8th ESA Round Table on Micro and Nano Technologies for Space Applications

15 – 19 October 2012

Section 3 – RF MEMS

12x12 Switch Matrix
Unit based on DPDT MEMS micro-switches in LTCC hermetic package

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Introduction

The present work has been developed under ESA contract Nr.14628/NL/CK by a Consortium composed by researchers of several organizations in Italy, France and Germany, leaded by Thales Alenia Space Italia as a prime contractor

- Thales Alenia Space Italia
  - Technical Managing, LTCC Packaging, Mechanical Design, Unit Manufacturing and Assembling
- Munich University of Technology – Institute for High-Frequency Engineering
  - Design of the Switch matrix (simulation and layout)
- Università degli Studi di Perugia – Electronics Engineering Dpt.
  - Design of the MEMS DPDT switches (simulation and layout)
- Fondazione Ugo Kessler Trento Italia
  - Fabrication of the MEMS DPDT switches
- Thales Alenia Space France Toulouse
  - Reliability Assessment
- Consiglio Nazionale delle Ricerche (CNR) – Istituto per la Microelettronica e Microsistemi
  - Switch Matrix Unit Test

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Object of the study

Manufacturing and testing of an Engineering Model (EM) unit of the 12x12 switch matrix

- The switch matrix is housed in an aluminum box having RF coax and DC connectors as an electrical interface
- The MEMS switches inside (DPDT) are driven by a control circuit housed in the unit box, which accepts the memory load (ML-16) configuration commands
- The unit box is also prepared for housing a DC-DC converter circuit suitable to power the control circuit and generate from the primary bus voltage the high voltage needed for the MEMS switches to close their membrane contact (+60V)
- The unit is being designed according to the flight standards and will be subjected either to electrical or environmental testing (TVAC, random vibration, ect.), in order to prove the flight worthiness of the design

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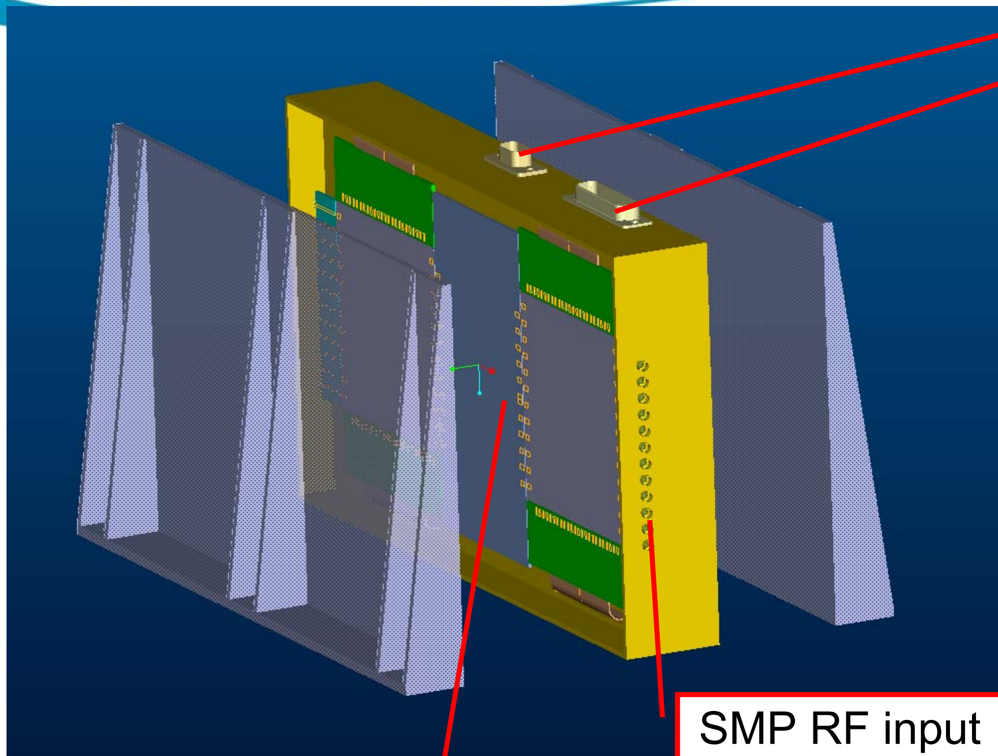
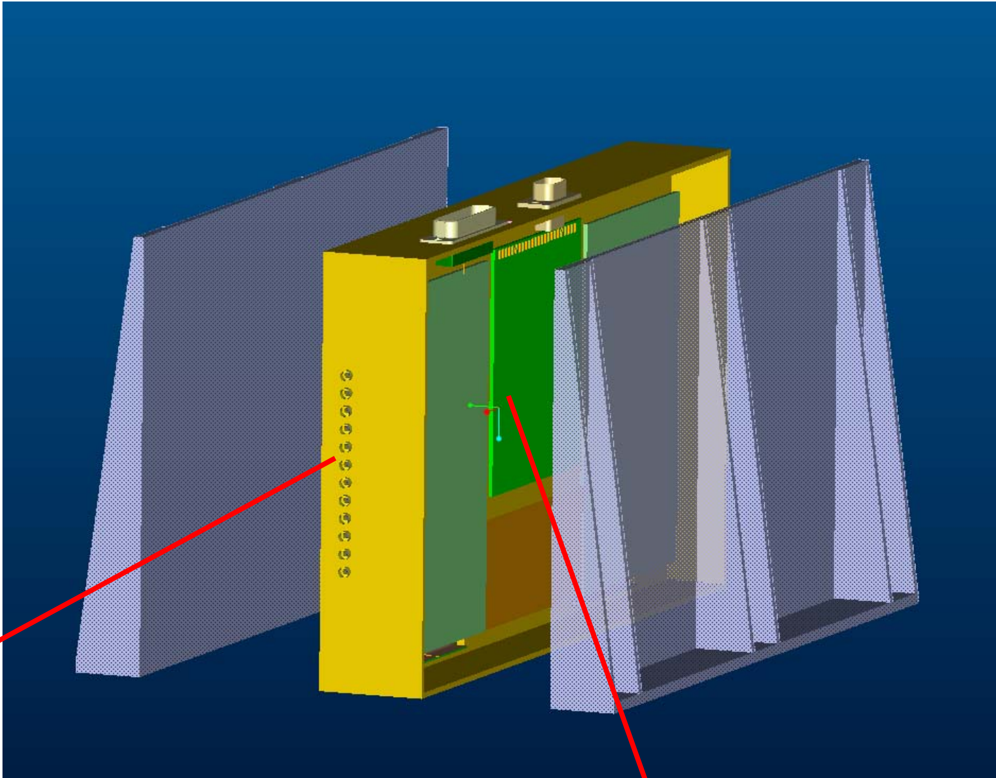
Switch Matrix Unit – Mechanical Sketch





