WE LOOK AFTER THE EARTH BEAT

esa

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European Space Agency

Section 1: MOEMS and Optical Sensors

Ultra compact 12x12 Switch Matrix integrating RF MEMS switches in LTCC hermetic packages

30/04/2014

Ref.:

83230347-DOC-TAS-IT-001

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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 Bruno 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

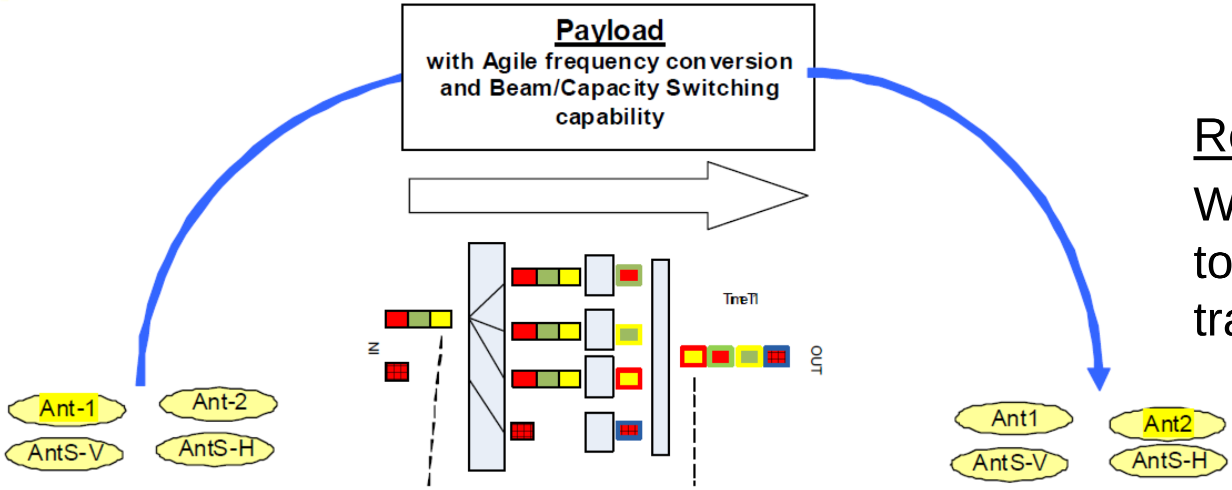
Design, manufacturing and testing of an Engineering Model (EM) unit of a 12x12 Switch Matrix based on RF MEMS technology

Size: 28x9x16cm (LxWxH)

Mass: 2.4Kg

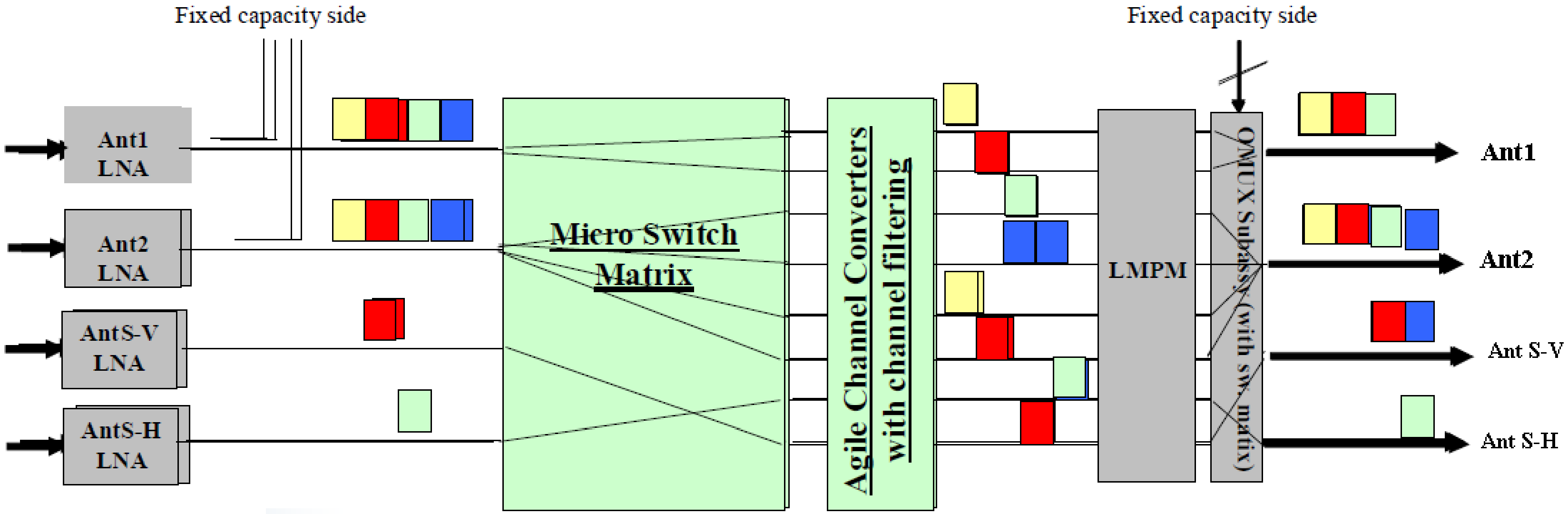
- The switch matrix is housed in an aluminum box having SMP RF coax and DC connectors as an electrical interface
- The MEMS switches inside (DPDT) are driven by a control circuit housed in the unit box, which accepts the memory load (ML-16) commands to set the matrix connectivity
- The unit box is also prepared for housing a DC-DC converter, which generates from the primary bus voltage the high voltage needed for the MEMS switches to close their membrane contact (+60V)

Example of use of RF Switch Matrices on Flexible Payloads

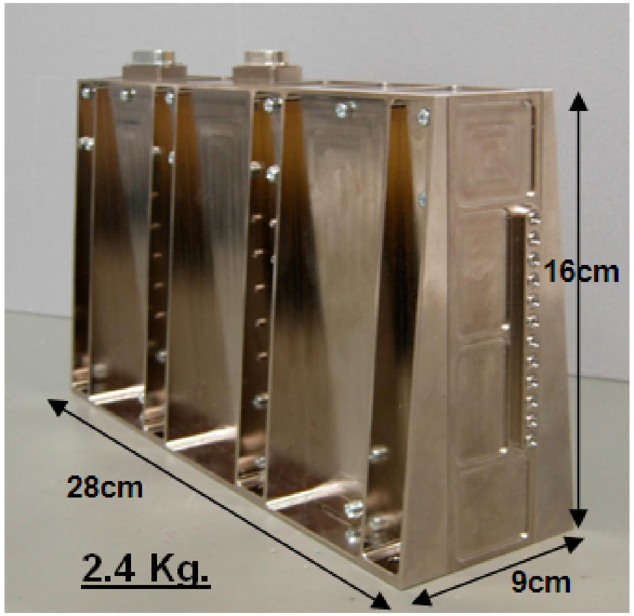


Required function:

