Impact of Meshed Ground Planes on the Electromagnetic Behaviour of Printed Circuit Boards

Martin Salter, Nick Ridler, Matthew Harper, Tian Hong Loh, David Hindley (NPL)
Ralph Green, Percy Phelps, Mark Walker (Astrium)

5th EMPPS Workshop, ESA/ESTEC

20-22 May 2014

Overview

1. Introduction
2. PCB Test Structures
3. RF testing of PCB Test Structures
4. Electromagnetic modelling of PCB Test Structures
5. Recommendations & Additional Studies
6. Summary & Conclusions

1. Introduction

Aim of this work:

To compare the high-frequency electromagnetic performance of meshed ground plane Printed Circuit Boards (PCBs) with solid (unmeshed) plane PCBs.

In particular, aim to investigate:

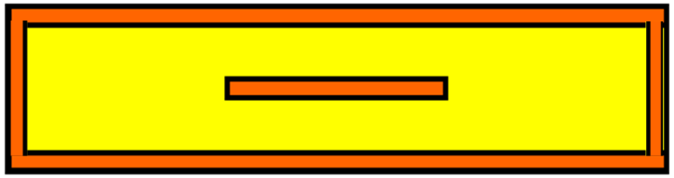
- *The impact of meshed planes on:*
    - *Radiated emission*
    - *Electromagnetic loss*
    - *Crosstalk between neighbouring tracks*
    - *Signal Integrity*

NPL
National Physical Laboratory

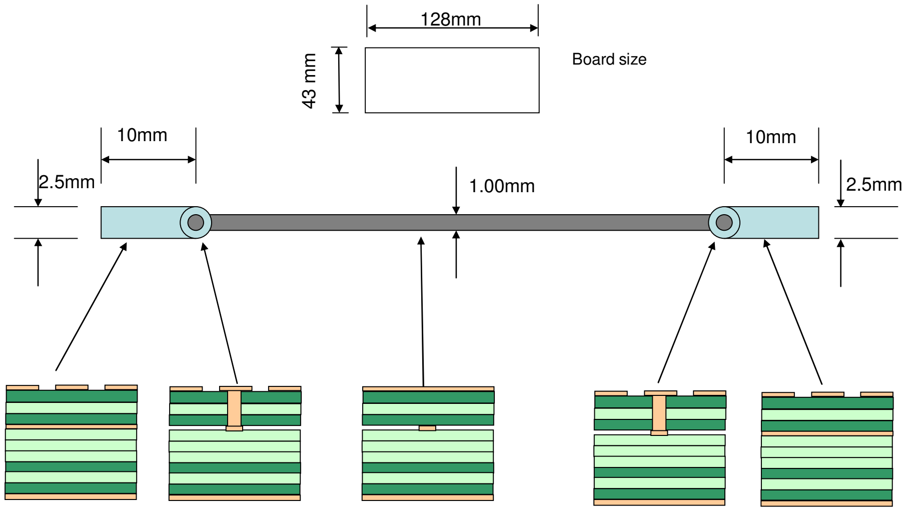
2. PCB Test Structures

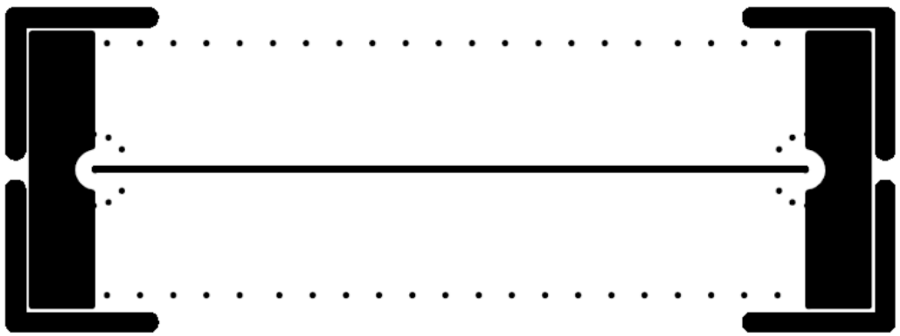
ASTRIUM
AN EADS COMPANY

PCB Test structure 1
Tri-plate transmission line (through line)



