

Dr. Christoph Kienmayer
office@pidso.com
**PIDSO - Propagation Ideas
& Solutions GmbH**



Dr. Christian Römelsberger
croemelsberger@cadfem.de
CADFEM GmbH

HIGH FREQUENCY SIMULATION

ANSYS and optiSLang were applied to optimize the geometry of different antenna types concerning resonance, interference and impedance behavior.

High frequency electromagnetics is concerned with the propagation of waves. In free space, electromagnetic excitations propagate with 300,000 km/s, the speed of light. For this reason, a wave length can be associated with a certain electromagnetic wave of a given frequency. For example, in a vacuum, the wave length at 1 GHz is 30 cm. Wave phenomena are only relevant if the considered structure has a size which is comparable to the wave length. For typical radio frequency (RF) applications, this implies that high frequency starts at the MHz to GHz range.

There are many high frequency applications in daily life. Most of them are concerned with the transfer and processing of information. However, there are also applications in radar technology, in medical imaging applications, as well as in microwave heating.

Field and circuit simulation

Electromagnetic waves, like radio waves, can propagate freely in space. But they can also be bound to conductors or waveguides as in coaxial cables or on micro strip lines. An antenna is a passive device that converts guided into free waves or vice versa. However, in the designing process of printed circuit boards or connectors, the goal is to prevent the signal from scattering off imperfections which would cause undesirable effects like reflections, cross talk or radiated emissions. In order to deal with such issues, ANSYS developed the Electromagnetics Suite containing industry standard field and circuit simulators. In this article, a special focus is placed on ANSYS HFSS as an all-purpose, three dimensional high frequency field simulator. This fully parametric simulation environment combined with automatic adaptive meshing can be used for robust design optimization of RF systems. The adaptive meshing

process ensures the desired solution accuracy for any required result, like impedances or scattering parameters. In this way Ansys HFSS eliminates numerical noise due to the meshing process.

Most RF applications are use effects like resonance, interference and matching of impedances as functioning principles:

1. For example, an antenna operating at resonance generates large currents on its structure while it is driven with a small input signal. The large currents produce electromagnetic fields which propagate into free space. The resonance on the antenna can also be seen as a standing wave. On a dipole antenna, the wave length of the standing wave is twice the length of the dipole. This describes the relation between the size of the antenna and the frequency of operation.

2. In the case of a microwave cavity filter, all three principles can be clearly observed. The filter has to have the appropriate number of resonances in the pass band, the coupling impedances between the different cavity resonators have to be chosen appropriately, as predicted in the ideal prototype filter and the structure of pass- and stop bands is due to constructive and destructive interferences between the reflected and transmitted waves of the different cavities.

As demonstrated above, the scattering parameters (S-parameters) or impedances represent important values to quantify the functioning principles mentioned above. They also can be used for a robust design optimization of RF components.

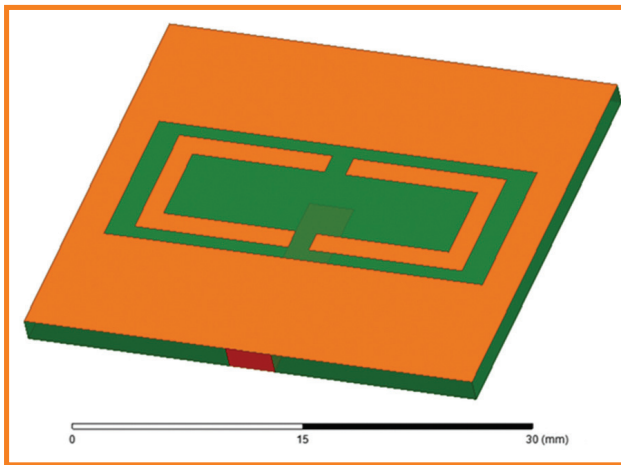


Fig. 1: Geometry of a dual band slot antenna

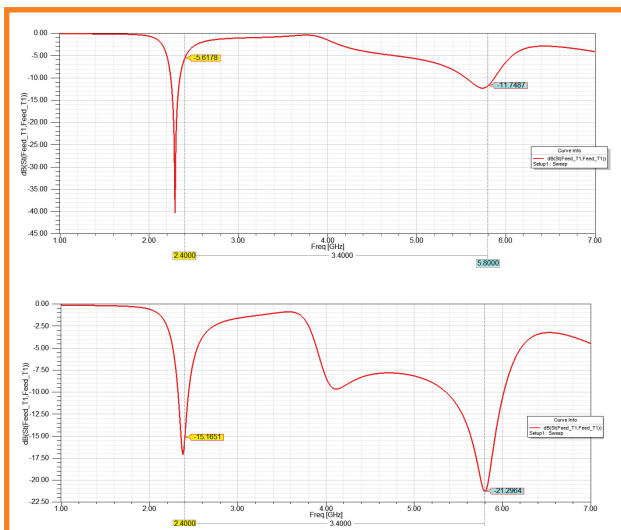


Fig. 2: Return loss of initial design (top) and optimized design (bottom)

