

Convergence Study and Numerical Kernel Settings in Microstrip Patch Antenna Simulations

The study of convergence of the results and choosing the optimal settings for a numerical kernel are both extremely important topics in numerical electromagnetics. The reason is quite simple - a user can start from an excellent EM model, but if subsequent simulations are carried out with a wrong kernel setting or without a convergence study, the results will not be sufficiently accurate. In addition, a suitable convergence study will ensure accurate results with optimally exploited hardware and time resources.

WIPL-D Pro CAD, a **full wave 3D electromagnetic (EM) Method-of-Moments (MoM) based software**, is one of WIPL-D Company flagship products. It has been used for modeling and simulations of the antenna outlined in this application note.

WIPL-D Pro CAD Model of Microstrip Patch Antenna

The WIPL-D Pro CAD preview of modeled and simulated microstrip patch antenna (MPA) is shown in Figure 1. The radiating patch is printed on the dielectric with $\epsilon_r=4.4$ and loss tangent of 0.017. Substrate height is 0.508 mm.

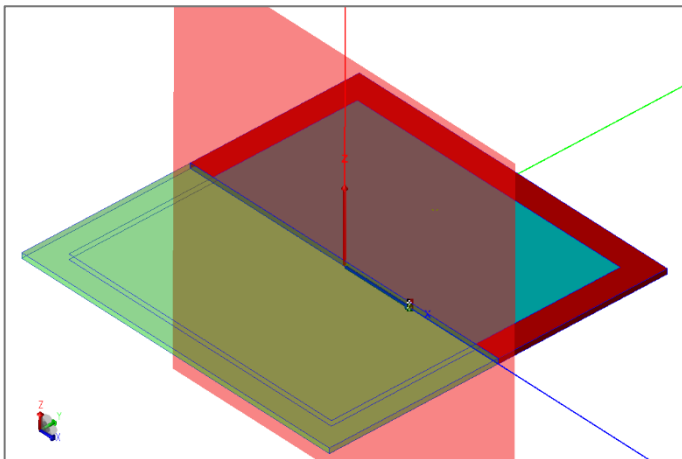


Figure 1. Microstrip patch antenna in WIPL-D Pro CAD with one symmetry plane applied

The antenna was easily created using built-in primitives and Boolean operations. It is fed with a probe modeled simply with a WIPL-D *Wire* entity. The model has one symmetry plane which is used to decrease the size of the problem. The simulations were performed from 2.25 GHz to 2.55 GHz at 11 frequency points. Central frequency of the band is 2.40 GHz. A laptop with the hardware specification presented in Table 1 is used.

Table 1. Laptop used for carrying the simulations

Hardware	Description
Processor	Intel® Core™ i7-8750H CPU @ 2.20GHz 2.21GHz
RAM	16 GB

Influence of The *Edge-ing* on The Results with Default Kernel Settings

Using the *Edge-ing* option when simulating printed microstrip structures is strongly advised. The option enables additional automatic meshing along the edges where the density of currents and fields increases abruptly, and is one of crucial parameters for accurate EM simulation (top of Figure 2). The bottom of Figure 2 illustrates a comparison of antenna S_{11} parameter calculated with or without *Edge-ing* applied. A difference in both, resonance frequency and depth of S_{11} parameter at the resonance, is obvious.