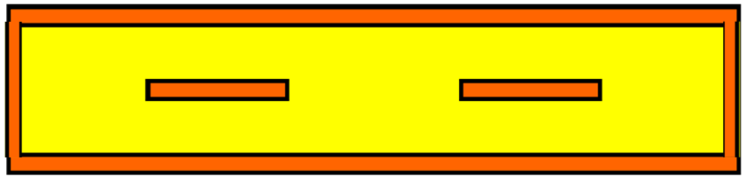
Straight transmission line

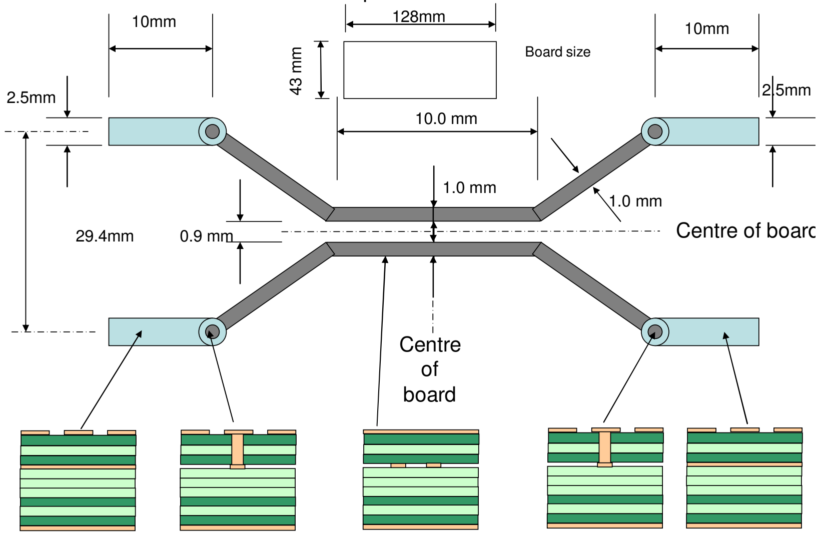


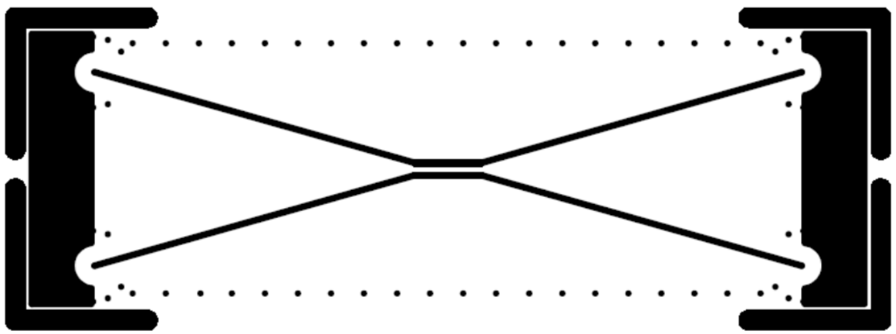


PCB Test structure 2

20 dB Tri-plate coupler

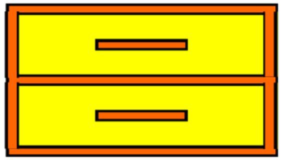




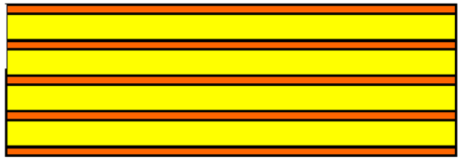


PCB Test structure 3
Tri-plate Isolated lines

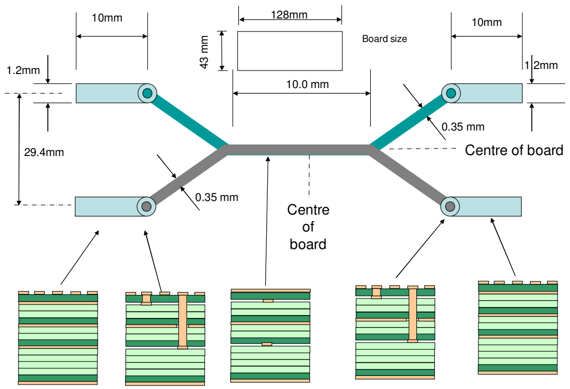
Cross section

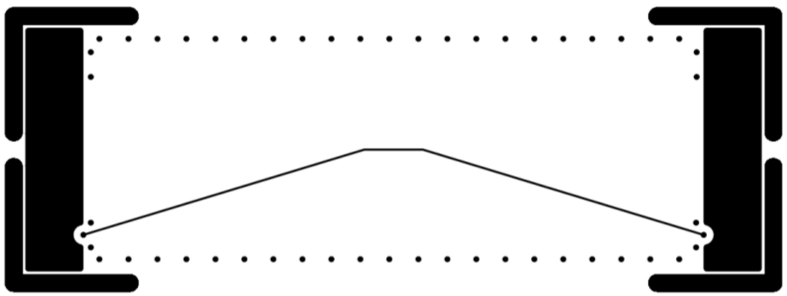


Longitudinal Section

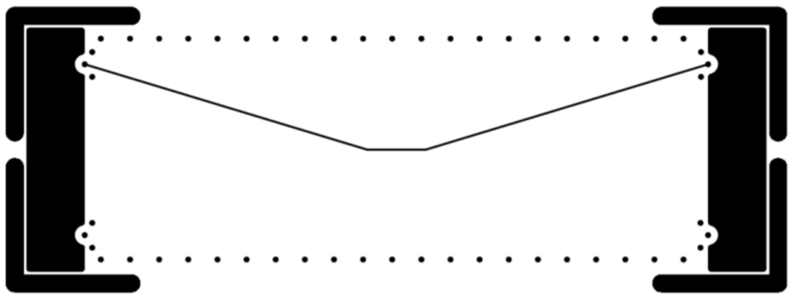


Coupled shielded transmission lines





Test Piece 3 Lower layer pattern

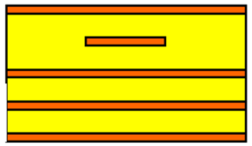


Test Piece 3 Upper layer pattern

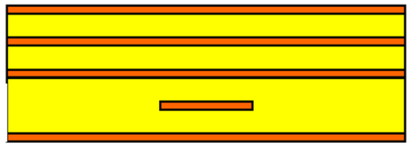
PCB Test structure 4

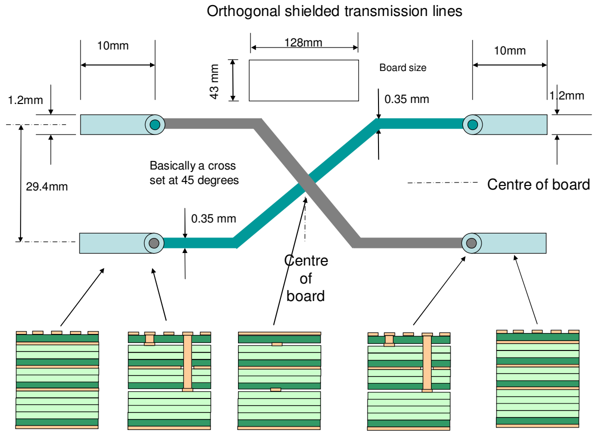
Tri-plate Orthogonal Isolated lines

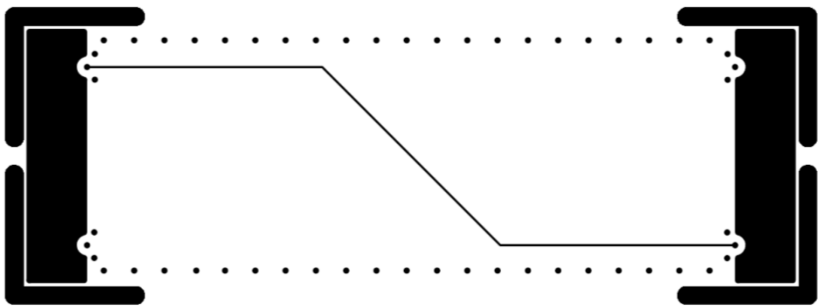
Cross section



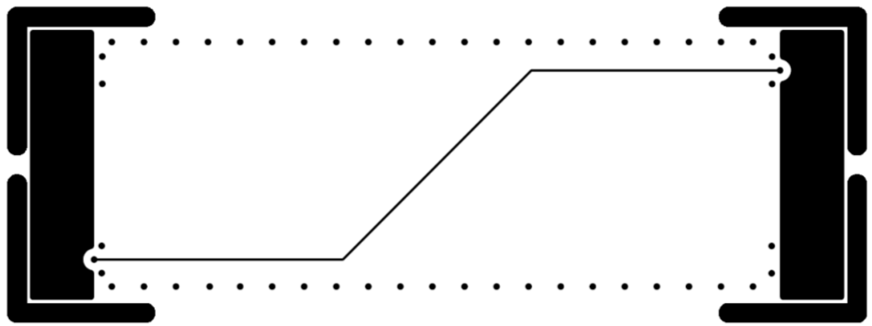
Longitudinal Section







Test Piece 4 Upper layer pattern



Test Piece 4 Lower layer pattern

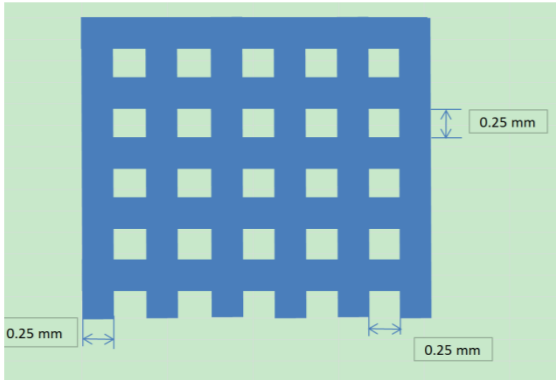
Test Structures

- Each design used three types of ground-plane:
  - Solid (no mesh)
  - Coarse mesh (500 µm spacing)
  - Fine mesh (250 µm spacing)

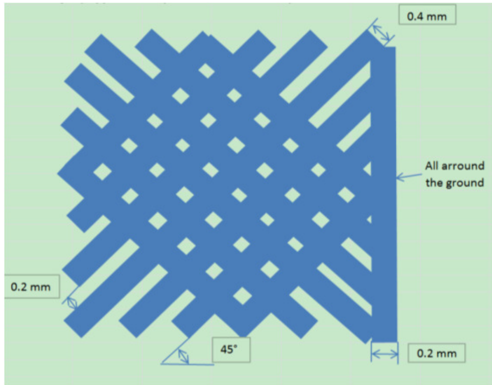
- 3 ground-planes applied to 4 PCB test structures:
  - $3 \times 4 = 12$ PCB test circuits

Test Structure Number	Circuit design	Ground plane type		
		a. Solid	b. Fine mesh	c. Coarse mesh
1	Through line	A-1	B-1	C-1
2	Tri-plate coupler	D-1	E-1	F-1
3	Tri-plate isolated lines	S-1	T-1	U-1
4	Tri-plate orthogonal lines	W-1	X-1	Y-1

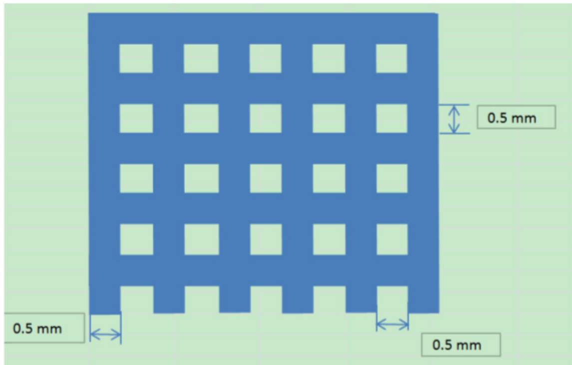
Mesh Plane format



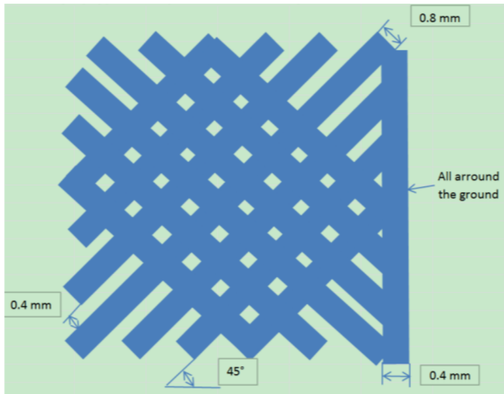
Fine mesh outer ground plane layer



Fine mesh internal ground plane layer



Coarse mesh outer ground plane layer



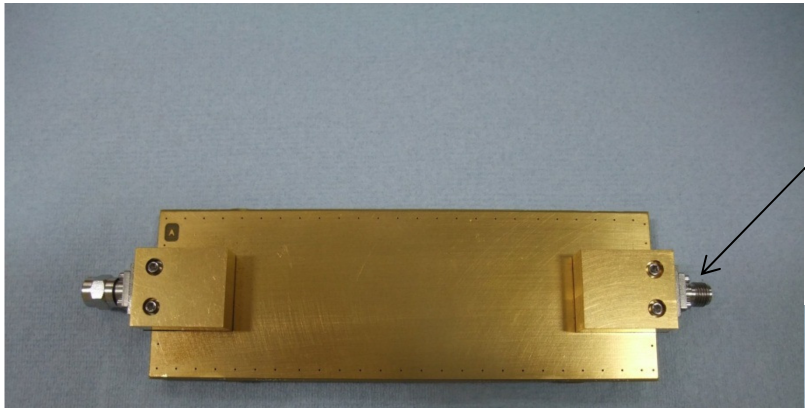
Coarse mesh internal ground plane layer

Constructional Analysis

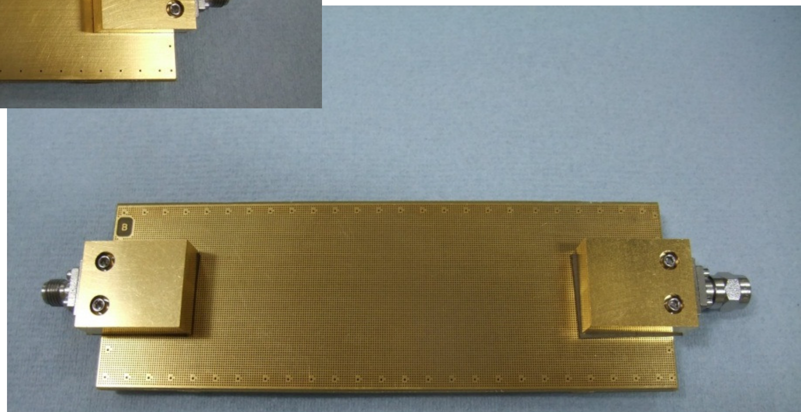
- The Test Structures were manufactured by Systronic (France)
- A constructional analysis (micro-sectional analysis) showed that the boards were manufactured in close agreement with the original design expectation to within a dimensional tolerance of ~5%.

