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Optimization of a Dual-Band-Antenna using Statistics on Structures (SoS)

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Abstract
With the advancement of the IoT (internet of things) miniaturization of wireless devices is very important. These devices are communicating in different frequency bands. One way of saving space is the use of multiple band antennas. The design of multiple band antennas is a task of reverse engineering in which the resonances of the antenna structure are tuned to given center frequencies.
In this presentation it is shown how SoS (Statistics on Structures) can be used to generate a field meta model of optimal prognosis for the frequency response of the return loss. This field meta model is used to optimize the antenna with no additional solver runs. Also, this procedure allows to re-define scalar optimization criteria, after the DOE (Design of Experiment) has been calculated, by extracting quantities like the position and width of minima from the field meta model for the full frequency response. This allows for a lot of flexibility during the process of optimization.

It is expected that by 2020 there will be about 20,000,000,000 devices connected to the internet. They will be in many different areas of application: household, cars, industrial facilities, medical devices, consumer goods and many more. Many of those devices should be wireless in order to be mobile or in order to make it easier to set up an infrastructure of connected devices. Furthermore, those devices should operate on various frequency bands to have different communication channels and on top of this many devices should be small, especially wearable devices. Those partly conflicting design requirements pose big challenges to antenna engineers. Multiple band antennas [1] are one possibility to tackle this task.
However, the design of multiple band antennas is not straight forward: A structure has to be found that has several resonances, one at each of the desired center frequencies. Furthermore, those resonances have to be of the right width and the radiation pattern has to be of the desired shape.
Numerical simulation is of great help for this kind of task, it allows predicting the product performance using a virtual prototype in a very fast and efficient way. This enables a strategy of fast design variation and makes such design tasks feasible! Another enabler is the automated parametric variation: In order to meet the various design goals of having the right center frequencies, the antenna geometry needs to have enough free parameters that can be adjusted. For example the resonance frequencies of a dipole antenna have a fixed relation, the first resonance is at $\lambda/2$, the second at $3\lambda/2$ etc. and the antenna also only has one relevant parameter, the dipole length. For this reason parametric models of multiband antennas should have several geometric parameters.
To be specific, we focus in this paper on the dual band slot antenna shown in figure 1 [1], the desired center frequencies are at 2.4GHz and at 5.8GHz where the return loss should be at least -18dB.

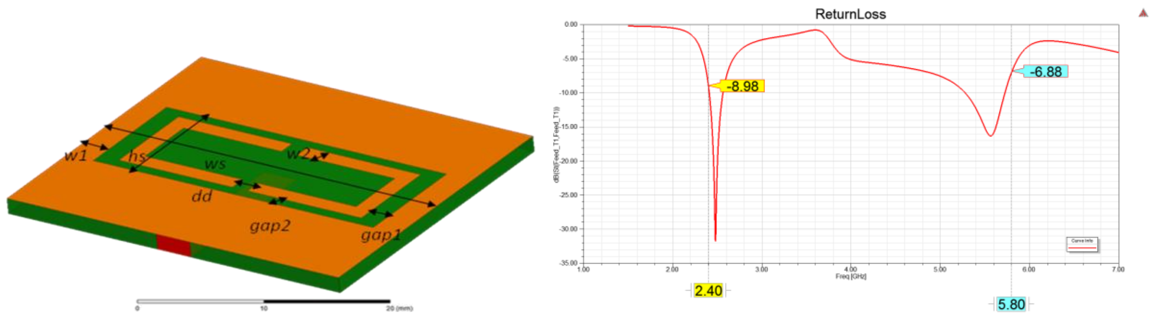

Figure 1: The dual band slot antenna under consideration is parameterized by 8 parameters, the 7 parameters depicted on the left together with the feed length. The return loss at some arbitrary parameter values shows two resonances.

ANSYS HFSS is a tool which is very well suited for this parametric simulation:

- It has a frequency domain solver which has proven to be very efficient for antenna simulation.
- The finite element method uses a conformal mesh which allows for an optimum compromise between geometric and physical accuracy and computational effort.
- Its adaptive meshing automatically ensures the desired numerical accuracy in parametric studies and eliminates the influence of numerical errors on the results.

In order to optimize the design one needs to understand the dependencies of the quantities of interest on the various parameters. However, for this amount of parameters this is in general quite difficult to do by hand.

optiSLang offers the possibility to perform a fully automated design of experiments using Latin hypercube sampling, which results in a very evenly distributed sampling of the design space using a moderate amount of samples.