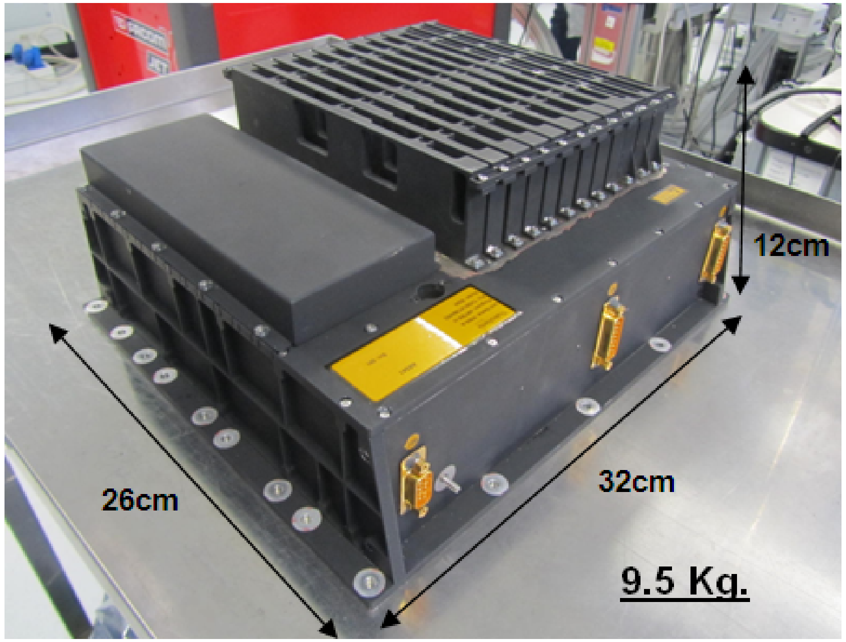
Wide Band Beam switching from the Uplink to the Channel Handling Resources (i.e. transponders)



Compact size, light weight, lower production cost

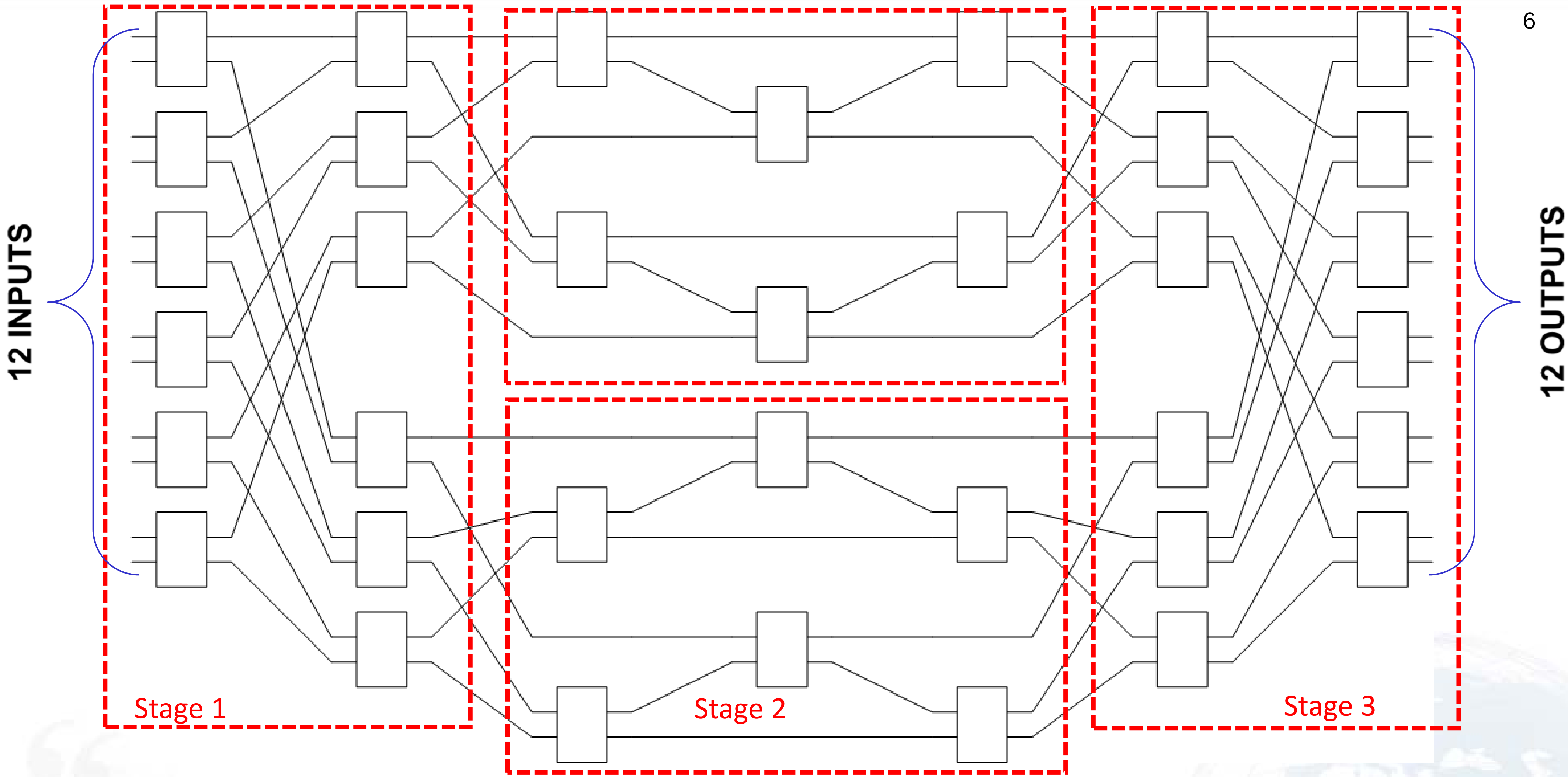


12x12 MEMS SW Matrix



12x12 Conventional 3D SW Matrix (AMOS4)

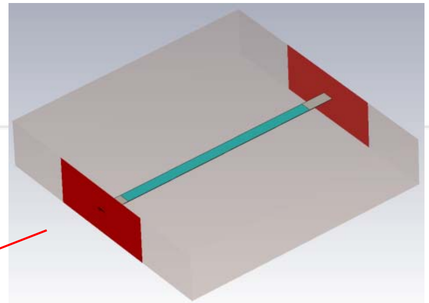
Chosen Switch Matrix Topology: Planar Benes Network