Assembled units
Test structure 1

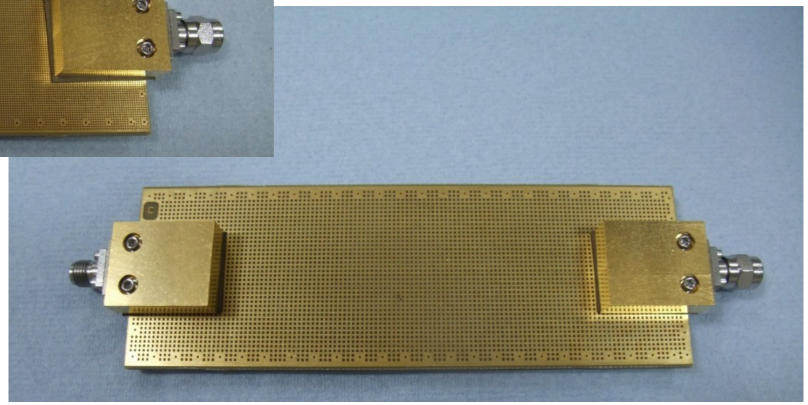
Connector and RF Shields



solid ground plane



Fine mesh
ground plane



Coarse mesh ground plane

3. RF testing of PCB Test Structures

3.1 Frequency domain testing (VNA S-parameters)

3.2 Time-domain testing (pulses and oscilloscopes)

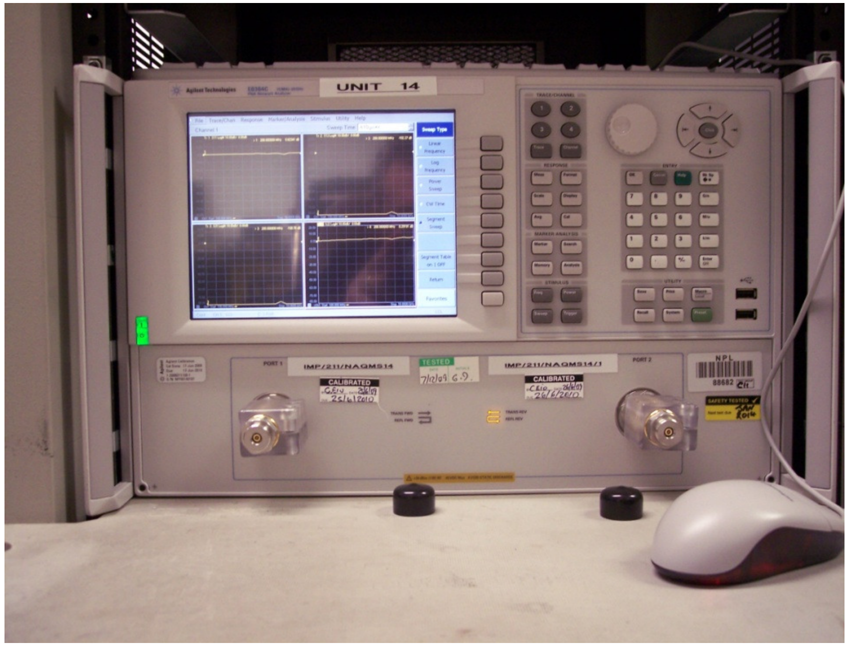
3.3 Free-field testing (Anechoic and Reverberation Chambers)

3.1. Frequency-domain testing

Scattering (S-) parameters to determine reflection and transmission properties (including crosstalk)

Measure to:

- ❑ 20 GHz (i.e. full bandwidth)
- ❑ 8 GHz (i.e. restricted bandwidth)



3.1. Frequency-domain testing (contd.)

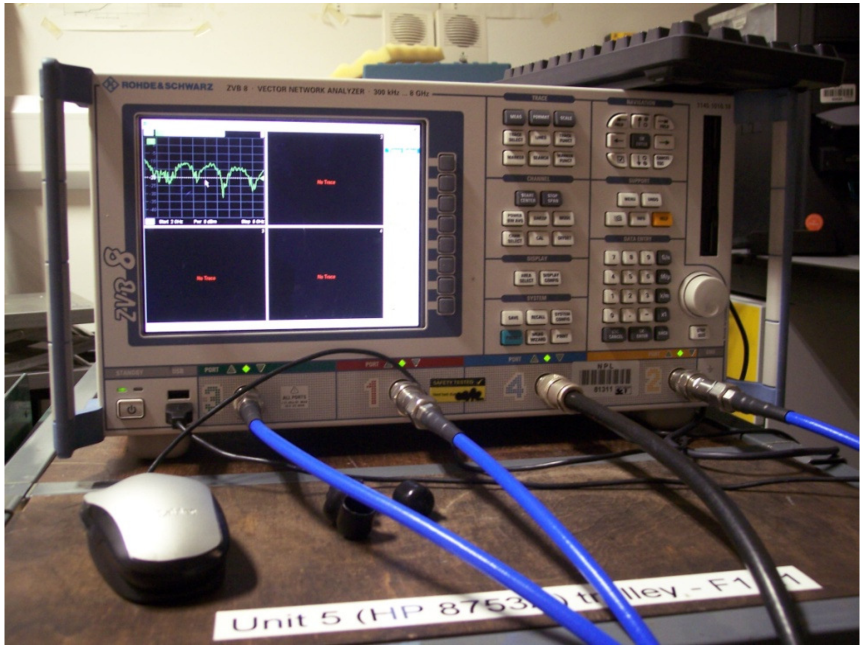
National Physical Laboratory

Gated time-domain responses

- ❑ electrically ‘remove’ the connectors

Mixed-mode S-parameters:

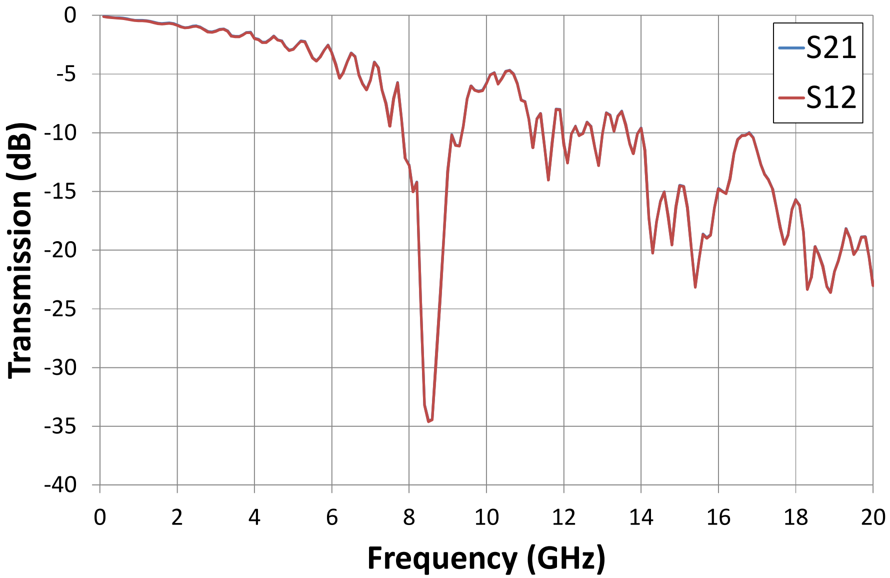
- ❑ Differential mode - Sdd
- ❑ Common mode - Scc
- ❑ Common-to-differential mode - Sdc
- ❑ Differential-to-common mode - Scd



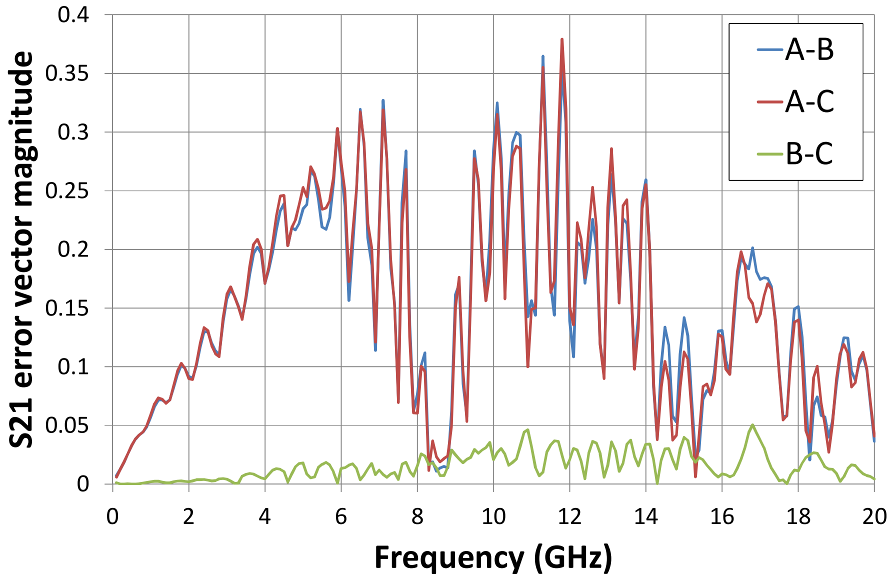
ASTRIUM
AN EADS COMPANY

S-parameters (transmission)
Test Structure 1

Transmission magnitude (dB)