Power and Command Connectors

SMP RF input connectors

LTCC hybrid modules

SMP RF output connectors

Control and DC-DC converter boards

Dimensions: 280mm x 160mm x 40mm
Mass= 1.790Kg

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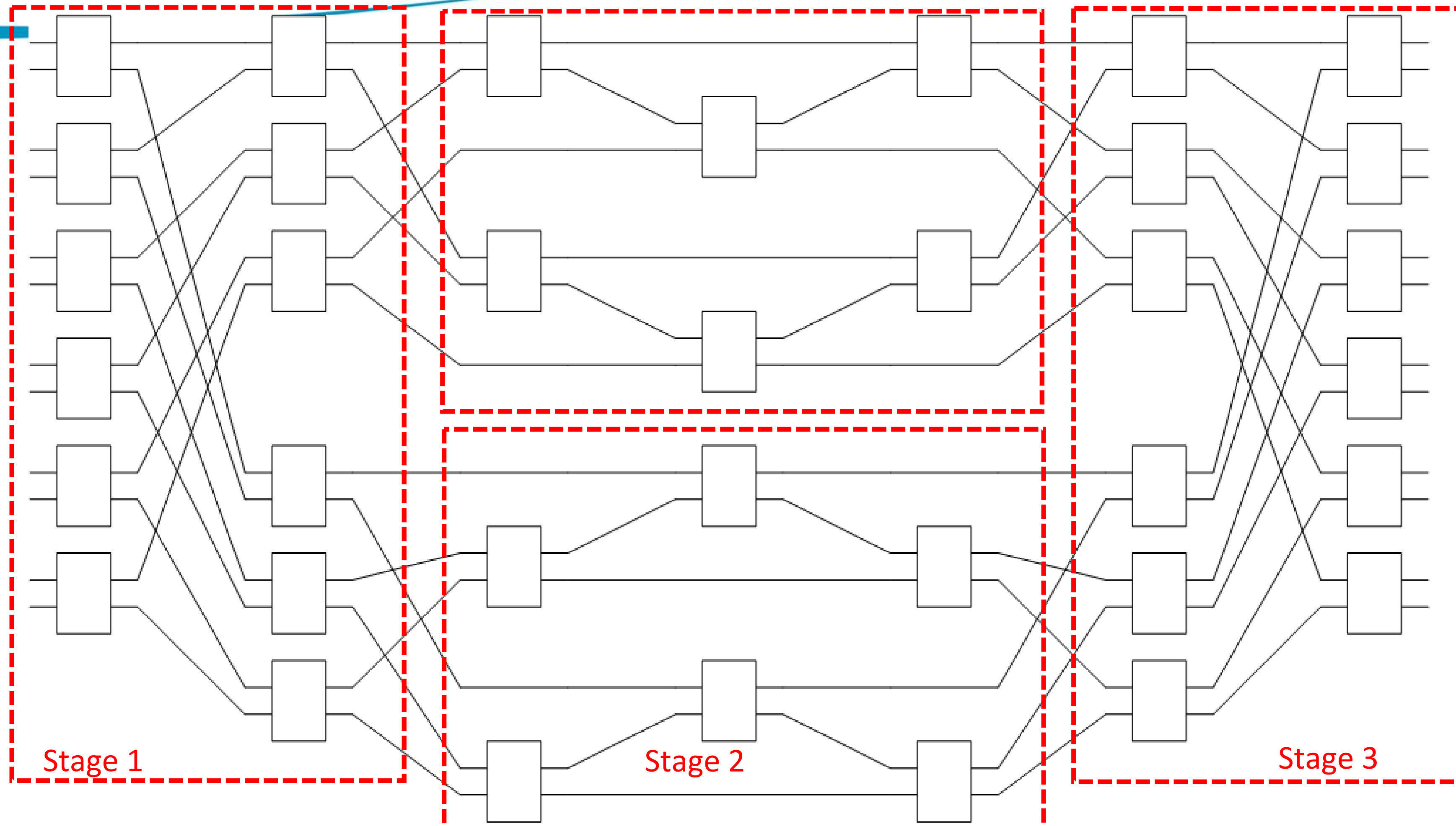
Chosen Switch Matrix Topology: Planar Benes Network



- Basic switching element: DPDT switch (2x2 ring matrix)
- The Planar Benes network can be realized in multilayer LTCC technology
- Four LTCC boards are realized - size 8.5x8.5cm (technology limit)

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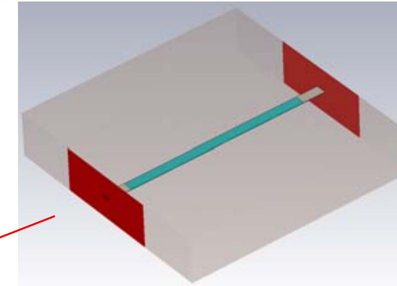
Planar Benes Network: balancing of the paths losses

Resistive lines are inserted to make IL be equal regardless of path assignments.



Inserting resistive lines

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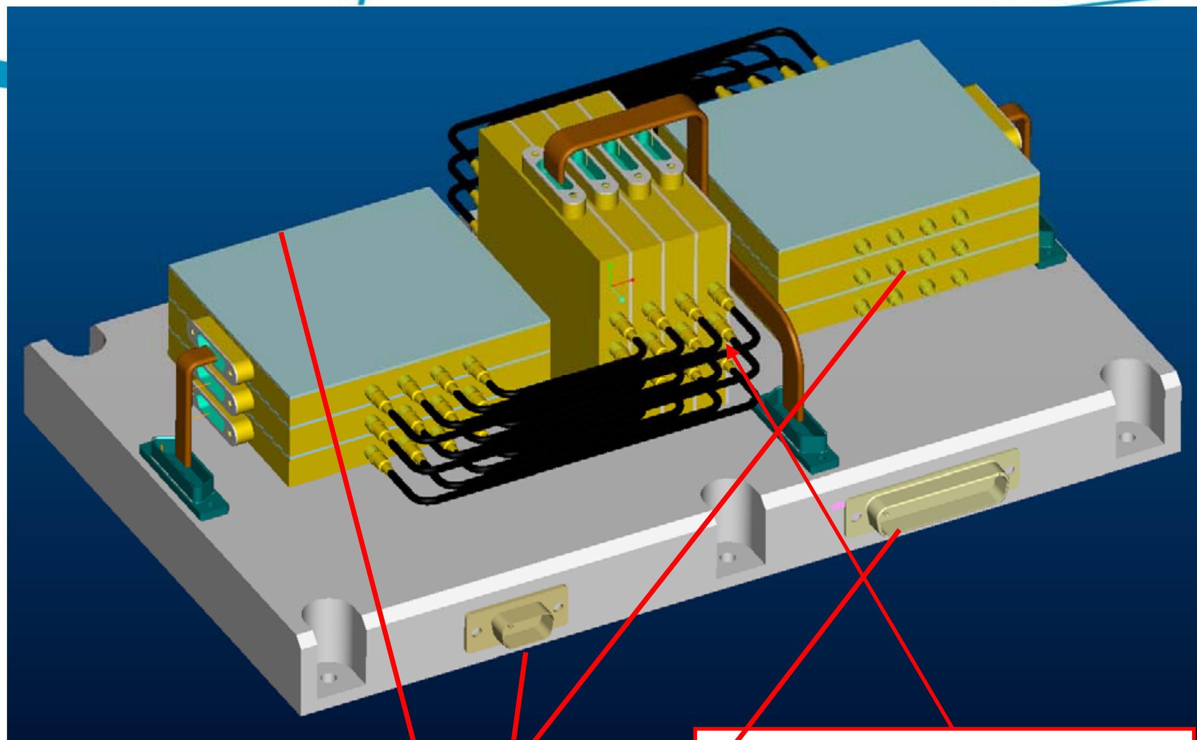
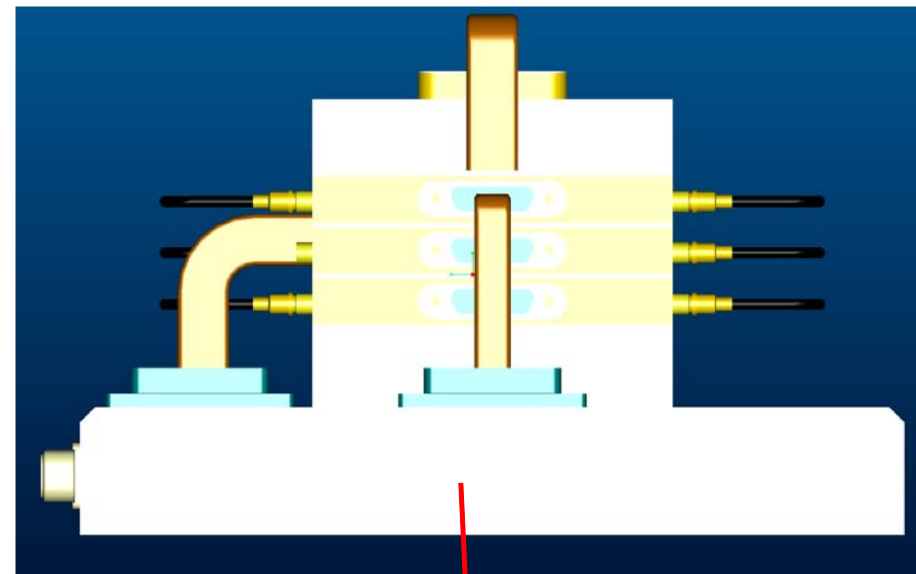
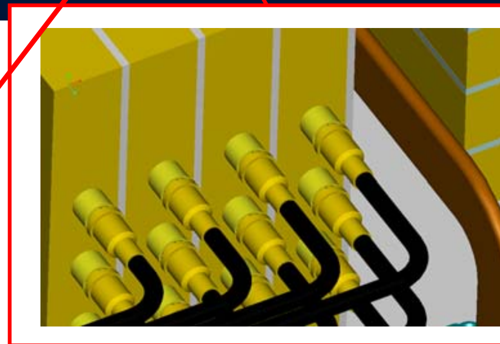
Alternate approach:
3D Configuration based on Clos-Benes Network







