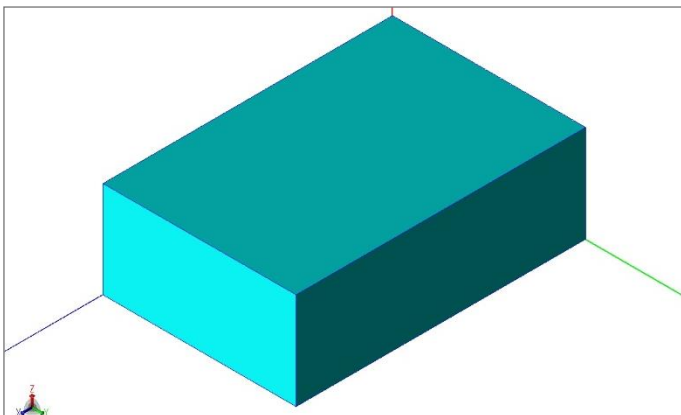


Figure 1. Rectangular waveguide cavity resonator

The resonator feeding is arranged as follows: the structure is fed using a dipole (Figure 2). To view the resonator interior, WIPL-D Pro CAD render mode should be set to *Contours*. The generator feeding a dipole (Figure 2) is highlighted as 'g1'.

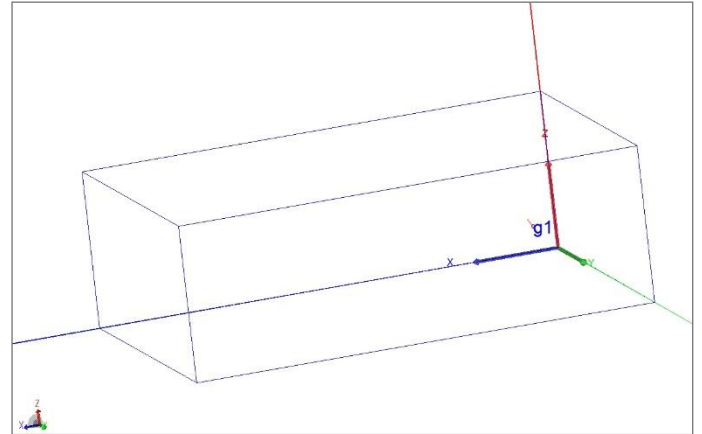


Figure 2. A dipole used for excitation of the cavity

### Simulations

The cavity resonator was simulated from 0.01 GHz to 10 GHz in 100 frequency points. High accuracy is achieved with **default settings of numerical kernel**. Computer used for these simulations is regular desktop with Intel® Core™ i7-7700 CPU @ 3.60 GHz. Number of elements, number of unknowns, computer memory required and simulation time per frequency are presented in Table 1.

Table 1. Number of elements, number of unknowns, computer memory and simulation time per frequency

Number of elements	Number of unknowns	Memory [MB]	Simulation time per frequency [sec]
14	318	0.77	0.03

### WIPL-D Results

Figure 3 illustrates real component of  $Y_{11}$ -parameter for a dipole which have been used for excitation of the cavity. **Resonant frequencies can be easily identified from  $Y_{11}$  peaks** and the accurate values of the resonant frequencies can be read using WIPL Graph markers. Similarly, Figure 4 illustrates  $Y_{11}$ -parameter with changed range of ordinate axis (the result becomes "zoomed").

The powerful built-in interpolation algorithm allows obtaining high precision frequency domain results with very low number of frequency points. A rough estimation is that it is sufficient to use just a couple (3-7) points per resonance.