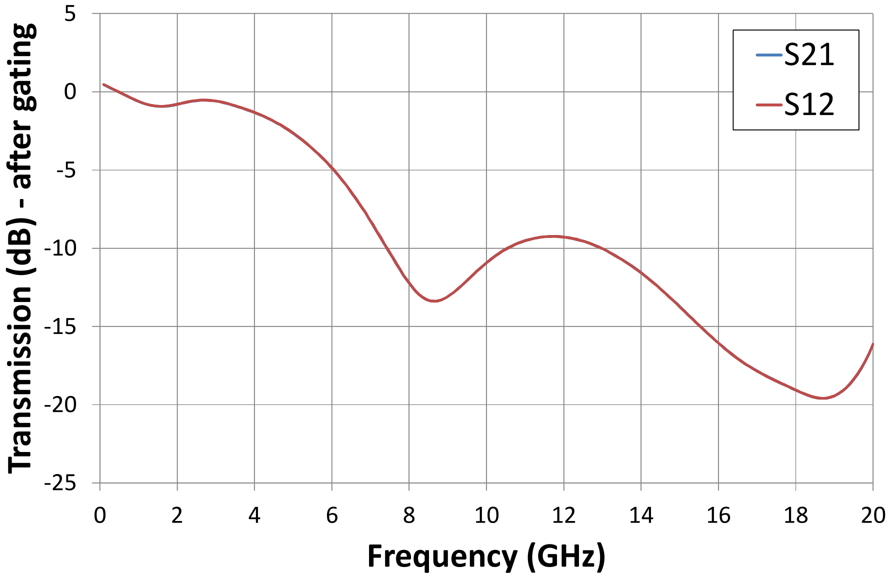


Transmission differences - solid versus mesh

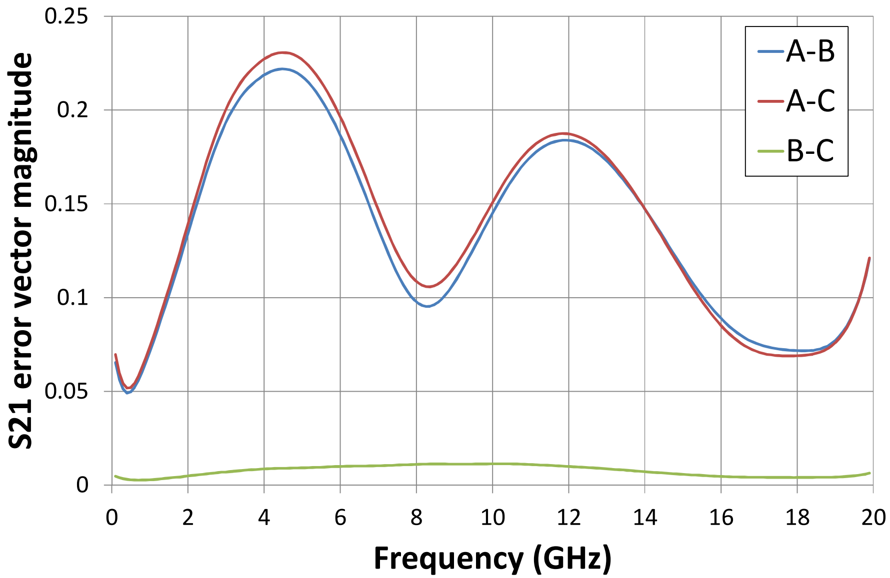


S-parameters (transmission; after gating) Test Structure 1

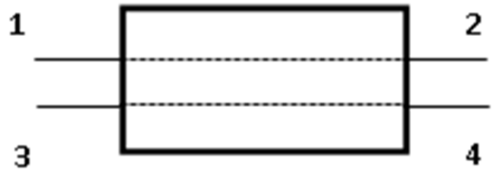
Transmission magnitude (dB)



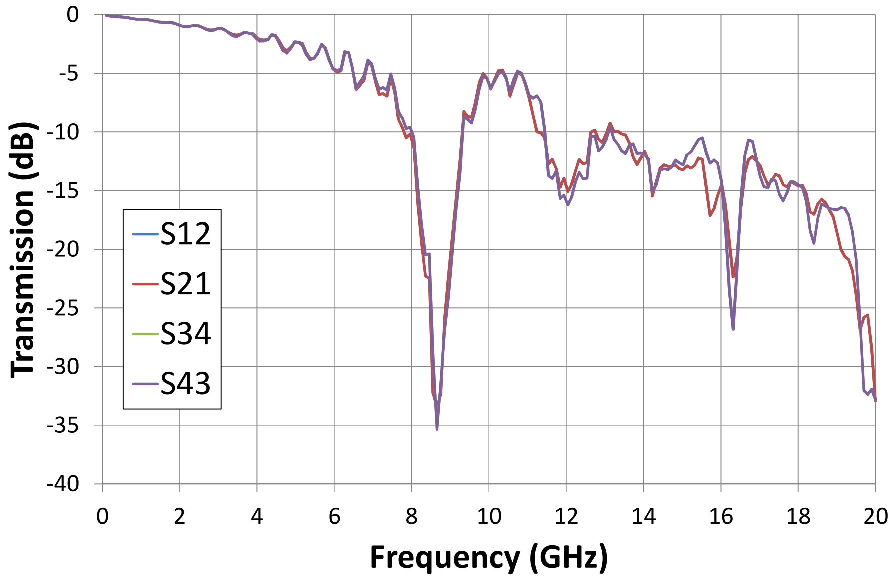
Transmission differences - solid versus mesh



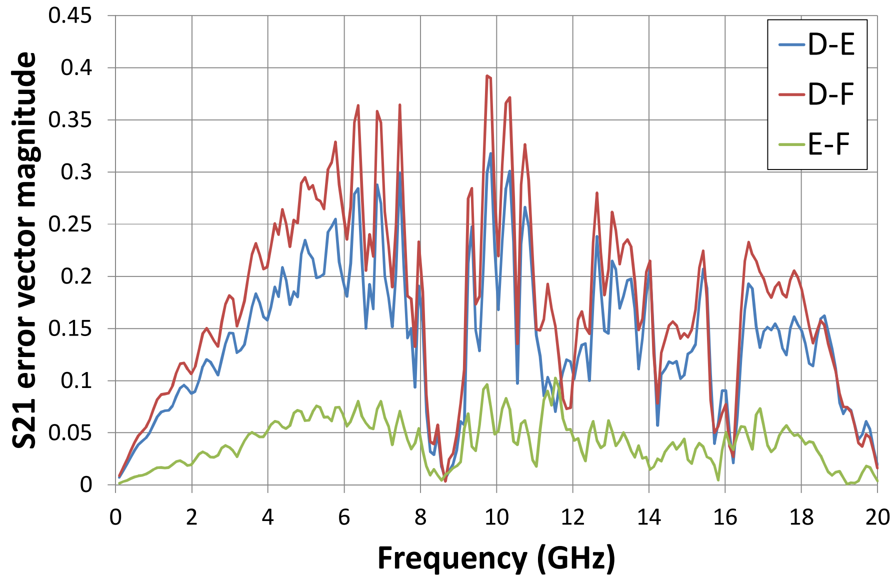
S-parameters (transmission) Test Structure 2



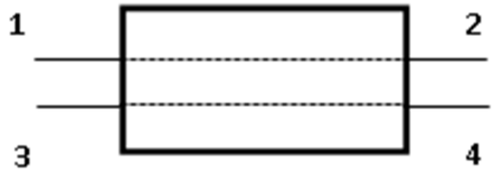
Transmission magnitude (dB)



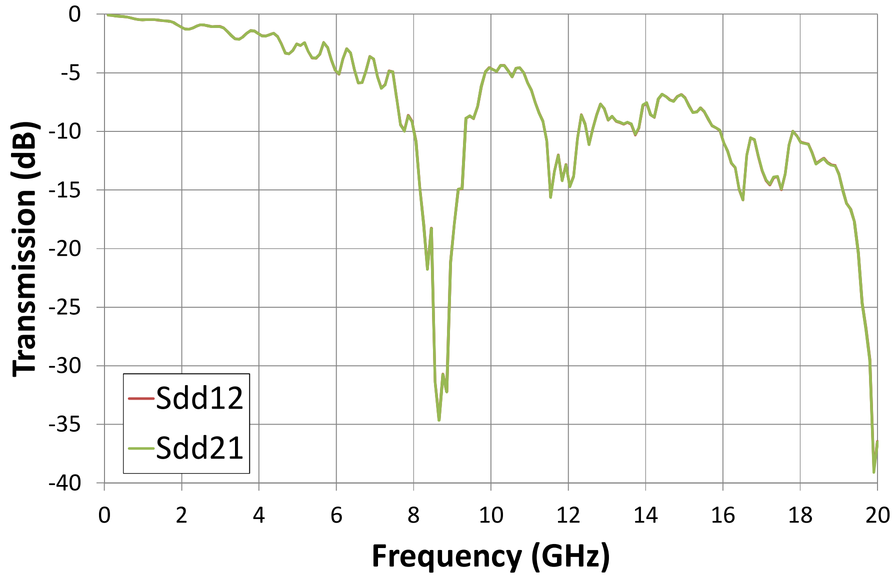
Transmission differences - solid versus mesh



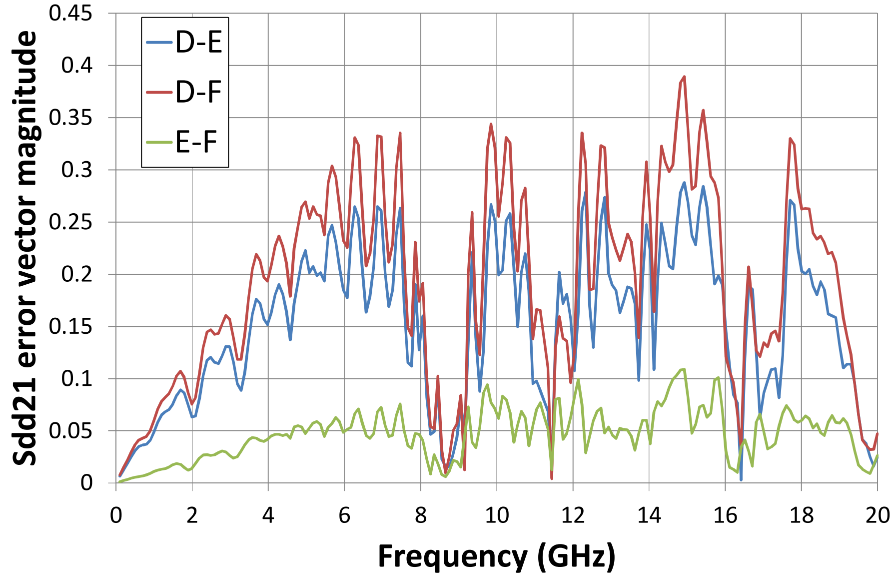
Differential S-parameters (transmission) Test Structure 2



Transmission magnitude (dB)



Transmission differences - solid versus mesh



Frequency domain testing – Conclusions

- Consistent signal drop out at around 8 GHz
- Drop-out could be due to PCB vias (or connector launches)
- PCBs with meshed planes are more lossy than solid planes
- There is little difference between coarse- and fine-meshed planes

3.2 Time-domain testing (1)

Root-Impulse-Energy loss

- ❑ Assess each mesh-plane loss with respect to the equivalent solid-plane loss

Effective response values:

