RF line impedance optimization methodology in laminate technologies

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Introduction

- RF Lines in a laminate package: challenges
  - When a maximum of power must be transmitted, a RF line must be adapted with both DIE and PCB (impedance conjugation).
  - Inside a package, the RF lines are never just a “long uniform straight routing”: impedance mismatches
    - bumps, vias, balls (always)
    - bends (sometimes)
    - Several material with different characteristics (loss tangent, dielectric constant etc…) close to a RF signal (always)
  - For cost purpose, more and more RF lines are present in a package with various disparities like length and metal routing level.

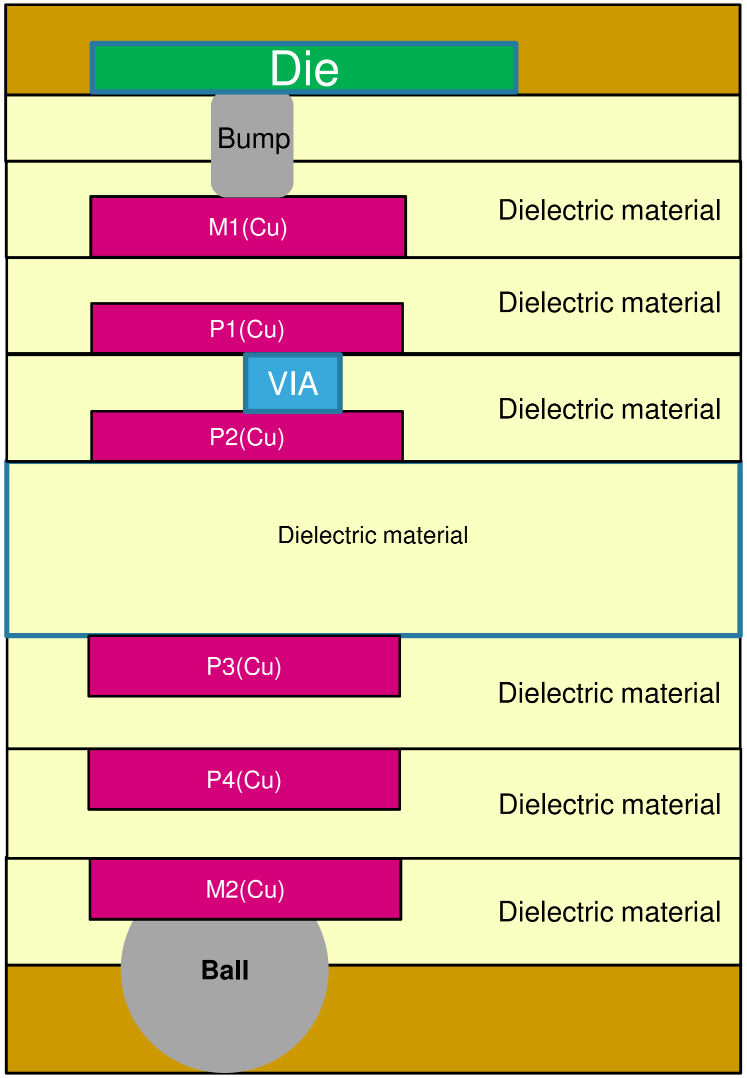
- 2 methodologies are presented:
  - Both use the split of the RF line with width/length variations of each part
  - Simulation tools: a 3d field solver (HFSS) and 2D cross-sectional field solver (ADS/CILD)
  - Each method has different advantages and limitations, the choice depends on the package configuration

Context

- Both methods have been applied with success in 8 projects (more than 200 RF Lines)

- The RF lines adaptations have been done in several configurations with the following specifications and constraints:
  - 50 ohm adaptation
  - Return Loss better than -20 db, Insertion Loss better than -0.5 db
  - Frequency bandwidth depends on projects, maximum was up to 20GHz.
  - Up to 33 RF Lines per package with different line length and metal routing level
  - Different number of metal layers
  - Bumps, balls, vias must be included in the line adaptation
  - A small PCB part with an ideal 50 ohm line is included in the simulations