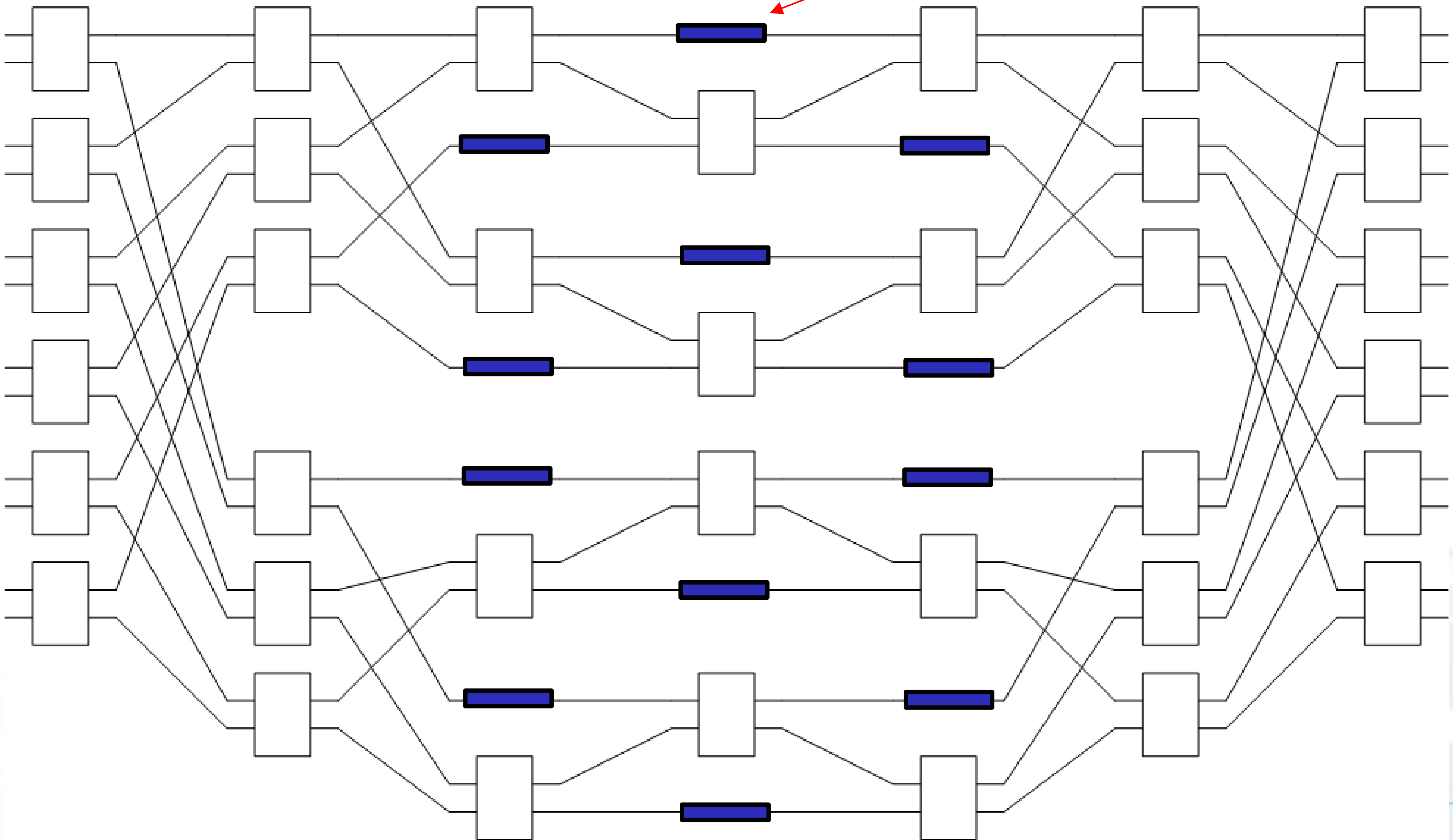
- Basic switching element: DPDT switch (2x2 ring matrix)
- The Planar Benes network can be realized in multilayer LTCC technology
- Four LTCC boards are realized – max size is 8.5x8.5cm (technology limit in TAS-I)

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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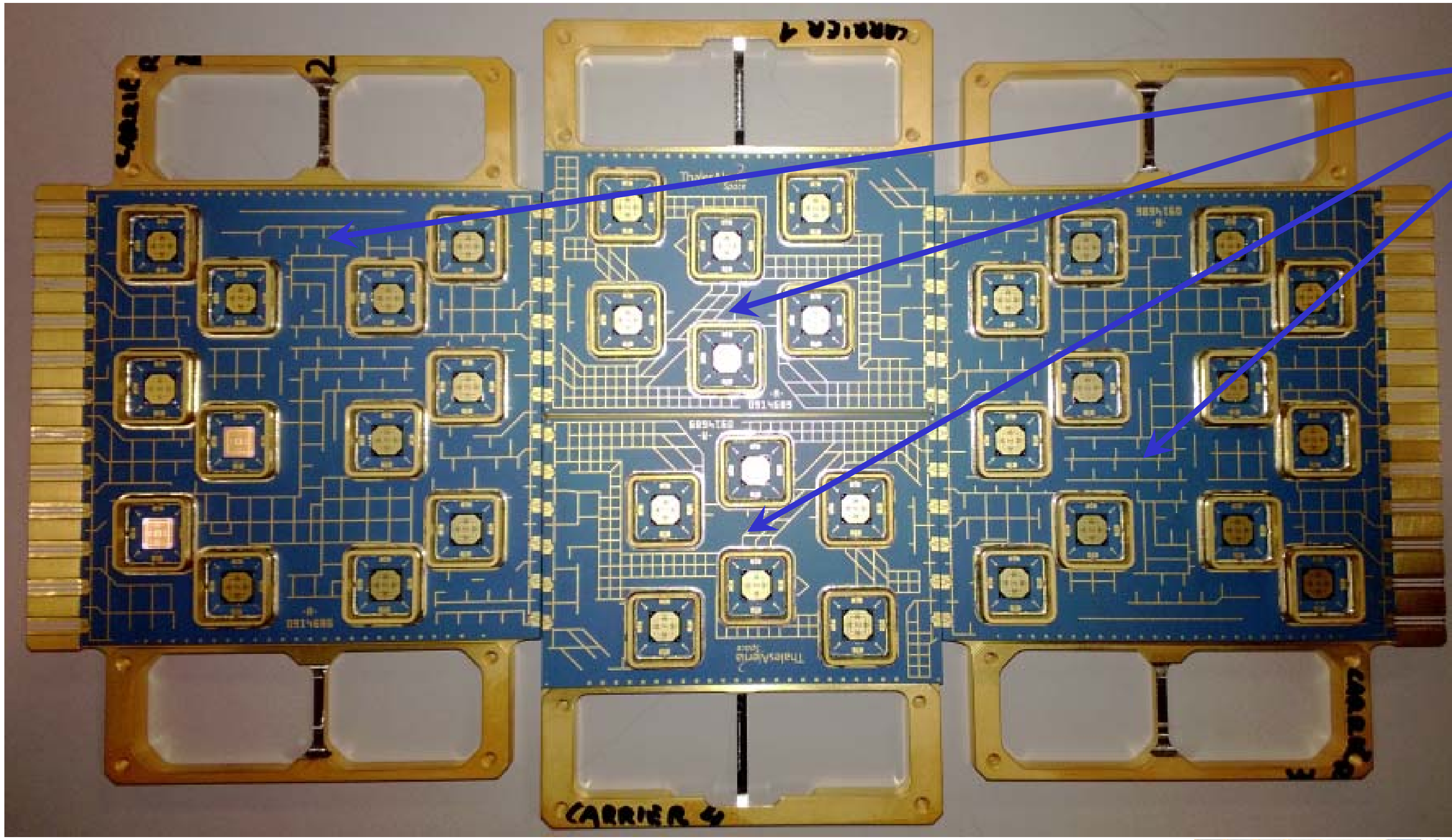
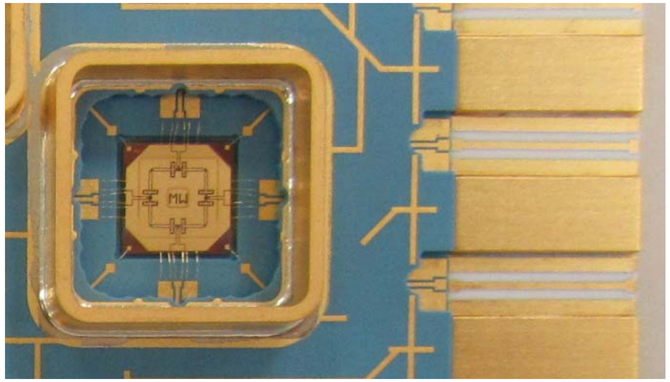
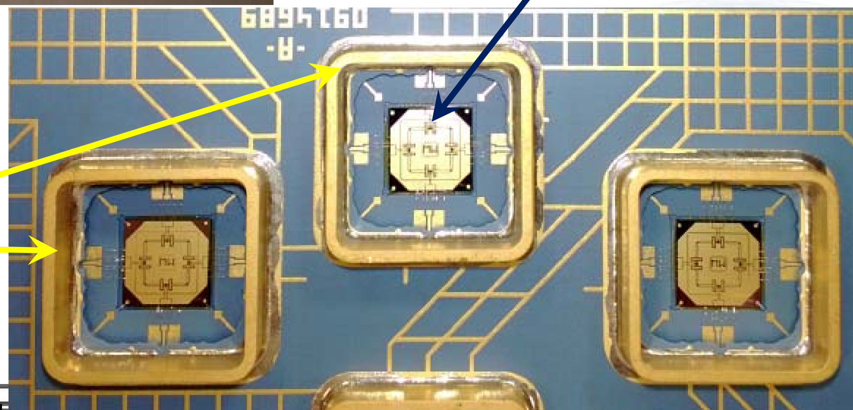
LTCC boards realizing the Benes Network