SMP RF input/output connectors

DC connectors

Control and DC-DC converter boards

Dimensions: 270mm x 160mm x 110mm
Mass= 3.500Kg

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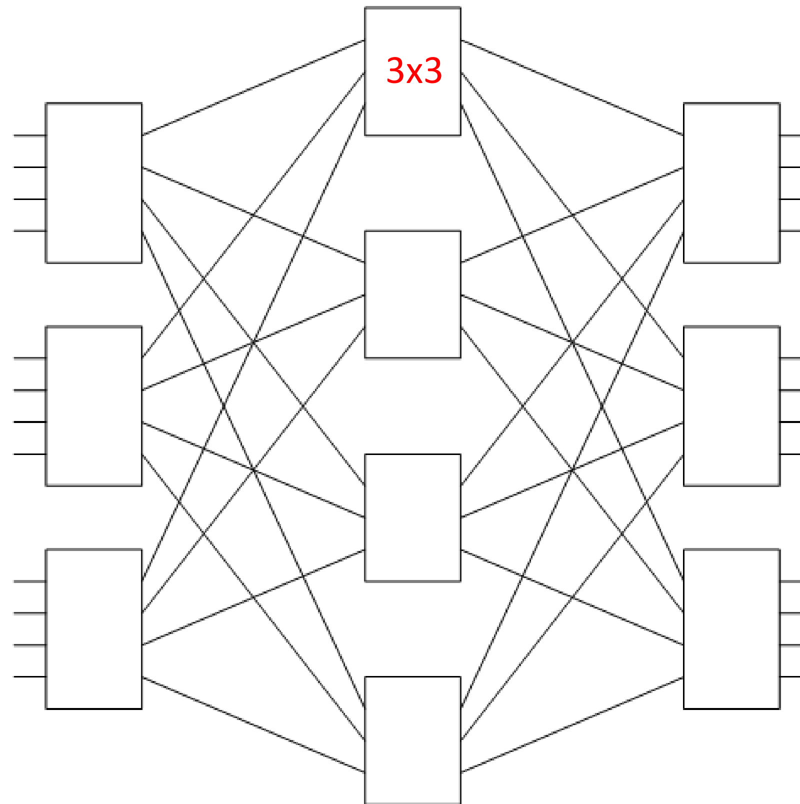
Alternate approach:
3D Configuration based on Clos-Benes Network



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Comparison of the two topologies

chosen option!

Planar Benes Topology

Advantages

- Low Cost
- Easy to assemble
- Reduced Footprint (the unit is mounted on the edge)
- Three hybrid modules only (12x12 matrix)
- High mechanical robustness and compactness

Drawbacks

- Poorer isolation (but 50dB can be met)
- Not a modular approach

Clos-Benes 3D Configuration

Advantages

- Modular Approach
- Better isolation

Drawbacks

- Very high cost (high number of coax cables is required)
- Larger footprint and Mass
- Hard to assemble for either RF or DC wiring
- Mechanically complex

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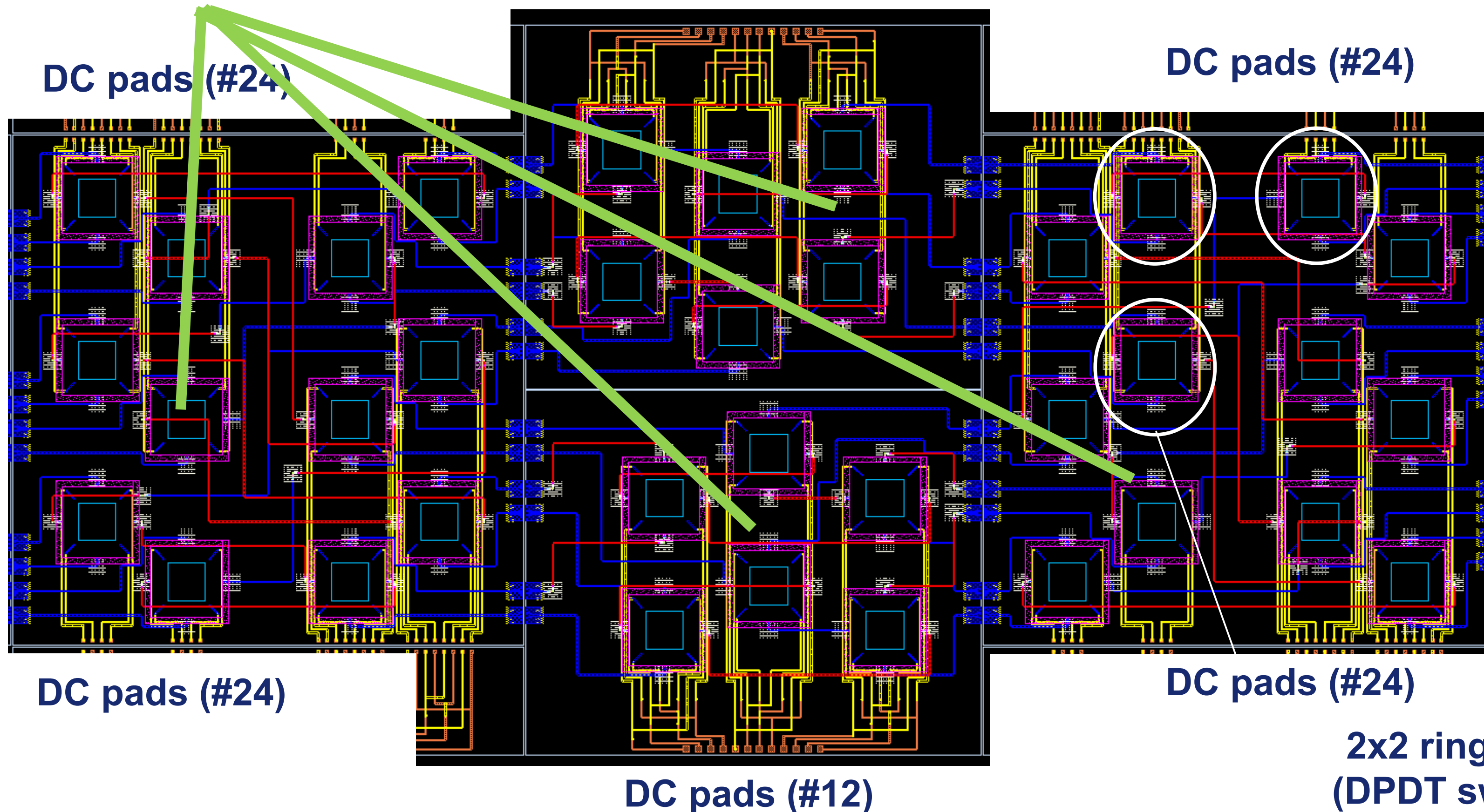
LTCC boards



- Four LTCC boards soldered on three carriers made of kovar
- LTCC boards have 14 layers, of which 2 in stripline are used for RF routing and crossing
- Other two layers are used for DC lines used for commanding the switches – in addition such DC lines are resistive to avoid any residual RF radiation that may reduce the isolation performance

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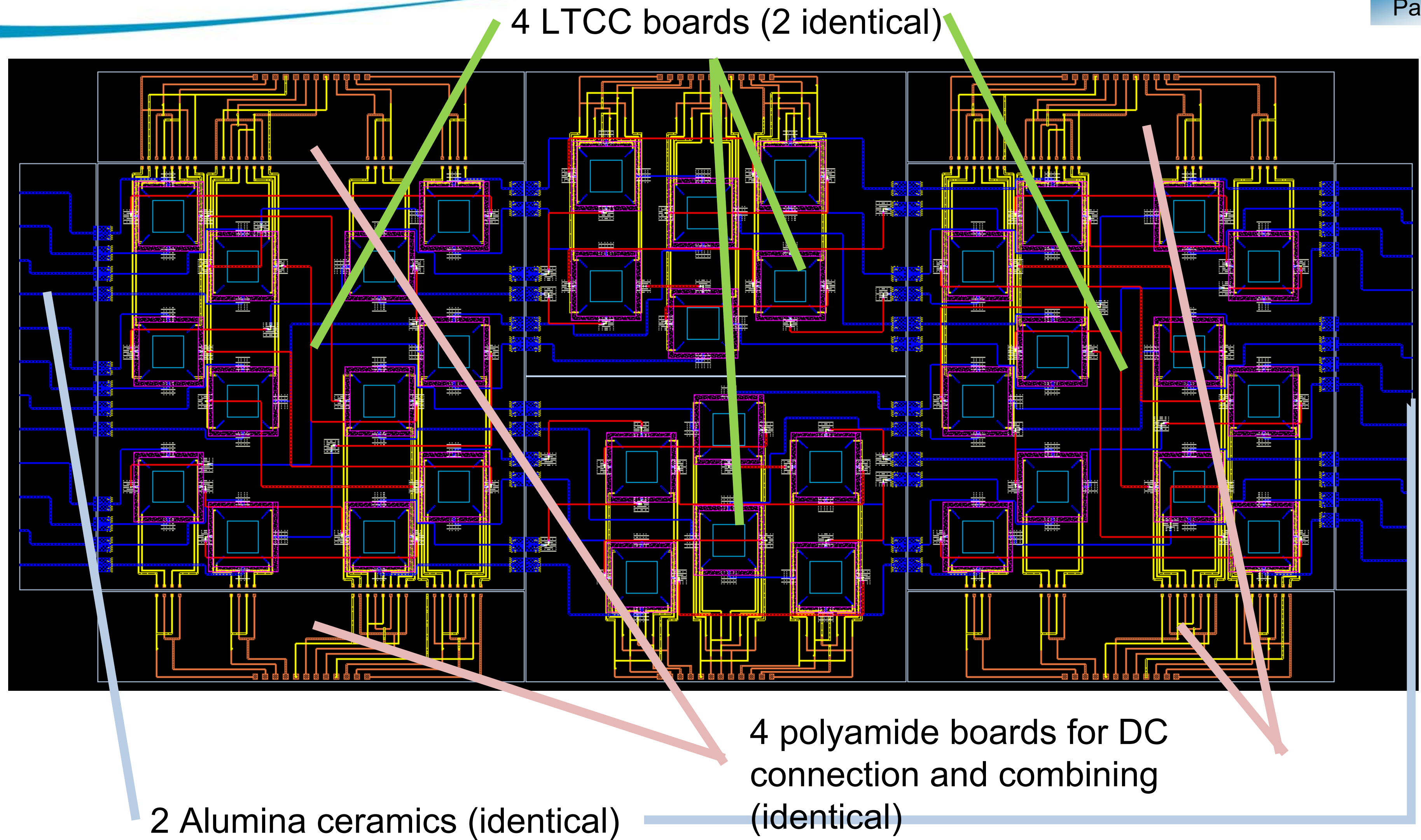
LTCC & ancillary boards