- ❑ Impulse response
- ❑ Step response

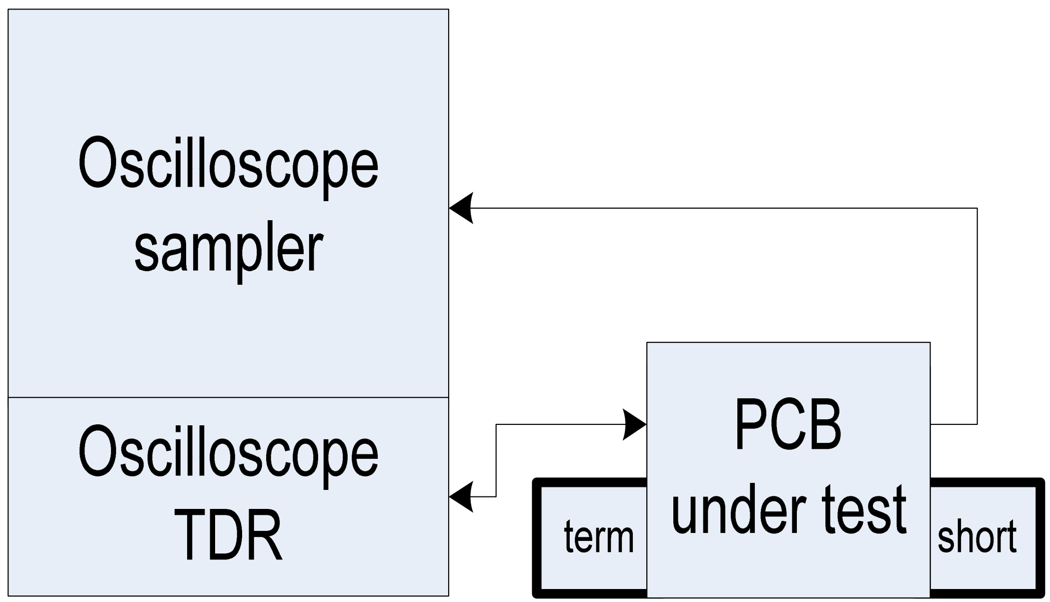
3.2 Time-domain testing (2)

Inspection of pulse structure

- Step waveform deformations

Crosstalk

- Circuit designs 2, 3 and 4
- Examine TDT response in ‘coupled’ line



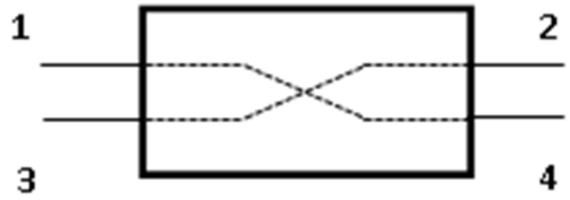
3.2 Time-domain testing (3)

- Root-Impulse-Energy (loss) tests – not much difference seen between meshed and solid ground planes
- Effective Response tests – Test Structure 1

Ground plane	Impulse response (ps)	Step response (ps)
Solid	51.0	81.0
Fine Mesh	54.8	81.0
Coarse Mesh	55.7	81.0

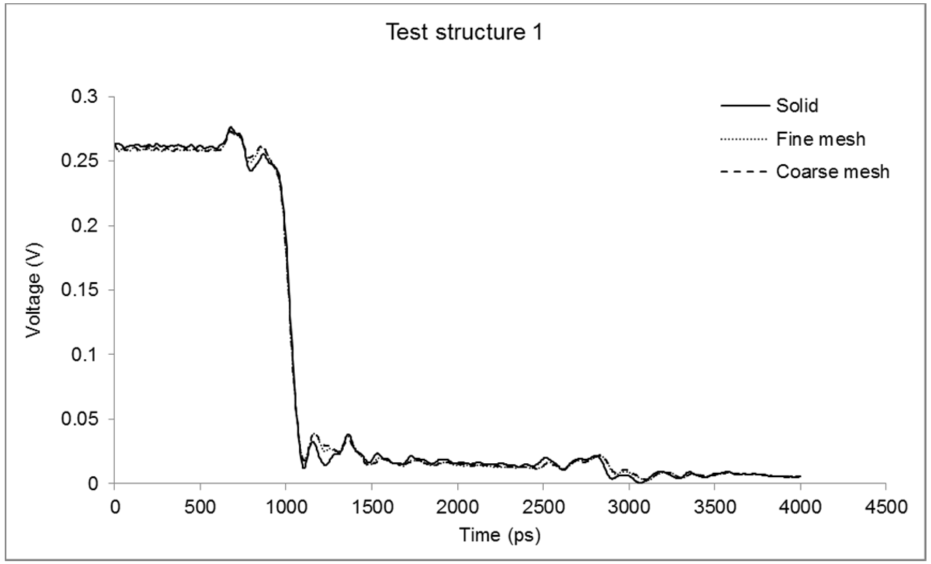
Measurement Uncertainty ±2.5 ps

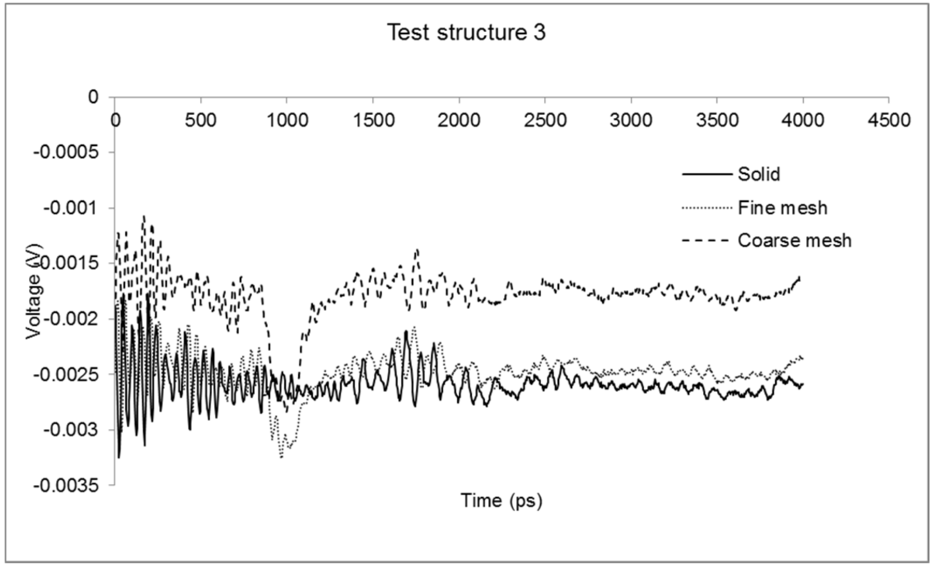
3.2 Time-domain testing (4)



Inspection of pulse structure – Test Structure 1

Crosstalk – Test Structure 3





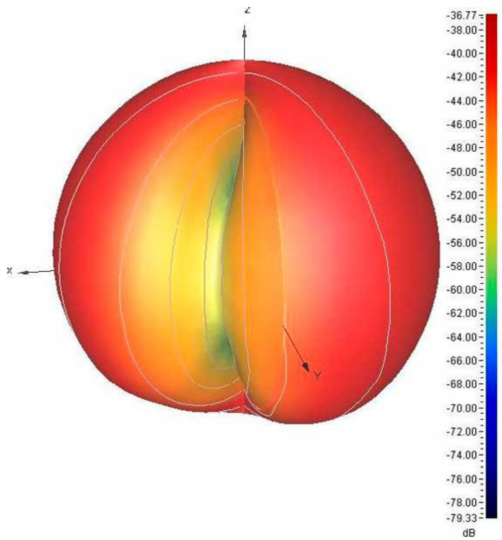
Time-domain testing - Conclusions

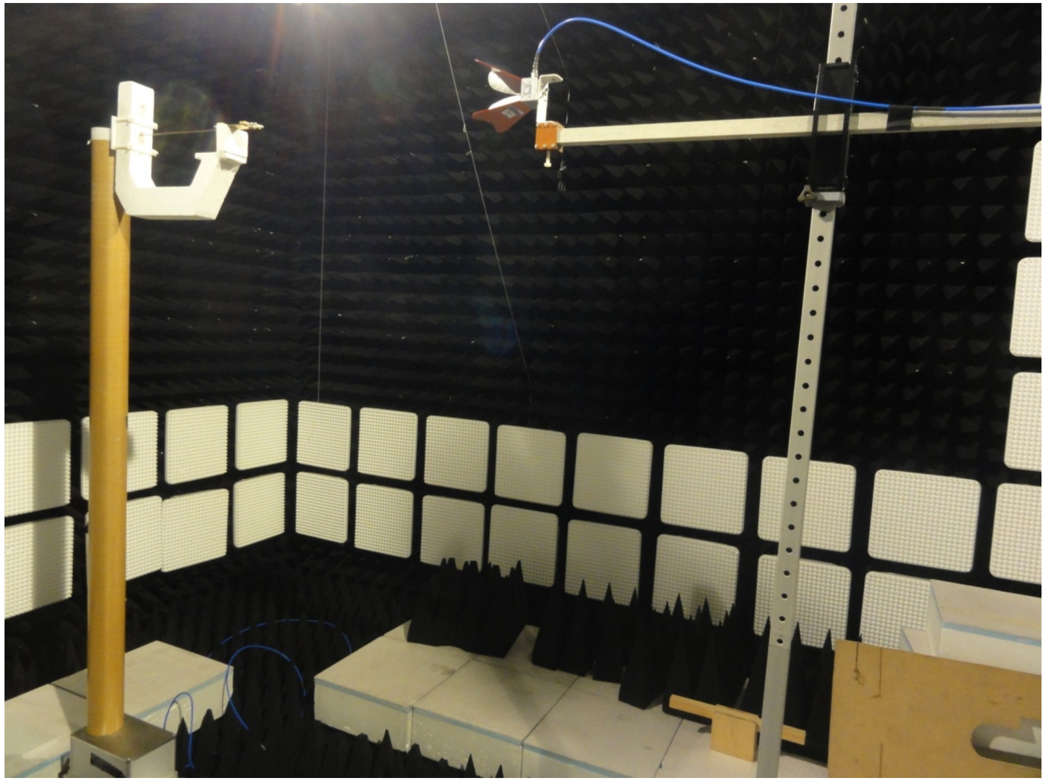
- No significant change in broadband loss detected (using RIE)
- Some pulse-broadening observed for impulse responses
- Very little change to pulse structure detected
- Some crosstalk detected for coarse meshes on ‘coupler’ circuits