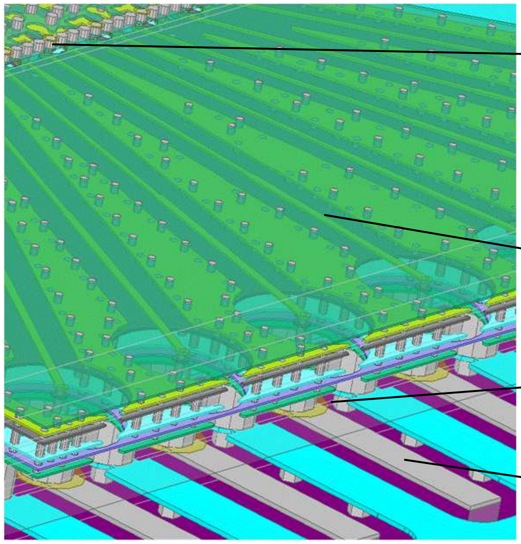
Laminate technology



- Any process which builds successive layers

- In our cases, a package laminate technology is used:
  - the layer stacking is made up of copper and dielectrics (cf picture)
  - Vias connect different metal levels, bumps connect the die to the package, and the balls connect the package to the PCB
  - RF lines can be
    - "striplines": ex/ RF line routed in P1 with M1/P2 ground planes
    - "microstrips": ex/ RF line routed in M1 with P1 ground plane

RF Line examples (3D view)