4 LTCC boards (2 identical)



4 polyamide boards for DC connection and combining (identical)

2 Alumina ceramics (identical)

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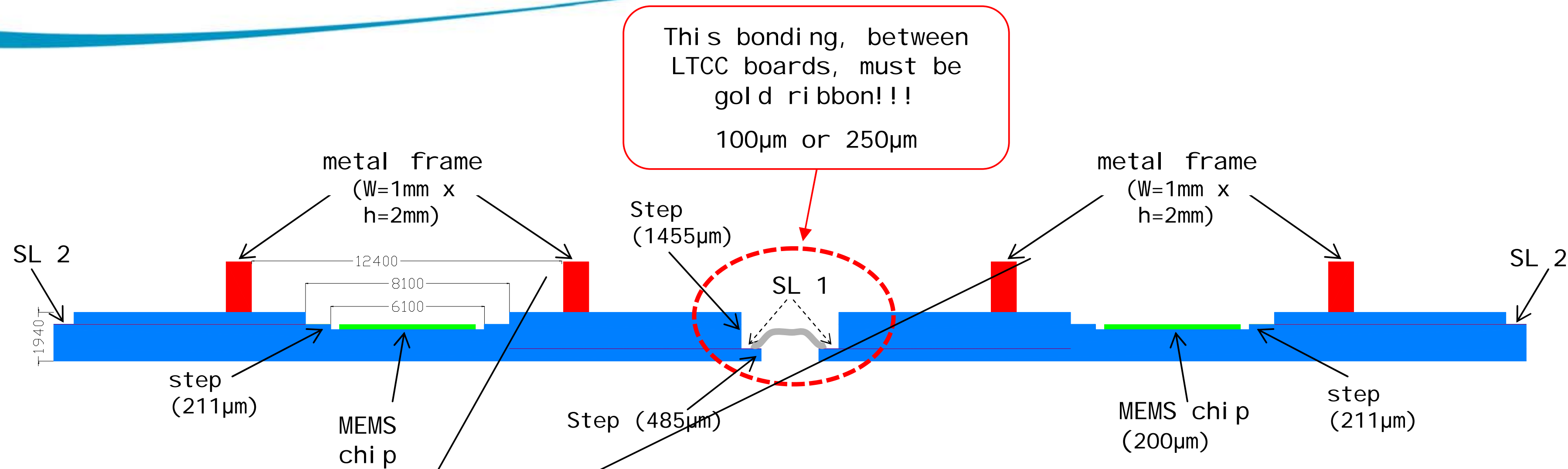
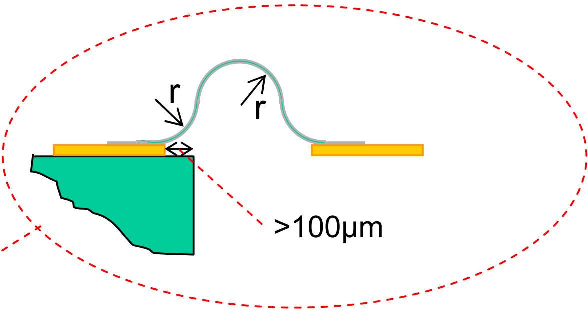
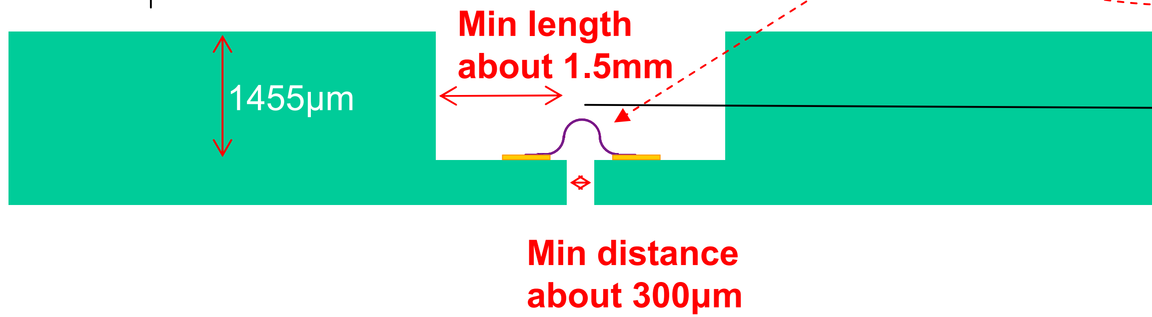
Details on LTCC board assembly



A metal cap is used to hermetically seal the switches → improve reliability





board-to-board connections have been simulated and checked at the assembly phase

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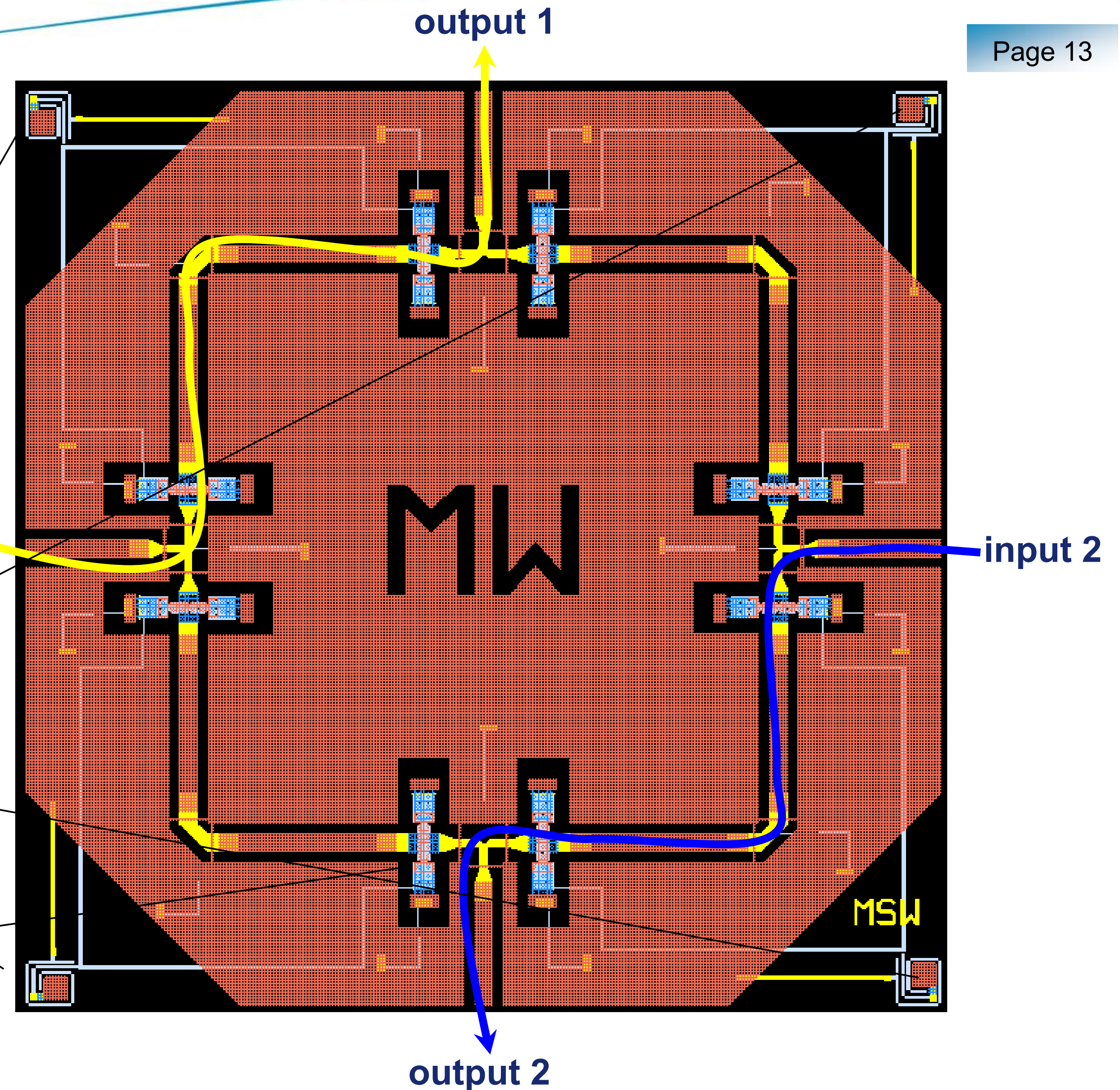
Basic switching module