On the basis of this sample correlations between the geometric parameters and result quantities can be found and a Meta Model of Optimal Prognosis (MOP) for the result quantities can be determined (see figure 2): A MoP is gotten by selecting some 60% of the calculated design points to determine a response surface for the result quantity under consideration. The remaining 40% of the calculated design points are used to determine the quality of the response surface, leading to the coefficient of prognosis (CoP). optiSLang does this division of design points in several different ways and takes the response surface with the best CoP as MOP.

If the prognosis quality of the MOP is good enough it can be used for optimization, i.e. during the optimization run no new design points have to be calculated using numerical simulation. Instead the MOP is used to predict the results for the respective design points. This is a very efficient way to accelerate an optimization run.

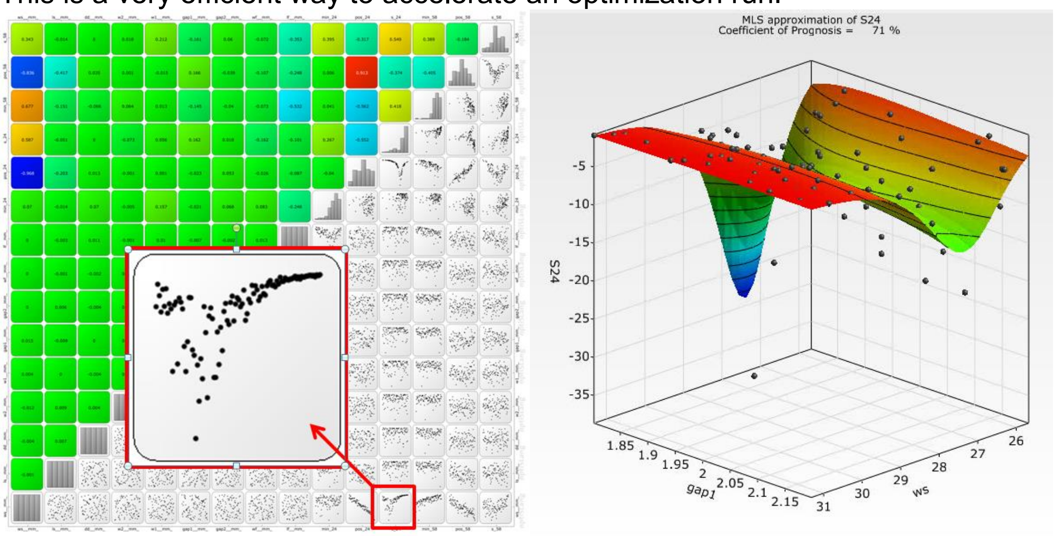

Figure 2: Correlations between geometric parameters and result quantities (left) and the Meta Model of Optimal Prognosis (MOP) for the return loss at 2.4GHz (right).

On the left hand side of figure 2 the correlations between various input and output quantities are depicted. There is for example a fairly strong, non-linear correlation between the slot width and the return loss at 2.4GHz. On the right hand side of figure 2 the meta model of optimal prognosis for the return loss at 2.4GHz is depicted, it shows this strong non-linear behavior and it has low CoP of 71%. For this reason the MOP for this is quantity is not good enough to run an optimization on it.
The optimization goal for this problem can be formulated using quantities that are better behaved: The positions of the resonances, i.e. the positions of the minima of the return loss usually behave in a much more predictable way and the values of the return loss at the minima also behave better. Indeed, the CoP for the positions of the resonances is way above 90% and the CoP for the minimuma of the return loss is around 80%, which allows for an optimization on the MoP.
In antenna and RF applications often the full frequency sweep of the S-parameters plays a central role. For this reason we are going one step further in this paper and use a meta model of optimal prognosis for the full frequency response of the S-parameters.In order to determine this field meta model of optimal prognosis (F-MOP) from the DOE the frequency response of the S-parameters for each design point is extracted. On the basis of this data the program SoS (Statistics on Structures) extracts the frequency dependent mean values of the S-parameters and the most important ‘shape functions’ to describe those S-parameters. It is then assumed that the S-parameters for an arbitraray design point can be represented as a the sum of a mean S-parameter and a linear combination of the ‘shape functions’ (see figure 3).

