WIPL-D in EuCAP Benchmarks

Introduction

In 2012, **European Association on Antennas and Propagation (EuRAAP)** Working Group (WG) on Software and Modeling Tools has continued with the activities on releasing benchmarks, collecting the results and publishing the **comparison of various EM simulation tools**. The particular benchmark was mostly focused to simulation of small antennas, although various benchmark requests were present. The idea behind the effort is to compare the EM tools by giving a chance to use the software for identical problems to the software most competent users – the vendors themselves. The results are periodically published at the **European Conference on Antennas and Propagation (EuCAP)**, and afterwards in **IEEE Antennas and Propagation Magazine**.

The antenna proposed in 2012 was a tri-band GSM antenna, integrated with the coplanar waveguide test board. The effort through several benchmark brought a lot of attention to the matter. In year 2012, the description of the geometry was provided to software vendors. Since the antenna was rather complicated, this brought differences when even substrate was modelled slightly different. The discrepancies between simulated results were significant.

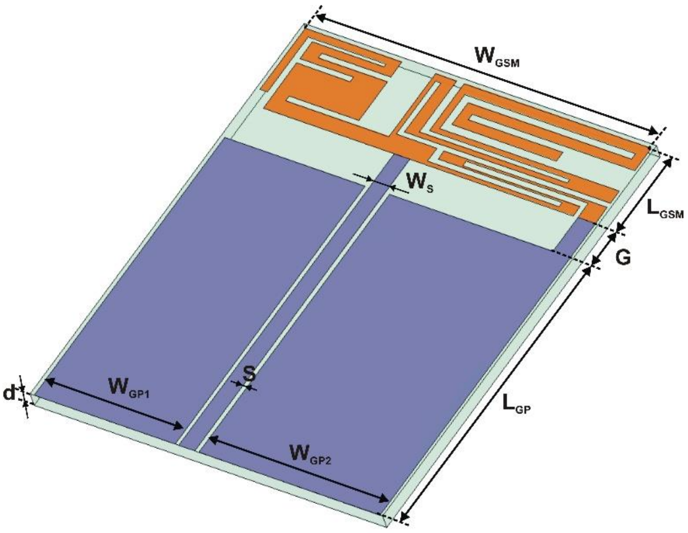


Figure 1. CPW-fed GSM antenna integrated on a test PCB

The proposed structure is the modification of the commercially available Rangestar UltimaTM 'World GSM antenna' (P/N 100709), covering the 3 GSM frequency bands. The frequency band of interest is located between 0.7 GHz and 2 GHz.

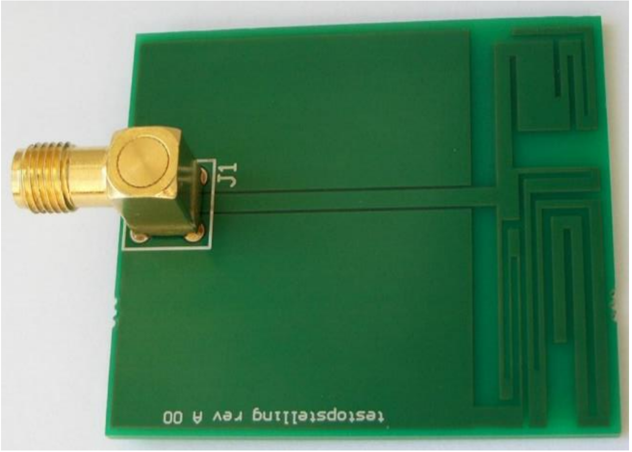


Figure 2. Top view of measured antenna set-up

WIPL-D 2012 Benchmarking

WIPL-D Pro is a general **3D full wave EM solver** based on very efficient implementation of **Method of Moments**. Efficiency of the code is based on usage of higher order basis functions, which allows simulation of structures meshed with quadrilaterals of size up to 2 wavelengths. As such, the code efficiently simulates structures as GSM antenna with large and small mesh elements within one model.

The geometrical structure was imported into WIPL-D software:

- as a text file with a list of nodes (no mesh included) that determines entire geometry of the benchmark,
- the file was provided by benchmark organizers as EXCEL file,
- after that the model was easily redrawn using the WIPL-D Pro GUI, which takes less than 20 minutes for a user with an average experience.

The mesh type is quadrilateral, non-uniform, without constrains for mesh element size, as illustrated in Fig. 3.