2x2 non-blocking ring matrix

- Combines two inputs and two outputs by avoiding any crossover
- consists of four CPW SPDT switches
- each SPDT includes two SPST air-bridge membrane series switch (ohmic contact)



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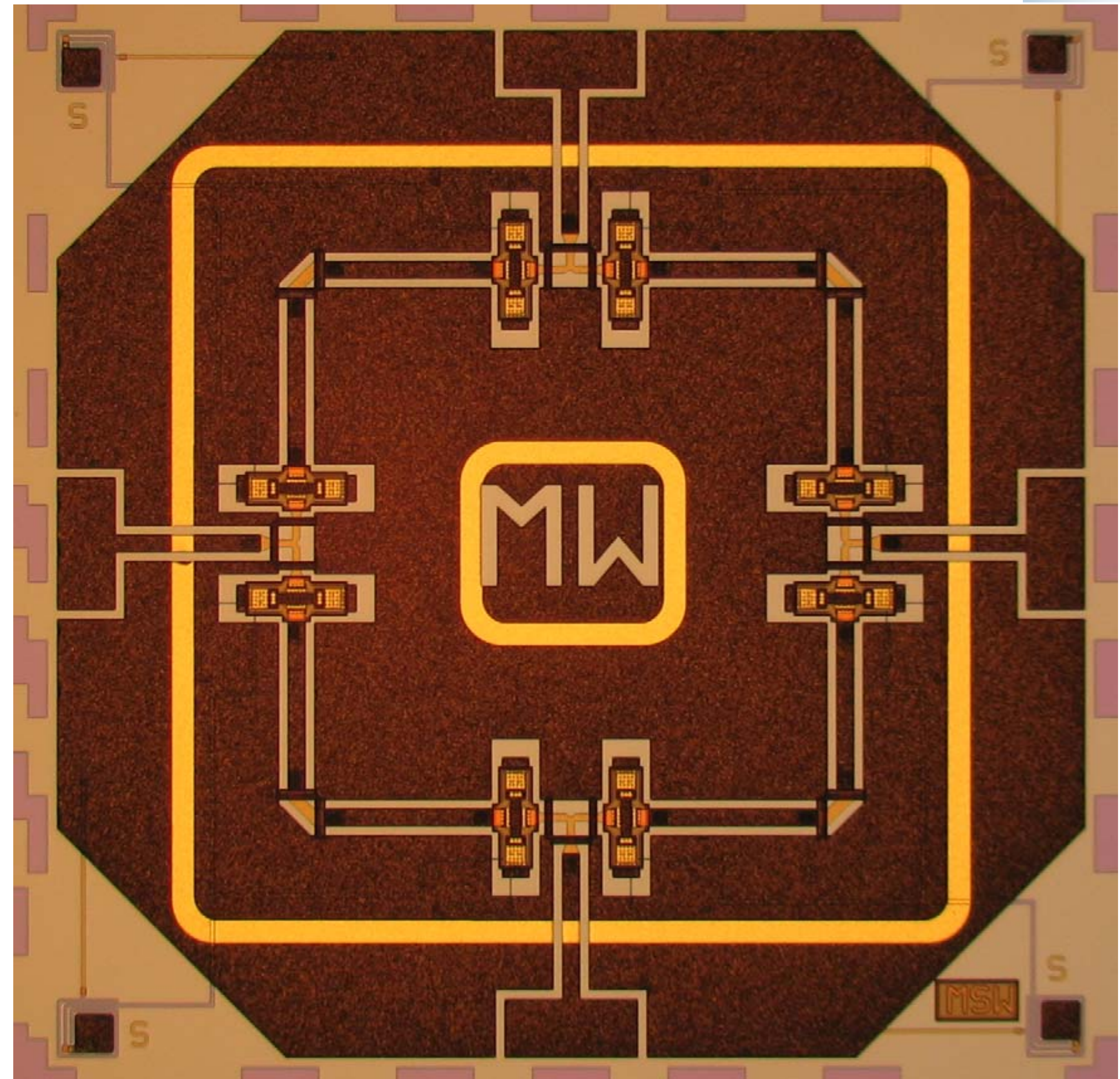
2x2 ring matrix

Fabrication Process

- Substrate: 200um thick high resistive silicon wafer(4 inches)
- 8-mask RF MEMS process developed in FBK
- Electro deposition of two gold layers
- Air bridge realized with no need of planarization steps by using 3um photoresist as a sacrificial layer
- The air-bridges release is done with a modified plasma ashing process, on order to avoid sticking problems
- The bias network uses high-resistivity 0.63um thick poly-silicon layer covered by silicon oxide. This layer is also used for realizing the contact bumps of the ohmic switches
- A third gold layer is deposited for the realization of low resistance metal-to-metal electro-mechanic contacts for the ohmic switches



Picture of the latest version

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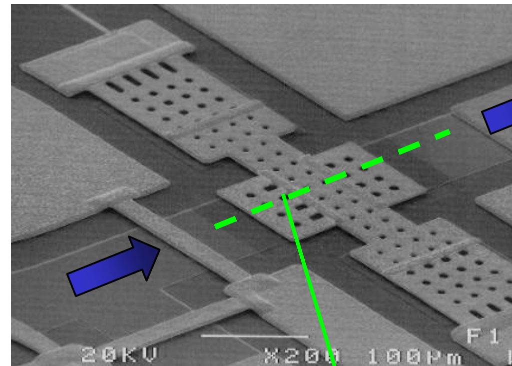
Air-Bridge membrane series switch

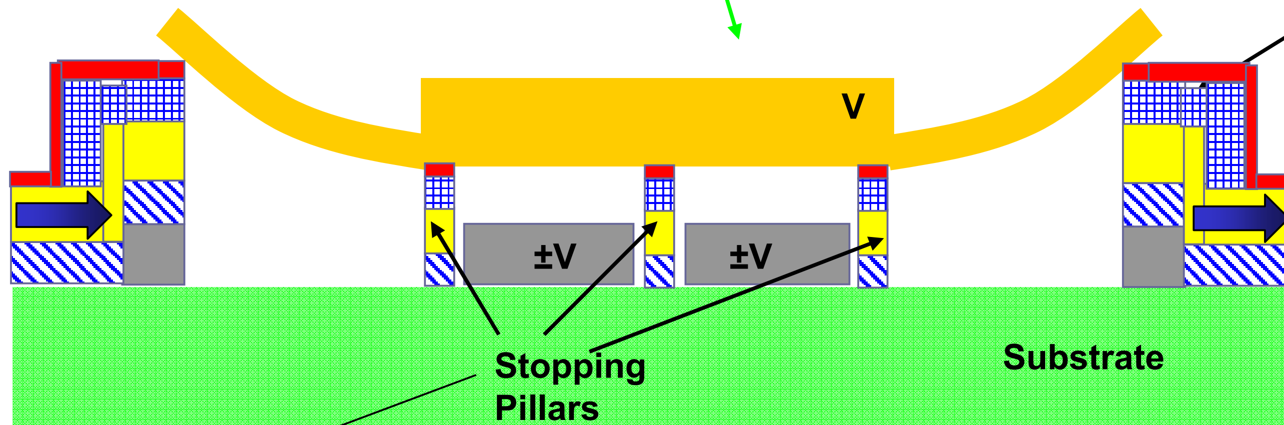
Contact-less activation electrode



RF line

30 nm thick gold
100 nm thick LTO dielectric
630 nm thick Multi metal
300 nm thick TeOs dielectric
630/400 nm thick polySi
Substrate