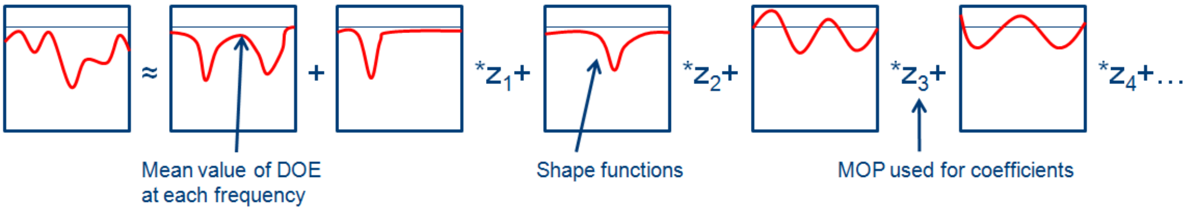

Figure 3: SoS divides Signals in a mean signal and a linear combination of ‘shape functions’.
optiSLang can determine a MOP for the coefficients of this linear combination leading to an F-MOP (Field Meta Model of Optimal Prognosis) for the S-parameters.
For the antenna at hand the F-CoP (Field Coefficient of Prognosis) is high enough in the regions of interest to run an optimization on it. The optimization goal has been taken to be that both minima are as low as possible with the constraint that their positions are in the right place. A downhill method leads to the result of figure 4. Here the gray curves are the F-MOP results for all the design points used to run the optimization and the light red curve is the F-MOP of the best design. This F-MOP for the best design agrees well with the HFSS result of for this design (solid red line), furthermore, the best design has a return loss of -20dB at both center frequencies, which is 2dB better than the minimum requirement.

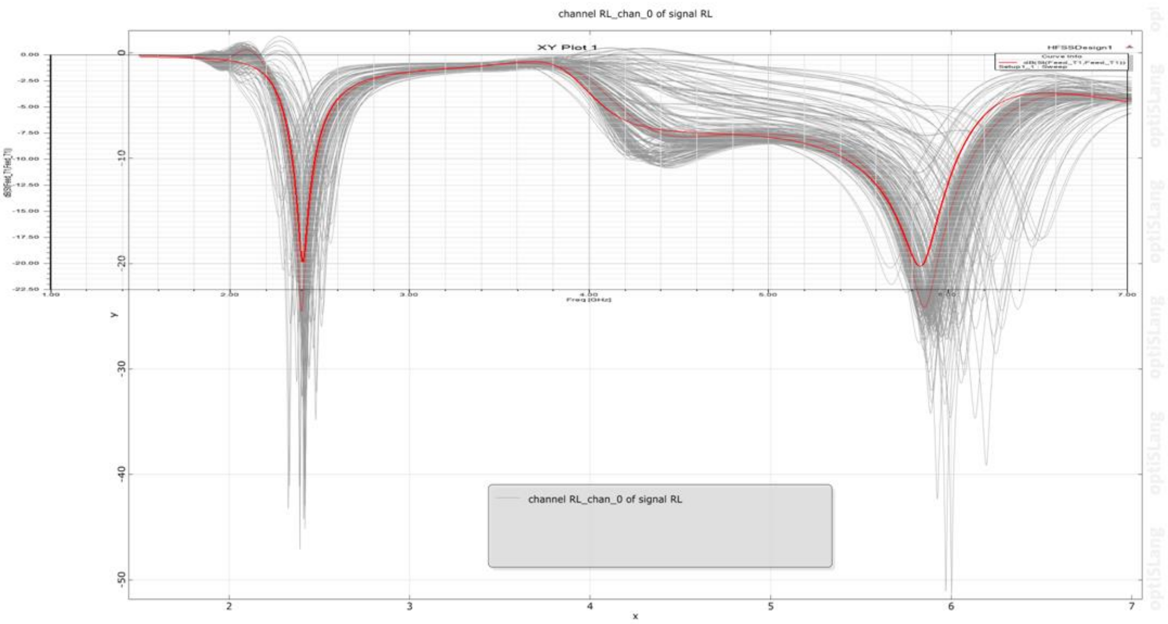

Figure 4: The F-MOPs for the return loss during the optimization run. There is a good agreement between the F-MOP for the best design (light red curve) and its verification in HFSS (solid red line).

In summary, we have shown, how the advanced optimization technologies of optiSLang and SoS can be used in combination with ANSYS HFSS to do a fast optimization of a dual band antenna. Furthermore, SoS allows to predict the full frequency response of S-parameters of the antenna as a function of input parameters. This allows deciding on optimization goals after the DOE has been calculated and to get an idea of the behavior of the full frequency responses during the optimization run and improves in this way the design understanding.

Bibliography

[1] S. Gai, Y.-C. Jiao, Y.-B. Yang, C.-Y. Li, and J.-G. Gong: DESIGN OF A NOVEL MICROSTRIP-FED DUAL-BAND SLOT ANTENNA FOR WLAN APPLICATIONS, Progress In Electromagnetics Research Letters, Vol. 13, 75-81, 2010