# WIPL-D Compared to Other EM Codes for the Analysis of Printed Antennas

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**Abstract:** This paper compares WIPL-D results with measurements and with two other known commercial EM codes for the analysis of selected configurations of printed antennas. Four examples are tested, ranging from the basic square patch to less trivial multilayer structures with thick substrates. Simulated radiation pattern and return loss results are compared with measured data, for proper assessment of the accuracy. The study also compares efficiency, flexibility and user friendliness. Rather than trying to rank the codes, the objective of the paper is to present and discuss results from systematic tests, and show strengths and trade-offs of the code.

**Keywords:** Printed Antennas, Numerical Electromagnetic Modeling

## 1. Introduction

WIPL-D is a numerical electromagnetic code based on the method of moments that can model general three-dimensional structures using wires and metal and dielectric plates. Wires can be cylindrical or conical, and plates are represented by bilinear surfaces. The composite structure is characterized by electric currents over metallic surfaces, and equivalent electric and magnetic currents over dielectric surfaces.

WIPL-D is being used for some time at the Instituto de Telecomunicações for the analysis of complex 3D electromagnetic problems (ex. analysis of dielectric horns, characterization of artificial dielectrics, scattering by wind power generator structures, etc. [1]). Given the quite good agreement between simulations and experimental results for 3D structures, the interest has turned also to the evaluation of WIPL-D performance for the analysis of printed planar antennas. In the quest for multi-band or broadband characteristics along with antenna compactness, some printed antenna designs are becoming more and more 3D. So there is a natural interest to find how full 3D numerical codes compare with time proven codes that are dedicated to the analysis and design of planar antennas. Accuracy of the simulation results can be checked against measurements, and efficiency can be compared with other known EM codes. This is the goal of the present paper.

ENSEMBLE 5.1 from Ansoft Corporation, and IE3D 7.0 from Zeland Software, Inc are used for comparison purpose. Like WIPL-D, ENSEMBLE and IE3D are based on full-wave moment method solutions of integral equation formulations. ENSEMBLE is a specific code for 2.5D planar antenna and circuit structures, while IE3D can analyse 3D structures. The latter has embedded optimization capabilities.

A set of commonly used microstrip patch antenna elements comprising different patch shapes, feeding methods and number of layers have been selected for the proposed tests:

i. Common coaxial probe fed rectangular patch printed on a thin substrate;
ii. Irregular shape patch printed on a thin substrate;
iii. Double-layer aperture coupled microstrip line fed rectangular patch;
iv. Rectangular patch printed on thick substrate.

Prototypes of these antennas were fabricated and tested. Return loss and radiation pattern characteristics were measured for each structure, for accuracy assessment of the EM codes.

