Symbiosis: Measurement and Simulation in Modern Device Design

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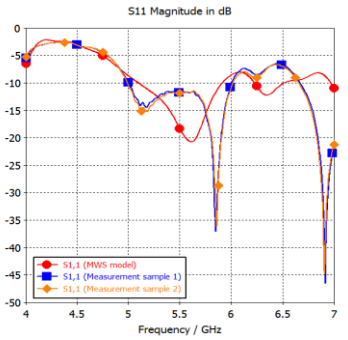
Simulations vs. Measurements

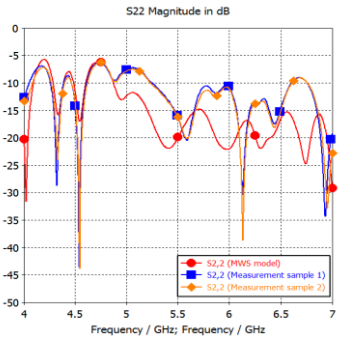
How well do simulations agree with measurement???

Simulations must be accurate ✓
Measurements must be accurate ✓

Simulation must represent reality: Geometry, material properties, feed mechanism, surroundings, etc... ✓

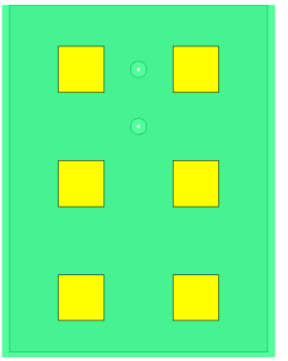
S-parameters Discrepancy





$\Delta S_{11} = 0.1098$ $\Delta S_{22} = 0.1279$

Average difference in magnitude (linear scale) in 5-6 GHz range



6 element patch array
(feed network not shown)

Discrepancy Sources

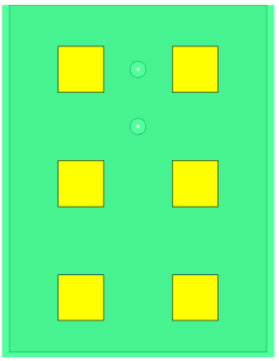
3D EM Simulation

- Mesh & Solver setting
- Material properties
- Different geometry (missing parts, manuf. tol.)

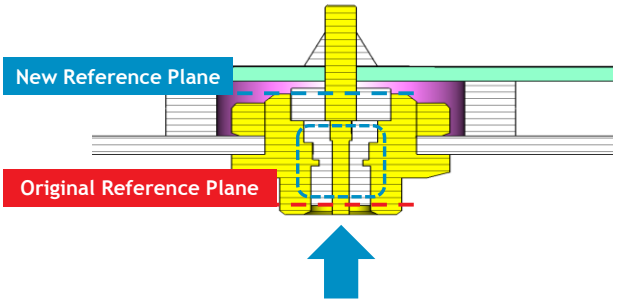
Measurement

- Improper calibration of VNA
- Different reference plane (adapters)
- Assembly repeatability

Simulation Model Corrections

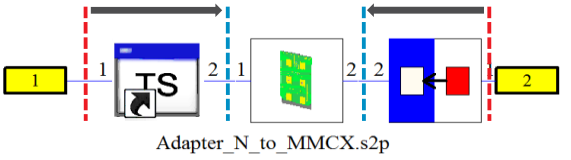


Width of the ground plate

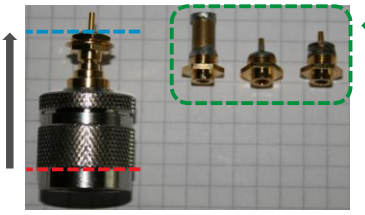


The inner structure of the MMCX connector is unknown. Therefore we should not rely on the model and the reference plane is due to this fact shifted to the end of a simple coaxial line.

Unterminating the N-MMCX Adapter



The 2-port circuit network has to be added to the simulated data.



The full 2-port S-parameters of the adapter* can be obtained from three 1-port (N) measurements using Open, Short and Match calibration standards (MMCX).