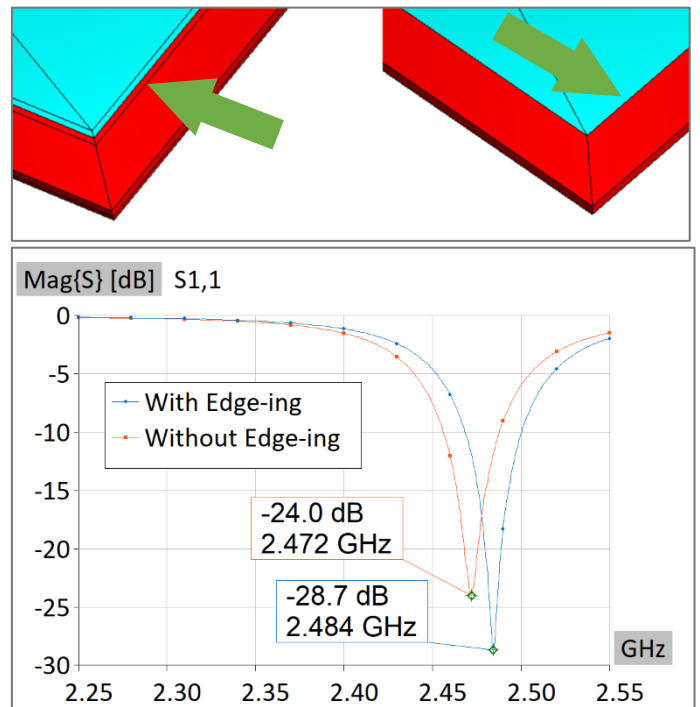


Figure 2. The influence of *Edge-ing* on the meshed structure and the difference between S-parameters with or without *Edge-ing* included

Usually, the following parameters can be used to define *Edge-ing* in simulations of microstrip and similar structures: *Max Edge Width* defined with *Substrate_Height/2* and 65%, and *Edge-ing* applied to *All* domains.

The number of elements, number of unknowns, and total simulation time required for two WIPL-D simulations used in *Edge*-ing influence study are given in Table 2. According to Figure 2 and Table 2 it can be seen that an application of *Edge*-ing influences the results and increases number of elements, number of unknowns, and simulation time. In other words, the increased accuracy comes with a cost.

Table 2. Number of elements, number of unknowns, and total simulation time in *Edge*-ing study

Model	Number of elements	Number of unknowns	Total simulation time
With <i>Edge</i> -ing	100	189	6 secs
Without <i>Edge</i> -ing	48	107	5 secs

Integral Accuracy Parameter

Increasing parameter *Integral accuracy (IA)* enables **improving the accuracy of numerical integration in matrix elements evaluation**. We will study the influence of the *Integral accuracy* on convergence of the results using the model with *Edge*-ing included.

Two results originating from the MPA simulations obtained by defining two consecutive values of *Integral accuracy* parameter are compared (Figure 3). Since they are similar, we can conclude that the results converged and that both results can be considered to be sufficiently accurate. For subsequent simulations the settings requiring **less computer and time resources should be selected**.

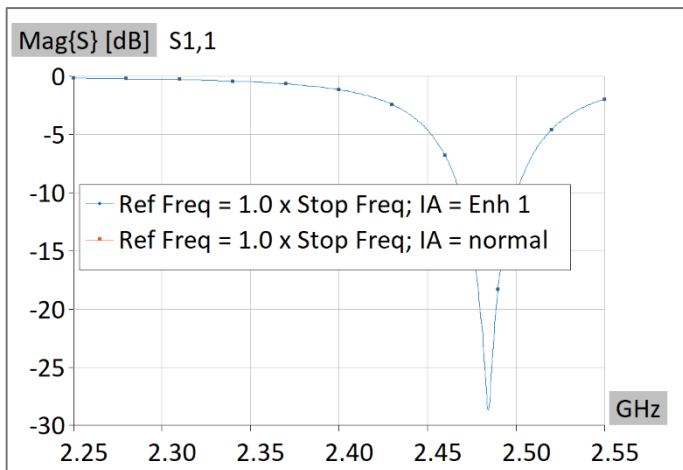


Figure 3. S-parameters with *IA* set to *normal* and *IA* set to *Enhanced 1*

The number of elements, number of unknowns, and total simulation time required for given two WIPL-D simulations of microstrip patch antenna in *Integral accuracy* study are outlined in Table 3. It can be concluded that setting the *IA* parameter to *normal* provides accurate results while **the higher values of *IA* raise simulation time by increasing time required for matrix elements evaluation**.