Bumps for an improved Ohmic Contact



they prevent dielectric charging

Δ stopper-electrode ~ 430/660 nm
Δ stopper-bump ~ 630/400 nm

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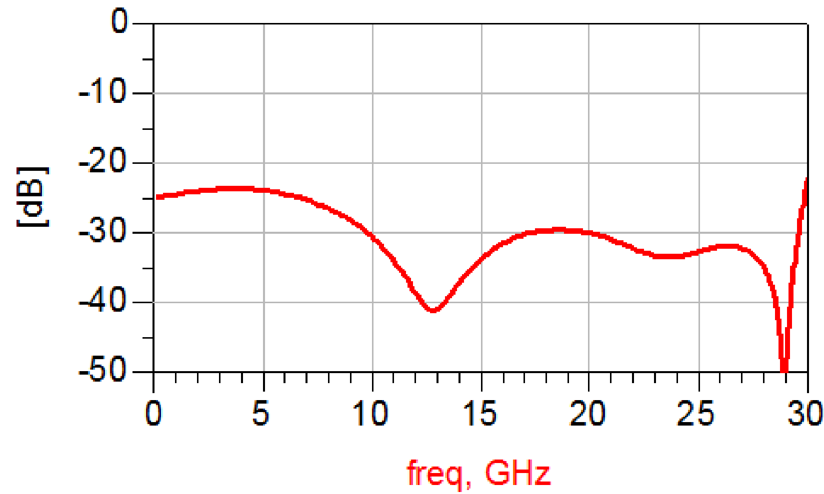
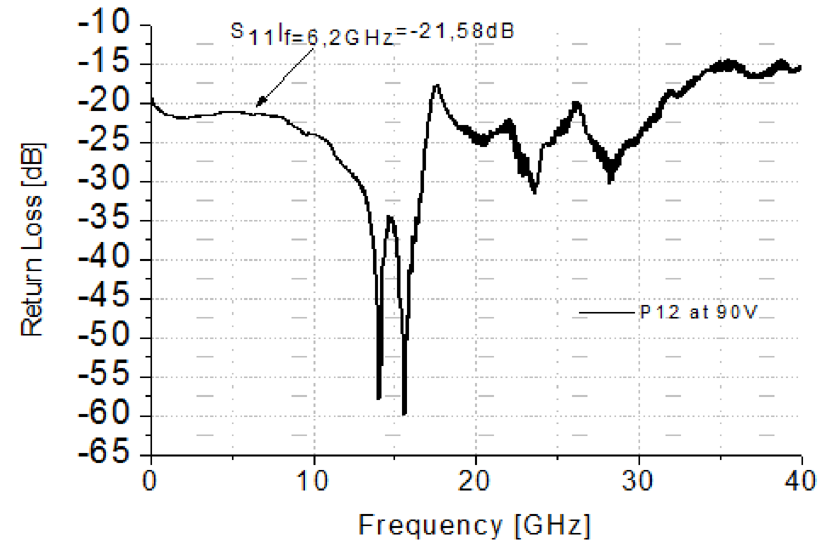
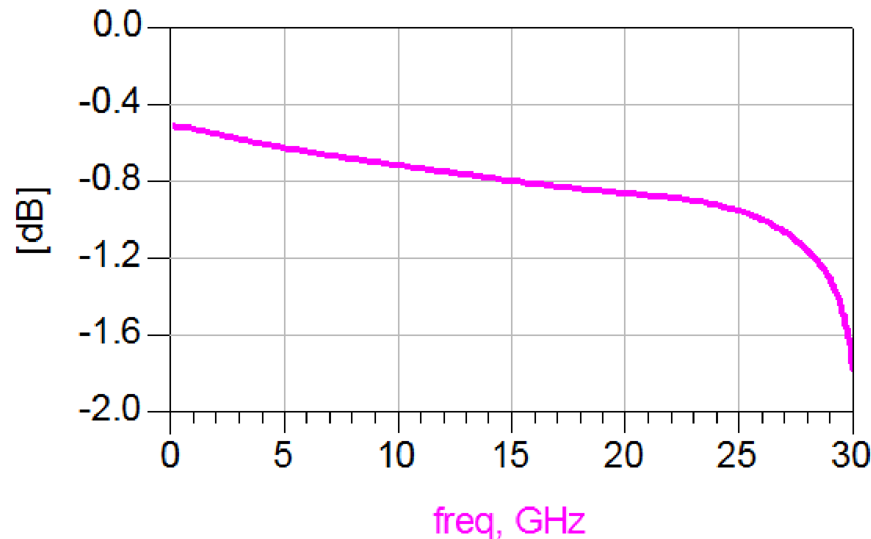
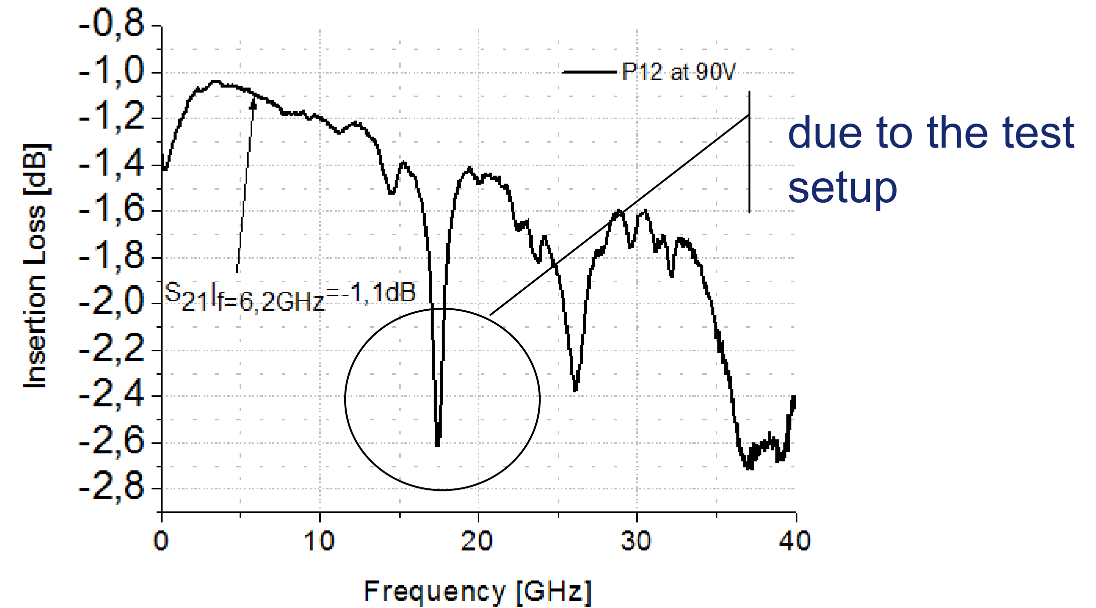
2x2 ring matrix– Electrical Performances (1st foundry run)









Simulation **Measurement**

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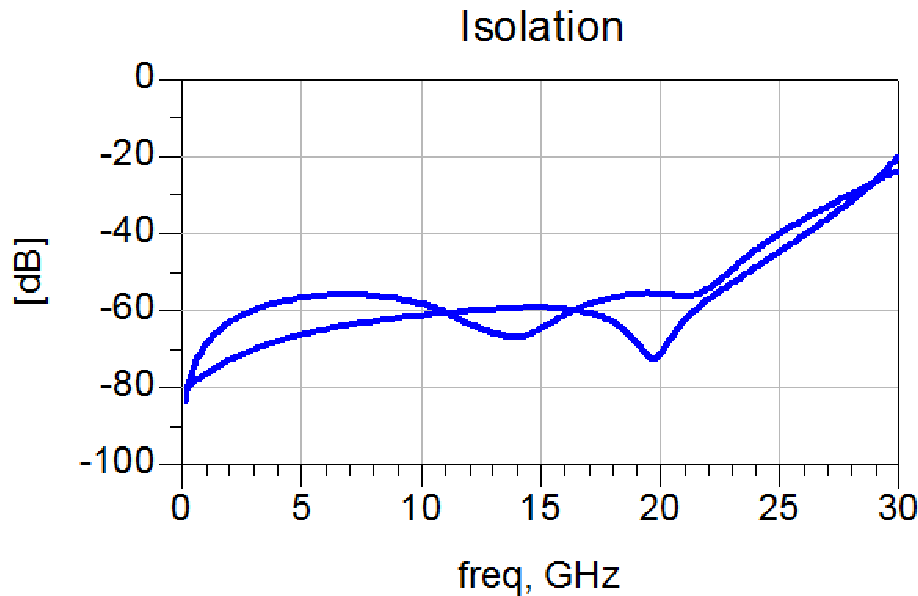
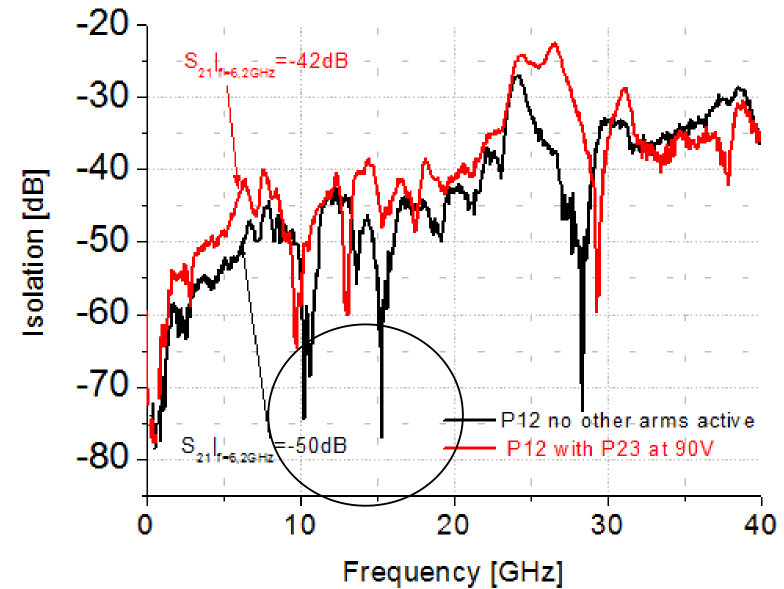
2x2 ring matrix– Electrical Performances (1st foundry run)





Simulation **Measurement**

The Isolation behavior shown an unexpected peak at 6.2GHz (42dB) and resonances, most likely due to the test setup.
The real behavior is closer to the simulation.

