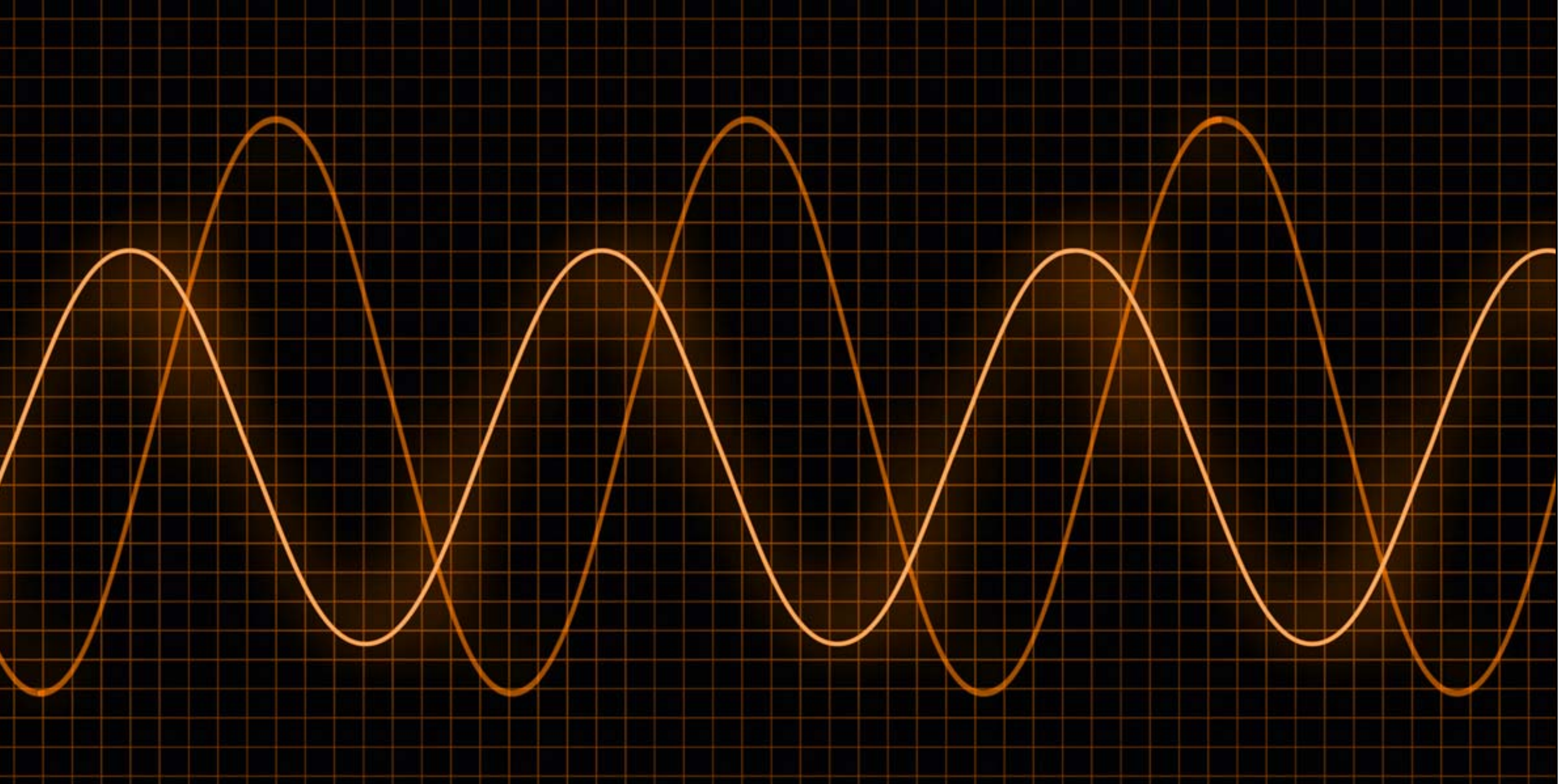

CUSTOMER STORY // ELECTRICAL ENGINEERING

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 specific 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 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. 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) and impedances represent important values to quantify the functioning principles mentioned above. They also can be used for a robust design optimization of RF components.