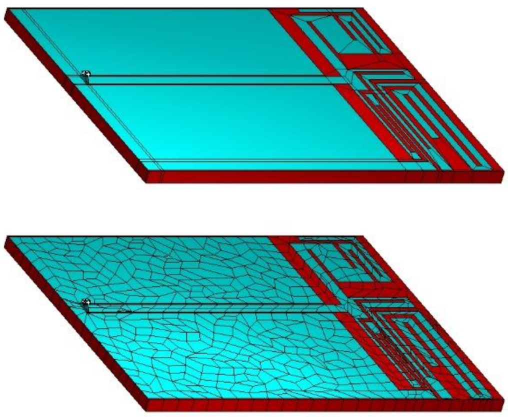


Figure 3. High-order and low-order mesh

WIPL-D Pro does not use any boundary condition and simulates geometry that corresponds to the actual structure, without any approximations. As it becomes obvious from Fig. 1-Fig. 3, the antenna is not symmetric. Accordingly, reduction of the problem complexity by exploiting the symmetry is not applicable. For this particular model, the excitation should be made as close as possible to a real position of the excitation as it is implemented in a real circuit. The code does not invoke infinite layers, but simulates a finite size dielectric layer.

The simulation is performed entirely in the frequency domain. Simulation time is directionally proportional to number of frequency points simulated. **WIPL-D uses powerful algorithm for interpolation based on rational polynomials**. It typically requires several frequency points per resonance (the number varies between 3 and 7). The benchmark requests 71 frequency point for comparing the results.

The WIPL-D simulator does not require air box or calibration line. In addition, WIPL-D does not use any approximation of the geometry provided. The only approximation we have to use is to use approximate feeding zone since the benchmark does not provide any details about the location and the dimensions of the coaxial feeder and connector.

Setting the simulation model and performing convergence test is done quickly. Few repeated simulations by slightly increasing the resources (number of unknowns and quality of numerical integration) are enough to ensure that results for input model are stable and accurate. **Simulation is fast**, even if simulation parameters are such that they provide most accurate results. Computational resources are minimal, **simulation can be performed on regular PC** with quad core CPU and 2 GB of RAM (Intel i7 950 processor (quad core CPU), CPU speed 3.0 GHz).

Simulation time per frequency, calculated as an average value from total time of 319 sec required to simulate 15 frequencies, was ~21 seconds. The results interpolated from 15 frequency points are highly accurate and conform with the benchmark requirement of 71 discrete frequency points. The problem requires 3,800 unknowns, which yields in 110 MB of RAM memory.

The major issue for a benchmark in general is a level of agreement between the simulation and the measurements. Initial simulations were performed using simple trapezoidal feeder typical for WIPL-D modelling (see Figure 4), but the agreement with the measurements was poor. After several additional simulations, it was found that the feeding mechanism has critical influence to the results. However, details described in the benchmark documents were not sufficient to reproduce the feeder structure in a simulation model. In that sense, we carried out a number of simulations to find a feeding mechanism producing the results in closest match with the measurements. We narrowed our final examination to the properties of two possible feeding mechanisms similar to what benchmark description and photos suggest: coaxial feeder and simplified coaxial feeder.

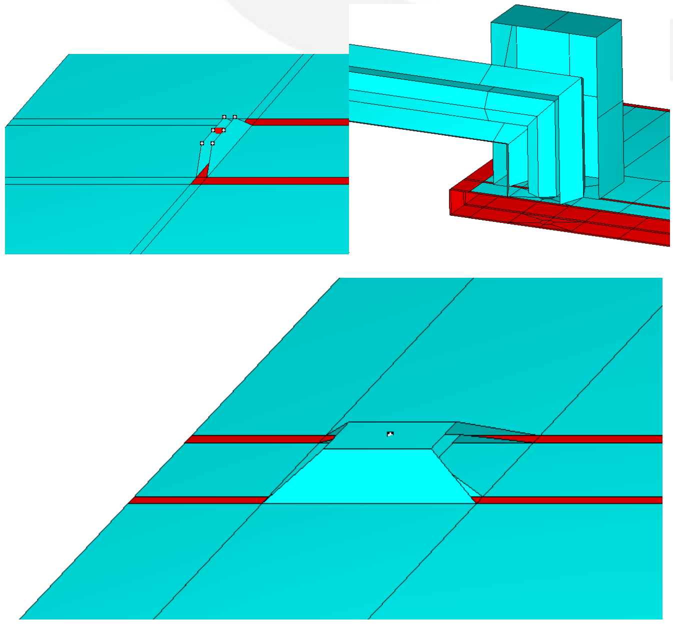
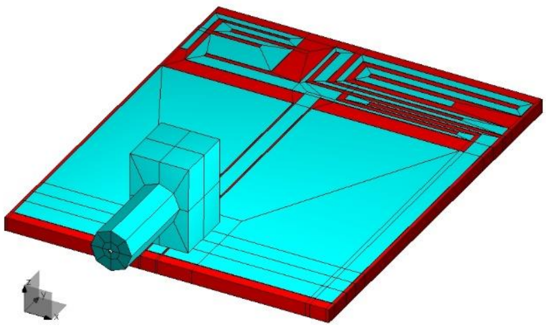


Figure 4. Three feeding mechanisms: simple, coaxial and simplified coax

The two modifications of the feeding mechanism are illustrated in Fig. 4. The modifications cause a change in simulated values for antenna return loss, as presented in Figure 5. It is seen that simplified (coaxial) feeder gives results very similar to coaxial feeder. Hence, we have used this simplified feeder for subsequent simulations.



