Probabilistic Simulation of Waveguide Hybrid Junction in CST Studio Suite

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Design Challenges

Variability, Uncertainty and Randomness

- A nominal Value of Design Parameter
- A arbitrary Stochastic Distribution

Causes

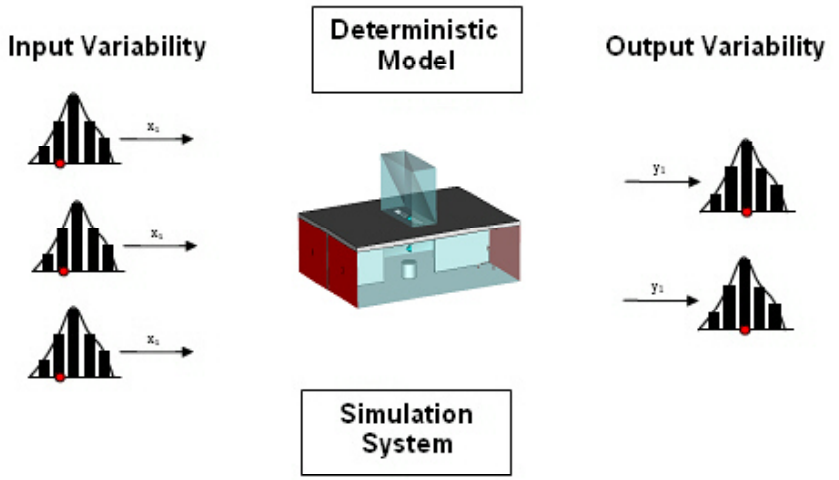
- Manufacturing Inaccuracy
- Material Property Scattering
- Environment Influences
- Process Uncertainty
- Human Factors etc.

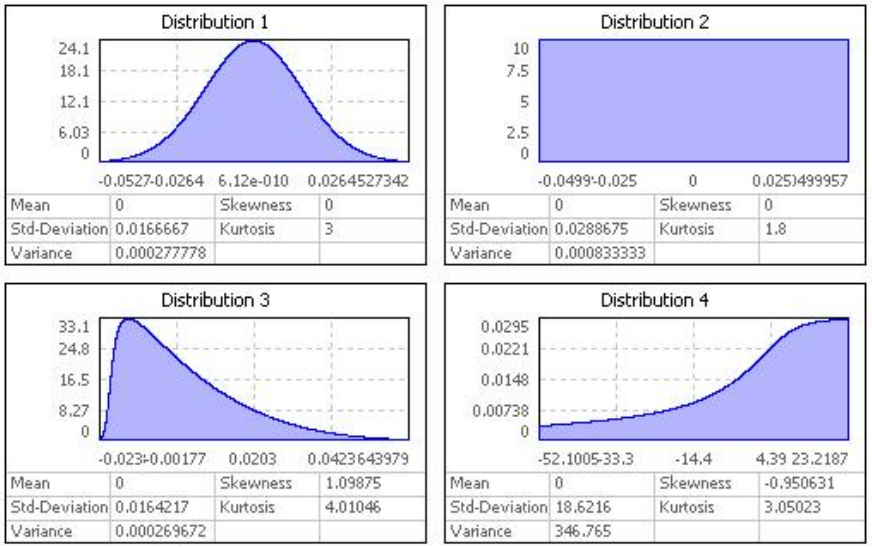
Problems

- Rejection at Manufacturing
- Low Reliability, Bad Quality
- Problem with Customers Warranty