4 LTCC BORDS soldered on 3 gold-plated Kovar carriers



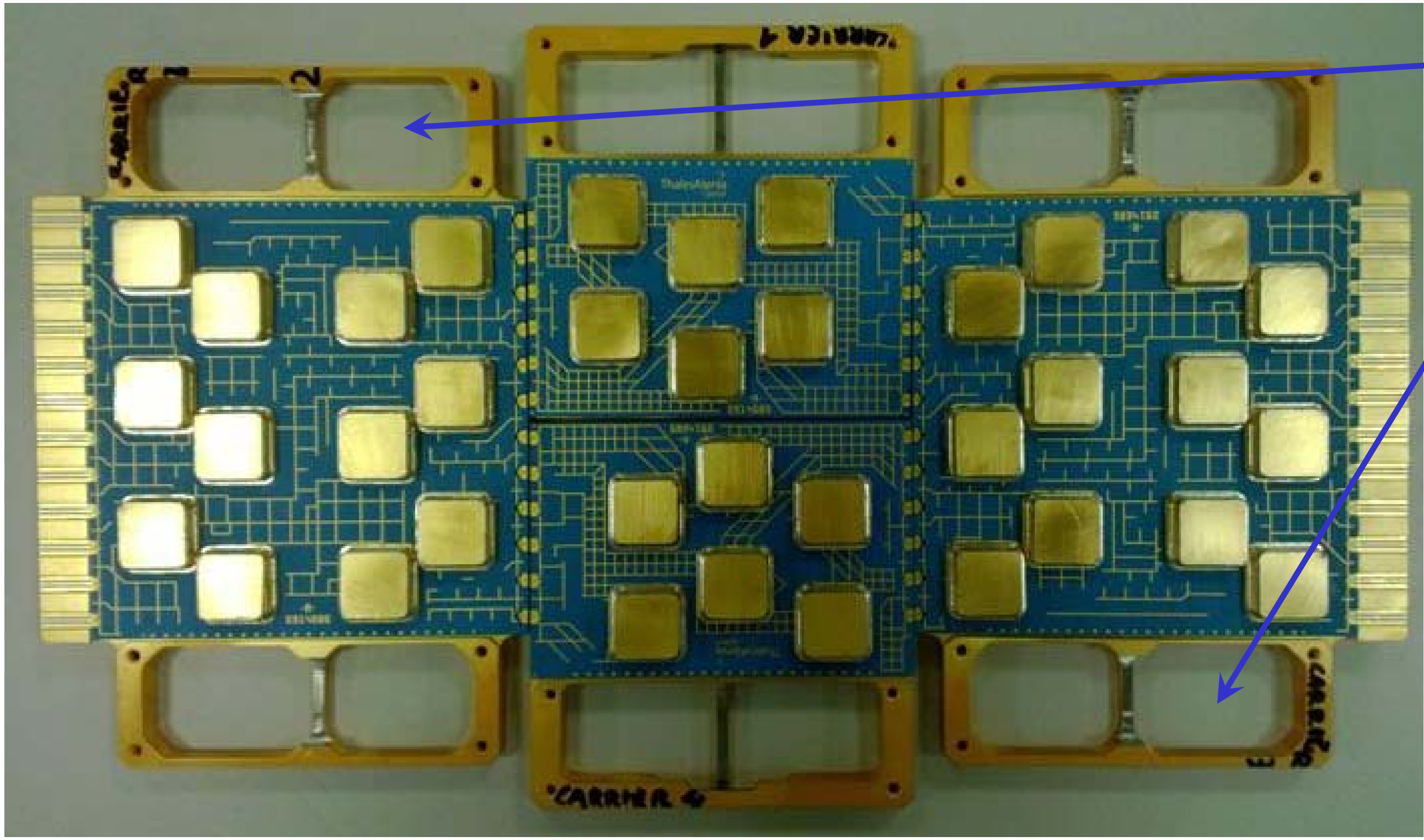
MEMS chip (6.1mm)



Metal Frames (12.4mm)

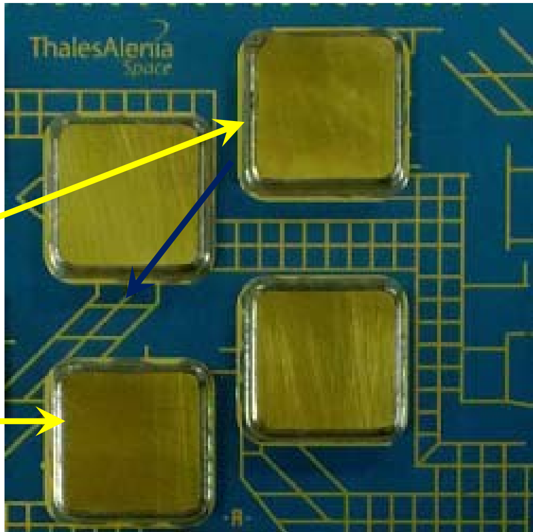
- -The LTCC boards have 14 layers, of which 2 are used for routing the RF signal (stripline)
- -Other two layers are used for DC lines used for commanding the switches

Capping of MEMS switch cavities



Assembly areas for 6 Polyamide BORDS

for distributed digital control



-The individual cavities are hermetically sealed by using the seam-sealing technique to protect the MEMS switches and guarantee their reliability

-Electrical isolation is also improved, as all the switches are shielded each other

Metal Lids

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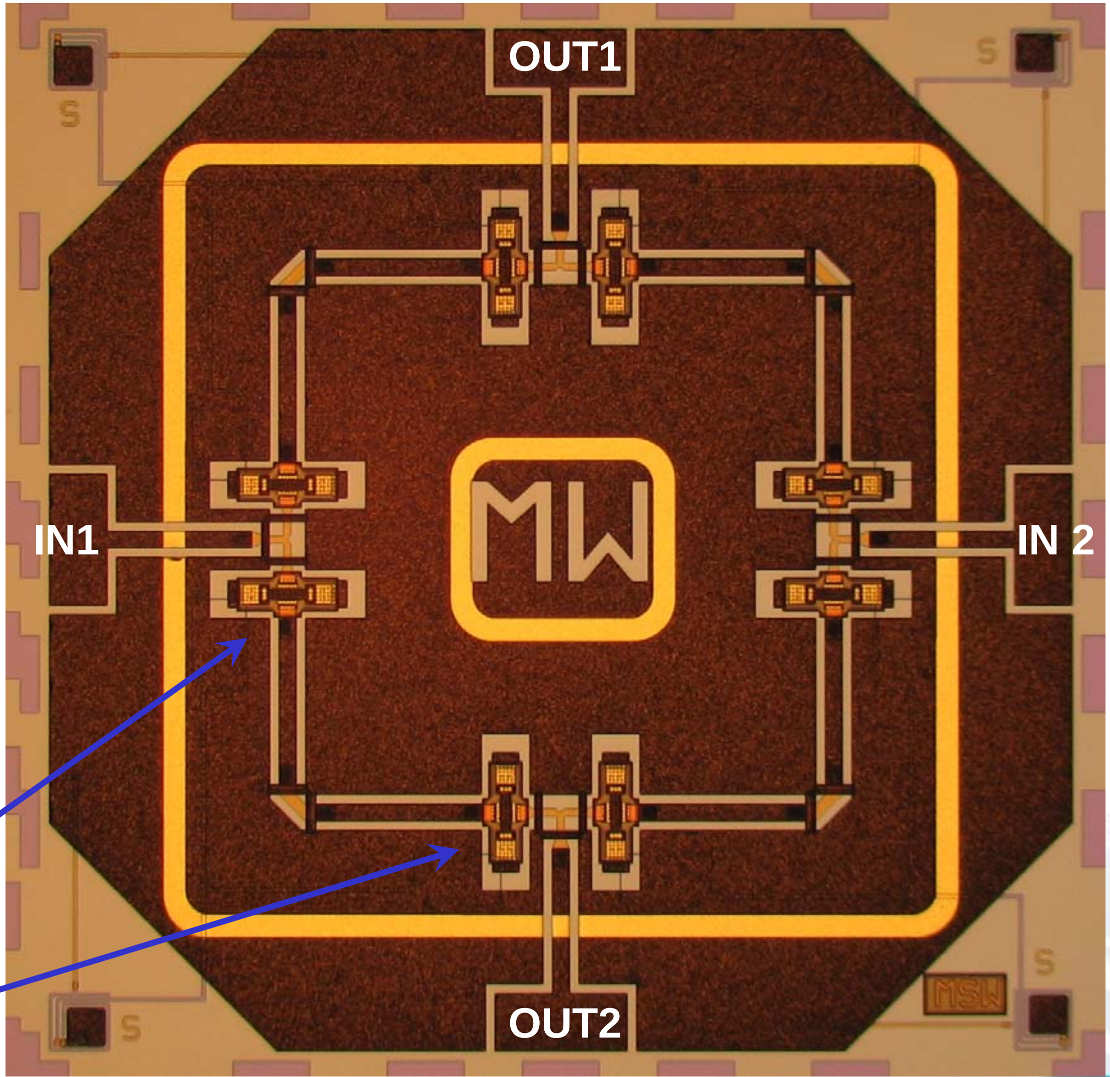
Fabrication Process