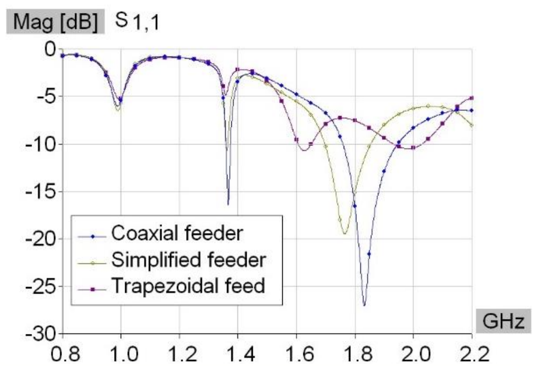


Figure 5. The simulation results with different feeders

Based on measuring distance by using photo of the antenna, we estimated the feeding position as 4.5 mm from end of the waveguide ground. It can be concluded from Fig. 6, where the changes in S_{11} values with varying feeding position between

3 mm and 6 mm are presented, that the exact position of the feed noticeably influences the results.

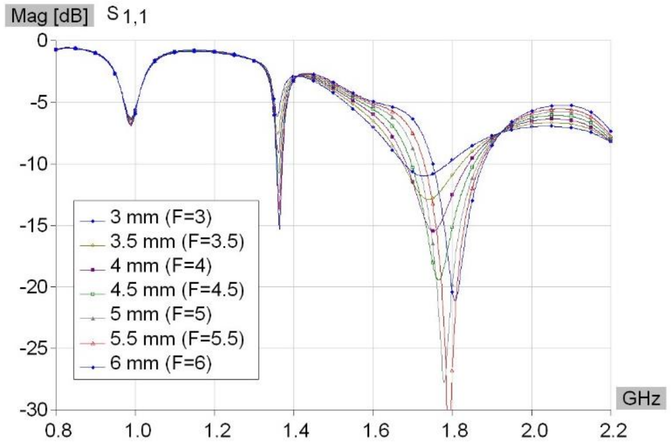
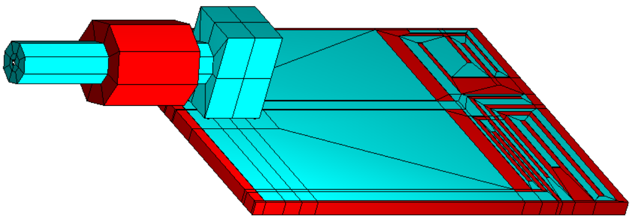


Figure 6. The influence of exact feeder position

WIPL-D team has made some additional efforts trying to achieve better agreement with the measured results. In addition to an influence of the feeding mechanism, we investigated the influence of losses, a presence of chokes described in the measurement setup, a presence of a long coaxial cable near the antenna, addition of a solder mask, and variations of substrate thickness and electrical properties. We found that each of these elements has a certain influence on S_{11}, but we could not substantially improve the agreement with the measurements.



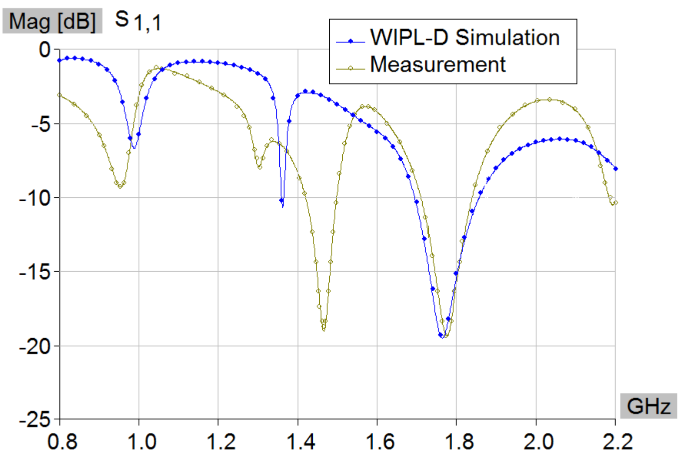


Figure 7. Agreement with the measured data

Benchmark 2013: CAD File

Based on vendor requests and complaints, the benchmark organizers have expanded the details in 2013/2014. Missing information included the specification of the material (FR4 with $\varepsilon_{relative}$ = 4.4 - j0.02). The value of the permittivity has been checked through measurements performed at KU Leuven on a similar substrate. The metallization thickness was: 0.035 mm.

