Design of Wave Ports in FDTD and Its Application to Microwave Circuits and Antennas

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Introduction

To simulate various transmission lines and their corresponding microwave circuits and antennas in FDTD, we need the excitation sources and S-parameter extraction methods. The excitation source can be discrete source or any source which can generate many modes. The excitation source can also be of any specific mode of the transmission lines although in many cases the fundamental mode is used. If one direction excitation source [1] is used in the simulation, S-parameters can be extracted straightforwardly. However, this method is not suitable to transmission lines when their propagation constants are unknown. For two directional excitation sources, various S-parameter extraction methods have been developed and we discuss some of them as follows.

The first method is to use a reference simulation. We calculate electric fields for an infinite transmission line case as a reference so that we can identify the incident wave and thus extract the reflection from the total by the difference of the total and the incident wave [2], [3]. The second one is to use three sensor planes. To avoid the extra reference simulation of the transmission line for extracting the incident wave, three planes are used for separating the incident wave and reflected wave [4]-[6]. Different parameters including electric fields, magnetic fields, voltages, currents and power can be used as sensors to calculate the S-parameters. The third one is a differential method. By using both the electric and magnetic fields and their derivatives along propagation direction, the reflection fields can be extracted from the total fields [7]. It should be noted that the second and third methods are not accurate for low frequencies due to the singularity in the algorithm. The fourth is an S-parameter extraction method which is suitable to inhomogeneous guides [8].

In this paper, we present a design of wave ports including rectangular and circular waveguides, coax, microstrip and strip lines in framework of commercial software XFDTD®. We show the simulation results of some microwave circuit or antenna examples for validating the wave ports design.

Design of Wave Ports

Fig.1 shows the design of a rectangular waveguide port. This port is completely separated from the FDTD simulation space. It means that it is updated independently. However, it exchanges data with the FDTD simulation space by the magnetic fields just outside of the waveguide aperture. The benefits of this design are as follows. We can reduce the memories in the FDTD simulation space and hence speed up the whole FDTD simulation. At the same time, we can obtain the correct phase information because we put sensors
right on the aperture of the wave ports. In addition, what is shown in the FDTD simulation space is simply a wave port, which gives a nice and clear presentation in the FDTD simulation space.

![Diagram of a rectangular waveguide port](image)

**Fig.1 Design of a rectangular waveguide port**

For the active port, the wave port includes the excitation sources and sensors which are required for extracting the S-parameters. For passive ports, only one sensor on the aperture at each wave port is needed. The S-parameter extraction methods such as reference simulation, three sensor planes and differential method can be applied. For microstrip lines and striplines, we need to design the wave ports which are significant larger than the area between the trace and ground plane. This is because there are no conducting walls as the cases for waveguides and coaxes. For this case, the sources and sensors are located in the middle of a transmission line rather than on the aperture for better accuracy, and the absorbing boundaries should be located right against the end of trace or substrate.

**Simulation Examples**

**Example 1: Rectangular waveguide:** An empty X-band waveguide was tested and the results showed that $S_{11}$ is below -75 dB for the frequency band and $S_{21}$ is basically very close to 0 dB. A WR-3 waveguide ($a=0.8636$ mm, $b=0.4318$ mm) with a dielectric slab filling of thickness $d=0.504$ mm and $\varepsilon_r=3.7$ was analyzed using the designed wave ports. The following meshing parameters were chosen: $d_x=d_y=0.035983$ mm and $d_z=0.036$ mm. Fig.2 shows the s-parameters of the WR-3 waveguide with a dielectric filling, which agree well with the published data [9]. It should be noted that the convergence can be slow, and for a good result at the low frequency portion, a large number of time steps is needed for meeting the convergence criteria. In addition, to obtain the correct results, conformal dielectric sheets on each side of the dielectric filling were added.

**Example 2: Microstrip antenna:** Microstrip fed patch antenna [3][4] was simulated using the sources and sensors located in the middle of the transmission line. Fig.6. shows the $S_{11}$ of the patch antenna obtained with a reference transmission line. The technique with a reference transmission line gives a better result at the low frequency end than the techniques with three reference planes.

**Example 3: Coax band stop filter:** A coax band stop filter [10] was simulated using the designed coaxial ports. The simulation results for an empty coaxial line showed that the return loss is better than -60 dB for low frequency band and better than -50 dB for high frequency band. Fig.4 shows the simulated s-parameters for the coax band stop filter.
Example 4 Circular waveguide: A thick circular iris in a circular waveguide [11] was analyzed by the designed circular waveguide port. The simulated S-parameters are shown in Fig.5.

Fig.2. S-parameters of a WR-3 waveguide with a dielectric slab filling

Fig.3. $S_{11}$ of a microstrip patch antenna

Fig.4. $S_{11}$ and $S_{21}$ of a coax band stop filter

Fig.5. $S_{11}$ and $S_{21}$ of a circular waveguide with a thick circular iris
Conclusion

Wave ports including rectangular and circular waveguides, coax, microstrip and strip lines were designed in the framework of commercial software XFdtd®. Some simulation results for microwave circuits and antennas are shown for validating the wave ports design. The use of wave ports allows us to enhance the capability of FDTD, save memories and fasten simulations.

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References