*N-MMCX adapter + internal structure of MMCX connector

Adapter Characterization

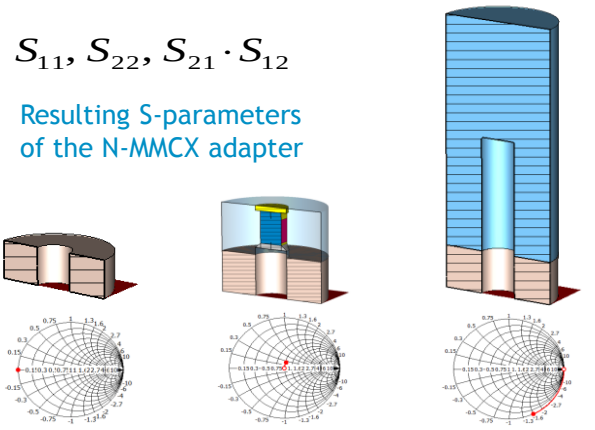
$$S_{11O} = S_{11} + \frac{S_{21}S_{12}\Gamma_O}{1 - S_{22}\Gamma_O}$$

$$S_{11S} = S_{11} + \frac{S_{21}S_{12}\Gamma_S}{1 - S_{22}\Gamma_S}$$

$$S_{11M} = S_{11} + \frac{S_{21}S_{12}\Gamma_M}{1 - S_{22}\Gamma_M}$$

$S_{11}, S_{22}, S_{21} \cdot S_{12}$

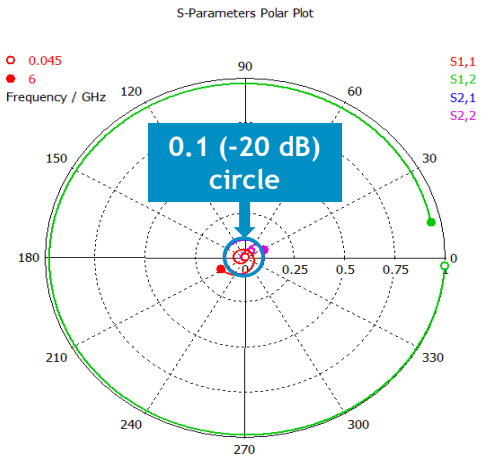
Resulting S-parameters of the N-MMCX adapter

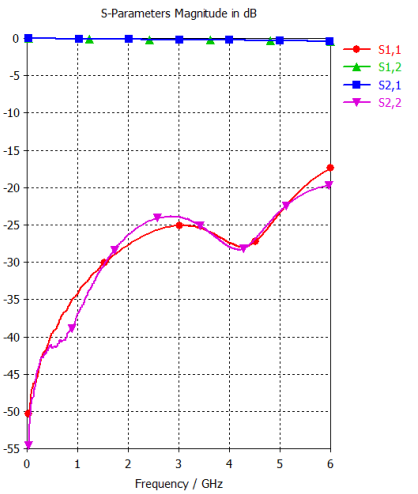


Measured data when the adapter is terminated with Open, Short and Match standards.

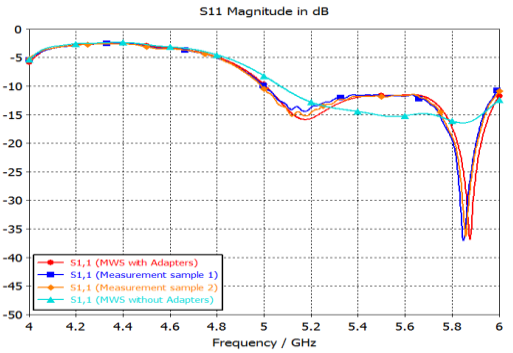
Γ_O, Γ_S and Γ_M are reflection coefficients of the calibration standards obtained by simulation in CST MWS.