Industry

- Prototypes (high time and cost effort)
- Design of Experiment





Design for Reliability and Robustness

Robustness Evaluation

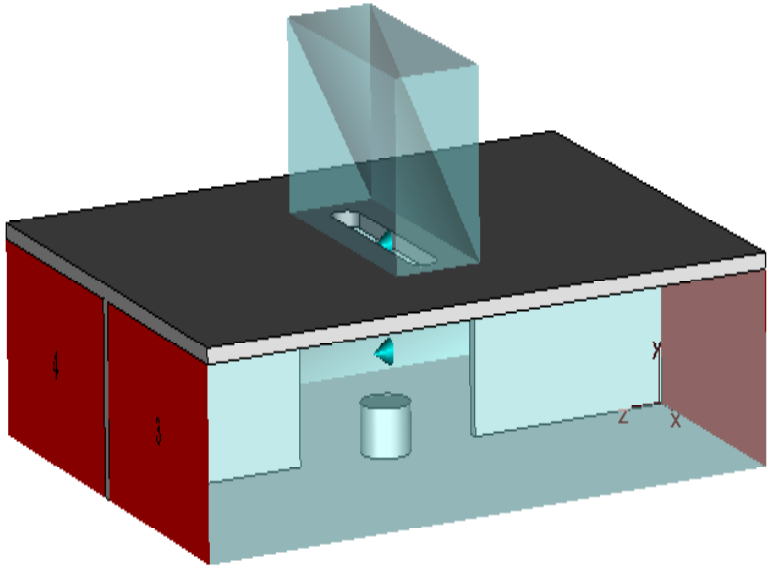
- A good Product Quality is characterized by a small Change of Outputs due to the same Input Variability
- Robust Design evaluate the Variance of the Output Distributions:
  - A small Variance of Output = Robust Design
  - A large Variance of Output = Non-Robust Design

Reliability Analysis

- Investigate the Violation of Constraint boundaries due to Input Variability
- Calculate the Rejection at a Mass Manufacturing Process based on the Probability Density Function (PDF)
- Design Goal: minimal Rejection (better Quality)

Sensitivity Study

- Identify the important Influence Design Parameters
- Disregard insignificant Design Parameters
- Investigate Interactions between Input Parameters