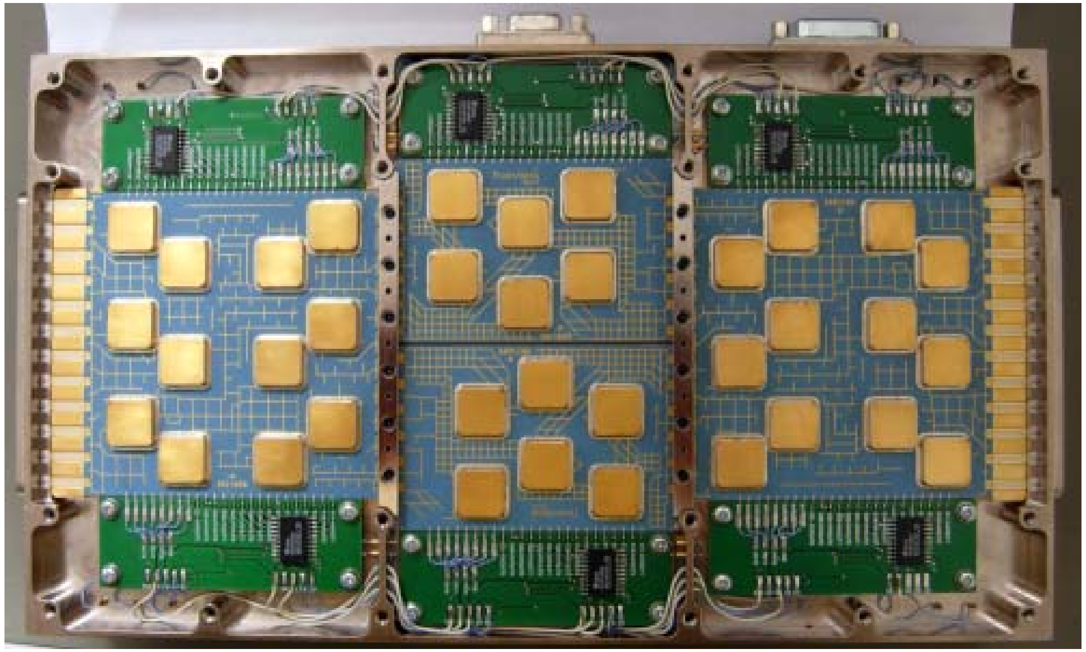
- Substrate: 200um thick high resistive silicon wafer(4 inches)
- 8-mask RF MEMS process developed in FBK
- Electro deposition of two gold layers
- Air bridge realized with no need of planarization steps by using 3um photoresist as a sacrificial layer
- The air-bridges release is done with a modified 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



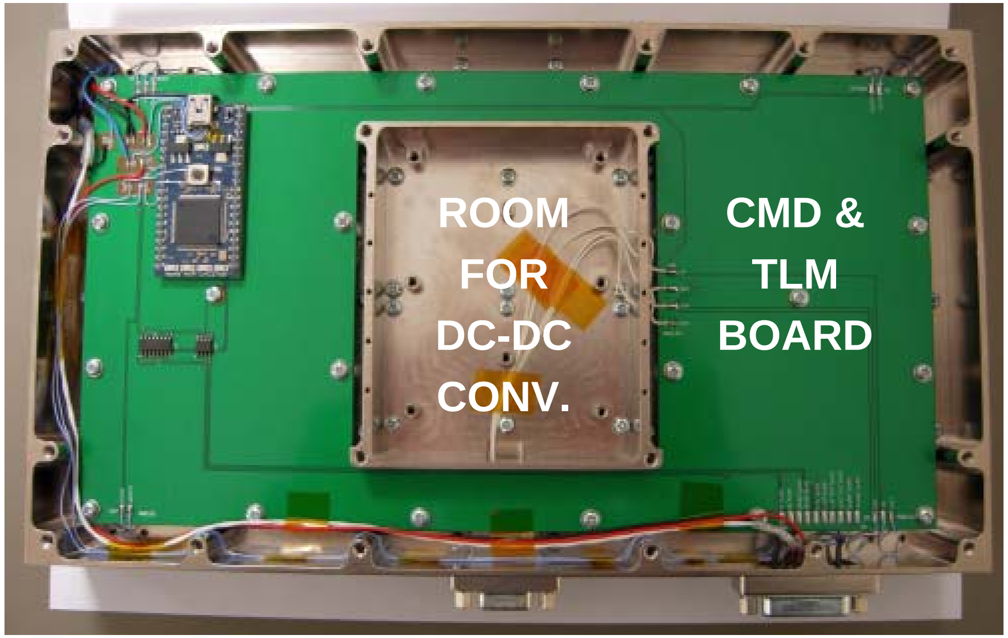
SPST MEMS Switches

12x12 MEMS Switch Matrix Unit Assembly

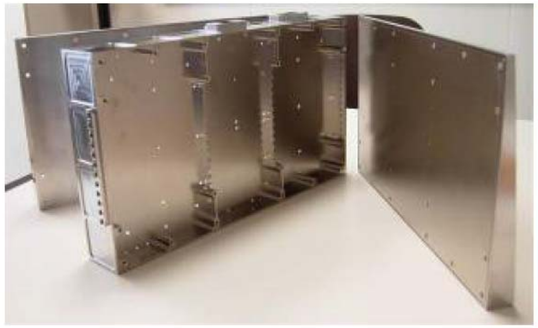
PWR CONN. CMD&TLM CONN.