A substrate size has been confirmed by measurements to be 37.6 mm x 46.275 mm instead of 38.7 mm x 45.6 mm used in the previous modeling cycle. Most importantly, geometry has been provided by benchmark organizers in a form of a CAD file. The structure with connector simplified is presented in Fig. 8.

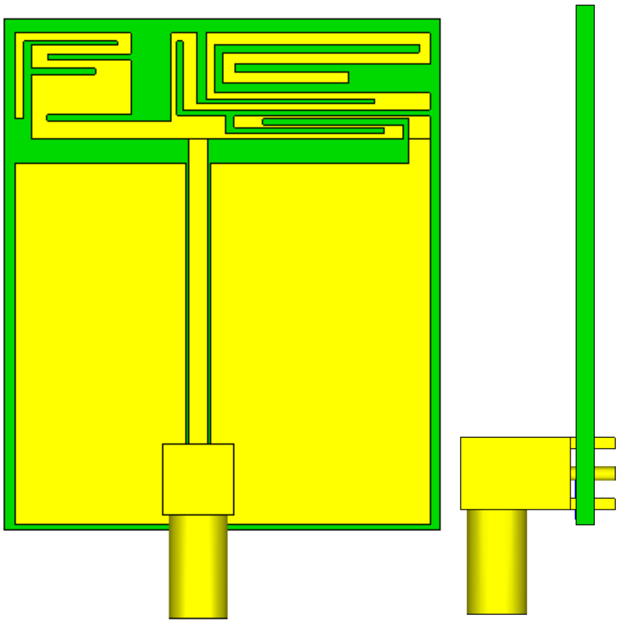


Figure 8. The geometry specified as CAD file

This time, the geometrical structure could be **imported into WIPL-D Pro CAD software as a CAD file** (specifically in ACIS SAT format). It was not inspected for possible errors or inconsistences.

As WIPL-D Pro CAD uses automated mesh and a structure from Fig. 8 has additional elements related to connector/feeder, a number of mesh elements is increased comparing with the original benchmark, and accordingly memory usage and simulation time are also increased.

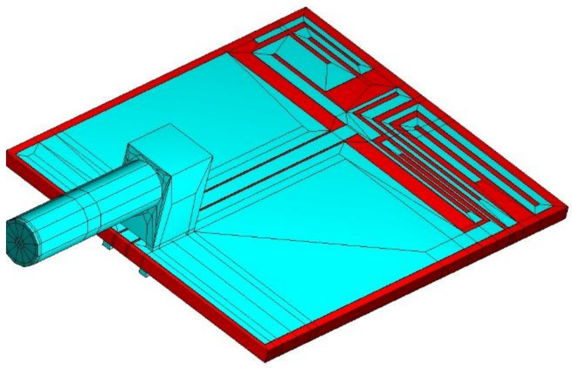


Figure 9. The meshed geometry of the imported antenna

50 Ohms coaxial feed was added and later its influence was de-embedded from the final results

The simulation has been performed on almost the same PC as in the case of previous benchmark, a **regular desktop PC** with the following configuration: single Intel i7 950 processor (quad core CPU), CPU speed 3.0 GHz, 8 GB of RAM memory. The memory resources needed for this problem are negligible.

Simulation time per frequency was ~37 seconds, based on simulation time of 777 sec for 21 frequencies, which is sufficient for accurate interpolation. The problem requires 5,200 unknowns, which translates to the requirement of 206 MB of RAM memory.

Comparing to the first benchmark the results are similar, except in the frequency range corresponding to the 2nd and 3rd resonance. The resonances appear to be slightly deeper and falling further away from the measurements.

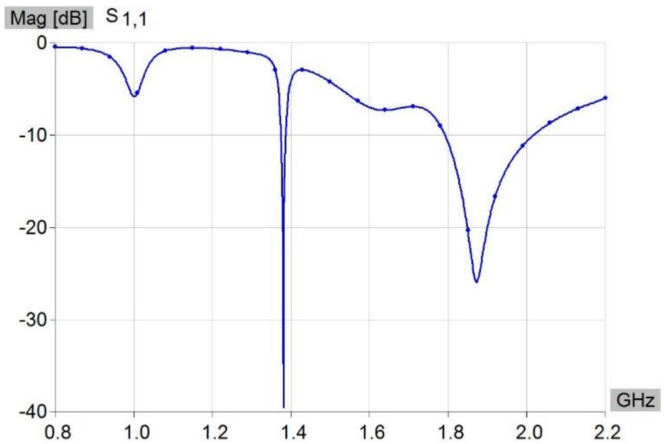


Figure 10. The results in the second benchmark

The benchmark results were presented in EUCAP 2013 and 2014 special sessions (Fig. 11). The results were also **published in AP Magazine**.