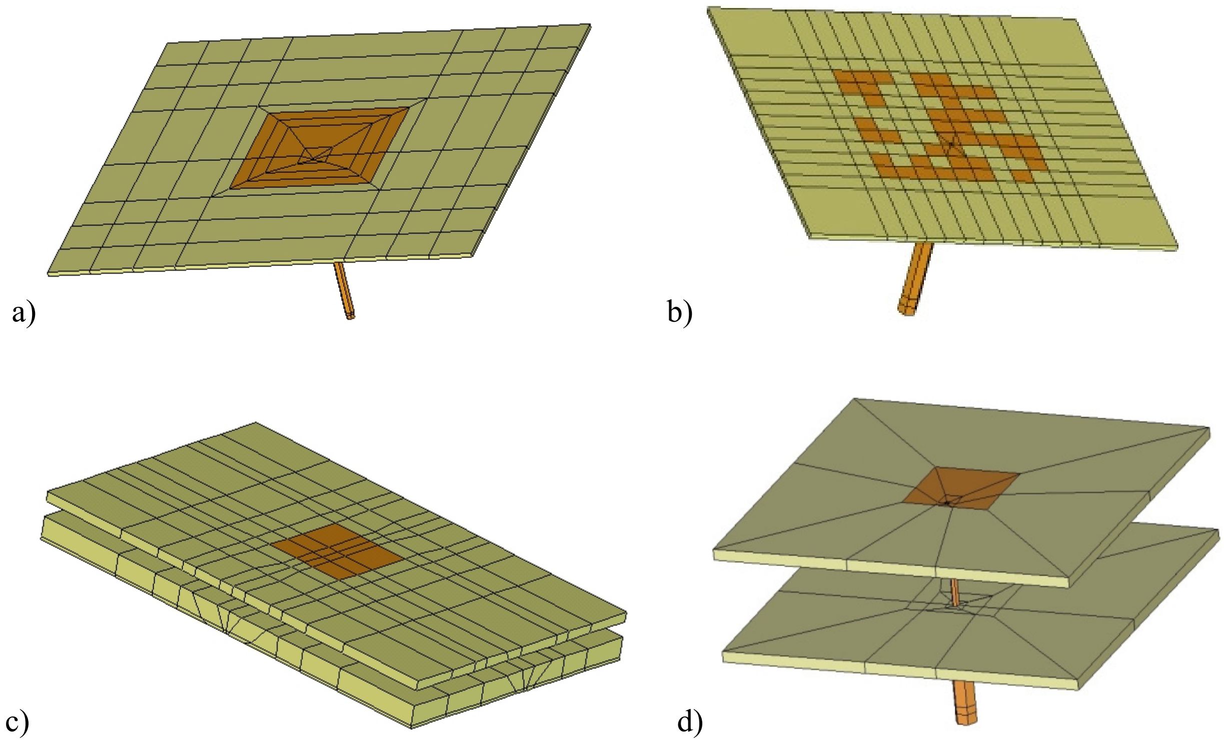



Figure 1 – Printed antenna configurations used for EM code assessment. A) Coaxial probe fed rectangular patch printed on thin substrate; b) Irregular shape patch printed on thin substrate; c) Double layer aperture coupled microstrip line fed rectangular patch; d) Rectangular patch printed on a thick substrate.

## 2. Rectangular patch on thin substrate

The study starts with a basic printed antenna: a conventional 50 mm × 50 mm patch on thin substrate, fed by a coaxial probe at $y_p$ = 17.7 mm. Ground plane is 150 mm × 150 mm, substrate thickness is 62 mils, and $\varepsilon_r$ = 2.2 (ROGERS 5880). A WIPL-D model of the antenna is shown Figure 1a. In WIPL-D, the feed is modeled as a 35 mm length coaxial cable.

Corresponding principal planes radiation patterns are shown in Figure 2. Results from WIPL-D (curve 1) are superimposed on IE3D (curve 2), on ENSEMBLE (curve 3 for infinite ground plane and curve 4 for finite ground plane), and on mesured results (curve 5). WIPL-D results are practically coincident with finite ground-plane results from ENSEMBLE in both planes, and very close to measurements. Differences between simulations and measurements near $\theta$ = 180º are due to antenna postitioner blocking in the anechoic chamber. As expected, results obtained for infinite ground plane deviate somewhat from mesurements near $\theta$ = 90º.

A critical parameter in simulations is the shift of the antenna ressonance frequency. Results from Figure 3 show some spread of $f_o$, reaching almost 1 % error in some calculations. For this example the IE3D model provides the best result, although the level of reflection loss is underestimated. These kinds of conclusions are not universal, and depend on a number of different factors that are discussed with more detail in Section 6.