SIDE A



SIDE B



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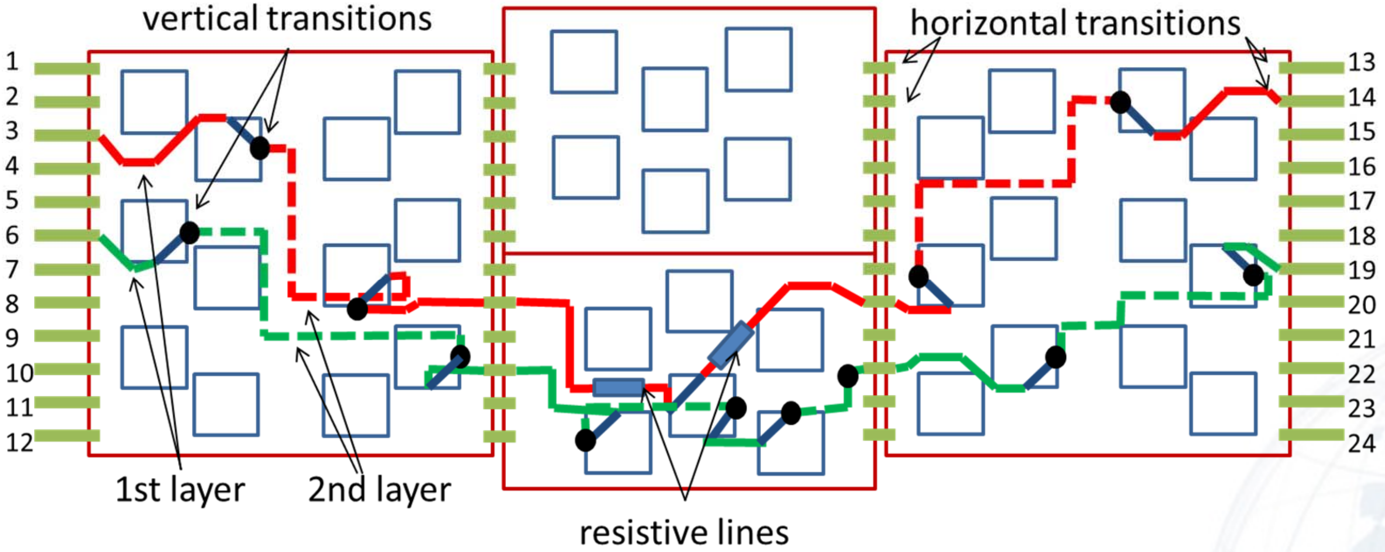
Switch Matrix Simulations and optimization

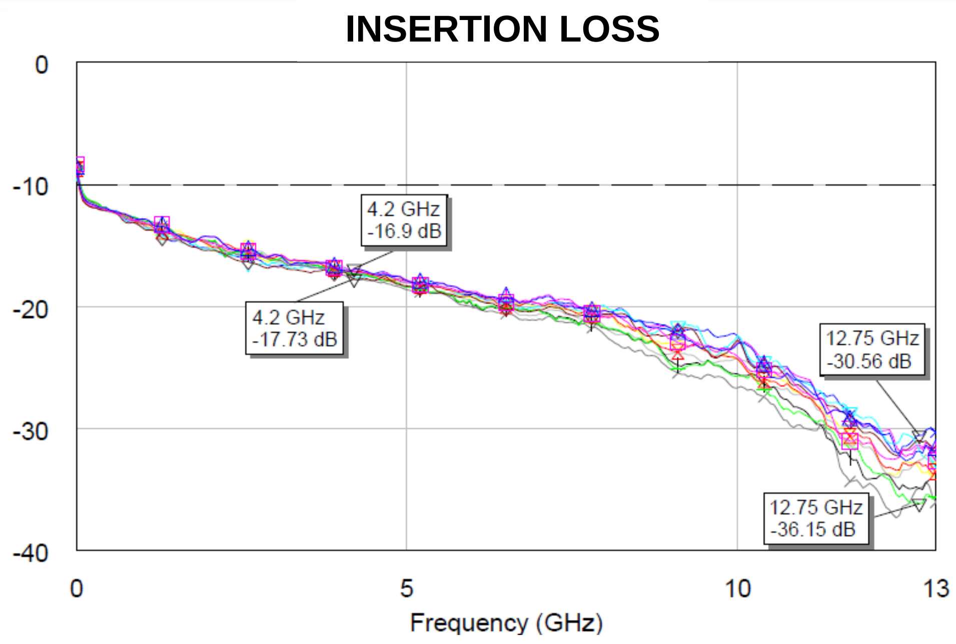
- For all single elements optimizations have been performed based on full-wave simulations:
  - Bond wire transitions between the different boards
  - Board-to-chip connections
  - Vertical transitions within the LTCC
  - CPW-to-strip line transitions and via fences used for shielding between adjacent lines
- All these results have been used for a circuit simulation together with measured results of DPDT switches from previous runs
- Also coupling between adjacent lines has been considered

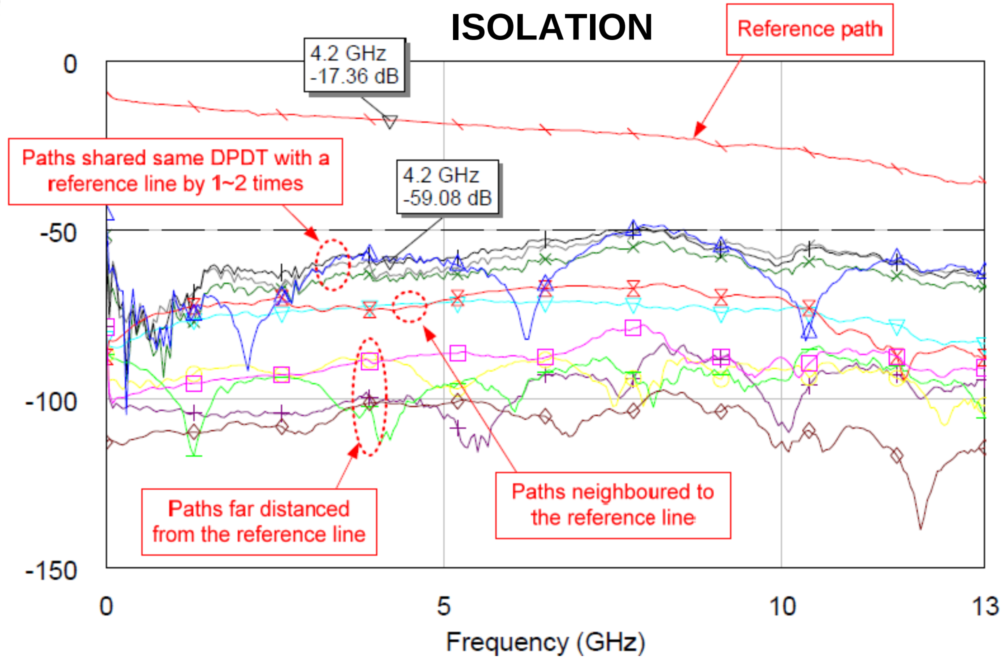
Paths are different in the number of crossed DPDT's (5 to 7) and vertical transitions (4 to 12)



Comparison between path 3-14 (5 DPDT's and 2 short resistive lines) and path 6-19 (7 DPDT's)