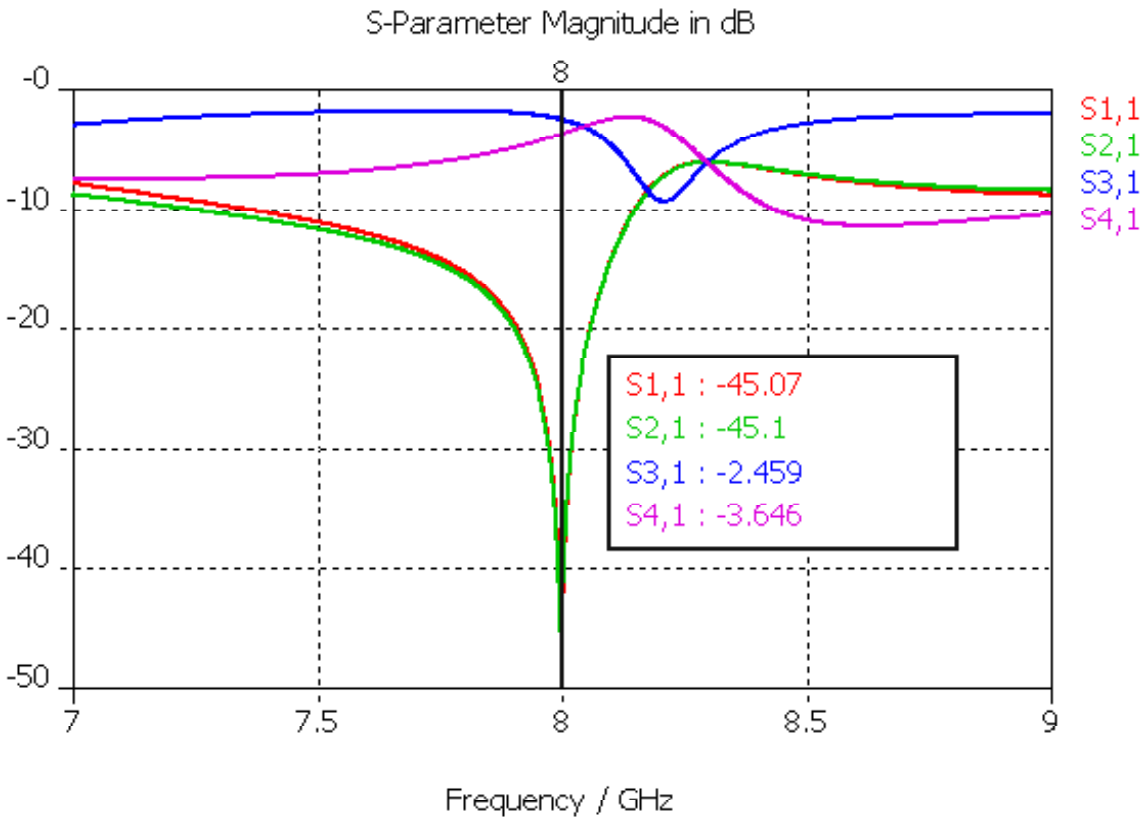
Waveguide Hybrid Junction

- The structure contains a coupling section with a small metallic disk and an external cavity resonator connected to the waveguides by a coupling hole.

- Manufacturing tolerances have great influence on junction performance, reliability and quality

Design Parameter	Nominal Value	Tolerance Value	Distribution
Hole Length	19.655	0.6	Normal
Hole Width	3.016	0.6	Normal
Gap	19.081	0.6	Normal
Disk High	2.994	0.6	Normal
Disk Radius	2.511	0.6	Normal

The Nominal Solution (Ideal Best-Case)
Deterministic Simulation in CST Studio Suite