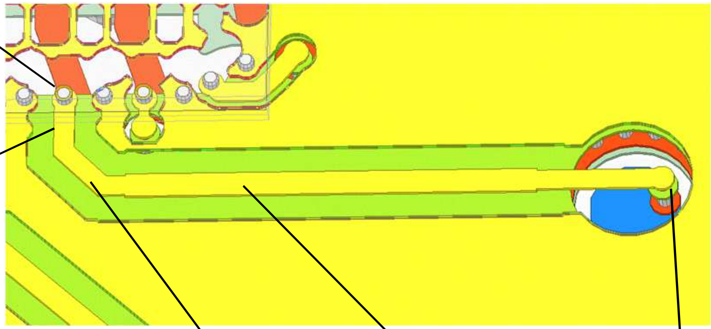


Bump vias

RF Lines

Ball/vias

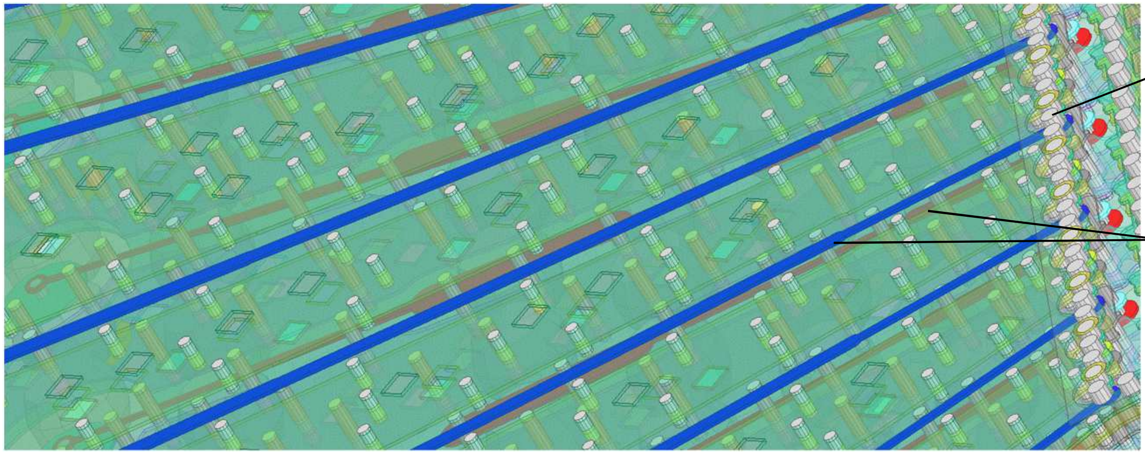
Ideal 50ohm PCB line



Bend

Microstrip

Vias/Ball



Bump/vias

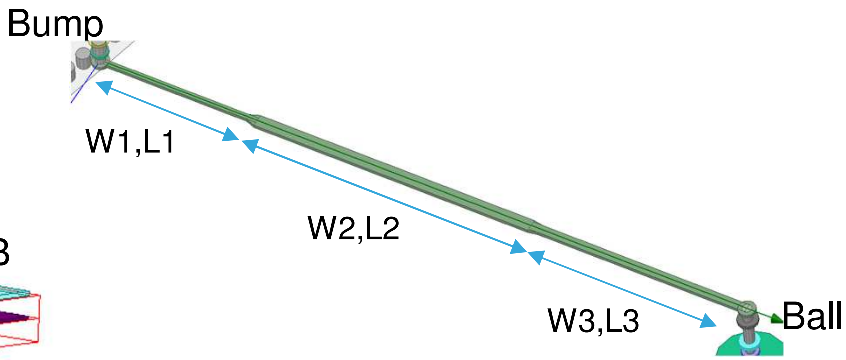
RF Lines (striplines) at different metal levels (ground planes in between).

1^{st} methodology: principles

- Based on the 3D field solver HFSS, and optimetrics runs (parameter sweeping)

- A 3D layout view is created which includes:
  - The RF stripline split in several sections. Each has its own Width and Length
  - Vias, bumps, balls, ground planes
  - Dielectrics
  - A part of the PCB with an ideal 50Ω line

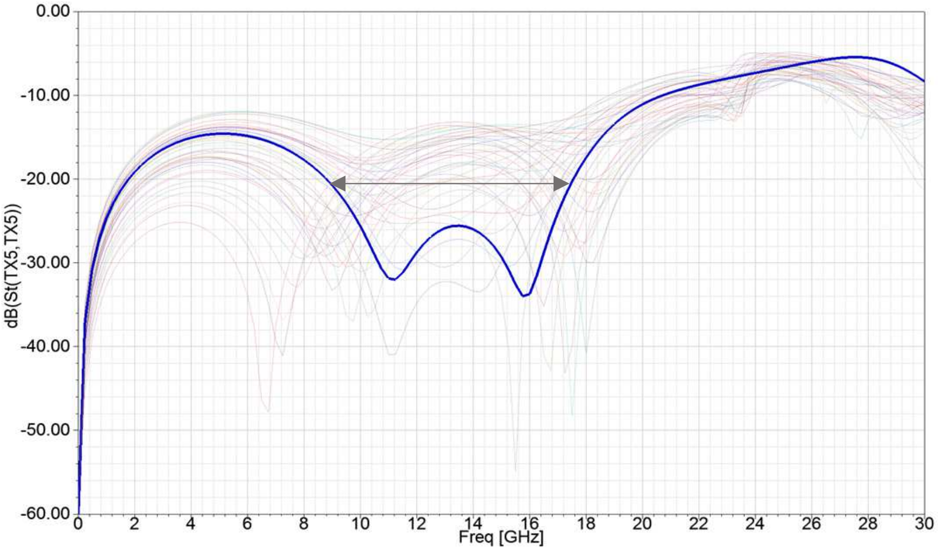
Port 50Ω
Bump,Vias Model
RF Cline
Vias, Ball Model
PCB 50Ω
Port 50Ω