3.3 Free-field testing

Anechoic Chamber:

- ❑ 3-D radiation patterns
- ❑ Total Radiated Power





National Physical Laboratory

ASTRIUM
AN EADS COMPANY

3.3 Free-field testing (contd.)

Reverberation chamber

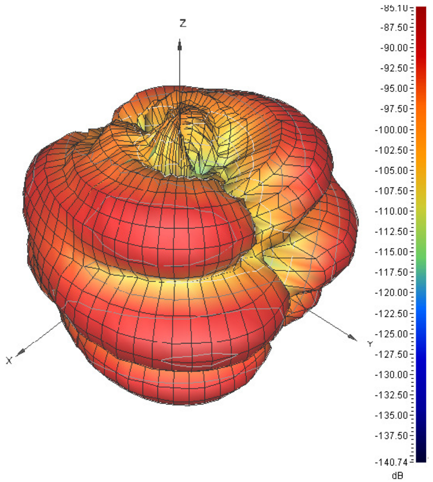
- ❑ Total Radiated Power

3D radiation patterns (1)

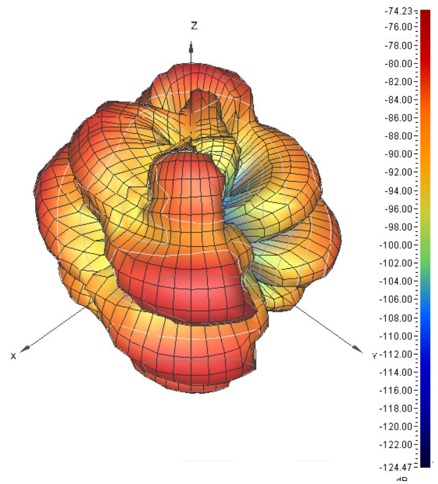
NPL National Physical Laboratory

Test Structure 1 – operating at 5 GHz

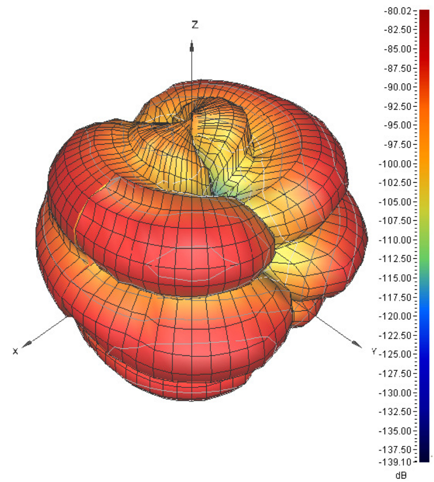
Solid



Fine mesh



Coarse mesh

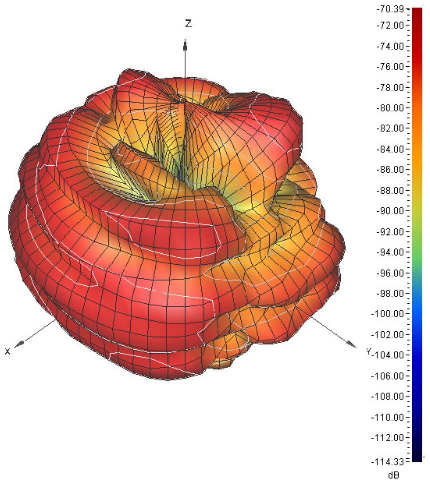


ASTRIUM
AN EADS COMPANY

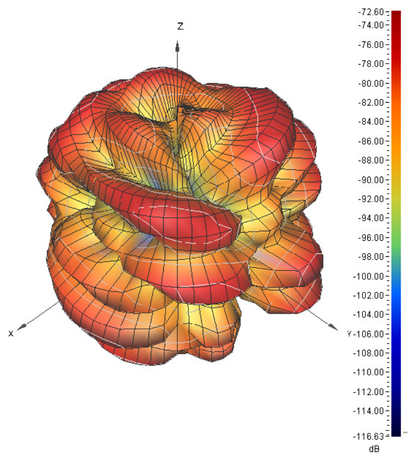
3D radiation patterns (2)

Test Structure 2 – operating at 10 GHz

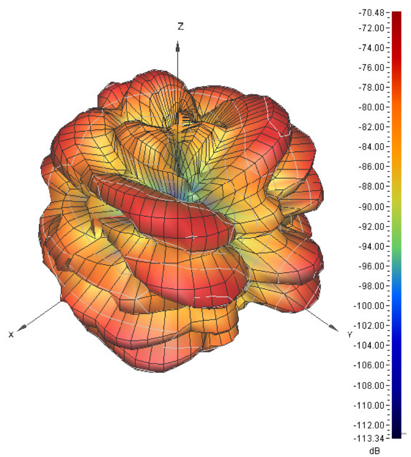
Solid



Fine mesh



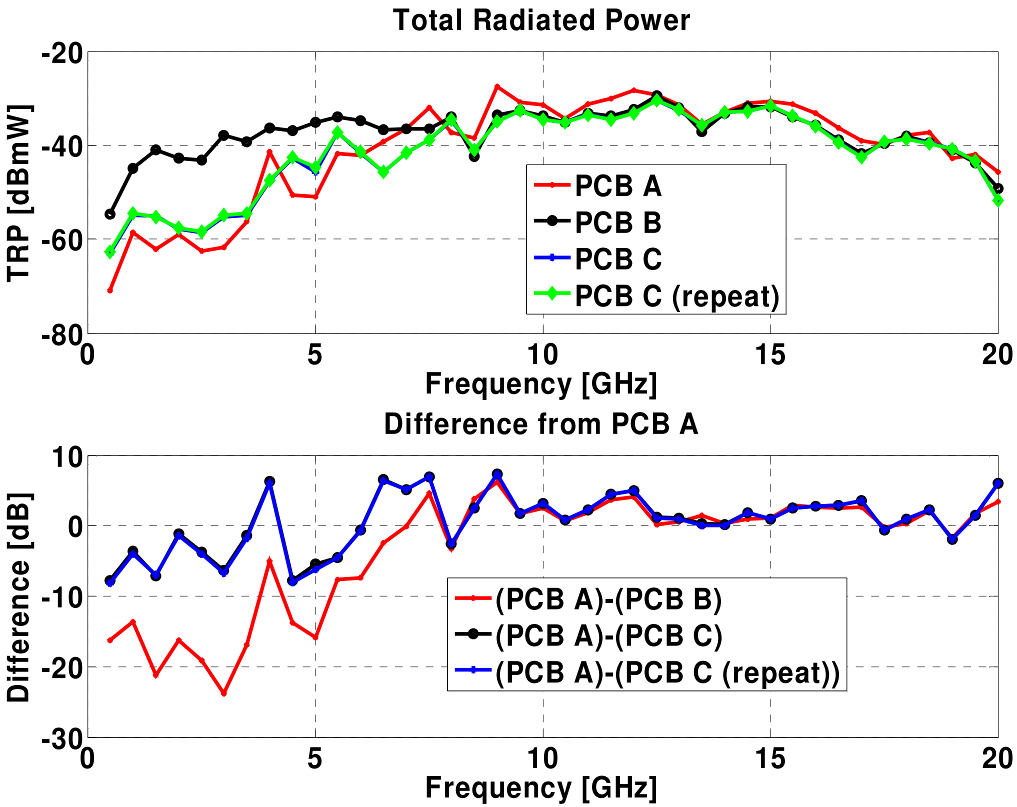
Coarse mesh



Total Radiated Power (Anechoic Chamber)

NPL National Physical Laboratory

Test Structure 1

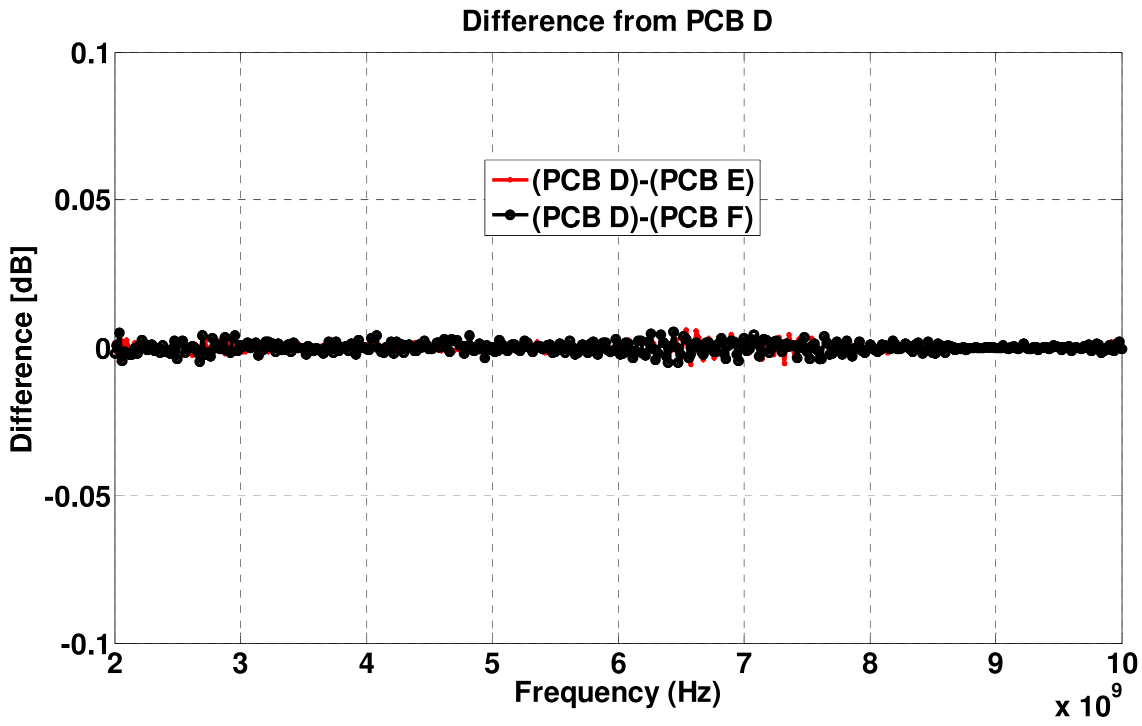


PCB A = Solid plane
PCB B = fine mesh plane
PCB C = coarse mesh plane

ASTRIUM
AN EADS COMPANY

Total radiated power (Reverberation Chamber)

