FDTD simulations in antenna impedance calculation

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Abstract

The feasibility of FDTD simulations for the investigation of characteristics of dual-resonant stacked patch antennas at 2 GHz was studied. The complex impedance characteristics were obtained with reasonably good agreement with the measurements. The agreement of radiation pattern results was also good.

1. Introduction

In this paper the feasibility of an FDTD program was studied for simulation of the impedance and radiation pattern of dual resonant patch antennas. Regarding the simulations, dual-resonant antennas are demanding due to their complicated impedance characteristics. Thus also the evaluation of the feasibility of simulations is not straightforward and a careful comparison of the complex impedance as a function of frequency should be performed.

2. Antenna structure

The antenna was designed for the 2154 MHz center frequency and for ±50 MHz bandwidth (with return loss $L_{ret} > 10$ dB). The polarization isolation was planned to be comparable with other antennas designed for good polarization isolation,

The antenna was made of two half-wave patches on top of each other above the ground plate, Figure 1. called stacked patch antenna [3]. The patches were made of 0.5 mm thick copper plate. The dimension of the lower patch d_1 = 60 mm, and the dimension of upper patch d_2 = 54 mm. The lower patch is connected to two probe feeds through an 1pF matching chip capacitor. The ground plate dimensions are 100x100 mm^2. Lower patch is 2 mm above the ground plate and the upper patch is 5 mm above the upper plate and 7.5 mm above ground plate because of the 0.5 mm thickness of the lower plate.

The simulated antenna had otherwise same dimension except the top plate (d_2) was 56 mm, since it gave more similar results to the measured ones than the 54 mm size. It is still within the accuracy of the FDTD simulator at 1 mm voxel cube and the prototyping tolerance of ±0.5 mm.

The voxel size in the simulations was $\lambda/140$ in order to achieve accurate impedance estimations. A simple line feed [1] was used.

The program does not calculate the coupling between two antennas (S21) automatically. Therefore a 50Ω line resistor was used as a load in the receiving antenna feed when calculating the coupling between antenna feeds. Prototypes were built and measured to verify the simulation results [2].

The program has absorbing boundaries for free space calculations. A 10 cell margin was used in the horizontal dimensions and 20 cell margin in vertical directions resulting in a 120x120x50 cell grid.

The parameters for the simulation were set in the following way: The material in the simulator representing the copper of the prototype is perfect electric conductor. The use copper as the material in the model did not make any real difference in the results, it only slowed down the calculations. The excitation is a line excitation between the bottom end of the feed probe and the ground surface. The load corresponds to a vertical (z-directional) line made of a σ = 20 S/m material. In the 1 mm grid the length of the load is 1 mm and the cross-section is 1 mm^2, which results to a 50Ω resistance. The load is in the corresponding place as the excitation (line feed) in the transmitting antenna: one end connected to the bottom end of the probe and the other end connected to the surface of the ground plane.

The voxel cube size is 1mm which corresponds the design unit of the prototype. The calculation consists of a 32 timesteps wide Gaussian pulse in order to get wideband impedance calculation for the frequencies between 0.1...30GHz. In order to get impedance values at relatively small frequency intervals (7.5 MHz), a relatively high number (8000) of iteration steps were used. Short frequency intervals are needed to see the double resonance in the output. The FDTD grid pattern representation is in Figure 2.