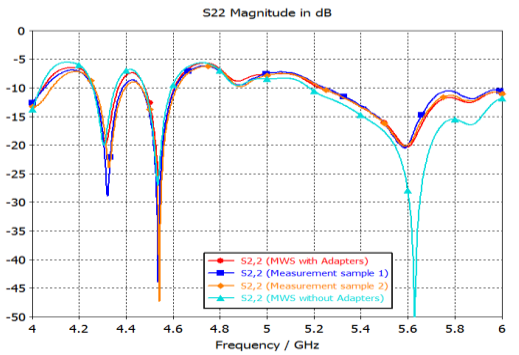
S-parameters of N-MMCX Adapter





Comparison of Reflection Coefficients



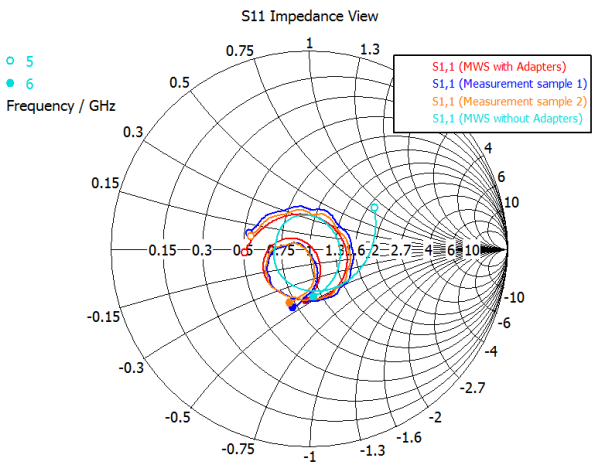


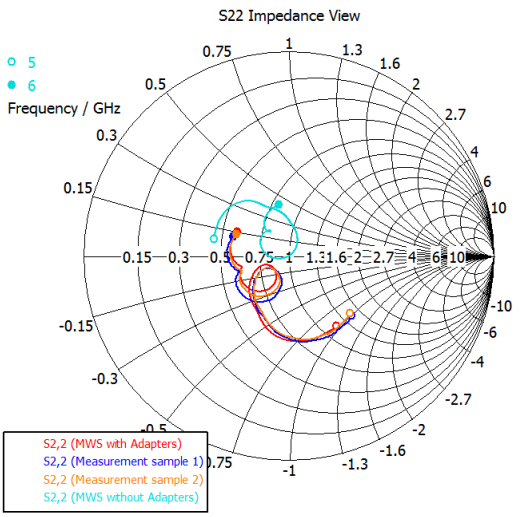
$\Delta S_{11} = 0.0182$

$\Delta S_{22} = 0.0099$

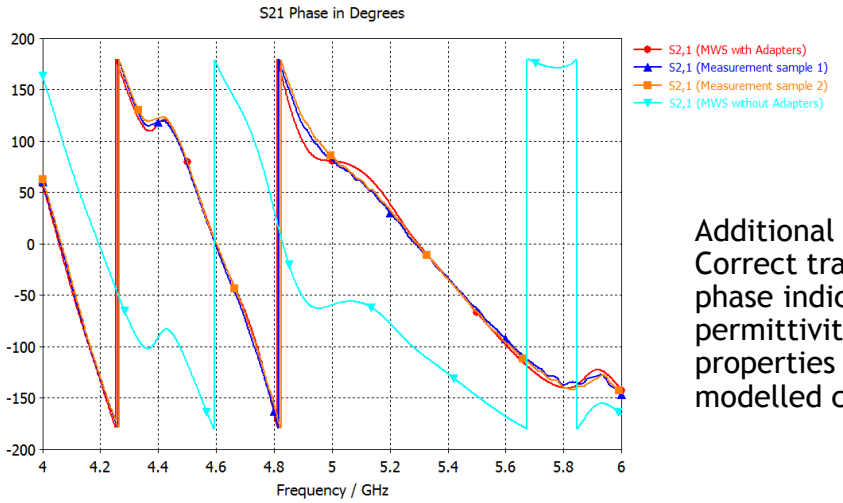
Average difference in magnitude (linear scale) in 5-6 GHz range

Smith Chart Comparison



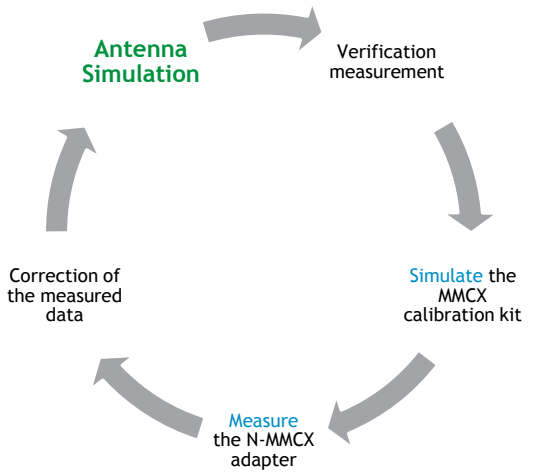


Phase of S21 - Permittivity Test



Additional validation: Correct transmission phase indicates that permittivity of substrate properties were modelled correctly.

Verification Process



What are the ACTUAL S-parameters of the antenna?!

Summary

- Both simulation and measurement results were necessary to improve correlation.
- The most significant source of the discrepancy was non-ideal adapter parameters.
- The S-parameters of the N-MMCX adapter have been extracted.
- The average magnitude difference between measurement and simulation has been reduced by a factor 10.