Test Structure 2



PCB D = Solid plane
PCB E = fine mesh plane
PCB F = coarse mesh plane

Free-field testing – Conclusions

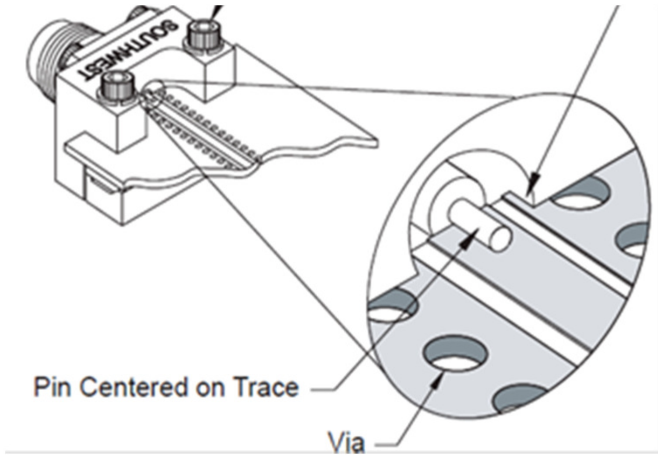
- The 3D radiation patterns for the three different ground planes are different
- However, there does not seem to be significant radiated power from any of these ground plane designs
- Differences in radiated power from the three ground planes are close to zero

4. EM modelling of PCB Test Structures

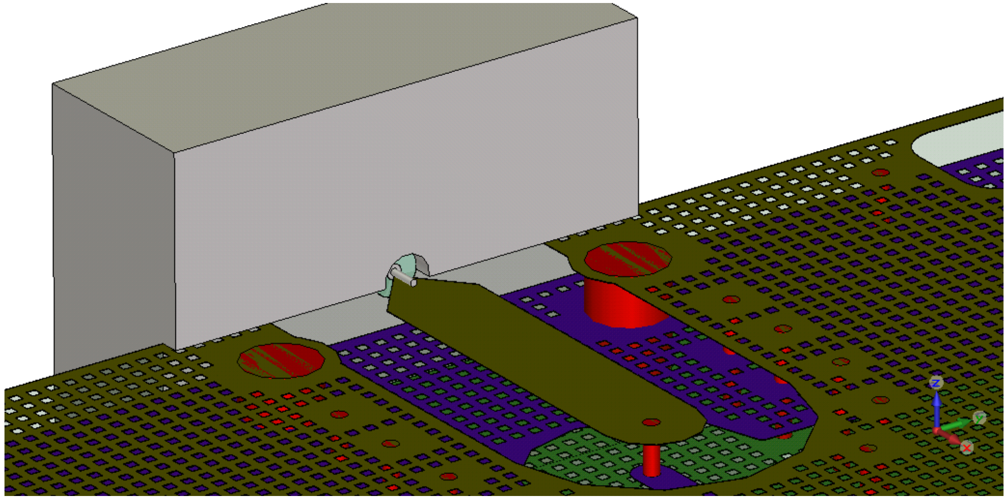
- The electromagnetic model was established using CST Microwave Studio

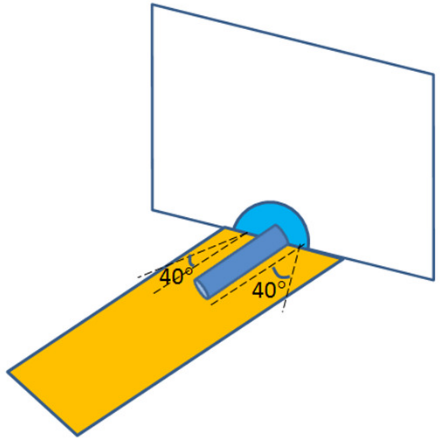
- Model details included:
  - PCB transmission lines (stripline)
  - PCB via holes
  - End-launch coaxial connectors and shielding
  - Ground plane mesh size

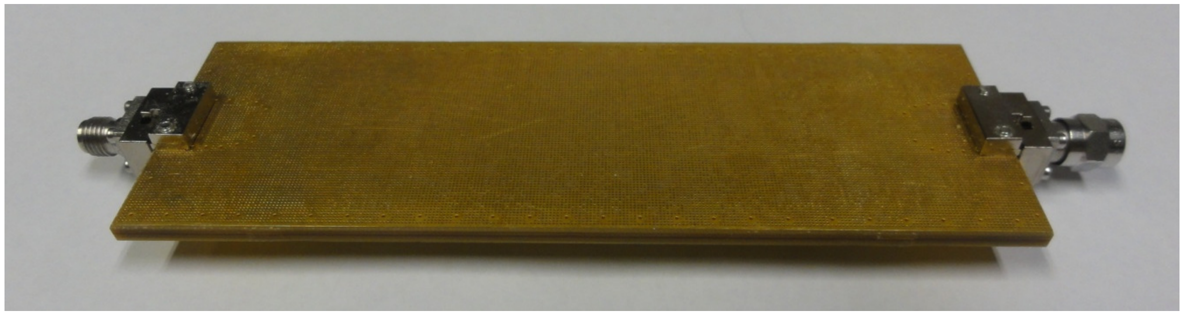
- Model mesh-size was a limiting factor on performance resolution



4. EM modelling of PCB Test Structures



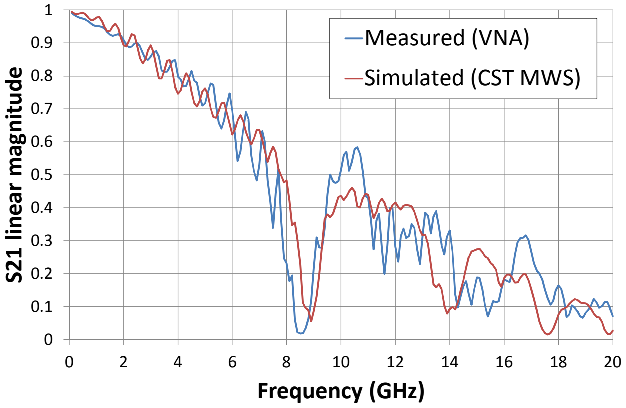




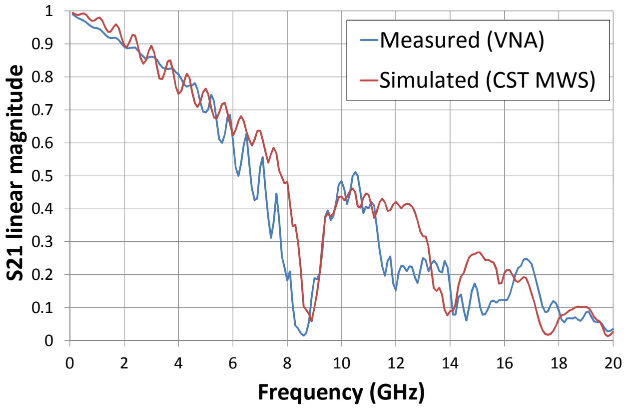
Validation of EM model (1)

Frequency-domain – Test Structure 1

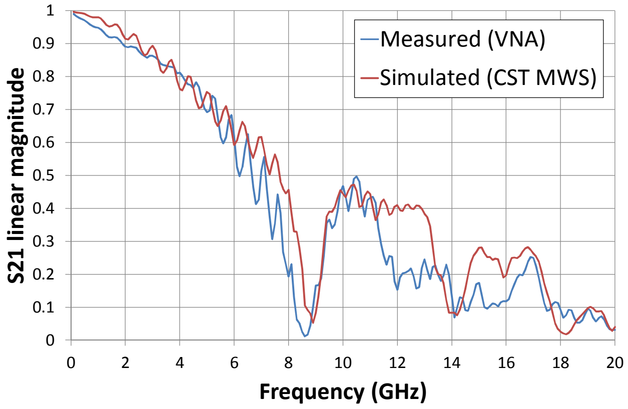
Solid



Fine mesh



Coarse mesh



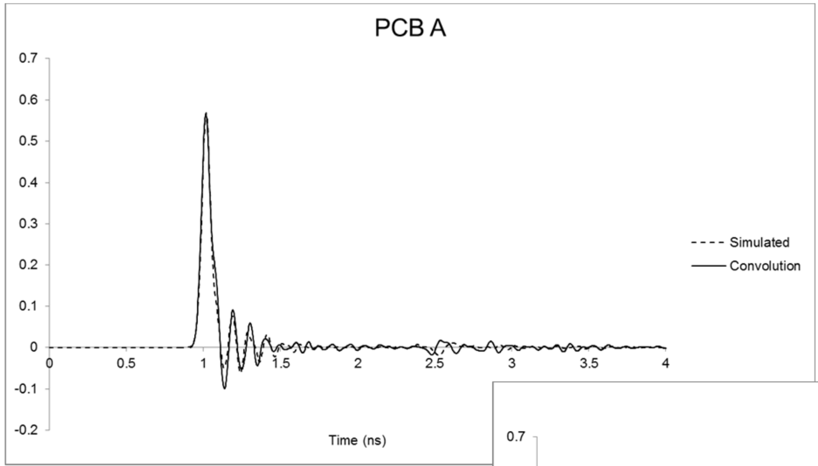
Validation of EM model (2)