Examples

Optimization of a dual band antenna

A dual band antenna works at two frequency bands. In Fig. 1, the geometry of a dual band slot antenna is shown. The return loss (see Fig. 2 top) of the initial design already had two resonances with one close to 2.4GHz and the other close to 5.8GHz. However, the first value was not at the right position and was very sharp. The second minima at -12dB shows a rather poor matching performance. To improve the design, an optimization using optiSLang was conducted. Afterwards, both minima were in the right position, well below -15dB (see Fig. 2 bottom) and also showed an extended bandwidth. 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.

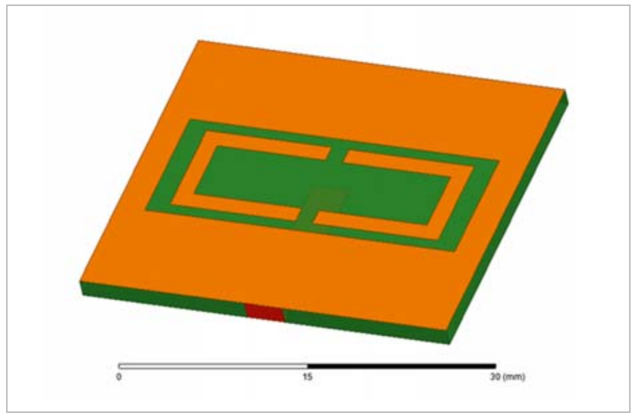

Fig. 1: Geometry of a dual band slot antenna

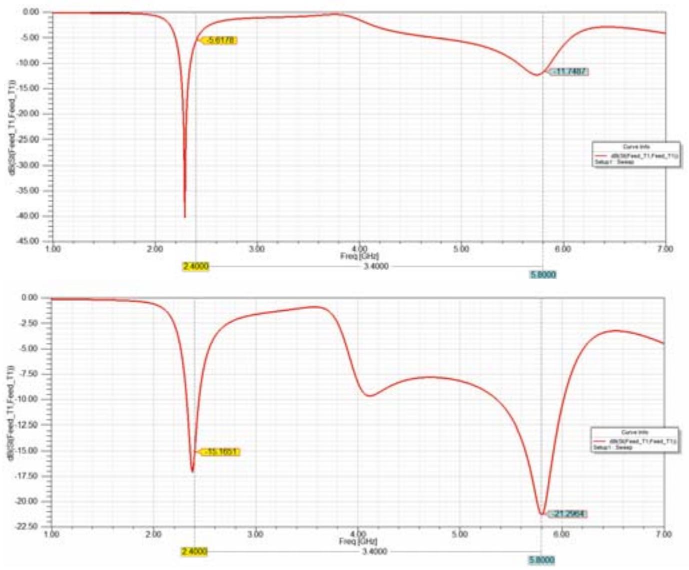

Fig. 2: Return loss of initial design (top) and optimized design (bottom)

Return loss optimization of a 2x2 antenna array

In cooperation with the Austrian antenna manufacturer PIDSO, a 2x2 antenna array was analyzed (Fig. 3), which is used for high-gain, line-of-sight data transmission towards moving objects (tracking). In order to track objects, the antenna array was installed on a gimbal assembly. 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 following relation describing the interference.

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

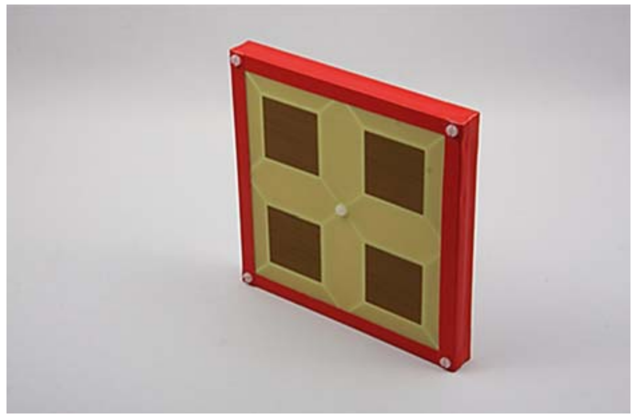

Fig. 3: The antenna array is used for directional data transmission

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. 4). 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. The plot (Fig. 5) 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. Fig. 6 shows the electric field strength distribution displaying that there is hardly any reception at the differential ports of the hybrid coupler if the waves arrive orthogonal 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 stub capacity for feed tuning of the patch antennas could be used as input parameters. Then, the gain plot of the antenna assembly can be simulated and optimized via the dynamic link between ANSYS designer and HFSS.