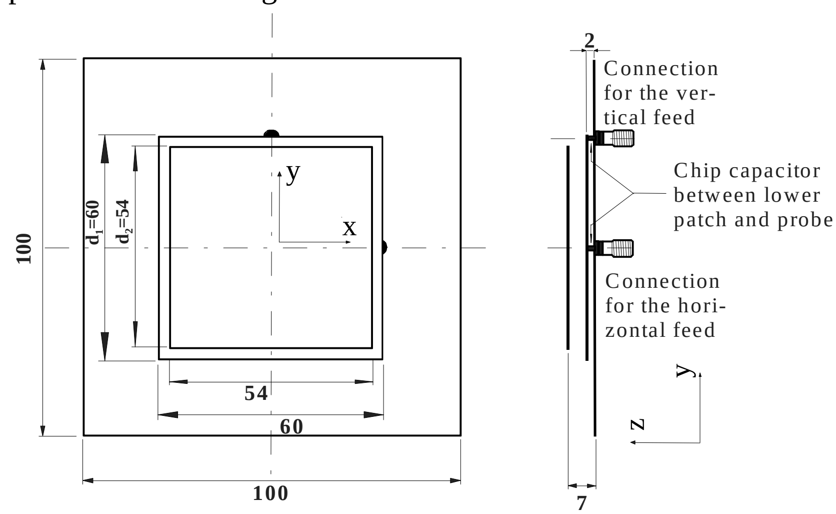

Figure 1. The dimensions of the antenna (in mm) The active feed in the simulations and measurements here is on the y-axis in the radiation pattern plots. Therefore the E-plane is in yz-plane, and the H-plane is in xz-plane. The angle is the deviation from the z-axis, and the angle is positive towards the positive y-direction in E-plane and towards the positive x-direction in H-plane.

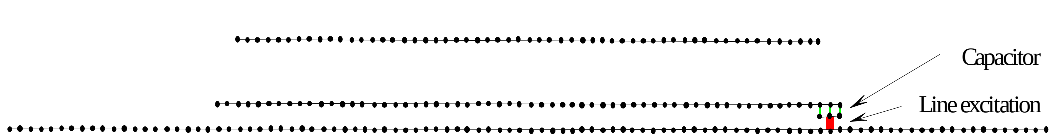

Figure 2. The FDTD grid pattern. The figure is a cross-section cut along the central y-directional line. The ground plate is only partially shown. The black lines represent y-directional PEC lines and the dots represent the x-directional PEC lines. The green lines represent the insulator in the capacitor, ε_r = 30, length of capacitor edge 2 mm. C = 1.1 pF. The grid is 1 mm.

3. Impedance matching

The reflection coefficient in Figure 3 shows that the antennas are similar both in measured and simulated cases. The center frequency is about the same. The measured 10 dB bandwidth is wider (10%) than the simulated bandwidth (4.8%). The curves have also different shapes but it turned out it is unwarranted to draw conclusions based on the reflection coefficient only.

Comparing the complex impedances shows much more similarity, especially when the effect of the position of the reference plane is eliminated, Figure 4.

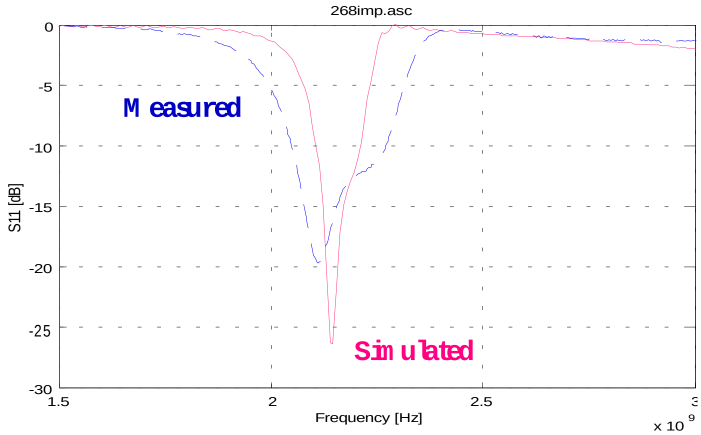

Figure 3. Reflection coefficient.

3.1 Impedance on Smith chart

When the impedance is shown on a Smith chart, it reveals the form of the double resonance of this type of antenna, both in the measured and the simulated impedance with the same frequency sweep. The small circle in the center in the chart is the 10 dB return loss circle. The impedance plot should reside inside the -10 dB return loss circle in order to achieve the widest bandwidth fulfilling the criterion of 10 dB return loss.