G. A. E. Vandenbosch and R. Gillard, “Benchmarking of optimally used commercial software tools for challenging antenna topologies”, IEEE Antennas Propagation Magazine, Vol. 55, No. 3, pp. 281-292, June 2013.

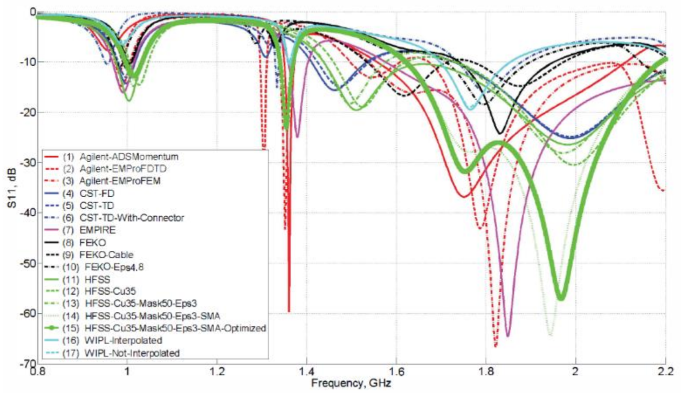


Figure 11. Compared results and vendors photo from the EUCAP 2014 session

In the second benchmark run, a simple flat diamond antenna was the second benchmark problem. The antenna was placed near large dielectric object and huge metallic corner ground (Fig. 12).

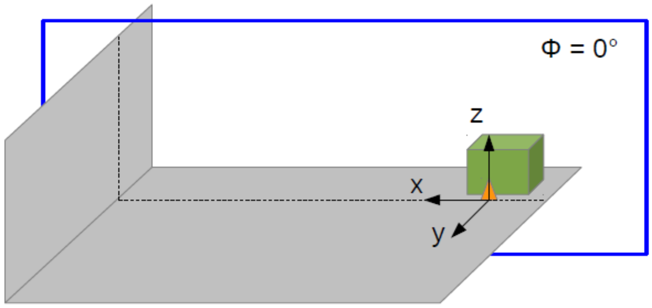


Figure 12. The second part of the benchmark, the diamond antenna

Unlike the benchmark related to CPW-fed GSM antenna integrated on a test PCB, here the agreement between the simulations from all of the vendors and measurements was excellent (Fig. 13).

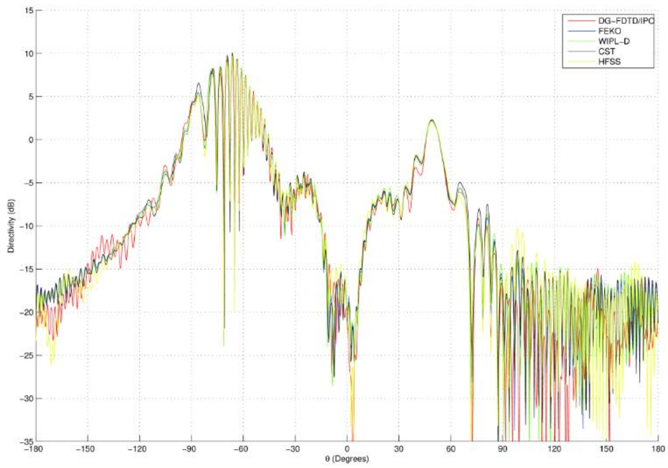


Figure 13. Excellent agreement between vendors in the case of the diamond antenna

Benchmark 2016: Focus to Measured

The efforts were continued in 2016, with several antennas (the reflector, MIMO and GSM antenna). The focus for the GSM antenna was to carry measurements of a single antenna prototype at several labs. The results of extended modeling work together with the measurements from four labs, were **presented in EUCAP 2018 in London**. The idea was to measure and simulate the antenna along with the coaxial cable. The reason for this is simple. This antenna has radiating ground and the current flow exists on the outer shield of the coax (leakage). The easiest way to observe this is to touch by hand or bring close any metallic object to the antenna or its coax cable. This causes a dramatic change of results during a measurement.

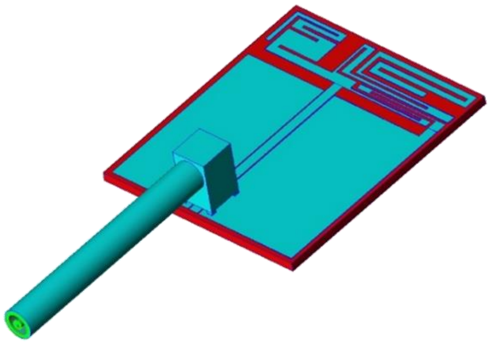


Figure 14. The final antenna structure

Simulation has been again performed on a **standard desktop quad core PC**. It lasts less than 30 seconds per frequency point. With the built-in interpolation applied, the entire simulation takes several minutes. This time, however, simulated results from 9 sources were in a good agreement, measured results from 4 sources were in a good agreement, but there was a large discrepanise between measured and simulated results (Fig. 15).