Table 3. Number of elements, number of unknowns, and total simulation time in *Integral accuracy* study

<i>Integral accuracy</i>	Number of elements	Number of unknowns	Total simulation time
<i>normal</i>	100	189	6 secs
<i>Enhanced 1</i>	100	189	8 secs

Assume that we simulate the model in which *IA* has to be increased several more times (*normal, Enhanced 1, Enhanced 2, Enhanced 3...*). The similar way of comparing the results and selecting optimum *IA* parameter should be applied in this hypothetical case, too.

Reference Frequency Parameter

In general, increasing *Reference frequency* increases number of unknown coefficients (number of unknowns) in a model.

The “unknown” represents an unknown coefficient used in the approximation of the current. The higher electrical size of the model, the larger number of unknowns is required. The similar conclusion is valid if a number of details in a model increases. In general, increasing a number of unknowns should produce more accurate results.

The stability of the results is confirmed if number of unknowns reasonably increases. In most cases, the aim is to increase number of unknowns for about 25% (somewhere between 10% and 30%). For the case of the patch antenna studied here, the increment of 50% of the *Reference frequency* value is selected as it will result in an optimal increasing of unknowns.

WIPL-D offers several ways to increase number of unknowns. The most often, number of unknowns is increased through increasing *Reference frequency* which is by default set to *Stop frequency*. According to previous, if microstrip patch antenna is investigated, *Reference frequency* is recommended to be increased for 50% of default *Reference frequency* which is actually the *Stop frequency*.

Figure 4 displays a typical situation when microstrip structures are simulated. In this case, WIPL-D usually requires *Reference frequency* to be increased for at least by 50%. It can be seen that default *Reference frequency* provide resonance frequency shift from the accurate solution of about 4%. The single increase of *Reference frequency* by 50% (i.e., to 1.5x*Stop frequency*) becomes very close to the convergent solution which is in turn obtained by setting *Reference frequency* to 2.0x*Stop frequency*.

The number of elements, number of unknowns, and total simulation time required for given three WIPL-D simulations in number of unknowns study are given in Table 4.

It can be seen that with “reasonable” increasing of number of unknowns we can assume that resonance frequency converges to about 2.40 GHz. Regarding on criterion of convergence, we can adopt here that both values of 1.5-times and 2.0-times initial *Reference frequency* can be considered as excellent.

Note that in WIPL-D, visual criterion of convergence is preferred. In the other words, for selected range, two results are considered to be in good agreement if they appear almost identical on a graph.

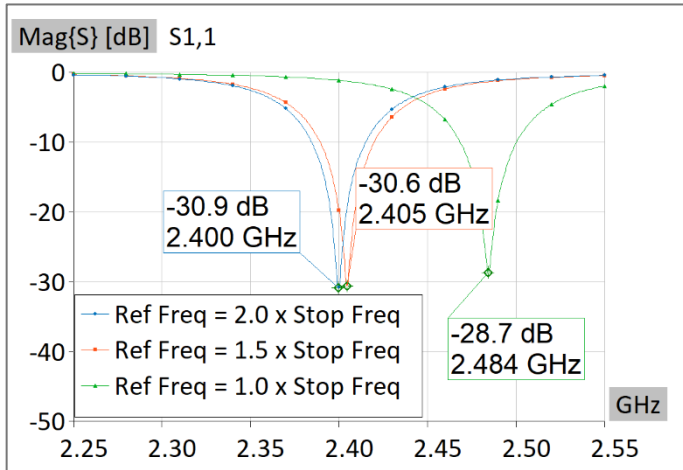


Figure 4. S-parameters with Reference frequency set to default value, increased for 50%, and for 100%

Table 4. Number of elements, number of unknowns, and total simulation time for Reference frequency (number of unknowns) study

Model	Number of elements	Number of unknowns	Total simulation time
2.0 x Stop Freq	100	346	9 secs
1.5 x Stop Freq	100	251	7 secs
1.0 x Stop Freq	100	189	6 secs

The Summary of Convergence Study

In general, the convergence study can involve varying many different parameters in a project and comparing the results. For an example, single\double precision, size of meshing elements on curved surfaces, various reduction levels and techniques etc. can all be adjusted to optimum values. However, usually, convergence study relates to variation of Integral accuracy which influences the accuracy of matrix elements evaluation which is followed with Reference frequency variation influencing number of unknown coefficients (number of unknowns). The outline of the most often used process of convergence study is shown in Figure 5.