Switch Matrix predicted performances





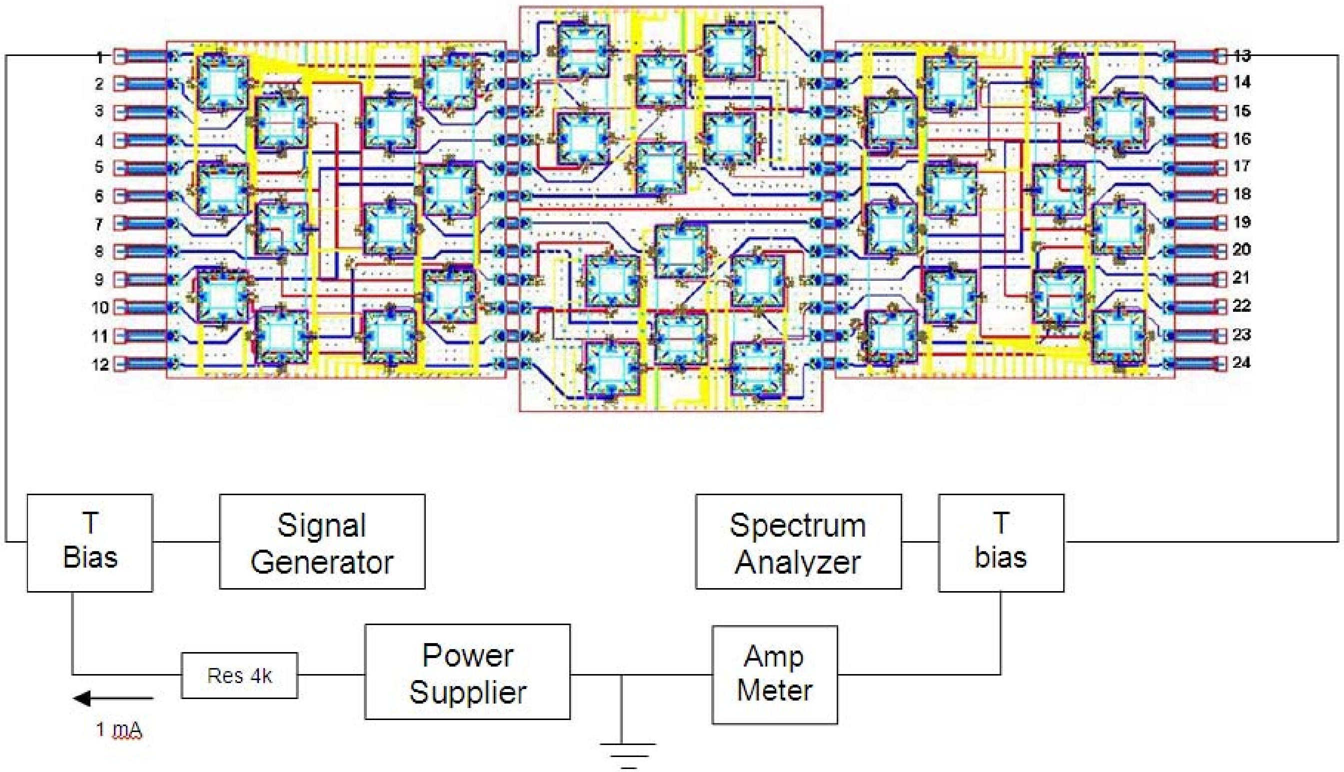
- According to simulation the IL in Ku band is 35dB (too high). Practical use is for frequencies up to C band.
- The tolerance of the resistive lines results in a larger spread of IL as the frequency increases
- Predicted performances are presented in Table up to 4.2GHz

Band	Max IL [dB]	Min RL [dB]	Min Isolation [dB]
L: 1.2-1.8 GHz	-15 ± 1	-15	45
S: 2.0-2.3 GHz	-16 ± 1	-15	45
C: 3.4-4-2 GHz	-18 ± 1	-15	44

Test Plan and Test setup

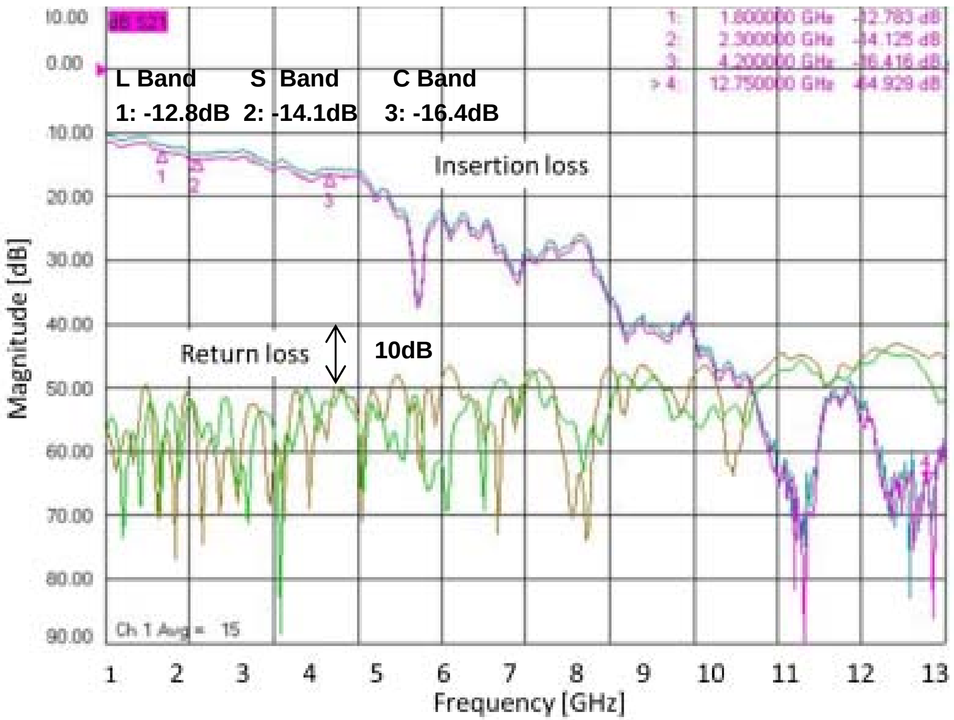
- First a DC current (1mA) has been injected to improve the contact resistance
- Among the factorial 12 configurations of a 12x12 switch matrix, two “worst case” configurations have been selected: Config.1 and Config.2 (=Config.1 inverted, in which all the switches have changed their state)
- Measured parameters (Ambient temperature):
  - Insertion and Return Loss of the “On” paths in Config.1 and 2
  - Isolation in Config.1 and 2

Configuration 1	
Input	Output
1	13
2	17
3	14
4	16
5	20
6	19
7	18
8	21
9	23
10	15
11	22
12	24

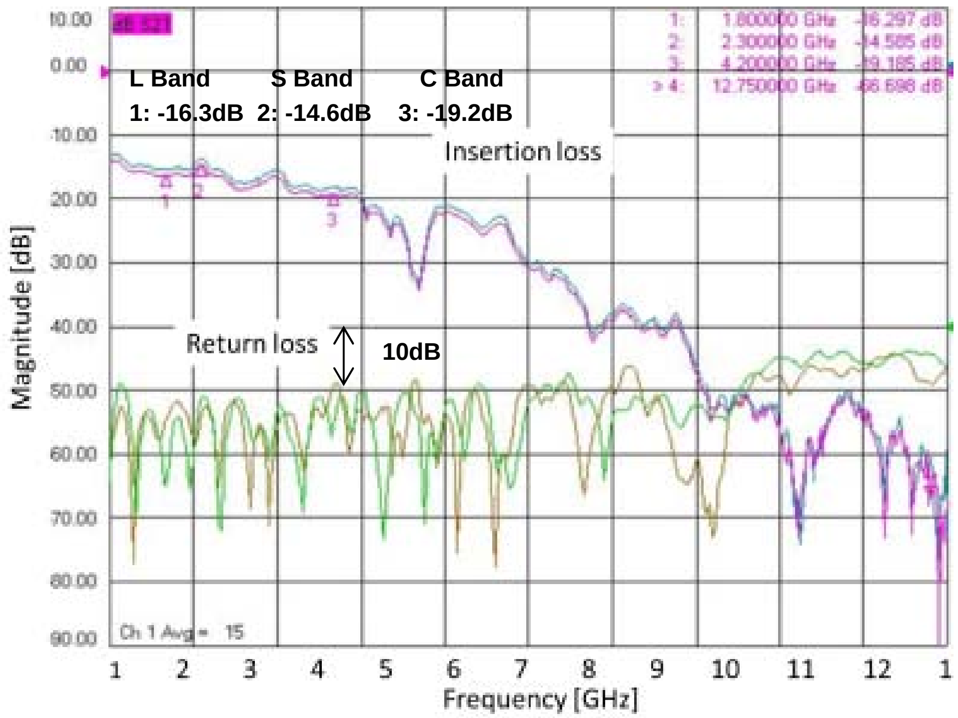


Configuration 2	
Input	Output
1	22
2	24
3	21
4	13
5	23
6	19
7	18
8	17
9	16
10	14
11	20
12	15