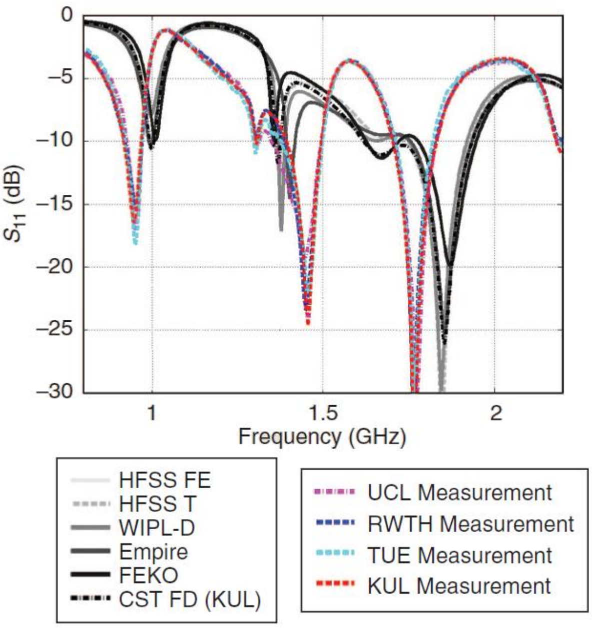
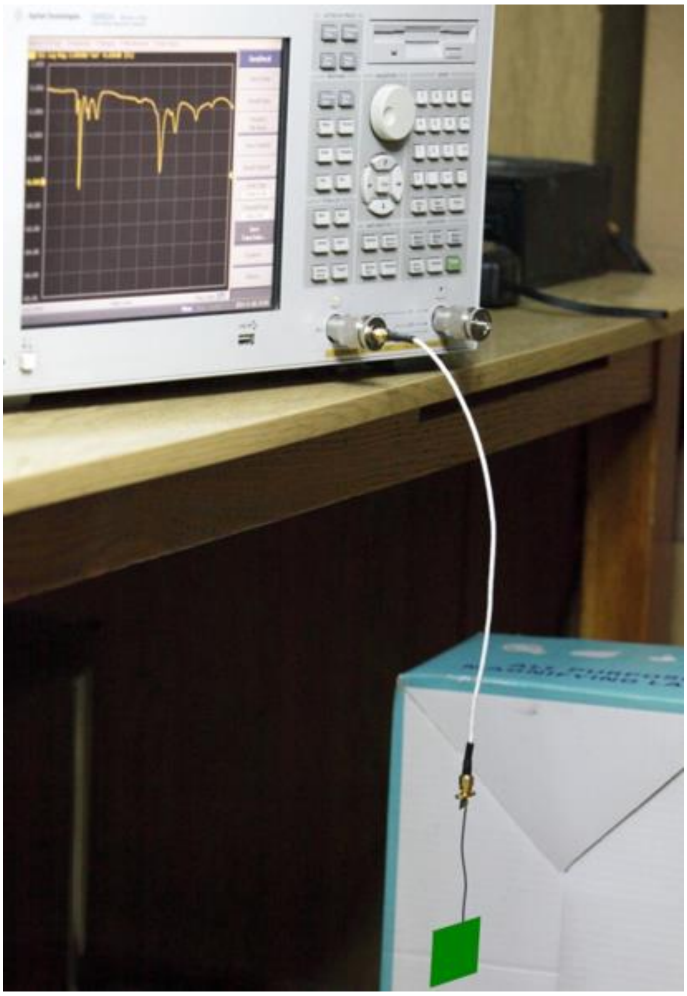


Figure 15. Final agreement between all measured and simulated data

Figure 16. Photo from the session (EUCAP 2018, London)



WIPL-D has made additional efforts to explain the gap between simulation and the measurements. To explain the gap, we have recalled an example of a collaboration from the past. Similarly to the EuCAP benchmark, a printed antenna on FR-4 has been measured using a cable connected to a network analyzer. The measurements were carried out **at School of Electrical Engineering, Belgrade**.

- Results are simulated/measured in the range from 2 MHz to 2 GHz
- Maximum size of scenario greater than 5 λ

- Minimum size of details λ /1,000,000

The measurements and the simulations are not in good agreement and the nature of the discrepancies seems to be very similar to the case of the benchmark example of GSM antenna. However, if the network analyzer housing along with the full length of the coaxial cable is taken into account, the agreement becomes excellent. No ferrites has been included (neither for simulation nor for the measurements). Perhaps the results obtained in the highlightened antenna measurement example point towards the root cause of the discrepancies between the simulation results obtained from the vendors of EM simulators on one side and measurements from four laboratory fascilities, on the other side (Fig. 17 and Fig. 18).