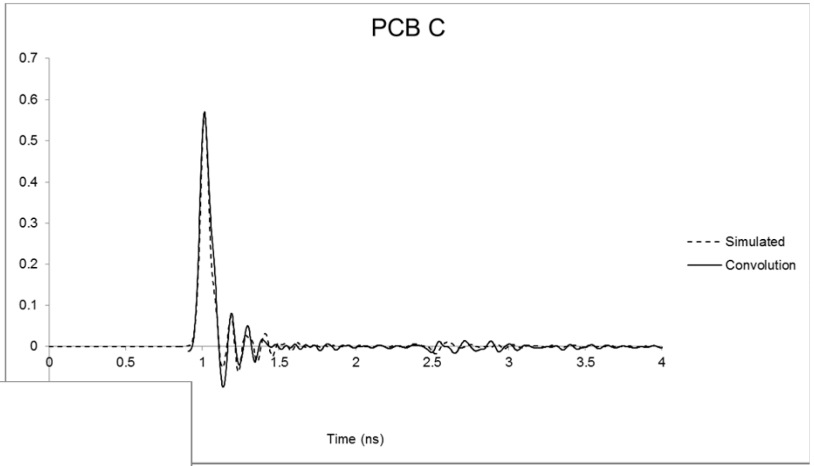
Time-domain – Test Structure 1

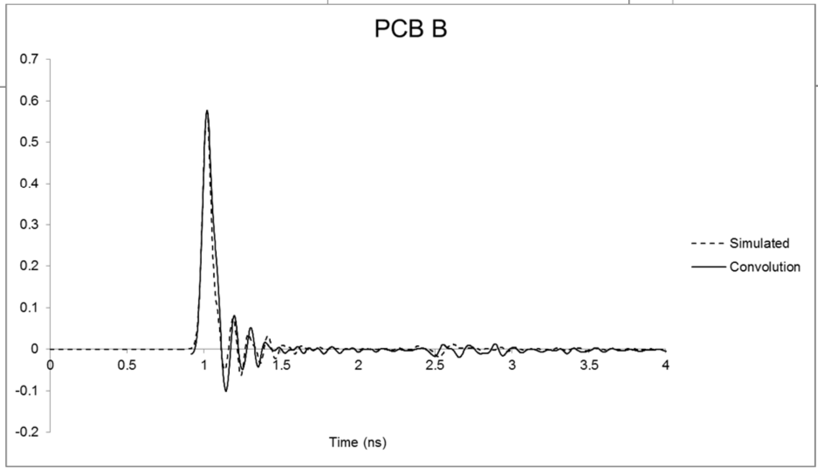
Solid

Fine mesh

Coarse mesh







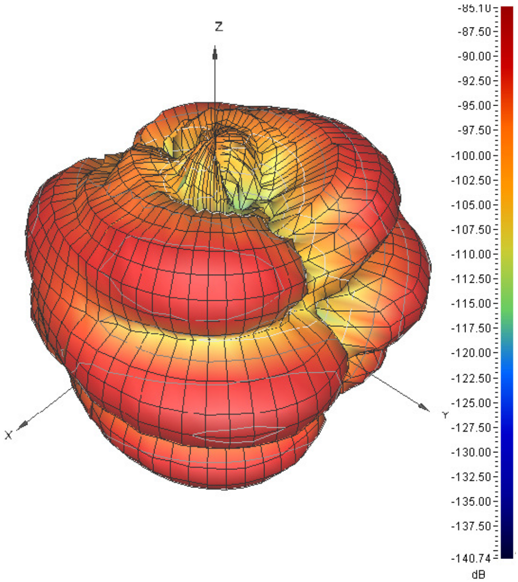
—— = Measured
- - - = Simulation

Validation of EM model (3)

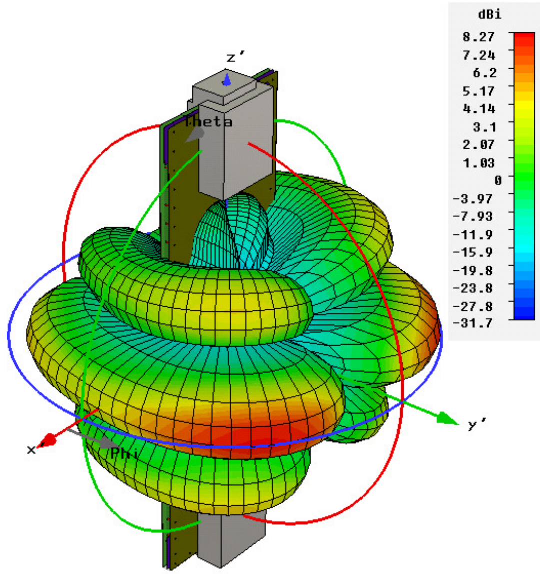
National Physical Laboratory

3D radiation Patterns – Test Structure 1 at 5 GHz

Measured



Modeled



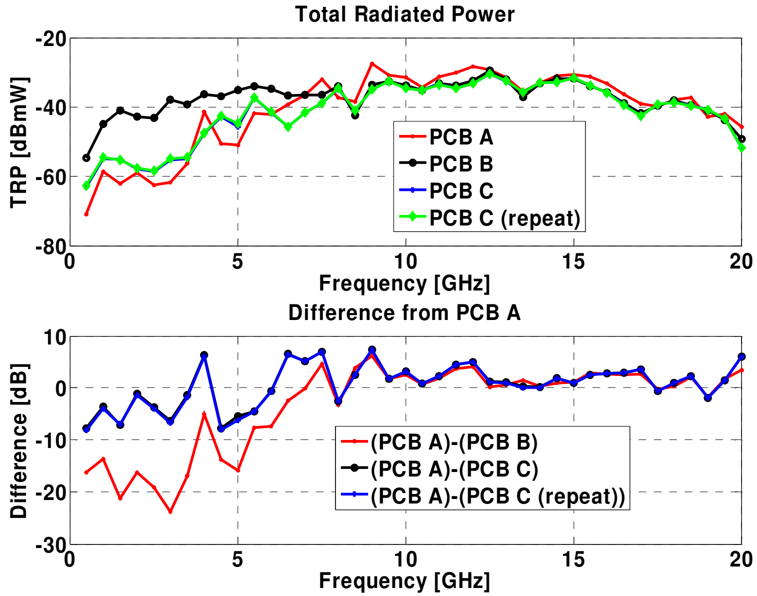
ASTRIUM
AN EADS COMPANY

Validation of EM model (4)

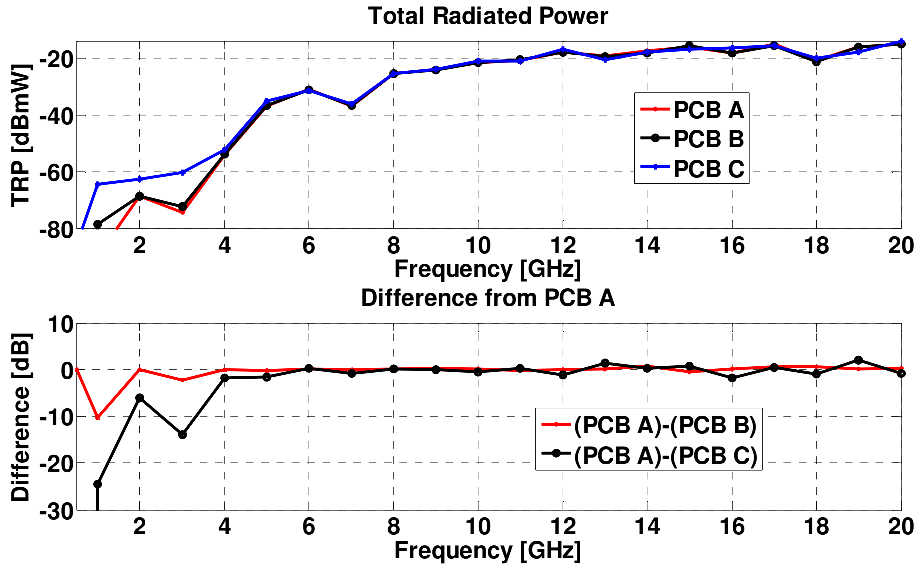
National Physical Laboratory

Total Radiated Power – PCB Test Structure 1

Measured



Simulated



ASTRIUM
AN EADS COMPANY

EM Modelling - Conclusions

- Generally good agreement between model and measurements
- Model can be used to predict trends (e.g. the ‘dip’ at 8 GHz)
- Some subtle variations in the measurements do not show in the model
- Improving the computational grid could improve the model performance (for subtle features, etc)
- Model still worked for low level signals (e.g. the 3D radiation patterns)

5a. Recommendations

- Since performance of the two mesh-planes was similar, larger mesh sizes may be acceptable for some applications, leading to:
  - Increased bonding strength for Multilayer PCB – physically more robust; delamination less likely
  - Less copper in the ground plane – saving on overall PCB mass
  - Help with thru via clearance on PCBs with high-density interconnects

5b. Additional Studies

- Extension of study to include larger mesh sizes
- Modify PCB structures to allow operation up to much higher frequencies
- Investigate performance with flexible substrates
- Investigate current carrying capability of mesh planes
- Develop standardised test method(s) for meshed PCBs
- etc.

6. Summary & Conclusions

- Meshed-plane PCBs exhibit more electromagnetic loss than solid-plane PCBs
- Increased loss is not due to radiation – therefore, loss must be occurring inside the PCBs
- Increased loss due to degradation in performance of the PCB transmission lines (mesh-planes make less effective ‘grounds’)
- Further study is recommended (e.g. for larger meshes, higher frequencies, etc)

Acknowledgement

This work was funded by the European Space Agency (ESA – ESTEC) under Contract No 4000101718/NL/SFe.

Thanks for your attention!

martin.salter@npl.co.uk