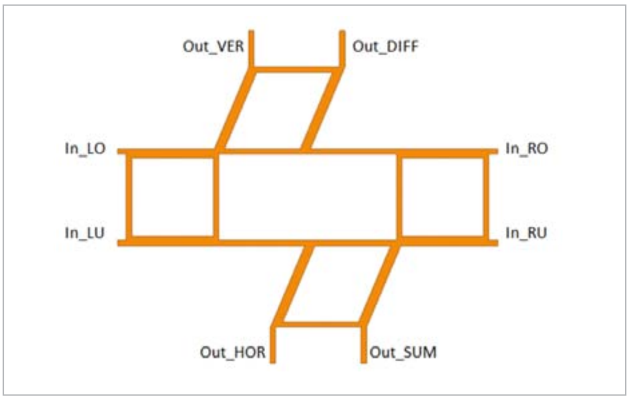

Fig. 4: The edges of the hybrid coupler are approx. one-quarter wavelength

Finally, after reassembling the entire antenna, a field simulation had to be conducted (Fig. 7). 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.

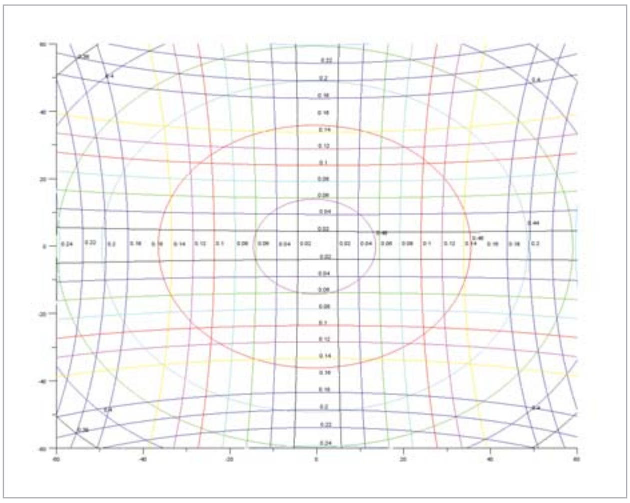

Fig. 5: The contour plot indicates the high quality of the optimization

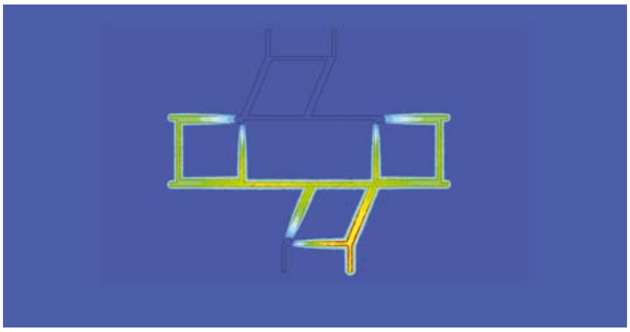

Fig. 6: The signals emitted from the antenna patches hardly reach the differential ports

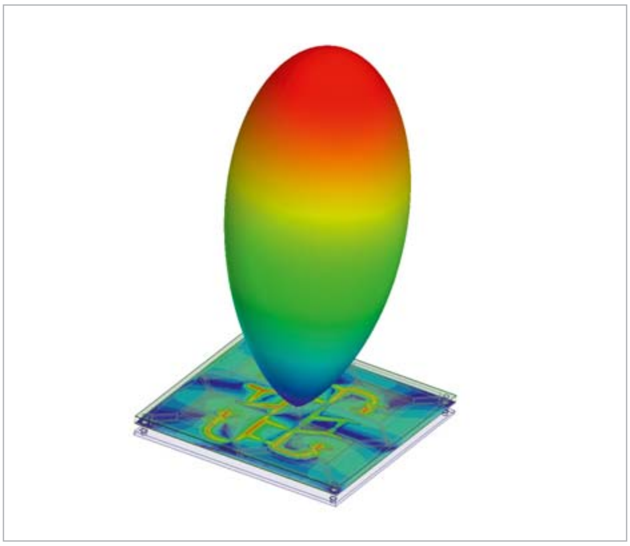

Fig. 7: Field simulation of the entirely assembled antenna

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