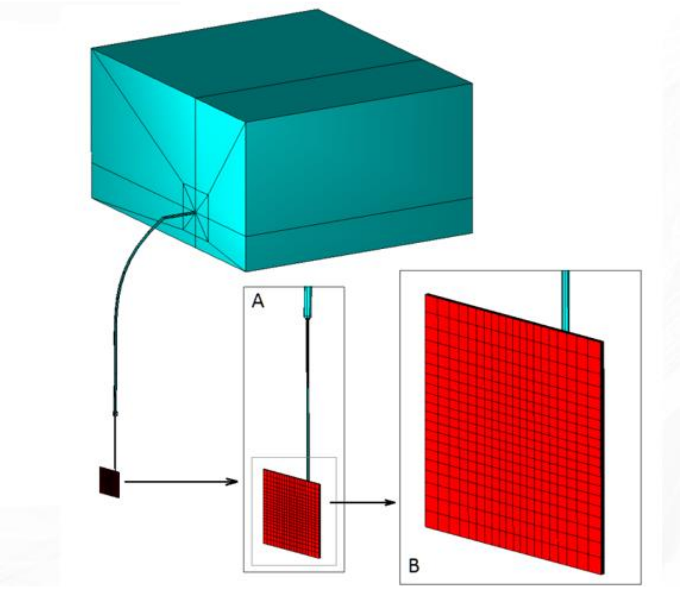
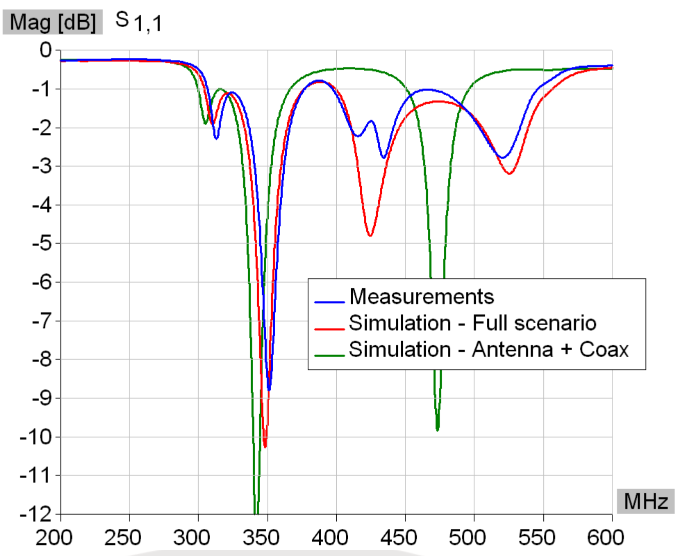


Figure 17. WIPL- D simulation and measurement setup



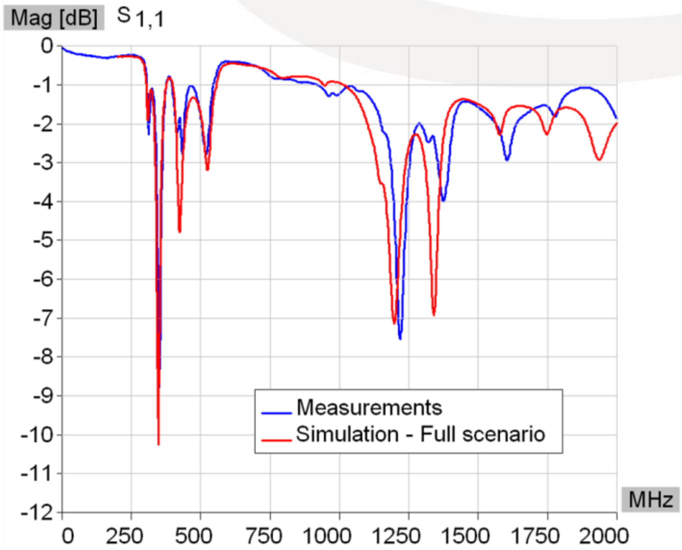
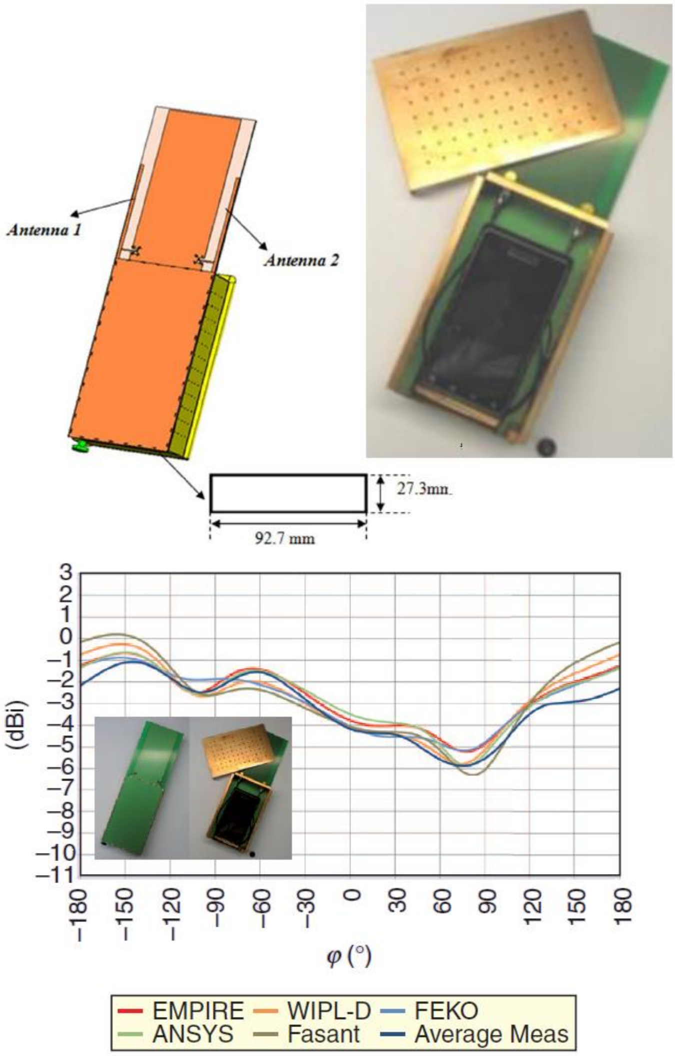