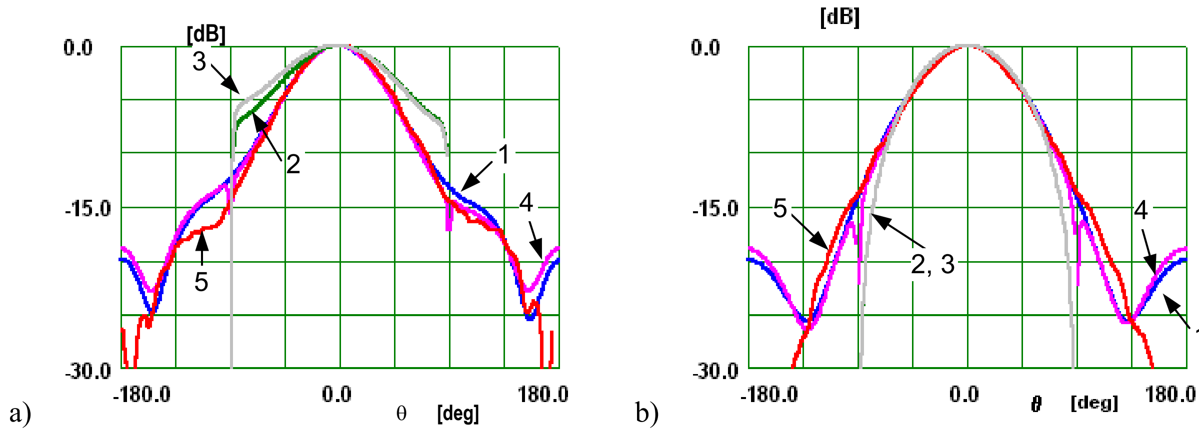



Figure 2 – Radiation pattern of rectangular patch on thin substrate. 1 (blue): WIPL-D; 2 (green): IE3D with infinite ground plane; 3 (grey): ENSEMBLE with infinite ground plane; 4 (magenta): ENSEMBLE with finite ground plane; 5 (red): measured. (a) E-plane; (b) H-plane.

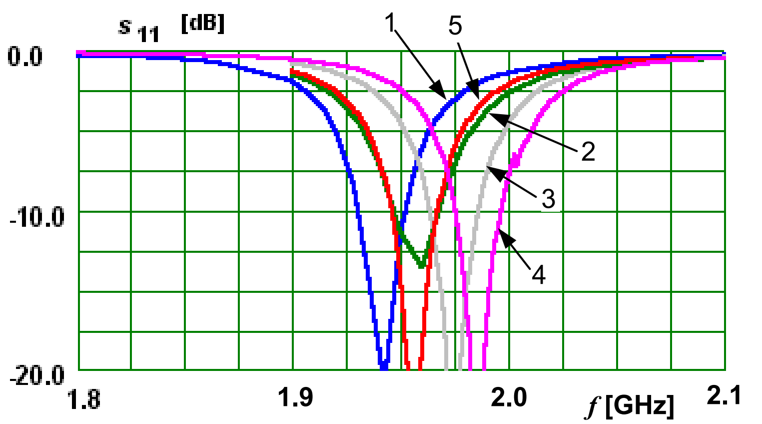



Figure 3 – Return loss of rectangular patch on thin substrate. 1 (blue): WIPL-D; 2 (green): IE3D with infinite ground plane; 3 (grey): ENSEMBLE with infinite ground plane; 4 (magenta): ENSEMBLE with finite ground plane; 5 (red): measured.

### 3. Irregular shape patch on thin substrate

One possible technique to reduce the ressonant frequency of a patch antenna is to adequately remove parts of its metalisation. Figure 1b shows one such example, which was optimised using genetic algorithms [2]. This example is particularly attractive for code assessement tests, because impedance and radiation pattern are quite sensitive to frequency: imprecise modeling causes visible deviations with respect to mesurements. Patch and ground plane dimensions are 32.9 mm × 32.9 mm, and 122 mm ×122 mm, respectively. The structure is fed by a coaxial cable and resonates around 1.8 GHz, which corresponds to 37% reduction with respect to full-metalized square patch.

Mutual proximity of many metal edges in this antenna render the modelling more challenging. E- and H-plane radiation patterns are shown in Figure 4. The curves bare the same color code as before. Again WIPL-D results agree well with measurements. Only the copolar components are shown because of space limitations, but the same type of agreement is obtained for the cross-polar components as well. Discussion on the deviation of infinite ground plane results with respect to measurements, and on the effect of positioner blockage near 180º is similar to the previous example. As for input reflection loss, simulated results (not shown here) point to up to

3.6 % shift in the ressonance frequency, which is of the order of the antenna bandwidth. This reflects the complexity of the model, with all the metal edges.