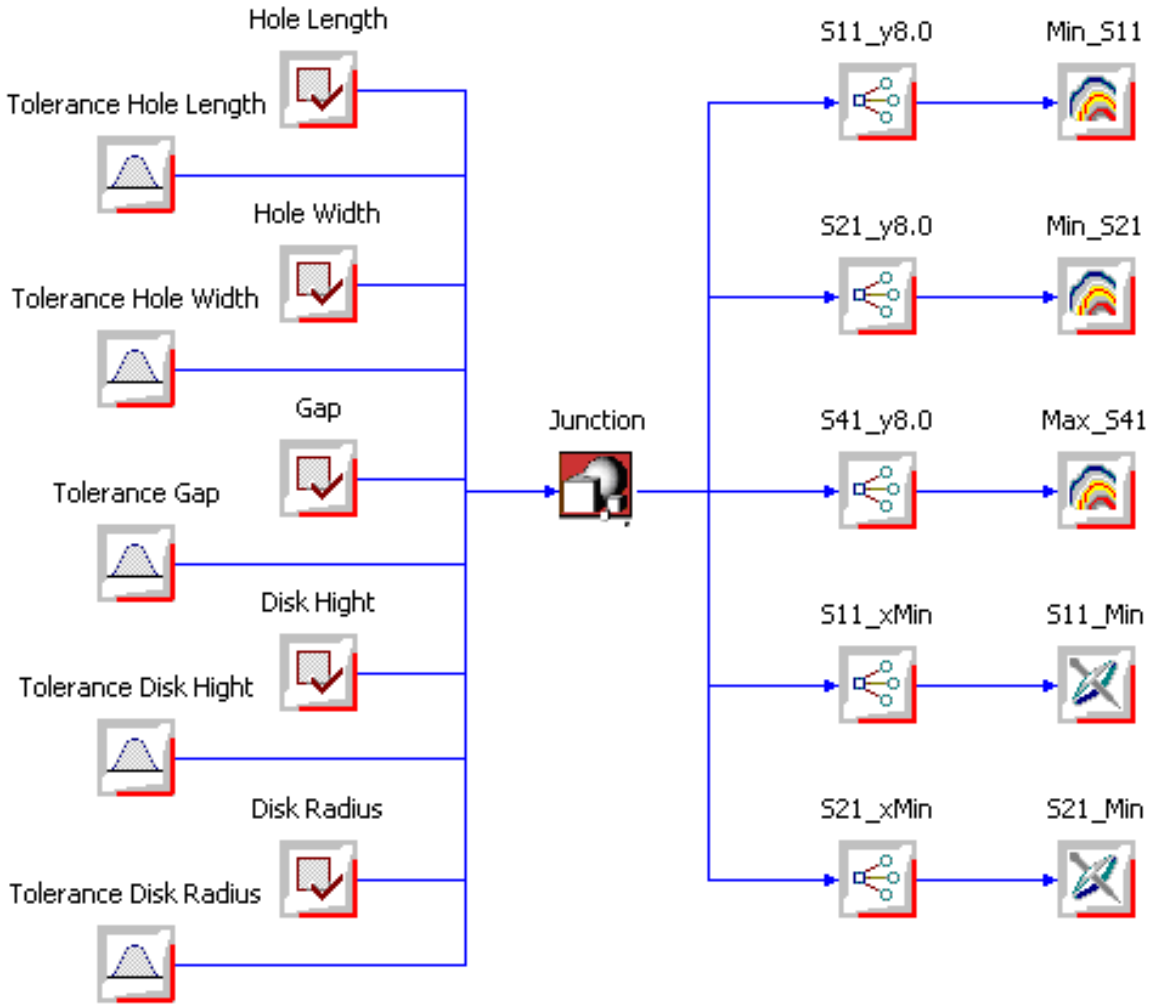


- The solution contains the following parameters:

Hole Length = 19.655
Hole Width = 3.016
Gap = 19.081
Disk High = 2.994
Disk Radius = 2.511

- The ideal operating point at 8 GHz is optimal (best case): maximal Transmission and minimal Reflection

OptiY Workflow for Coupling with CST Studio Suite



CST Studio Node in OptiY

- Easy of use

Design of Experiment:

- Second Order Moment
- 51 Model Calculations

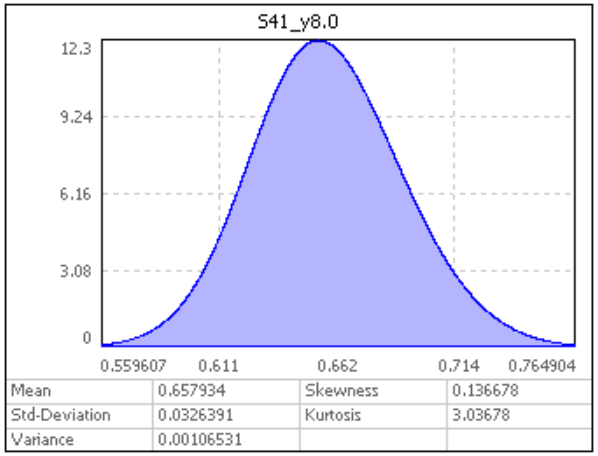
- Reduced Second Order
- Without Interactions
- Only 11 Model Calculations

The goal is to explore the operating design point at 8 GHz:

- Customers requirement: reflection tolerance only 0.1 GHz (7.95 – 8.05 GHz)

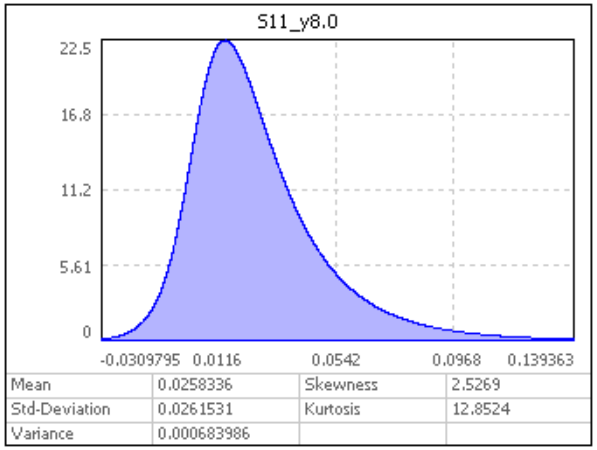
Robustness and Reliability of Reflection and Transmission

- The zero-reflection frequency: 7.9–8.1 GHz (specification: 7.95-8.05 GHz)
- 12.5% of all mass manufactured parts will fail the customers requirement
- Significant Worst Reflection at operating point 8GHz = 0.13 (linear)
- Significant Worst Transmission at operating point 8GHz = 0.55 (linear)