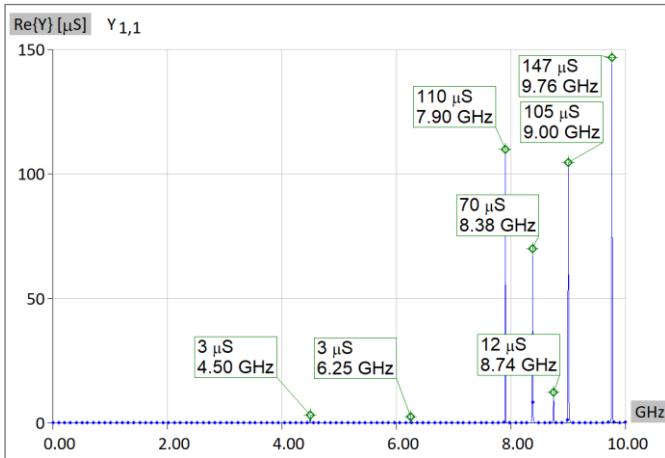


Figure 3. Resonant frequencies and  $Y_{11}$

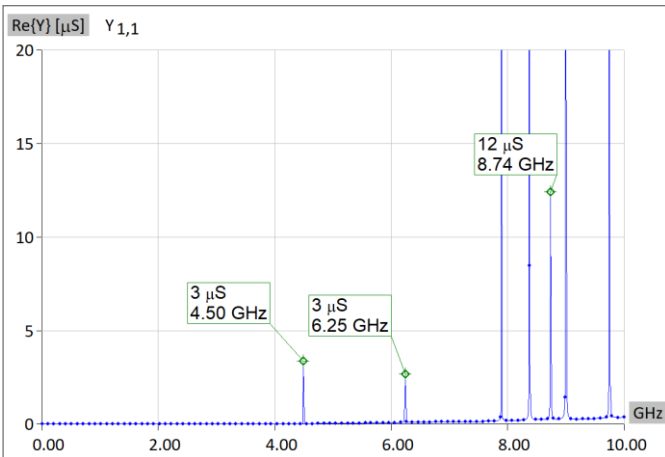


Figure 4. Resonant frequencies and  $Y_{11}$ -zoomed results

### Comparison with Theory

For the case of the rectangular waveguide cavity analytical solutions of the resonant frequencies are available. The **analytical expression** for the resonant frequencies based on the theoretical analysis is:

$$f_{mnp} = \frac{c}{2\pi} \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{p\pi}{d}\right)^2},$$

Where  $c$  is speed of light in vacuum,  $a=40$  mm,  $b=20$  mm,  $d=60$  mm, while  $m$ ,  $n$ , and  $p$  represent numbers of variations in the standing way pattern. The results obtained using WIPL-D simulation of the cavity and the results obtained after applying presented formula are listed in Table 2.

Table 2. Numbers of variations in the standing way pattern, theoretically determined resonant frequencies and resonant frequencies obtained using WIPL-D software.

m	n	p	Theory; Frequency [GHz]	WIPL-D; Frequency [GHz]
1	0	1	4.50	4.50
1	0	2	6.25	6.25
0	1	1	7.90	7.90
1	0	3	8.38	8.38
1	1	1	8.74	8.74
0	1	2	9.00	9.00
1	1	2	9.76	9.76

### Conclusion

This application note presented comparison of the results obtained using WIPL-D Pro CAD, a full-wave 3D EM MoM based solver and the results obtained according to EM theory. The structure was excited with a dipole. The resonant frequencies in rectangular cavity resonator were calculated for frequencies between 0.01 GHz and 10 GHz.

The comparison of the results suggests that exciting the cavity with a dipole and a generator is **highly effective**. From the results presented in Figure 3 and Figure 4, all resonant frequencies can be identified. Furthermore, all of the resonant frequencies calculated using simulations coincide with the values obtained using analytical formulas. This means that resonance frequency results are obtained accurately with **default numerical kernel settings**. Also, the simulation time listed in Table I suggest very high numerically efficiency of the calculations with **standard desktop or laptop platform** is used for simulation.

Finally, the approach applied can be **utilized in the other models** of resonators; e.g. circular waveguide resonator, 'arbitrary' resonant structures etc.