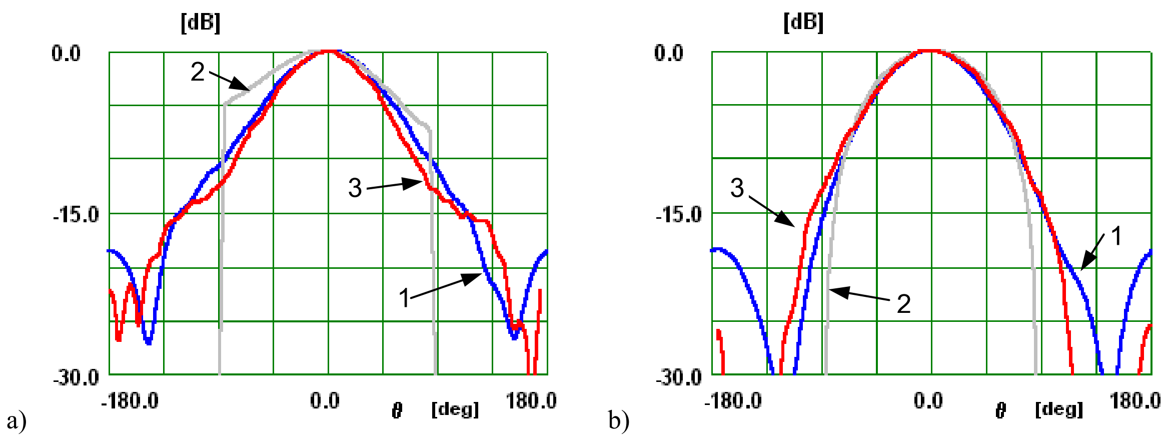



Figure 4 – Radiation pattern of irregular patch on thin substrate. 1 (blue): WIPL-D; 2 (grey): ENSEMBLE with infinite ground plane; 3 (red): measured. (a) E-plane; (b) H-plane

## 4. Double-layer aperture coupled microstrip line fed rectangular patch

The third test example corresponds to a 44% bandwidth structure, based on a two stacked patch configuration with thick substrates and an air gap, fed by a microstrip line through a coupling slot in the ground plane (Figure 1c). The structure was optimised with ENSEMBLE. E- and H-plane radiation patterns are shown in Figure 5. The lack of symmetry in the measured results is due to the especific mounting configuration that was adopted to alow measurement of the back lobe at –180º. Positioner blockage is visible in the measured results near θ = 90º, but the agreement is otherwise reasonable. Note that away from θ ~ +90º, the infinite ground plane results are mostly coincident with WIPL-D (which used the exact finite ground plane model).

As will be presented at the conference, both WIPL-D and ENSEMBLE predict quite well the wide bandwidth of reflection loss characteristic of this structure.

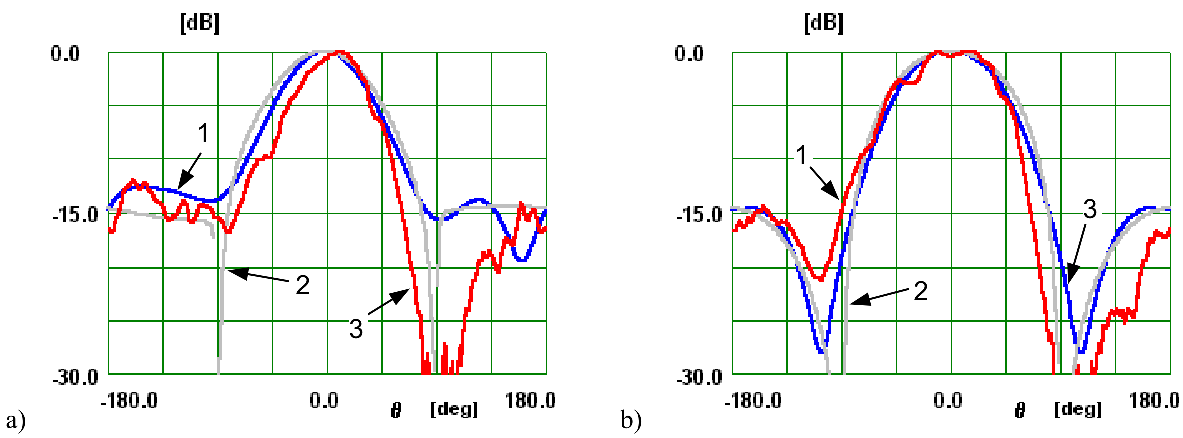
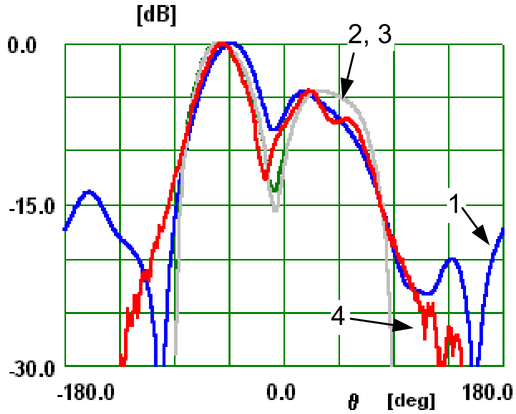