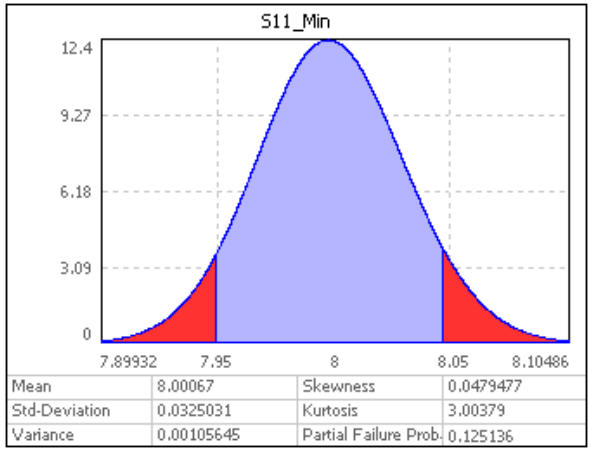
Mean	0.657934	Skewness	0.136678
Std-Deviation	0.0326391	Kurtosis	3.03678
Variance	0.00106531		

Transmission at 8 GHz
Mean: 0.657
Std Deviation: 0.0326



Mean	0.0258336	Skewness	2.5269
Std-Deviation	0.0261531	Kurtosis	12.8524
Variance	0.000683986		

Reflection at 8 GHz
Mean: 0.0258
Std Deviation: 0.0261

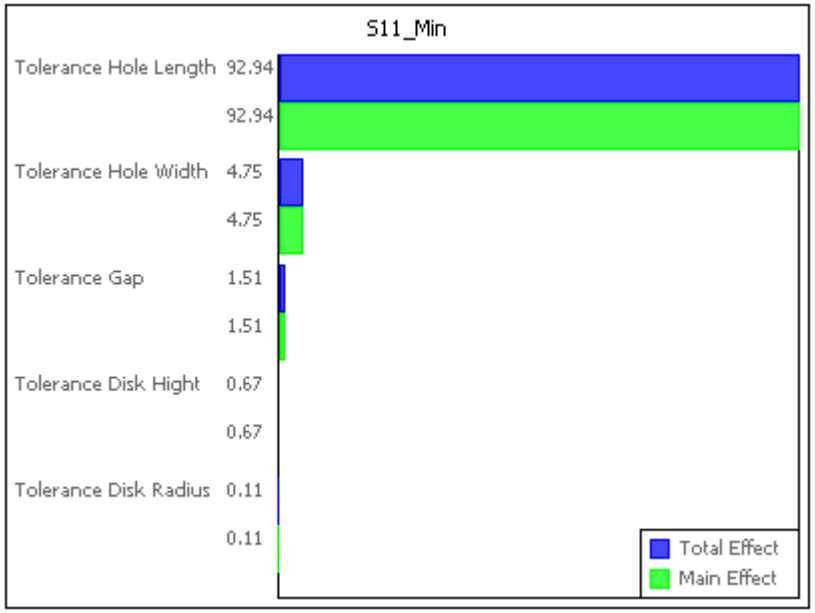


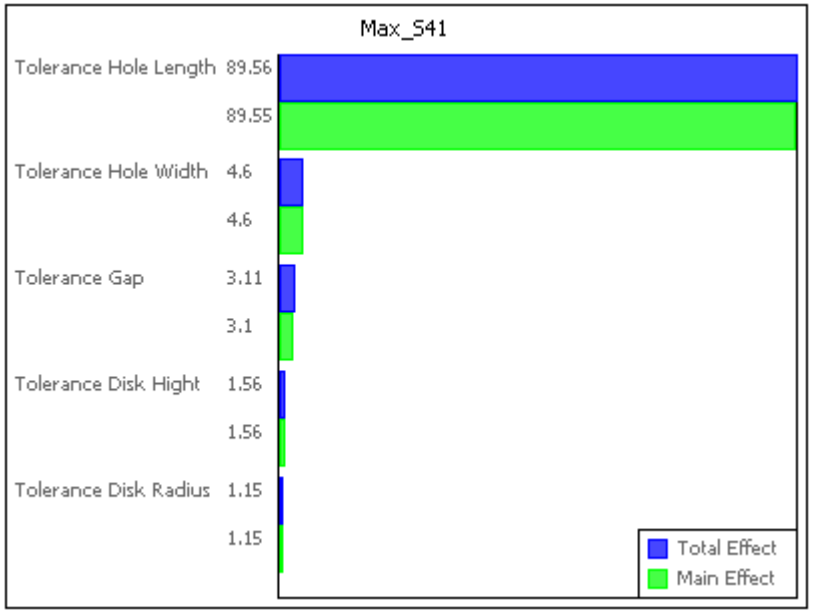
Mean	8.00067	Skewness	0.0479477
Std-Deviation	0.0325031	Kurtosis	3.00379
Variance	0.00105645	Partial Failure Prob.	0.125136