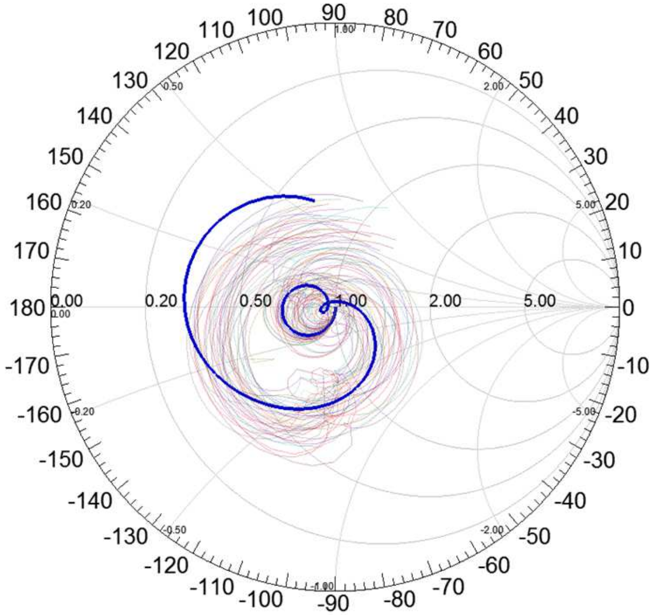
1st methodology: optimetrics simulation

- Several optimetrics simulations are done in HFSS: variation of the W,L of each RF line sections
  - The runtime is linked to the number of RF line sections and the line lenght

- From these simulations, a line selection can be done, fulfilling the initial constraints.



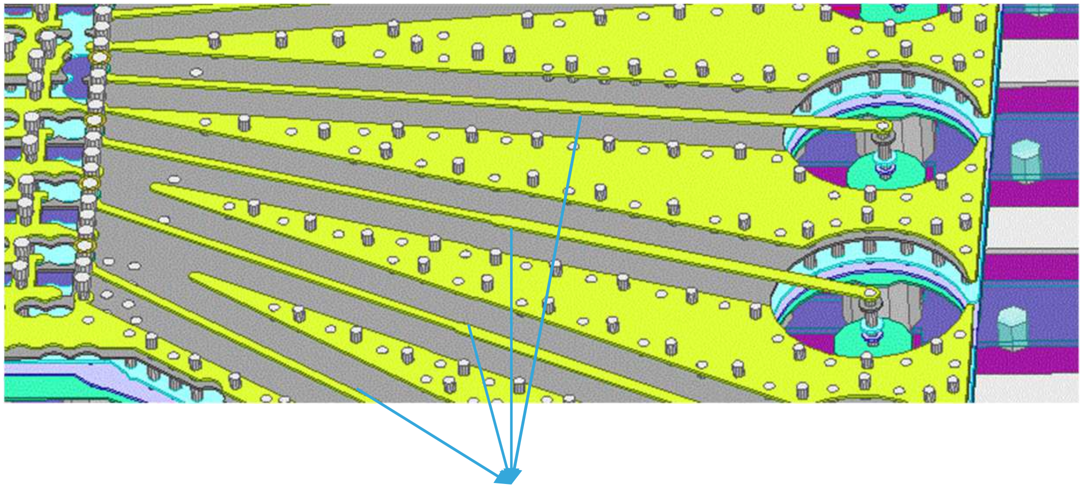
Return Loss, 1 line selected
(better than -20dB in [9 ; 17] GHz)



Smith diagram
Impedance control (50Ω)

1st methodology: verification

- This methodology is reproduced for all the RF Lines of the design
- The RF lines are designed in the package and exported in HFSS for the final simulation. We check the correlation with the optimetrics run.