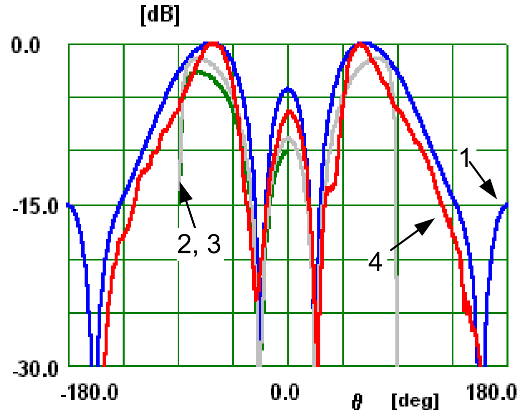

Figure 5 – Radiation pattern of double-layer wideband patch. 1 (blue): WIPL-D; 2 (grey): ENSEMBLE with infinite ground plane; 3 (red): measured. (a) E-plane; (b) H-plane

## 5. Rectangular patch printed on thick substrate

The final example corresponds to a probe-fed square patch with very thick substrate. Actually this large thickness is obtained with a generous air-gap between two thin substrates (see Figure 1d). The 10-dB bandwidth is of the order of 5 %. This structure is not very interesting as an antenna, but it is useful to test the performance of numerical codes for very thick structures. The corresponding radiation patterns are shown in Figure 6, where satisfactory agreement is obtained for all codes. Both for 2.5D and 3D codes, simulated reflection loss curves in Figure 7 agree satisfactorily with measurements.



a)



b)

Figure 6 - Radiation pattern of thick patch. 1 (blue): WIPL-D; 2 (green): IE3D with infinite ground plane; 3 (grey): ENSEMBLE with infinite ground plane; 4 (red): measured. (a) E-plane; (b) H-plane

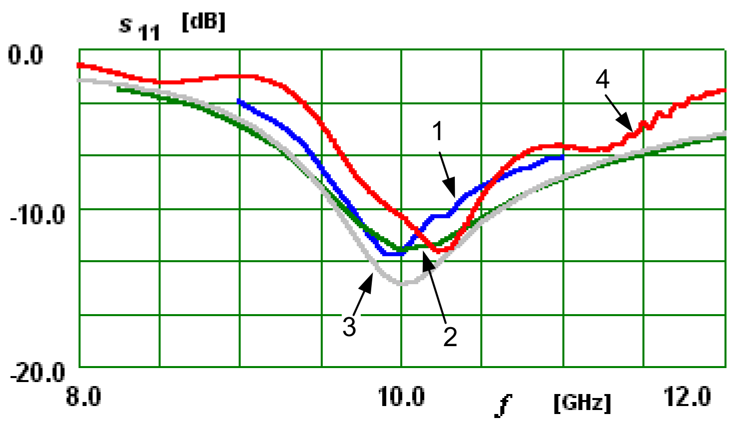



Figure 7 - Return loss of thick patch. 1 (blue): WIPL-D; 2 (green): IE3D with infinite ground plane; 3 (grey): ENSEMBLE with infinite ground plane; 4 (red): measured.