Zero-Reflection Frequency
Mean: 8.0
Std Deviation: 0.0325

Sensitivity Study

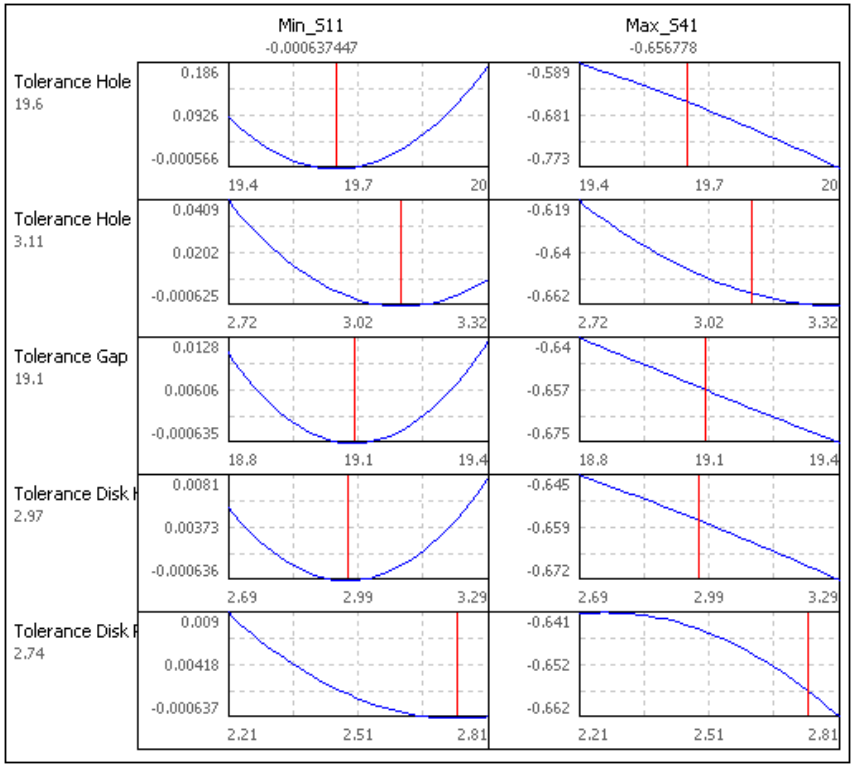
- The Hole geometry tolerances (Length and Width) contribute the most to the variability of reflection and transmission. Its should be minimized to reduce the output variability
- The Disk geometry and the Gap are insignificant and can be eliminated from the model
- There are no interactions between inputs (main effect = total effect)
- Reduced Second Order as Design of Experiment being used to reduces number of model Calculations