Test Results – Insertion/Return Loss



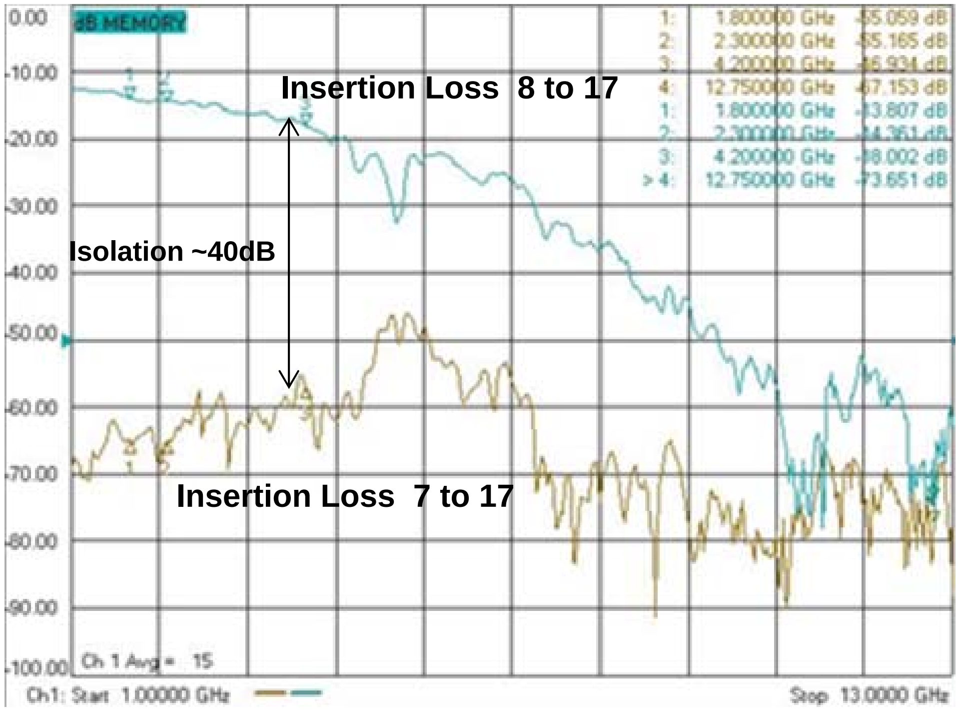
Measured insertion and return loss of path 6-19 (7 DPDT's – 8 vertical transitions)



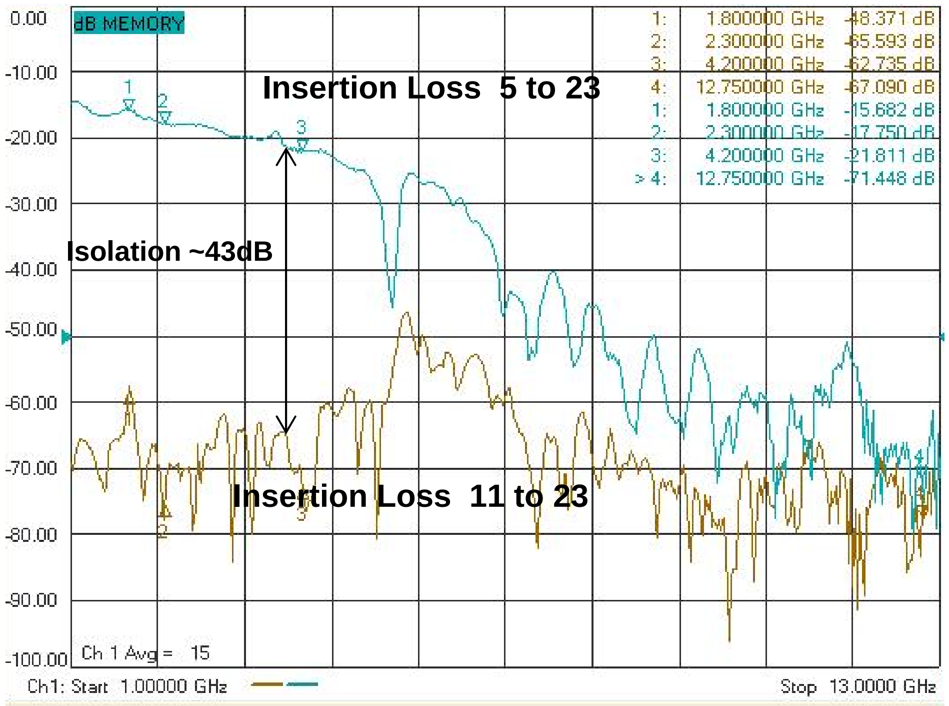
Measured insertion and return loss of path 3-14 (5 DPDT's – 4 vertical transitions)

- Good performance are shown up to 5GHz: IL is below -20dB. A resonance is visible between 5 and 6 GHz
- At higher frequency the IL drops
- Return loss is 10dB
- The balancing between the two paths works. A slight overcompensation can be observed

Test Results – Isolation



Paths 8-17 and 7-18 share 2 switches and 2 exterior transitions



Paths 5-23 and 11-20 share 2 switches

- About 40dB of isolation have been achieved up to C band, in good agreement with simulations
- Above 5GHz the isolation drops

Summary of Test Results

Band	IL 3-14 [dB]	IL 6-19 [dB]	IL (Av.) [dB]	RL [dB]	ISO (Av.) [dB]
L	-16.3	-12.8	-20.2	< -10	41.5
S	-14.6	-14.1	-21.1	< -10	41.7
C	-19.2	-16.4	-24.6	< -10	36.2

- Good performances up to C-Band (4.2GHz) are demonstrated
- The spread in performance is however rather large

  Ongoing Investigation / Lesson learned:
  - Switches shall be selected by IL RF test (not only by DC resistance test)
  - The RF losses of Resistive lines are not fully characterized (never used before for this kind of application)
  - The DC resistance of the switches of this foundry run has been found somehow changeable over repeated On/Off sequences → this problem makes hard any further analysis/testing
- Losses of the LTCC stripline need to be better characterized above 5GHz

Achievements / Conclusions

- The feasibility of a large order Switch Matrix exploiting the MEMS RF Switch technology has been proven
- A dramatic saving of mass and footprint compared to conventional Switch Matrix has been achieved by combining RF MEMS and LTCC multilayer technologies
- The LTCC technology can be used to hermetically package the RF MEMS switch, providing them with the proper environment to work in reliability conditions
- The RF performances are in agreement with simulation up to C Band (4.2GHz)
- For higher frequencies the LTCC substrate shall be more carefully characterized, as well as all the discontinuities (e.g. transitions, bonding etc..)
- TAS-I is working on extending the use of LTCC, e.g. in the frame of an ongoing ESA study (i.e. Solid State Ka band matrix), sharing the same packaging approach

Acknowledgement: Francois Deborgies (ESA) for his effective participation in this project