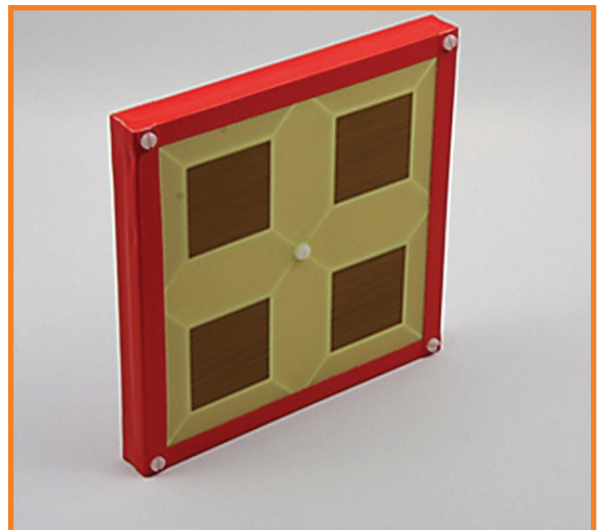


Fig. 3: The antenna array is used for directional data transmission

Examples

Optimization of a dual band antenna

A dual band antenna works at two frequency bands. In figure 1, the geometry of a dual band slot antenna is shown. The return loss (see fig. 2) of the initial design already had two minima with one close to 2.4GHz and the other close to 5.8GHz. However, the first value was not at the right position and very sharp. The second minima was with -12dB not deep enough. To improve the design, an optimization using optiSLang was conducted. Afterwards, both minima were in the right position and well below -15dB (see fig.3).

The production of printed antennas involves many uncertainties concerning the electric material properties of substrates, like FR4 and, of course, there are tolerances in the process of fabricating a printed circuit board (PCB). A robustness analysis of the design using optiSLang quantifies the maximum allowed tolerances and provides a profound understanding useful for appropriate decision making concerning cost versus accuracy issues and material quality management.

Optimization of a 2x2 antenna array

In cooperation with the Austrian antenna manufacturer PIDSO, a 2x2 antenna array was analyzed (fig. 4), which is used for focused signal transmission towards moving objects (tracking). In order to track objects, the antenna array was installed on a gimbal. A four-port hybrid coupler was integrated for transforming four output signals into composite ones for signal transmission as well as differential ones for tracking. An incident wave that is received at an angle by the antenna array causes phase-shifted signals at the patch antennas. Here,

the hybrid coupler should use constructive and destructive interference to generate sum and differential signals. The edge length of the hybrid coupler is approximately a quarter wave length. The S-matrix for the transmission behavior of the coupler from input to output ports has to satisfy the relation which is the phase relation describing the interference.

$$S_{\text{Out,In}} \sim \begin{pmatrix} i & 1 & i & 1 \\ 1 & i & 1 & i \\ -i & 1 & i & -1 \\ -1 & i & 1 & -i \end{pmatrix}$$

To adapt the coupler to a given frequency, the geometry had to be parameterized. Due to the geometry's symmetry, five edge lengths, one angle as well as the position of the parallelogram in regard to the rectangles, were considered (fig. 5). The field simulation of the parameterized structure at the given frequency was performed with ANSYS HFSS. The aim of the optimization using optiSLang was to minimize the mean square deviation between the real coupler S-matrix and the ideal one adapted by a corresponding multiplicative (complex) constant. Moreover, the return loss of the sum port should be less than -12dB. The sensitivity analysis using optiSLang revealed that six of the seven parameters have significant influence on the two target parameters. An optimization applying an adaptive response surface method resulted in a sufficient geometry after running an overnight computation.