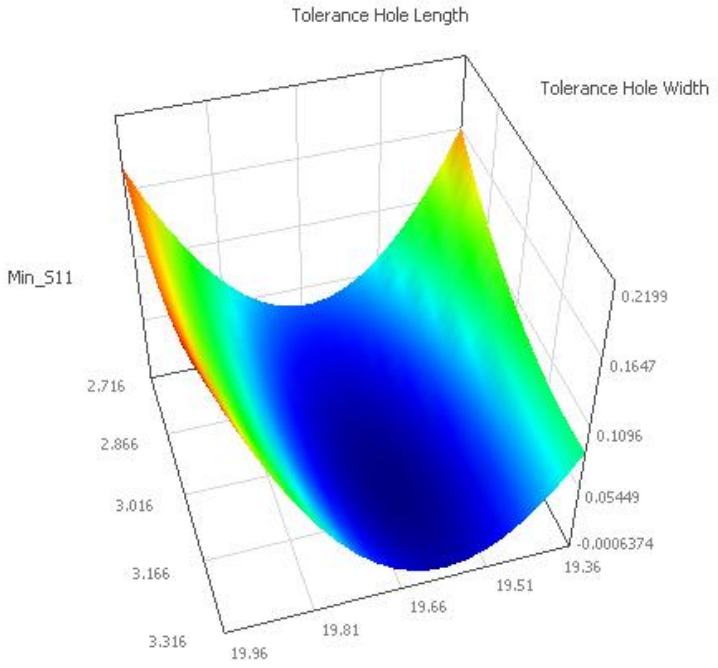




Response Surface Modeling

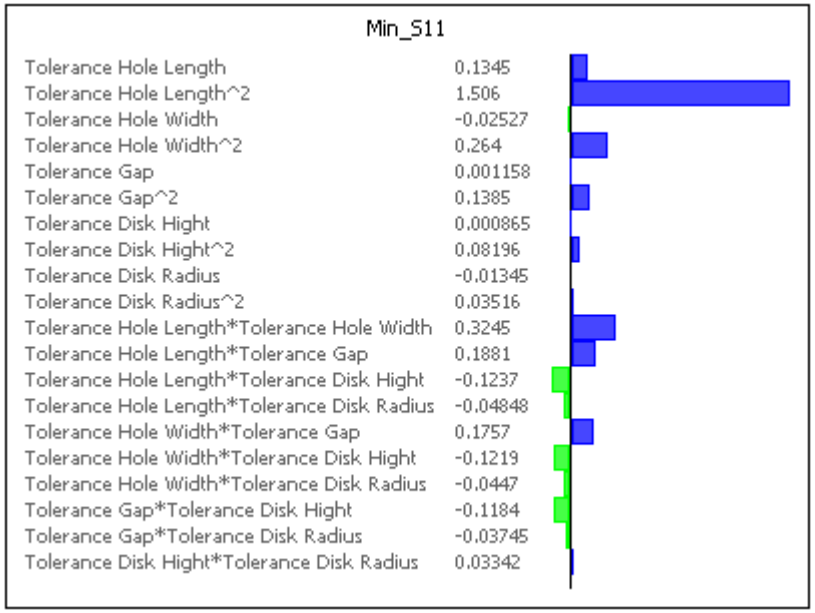
- Graphical 2D and 3D Diagrams of the meta model
- The meta model visualized the entire design space
- Fast Robust Design Optimization with the meta model
- Best- and Worse-Case Simulation