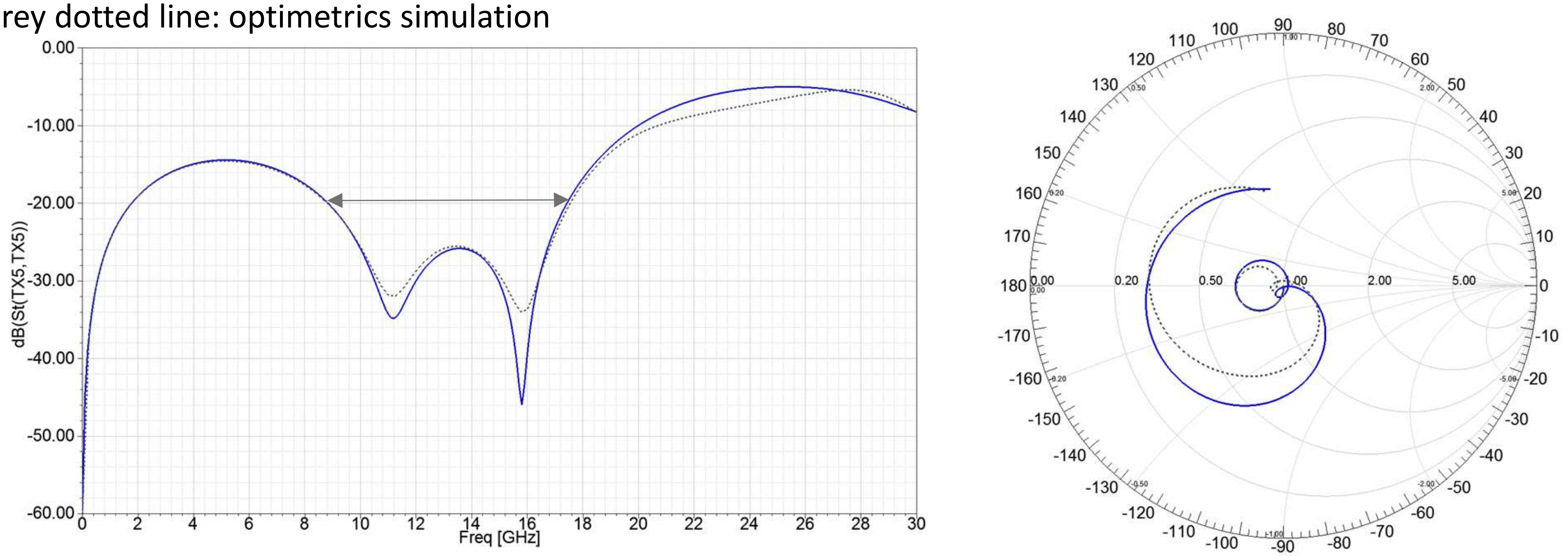


Substrate design (3D view) with several RF lines adapted

(some layers have been hidden to clearly show the RF lines)

1st methodology: verification

Blue line: final simulation in context
Grey dotted line: optimetrics simulation

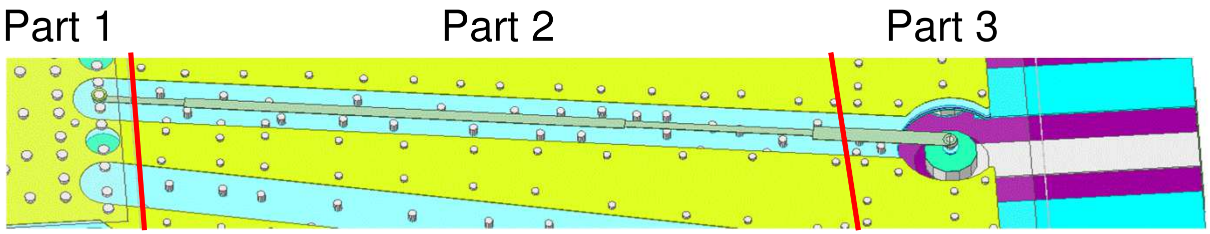


Return Loss and Smith chart: final simulation and correlation

- The return loss is lower than -20dB with margins, and impedance close to 50Ω. Matching between the final simulation (blue line) and the optimetrics simulation (grey dotted line) is really good
- Why do we need another methodology ?

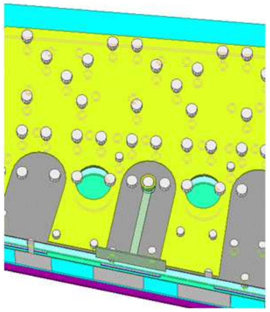
2nd methodology: principles (1/2)

- Based on Keysight ADS/CILD tool and Ansys HFSS 3D
- The first step is to split the RF path in 3 parts:
  - The first includes the bump/vias and a small part of the RF line (part 1)
  - The second is the RF line which will be split and tuned (part 2)
  - The third is a small part of the RF line and the vias/ball/PCB (part 3)