## 6. Discussion and conclusions

Because numeric simulation codes have different degrees of freedom to model a problem, due to different possibilities to represent the object details, the sources, different meshing algorithms, different accuracy options, etc. it is impossible to directly compare the results and rank the codes in absolute scale. In general universal conclusions are not possible.

Table 1 summarizes some key simulation indictors for the tested examples. The set-up time is subjective, and depends decisevely on user experience. As for unknows and computation time, it is important to mention that ENSEMBLE and IE3D results and indicators refer to infinite ground-plane structure, while WIPL-D modelling corresponds to finite ground-plane. It is also important to stress that the coaxial cable in WIPL-D model can be replaced by a basic point-source; for the first structure in Table 1, using the basic source reduces WIPL-D number of unknowns to less than half, without affecting the accuracy of the results. Finite ground plane ENSEMBLE results were also obtained for the first structure: computation time was 6× higher than for the infinite ground-plane case.

Accuracy of the obtained simulated results is satisfactory. In order to improve accuracy it is important that the user can use his judgement to complement the code automatic meshing, for instance. Flexibility of WIPL-D in this aspect can be used with advantage, although at the cost of more time consuming input procedure. Key aspects for accurate printed antenna analysis are the possibility to automatically improve meshing near critical metal edges, and the possibility to chose a meshing for the ground plane that is similar to the meshing used for the patch on the other face of the substrate.

Results show that full 3D codes like WIPL-D can compete with planar antenna dedicated codes in terms of accuracy of the results. Flexibility of general purpose codes can be an advantage to improve the accuracy of the results especially in very complex configurations, but it requires that the user has a strong knowledge of the numerical tool. Set-up time and computation time may be longer.

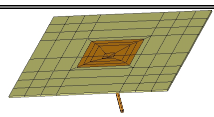
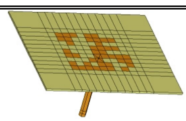
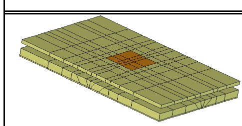
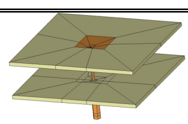
| **Structure** | **Code** | **Setup time [min]** | **Unknowns** | **CPU [s] per freq.** | $\Delta f_o/f_o$ **[%]** | $\Delta s_{11}$ **[dB]** |
|---|---|---|---|---|---|---|
|  | Wipl-D | ±10 | 1050 | 140 | 0.07 | -24 (-27) |
| | IE3D | ±5 | 500 | 6 | 0.2 | -3.5 (-27) |
| | Ensemble | ±5 | 240 | 4 | 0.97 | -38.5 (-27) |
|  | Wipl-D | ±25 | 1714 | 140 | 1.76 | -9.6 (-12) |
| | IE3D | ±15 | | | -0.81 | -3.5 (-12) |
| | Ensemble | ±15 | 220 | 5 | -3.6 | -24.5 (-12) |
|  | Wipl-D | ±25 | 2600 | 1700 | | |
| | IE3D | | | | | |
| | Ensemble | ±10 | 300 | 11 | -5.66 | -27.8 (-19) |
|  | Wipl-D | ±20 | 1950 | 650 | -2.3 | -12.9 (-12.6) |
| | IE3D | ±7 | 729 | 90 | -2.3 | 12.7 (-12.6) |
| | Ensemble | ±7 | 250 | 22 | -2.3 | -14.7 (-12.6) |

Table 1 - Comparison of simulation indicators. Ensemble and IE3D results refer to infinite ground plane structure. WIPL-D results and indicators correspond to finite ground-plane. CPU time refers to a Pentium III @ 450 MHz.

**References**

[1] C. A, Fernandes; C. Salema; M. Silveirinha; "WIPL-D Compared with Theory and Experiment", Proc. ACES - Applied Computational Electromagnetics Society Conference, Monterey, California, pp. 277-284, Mar. 2001.

[2] N. Herscovici; M. F. Osorio, C. Peixeiro; "Minimization of a Rectangular Patch Using Genetic Algorithms", Procs. IEEE Antennas and Propagation Society International Symposium, vol. 4, pp. 34-37, Boston, U.S.A., Jul 2001