Conclusion

A demonstration example of convergence study of calculated S-parameters was presented in this application note. The convergence study relates to simulations using WIPL-D Pro CAD, which is a full wave 3D electromagnetic Method-of-Moments based software. The EM model used for demonstrational purposes is a microstrip patch antenna operating around

2.40 GHz. All the conclusions derived here can be directly applied to many EM components operating in this widely exploited frequency band.

The application note covered a convergence study of the results on the model which can be considered as a sample of widely simulated modest\lower electrical size EM models. This convergence study was based on proper increasing of Integral accuracy and Reference frequency parameters. Also, the application note contains a recommendation for applying Edge-ing in printed structures simulations.

It was shown that changing numerical settings can improve the convergence of the output results. Thus, it is highly recommended to be performed. It was also shown that optimal numerical kernel settings should be exploited, since changing of numerical settings increases simulation time and number of unknowns which becomes very important when working with electrically large or detailed models.

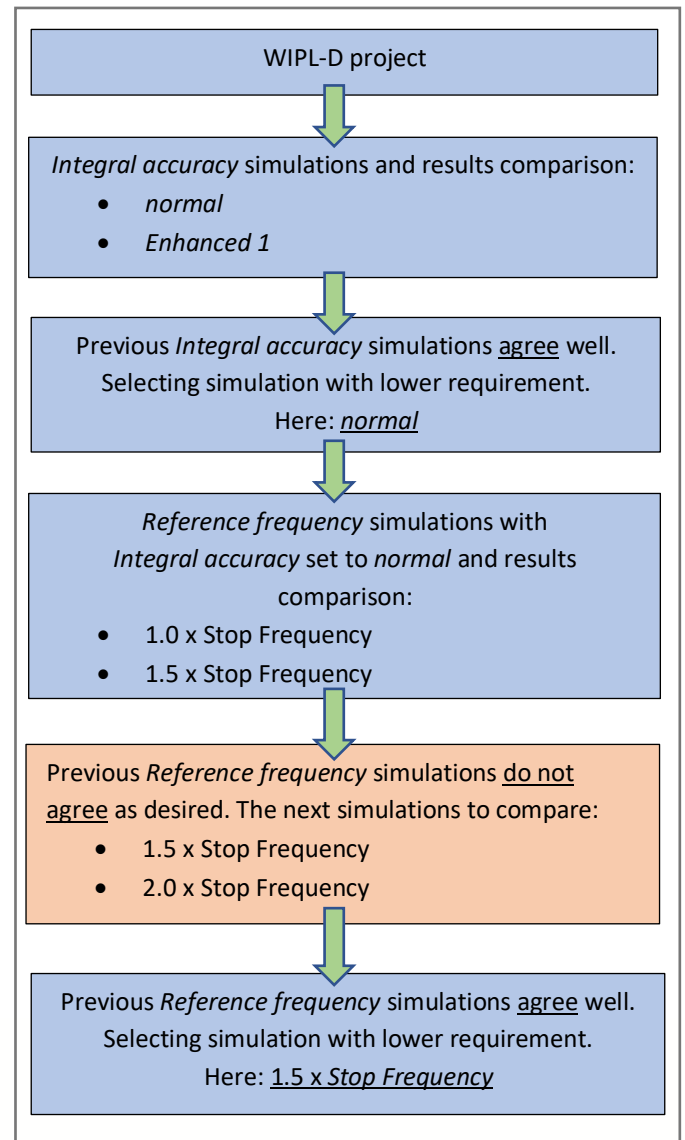


Figure 5. The example of the most common process of convergence study