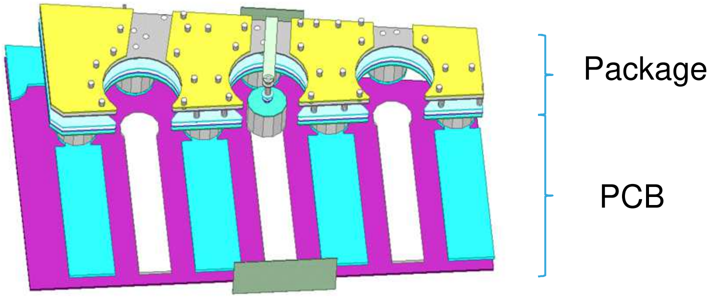


- The part 1 and part 3 are simulated in HFSS 3D

Part 1



Part 3

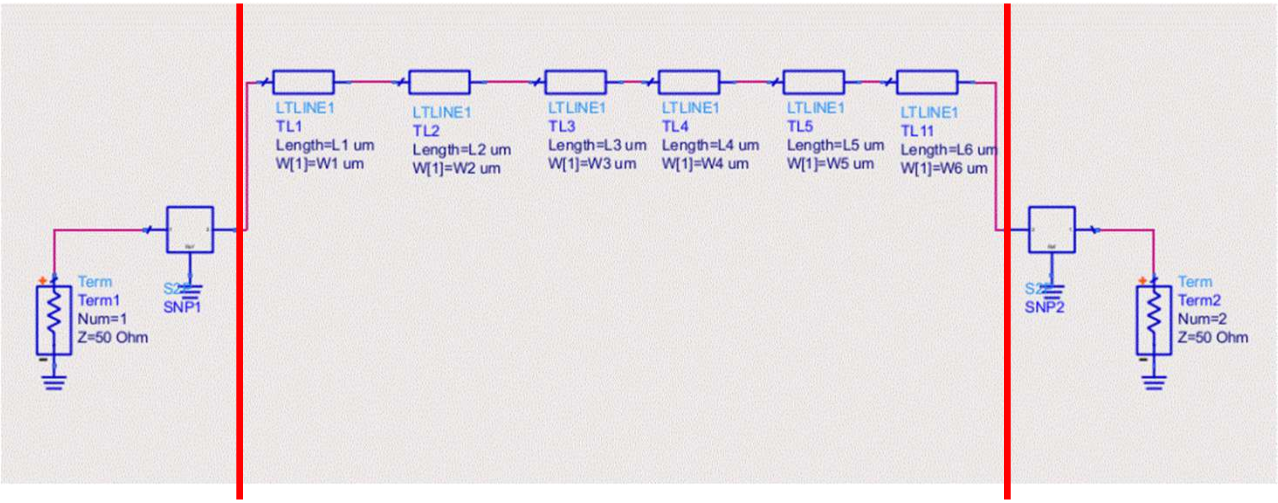


2nd methodology: principles (2/2)

- ADS/CILD : 2D impedance and line characteristic calculator, based on the package cross-section and RF Line information.

- T-Lines (transmission line model) are generated from CILD

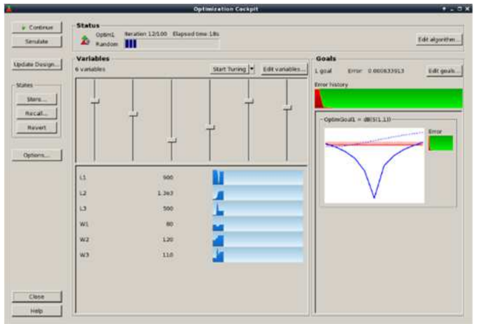
- An ADS schematic view is created using previous generated touchstone and T-Lines



Part 1 Part 2 Part 3

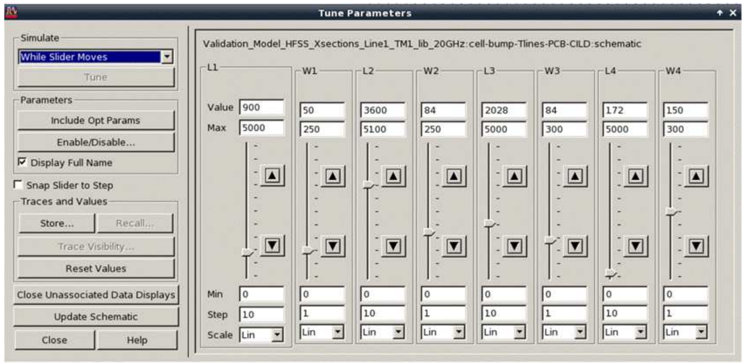
2^{nd} methodology: ADS/CILD tuning

- Optimization Mode
    - Automatic tuning and optimization of the Width and Length of each T-lines: fast approach but doesn't guarantee to define an optimized RF line