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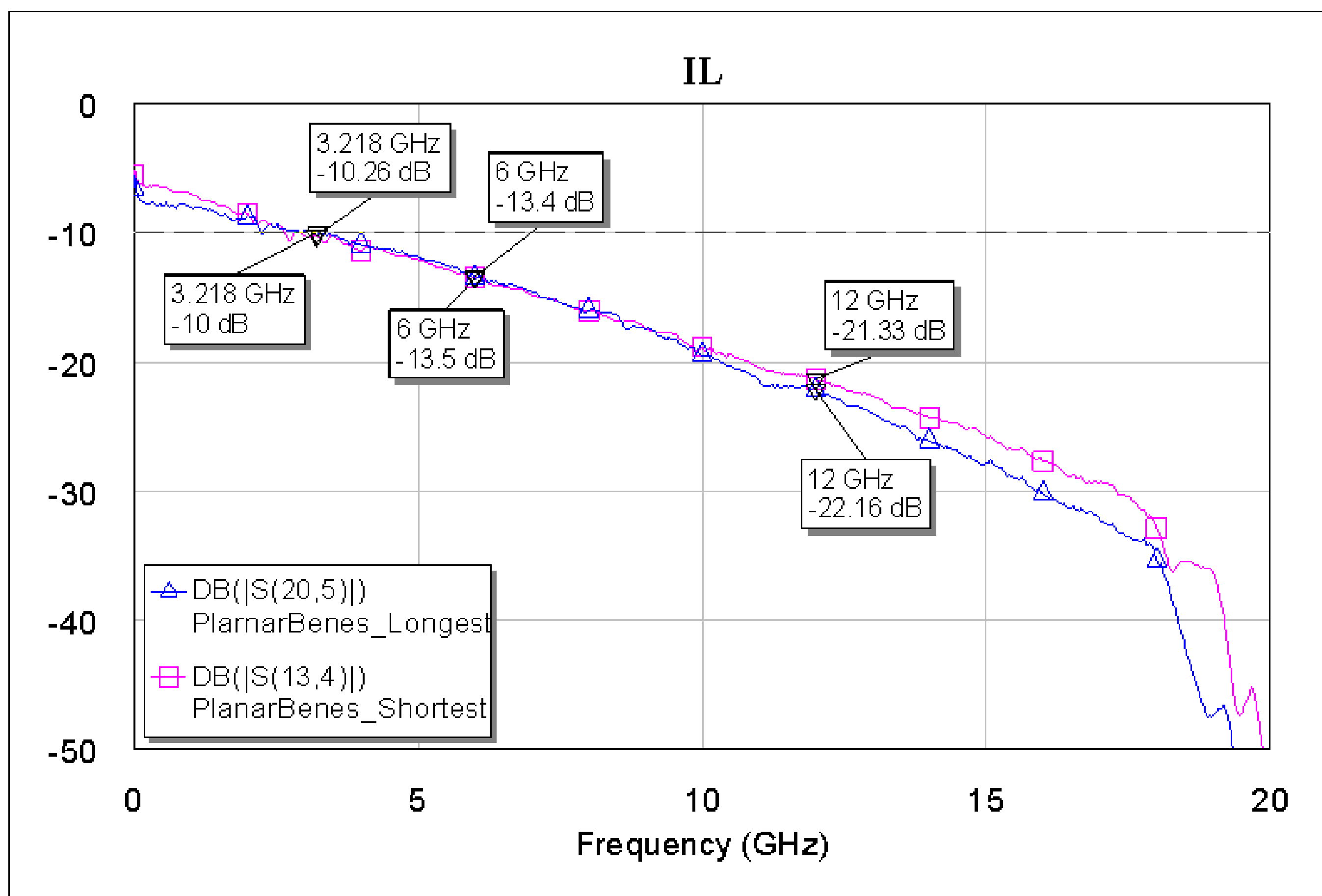
12x12 Switch matrix Simulated Performances



- IL simulation includes: measured DPDT SW performance, Full Wave simulation of : Si-LTCC transition, stripline-to-stripline via, board-to-board transition, board-to-alumina transition, Striplines

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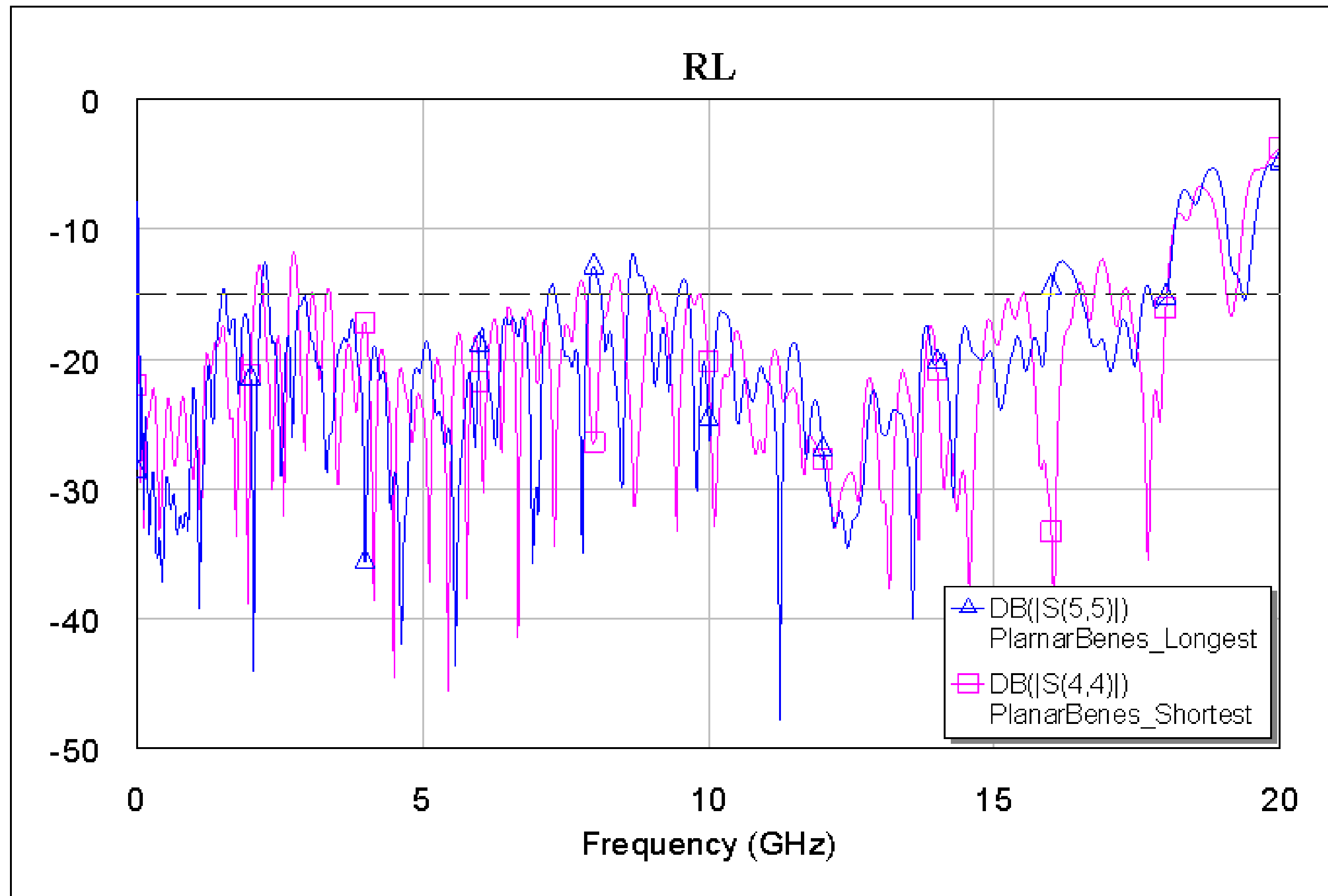
12x12 Switch matrix
Simulated Performances