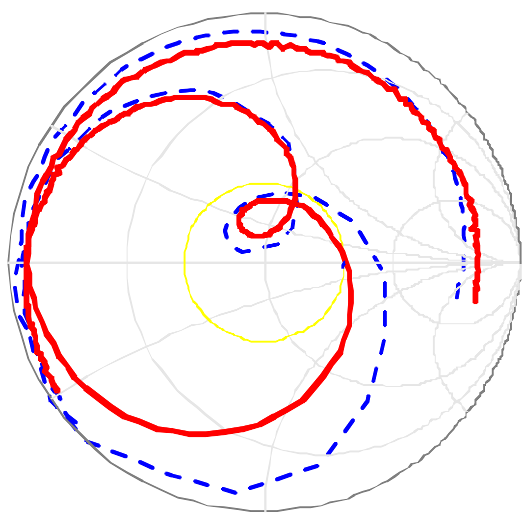

Figure 4. Simulated impedance between 1442...3867 MHz on Smith chart (dotted line). Measured impedance between 1500 ...3000 MHz on Smith chart. The inner circle is the 10dB return loss limit.

The reference plane of the simulation was moved $0.143 \cdot \lambda$ towards the generator so that the simulated and measured impedance are positioned having the measured loop completely inside the simulated loop. The SMA connector (with Teflon insulation) used in the measurement corresponds $0.107 \cdot \lambda$ rotation. From Figure 4 one can see that the measurement and the simulation agree very well in the shape of the impedance curve. The small differences are caused by prototyping tolerances and the simplifications made in the simulation model, and the model voxel size.

Although the simulated results are not exactly same as measured, it was shown that the simulations are useful for supporting the design process of the antenna. The simulated results predict the changes of the antenna properties reasonably well when antenna dimensions are varied.

3.2 Radiation pattern in H-plane and cross-polar isolation

If there are problems in the cross-polarization separation, it will be most apparent in the H-plane radiation pattern. Therefore only the H-plane radiation pattern is shown here, Figure 5 and Figure 6.

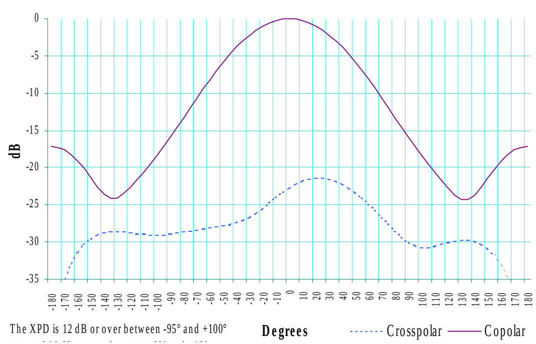

Figure 5. Simulated radiation pattern of the stacked patch antenna, H-plane. Normalized dB-scale. The simulation included the 50 Ω load at the second feed.

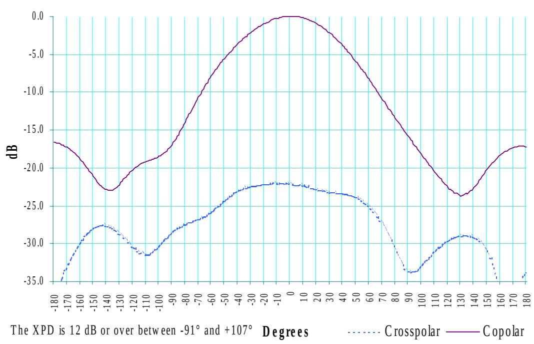

Figure 6. Measured radiation pattern of the stacked patch antenna, H-plane. Normalized dB-scale. The measurement included the 50 Ω load at the second feed.

The isolation between feed ports in the same antenna patch $|S_{21}|$ (inverse of cross-polarization isolation XPI) was measured and it was 21dB at 2154 MHz. The simulated XPI was 21.4 dB, when using sinusoid excitation at 2154 MHz.

4. Conclusions

The similarity of the measurements and simulations is apparent when complex impedance curves are compared, in spite of the limited geometrical characteristics of the FDTD software used. FDTD is useful when designing prototypes and when evaluating the effect of changes in the design before modifying the prototype.

5. References

[1] P. Koivisto, “Comparison of Measured and FDTD Calculated Distortions of Antenna Radiation Patterns due to Nearby Boards”, *Journal of Electromagnetic Waves and Applications,* Vol. 12, No 12, 1998, pp.1679-1699

[2] V. Voipio, *“Wideband Patch Antenna Array Techniques for Mobile Communications,”* Licentiate thesis, Helsinki University of Technology, 23rd November 1998, 109 pp.

[3] D.M. Pozar, D.H. Schaubert (editors), *Microstrip Antennas*, New York, NJ, IEEE Press, 1995, 431p.