Figure 18. Measurements at School of Electrical Engineering

The part of the 2016 benchmark were the MIMO antenna, as well as the reflector with realistic horn, but the agreements were much easier (Fig. 19).



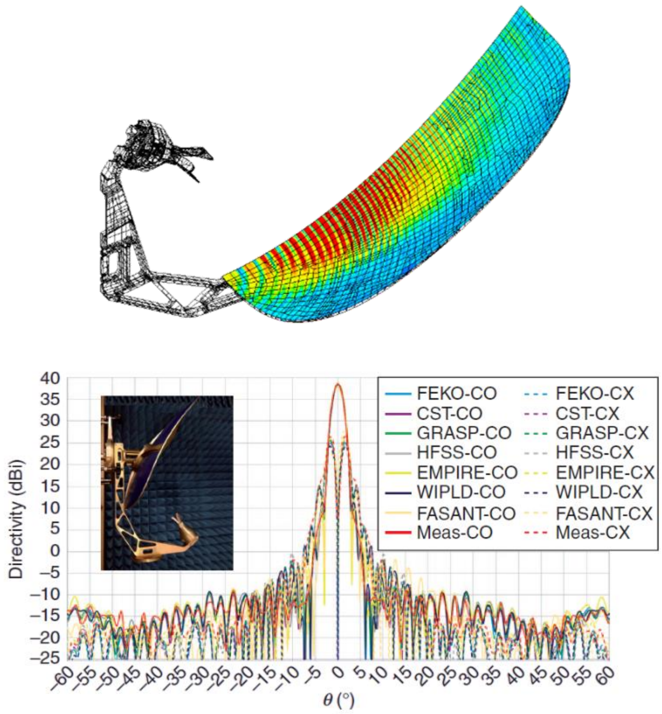


Figure 19. Two additional benchmarks in the 2016 run

Conclusion

This application note presents the most significant part of the WIPL-D participation of the convened session of the **European Association on Antennas and Propagation (EuRAAP)** Working Group (WG) on Software. The results were continually presented in the **European Conference on Antennas and Propagation (EuCAP)** in the period 2012-2018.

The results were in the last stage (2016-2018) **compared to the measured data** obtained in cooperation with the EuRAAP WG on Measurements. The effort integrated software and measurements that were performed by experts (vendors of measurement equipment).

Traditionally, a report on benchmark activities is **published in IEEE Antennas and Propagation Magazine**.

WIPL-D participated in each run, contributing results, ideas for improvements, trying to achieve better agreement between the results etc.

At the end, the organizers present an exceptional understanding of how far benchmarking can bring the EM community. **Several software tools correlate quite well when they are analyzing exactly the same structure**, including a full analysis of the complete connector topology (in the case of the most demanding structure, the GSM antenna).

Several structures were presented. **In most cases, the agreement between the simulated results was quite well**. **The agreement was quite good between the simulated and the measured data.** Through the entire benchmark, the most demanding was the simulation and measurement of the tri band GSM antenna. All the efforts done in this area has improved the cooperation in the EM community and lead to the increased capabilities to compare the simulated and the measured data between different institutions. This can be seen by the easiness shown in comparing the results even for the most complicated structures. However, the agreement on the GSM antenna remained the most challenging task through the entire benchmark activity.