L1 900
L2 1.3e3
L3 500
W1 80
W2 120
W3 110

- Tuning Mode
    - On the fly width and length modification of each T-Lines with immediate simulation result



Simulate: While Slider Moves

☑ Display Full Name

☐ Snap Slider to Step

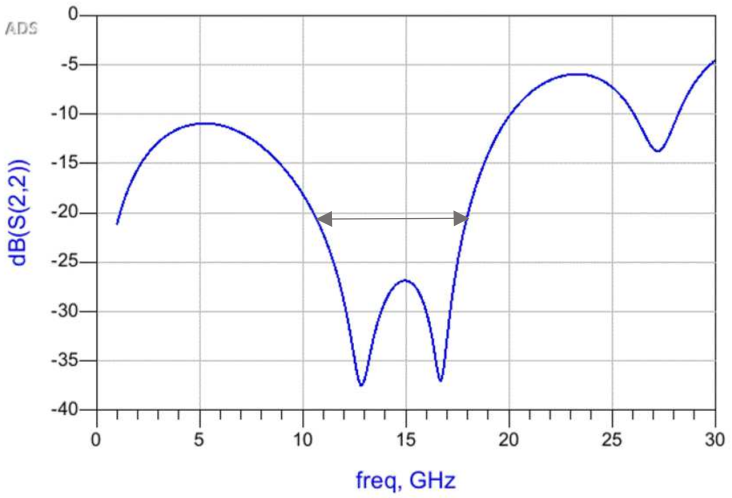
Validation_Model_HFSS_Xsections_Line1_TM1_lib_20GHz:cell-bump-Tlines-PCB-CILD:schematic

	L1	W1	L2	W2	L3	W3	L4	W4
Value	900	50	3600	84	2028	84	172	150
Max	5000	250	5100	250	5000	300	5000	300
Min	0	0	0	0	0	0	0	0
Step	10	1	10	1	10	1	10	1
Scale	Lin	Lin	Lin	Lin	Lin	Lin	Lin	Lin

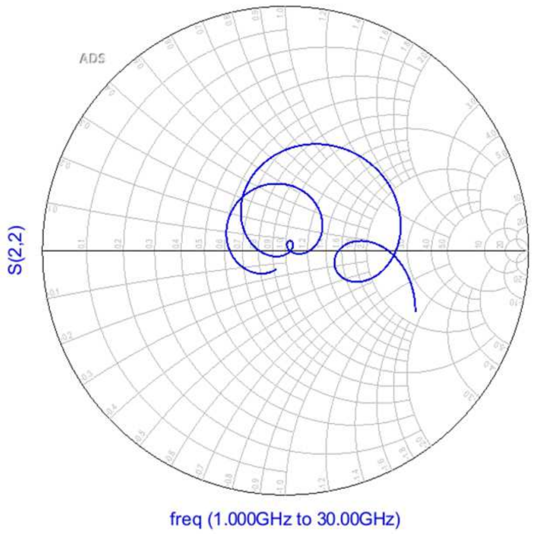
2nd methodology: ADS simulation

- The tuning mode is used, and a width/length for each RF line part is chosen (and for each RF Lines)