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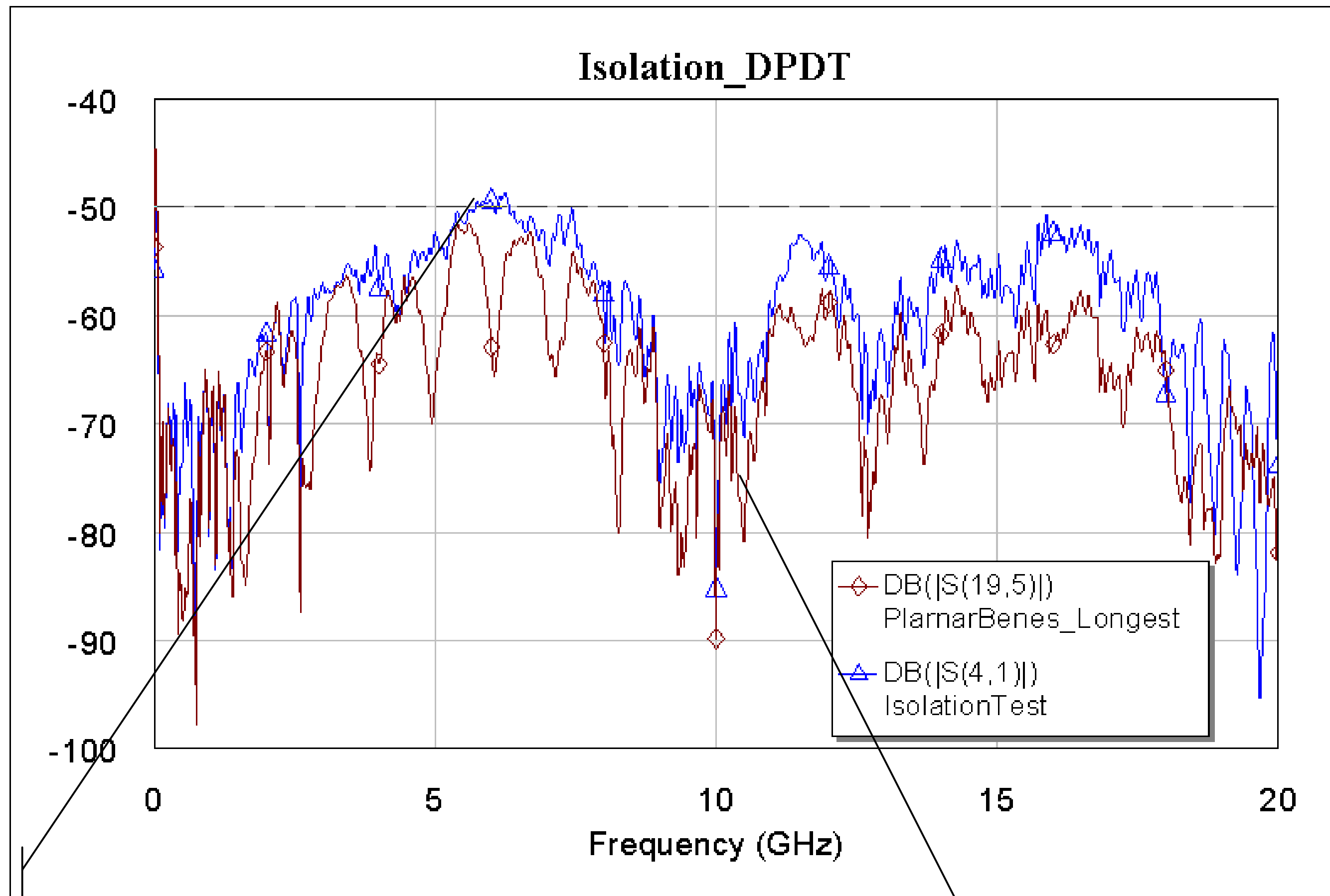
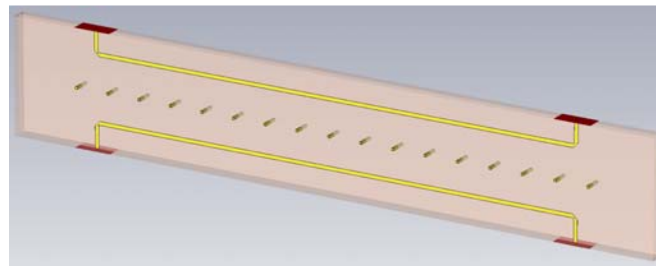
12x12 Switch matrix Simulated Performances





Considering coupling either in DPDT switches or between strip lines in the LTCC (blue line)

Considering the coupling in the DPDT switches only (black line)

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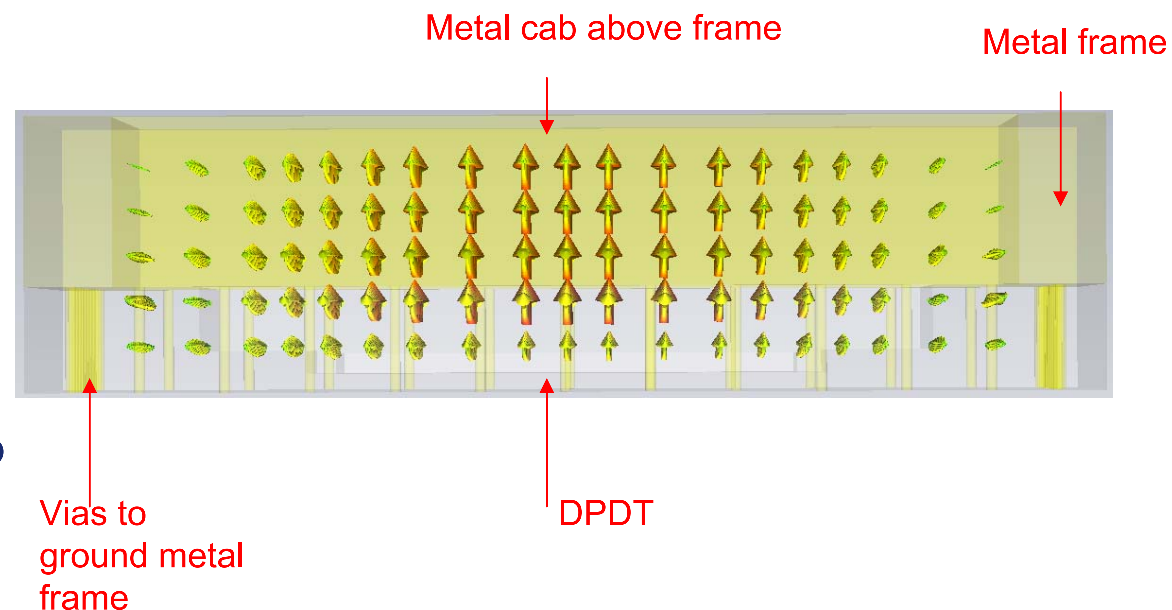
12x12 Switch matrix
Summary of Expected Performances

Return loss and Insertion loss

Bands	RL[dB] (Longest)	IL[dB] (Longest)	RL[dB] (Shortest)	IL[dB] (Shortest)
L(1.2~1.8GHz)	-14.59	-8.955	-17.44	-8.518
S(2.025~2.3GHz)	-12.5	-9.696	-12.75	-9.064
C(3.4~4.2GHz)	-16.89	-11.12	-15.51	-11.13
Ku(10.7~12.75GHz)	-18.69	-23.48	-19.28	-22.37

Isolation

Bands	Isolation[dB]
L(1.2~1.8GHz)	-65.625
S(2.025~2.3GHz)	-60
C(3.4~4.2GHz)	-56.128
Ku(10.7~12.75GHz)	-52.495



Note: resonance occurs at 14GHz due to the metal cap, which limits the max freq. of operation

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Conclusion

- The design of a 12x12 Switch Matrix unit based on silicon micro-mechanical switches (RF MEMS) has been presented
- At present, the first design of the silicon MEMS switches has been fabricated and tested showing performances in line with the project specification
- An updated design of the switches has been fabricated to improve the reliability of the membrane contact and their testing is just started
- The switch matrix path routing is realized by using the TASI in-house multilayer LTCC technology
- Simulations and expected performances are available and the LTCC board layers are about to be released for manufacturing
- Expected completion of the Switch Matrix unit fabrication and testing is planned by March 2013

Acknowledgement: Francois Deborgies from ESTEC for his support and suggestions

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