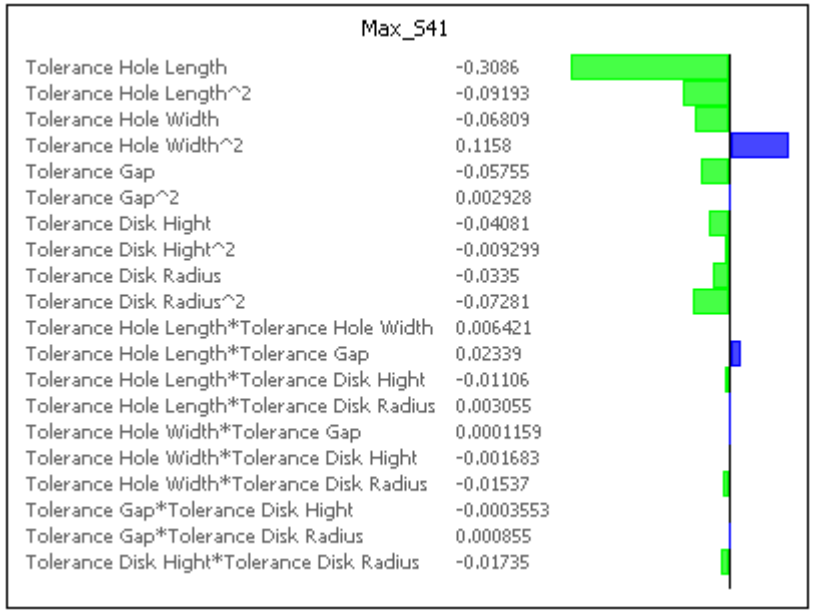




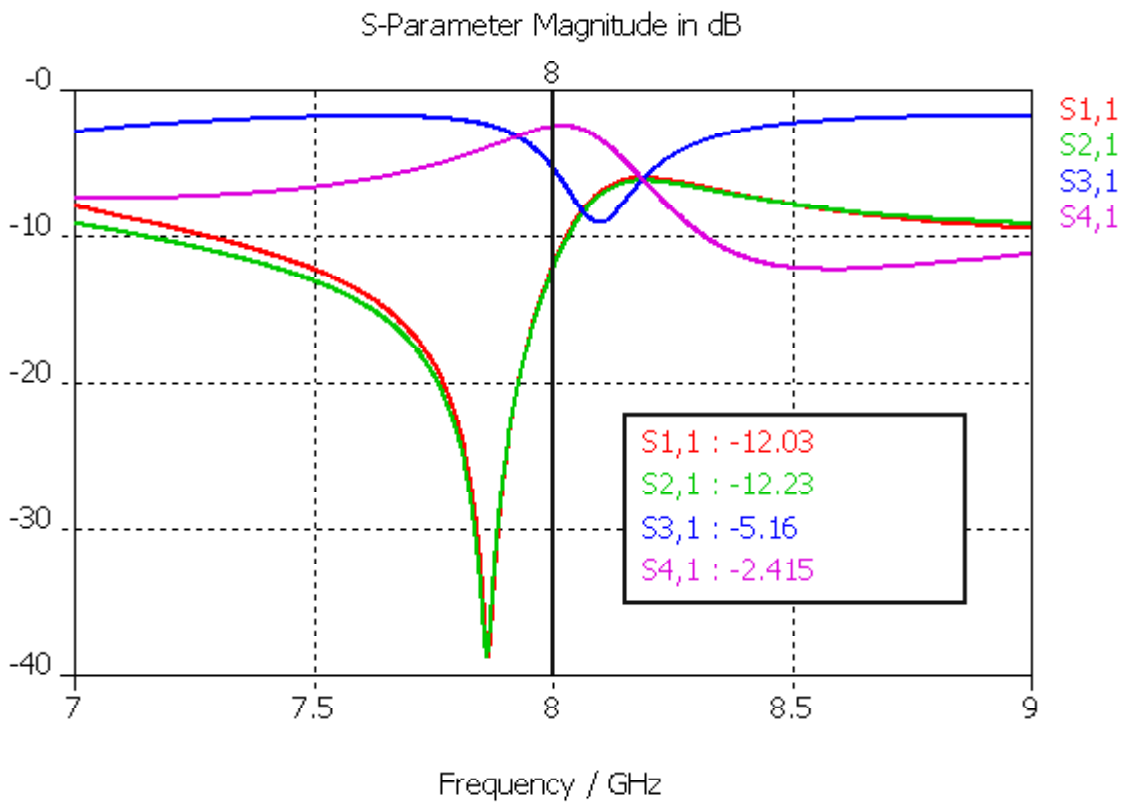
Coefficients of the Response Surface Model

- The coefficients of the Taylor-series are shown
- representation as local sensitivities
- Export of the meta model into Matlab/C





The Worse-Case Simulation



The worse case solution within the tolerance space at the operating design point 8GHz:

Reflection: -12 dB
Transmission: -2.4 dB

At the design parameter combination:

Hole Length	=	19.952
Hole Width	=	3.316
Gap	=	19.378
Disk High	=	2.698
Disk Radius	=	2.211

Conclusions

- Variability, Uncertainty and Randomness play an important part in the Design Process for Reliability and Robustness
- Demonstration on the Hybrid Waveguide Junction shows the lack of deterministic Simulation today. Probabilistic Simulation brings the virtual Components closer to Reality
- Reliability and Robustness can be evaluated based on output variability
- Sensitivity Study can identify most influenced parameters to the output variability
- **OptiY** for probabilistic Simulation is easy to connect to **CST Studio Suite** deterministic Simulation