- The ADS simulation results are presented here for 1 line

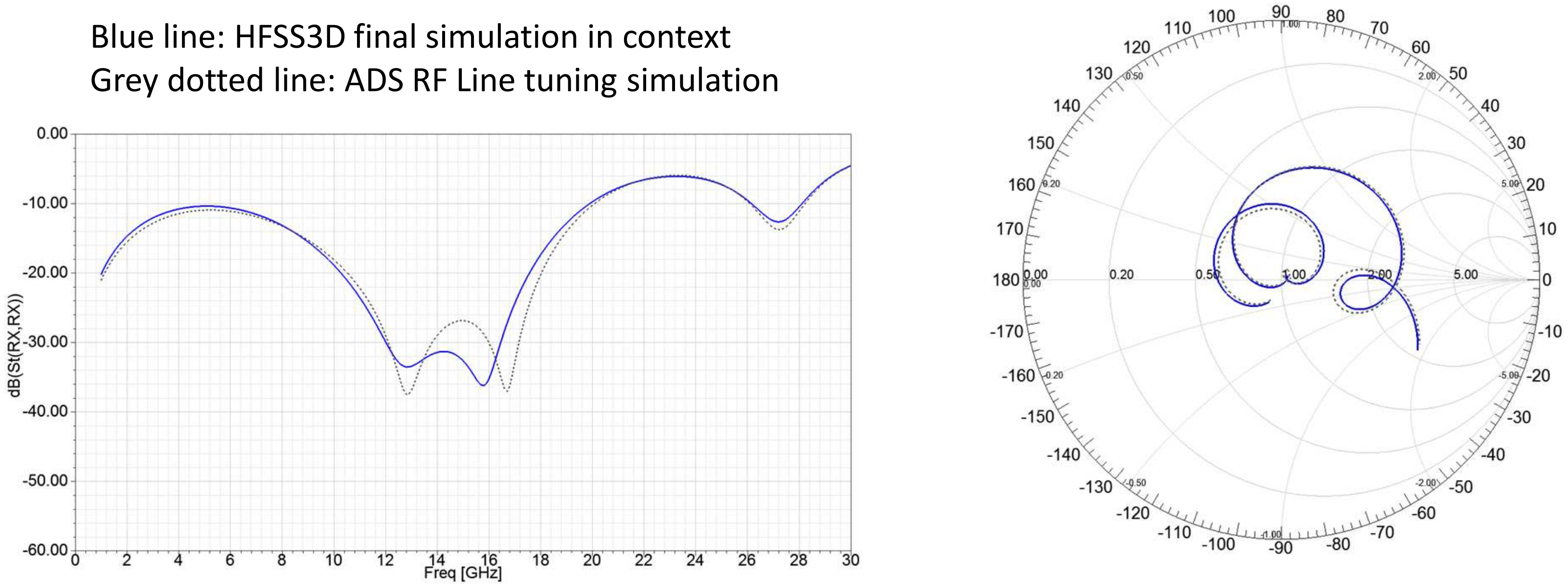


Return Loss, 1 line selected
(better than -20dB in [11 ; 18] GHz)



Smith diagram
Impedance control (50Ω)

2nd methodology: verification


Blue line: HFSS3D final simulation in context
Grey dotted line: ADS RF Line tuning simulation

Return Loss and Smith chart: final simulation and correlation

- The tuned RF line is designed and simulated in HFSS for verification.
- The blue (HFSS3D) and grey (ADS) lines can be compared and allow to validate the approach.
- This method can often request few iterations between the ADS tuning mode and the HFSS3D simulation/verification

Conclusion

- Limitations of both methodologies, and utilization
  - The 2nd methodology has a fast runtime during the tuning phase: ~1 second per simulation. Whereas the 1st methodology requests about 30mn per simulation (magnitude order).
  - The 2nd methodology has a lower accuracy and often request 3/4 loops between ADS and HFSS3D, which is time consuming.
  - For designs with many different long RF lines split in many parts, the 2nd method is clearly preferred. For shorter lines, the 1st method will be often better.

- Conclusion
  - 2 methodologies have been presented with their own strengths and limitations. Depending on design cases, one will be clearly faster than the other
  - In any case, the key point for a line adaptation in a package is to simulate and modelize any “complex” RF line part in a 3D simulation tool (ball/bump/via, bends …): this is true in the 2 methodologies. The RF line tuning can be done in a 3D or 2D simulation tool, here the best choice really depends on the design configuration.