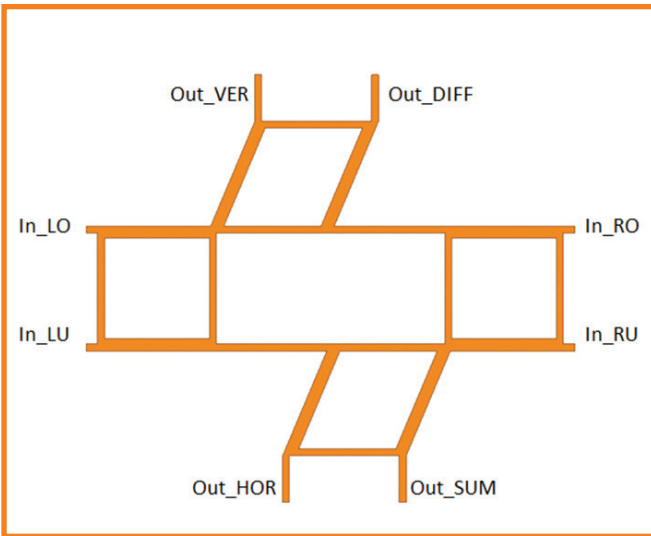


Fig. 4: The edges of the hybrid coupler are approx. one-quarter wavelength

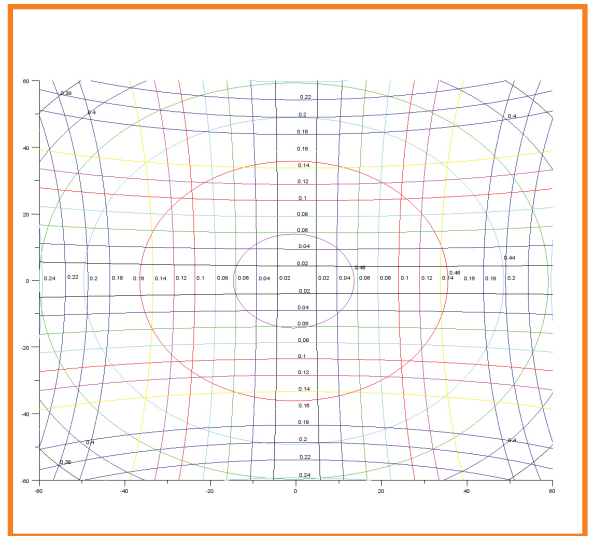


Fig. 5: The contour plot indicates the high quality of the optimization

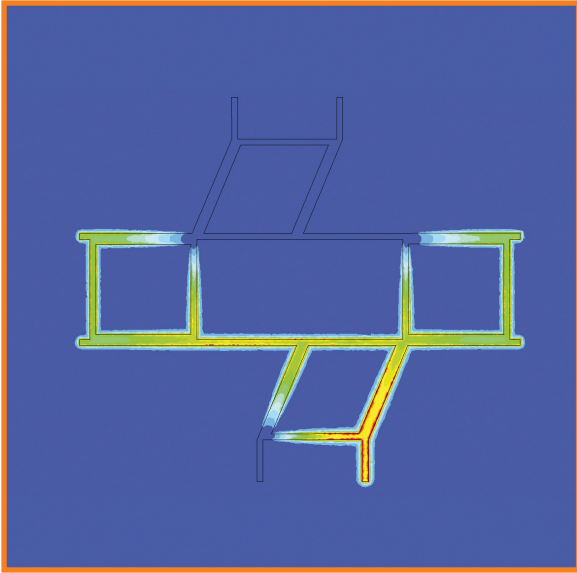


Fig. 6: The signals emitted from the antenna patches hardly reach the differential ports

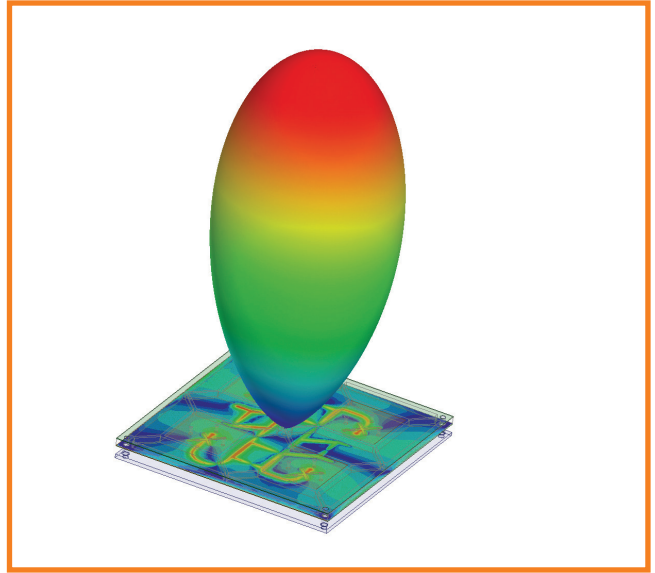


Fig. 7: Field simulation of the entirely assembled antenna

The plot (fig. 6) of the output signals at the sum port as well as at the horizontal and vertical differential ports show the high optimization quality. The contours of horizontal and vertical differential signals form a rectangular coordinate system across a large angular range. It additionally indicates that the sum signal hardly depends on the phase differences. Figure 7 shows the electric field strength displaying that there is hardly any reception at the differential ports of the hybrid coupler if the waves propagate vertically at the antenna patches. A further step towards the entire design of the antenna is the connection of the hybrid coupler to the antenna array via a microstrip line. For this purpose, a circuit simulation is conducted with ANSYS designer. Here, for example, the difference in length of the microstrip lines and the capacity for feed adaption of the patch antennas could be used as input parameters. Then, the gain of the antenna in vertical direction can be applied and optimized via the dynamic link between ANSYS designer and HFSS.

Finally, after reassembling the entire antenna, a field simulation had to be conducted (fig. 8). The necessary geometry was derived from the result of the circuit simulation. By this approach, the design process was accelerated significantly. In further steps, ANSYS combined with optiSLang also allowed to analyze the robustness of designs exposed to other physical influences.

Title Images: © julvil-Fotolia

Legends

Fig. 1: geometry of a dual band slot antenna

Fig. 2a: return loss of the initial design

Fig. 2b: return loss of the optimized design

Fig. 3: The antenna array is used for directional signal transmission

Fig. 4: The edges of the hybrid coupler are approximately one-quarter wavelength

Fig. 5: The contour plot indicates the high quality of the optimization

Fig. 6: The signals emitted from the antenna patches hardly reach the differential ports

Fig. 7: Field simulation of the entirely assembled antenna