esa space passive component days
12 - 14 october 2016
European Space Agency


# Ka-band Surface-Mountable Pseudo-elliptic Filter in Multilayer Micromachined Technology for On-board Communication Systems

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# Outline

- Motivation
- 4th-order Ka-band filter in multilayer micromachined technology
  - Design
  - Manufacturing
  - Experimental results
- Conclusions

# Motivation

**Satellite market** demands for innovative miniaturized technologies to reduce the dimensions, weight and cost of satellite equipment

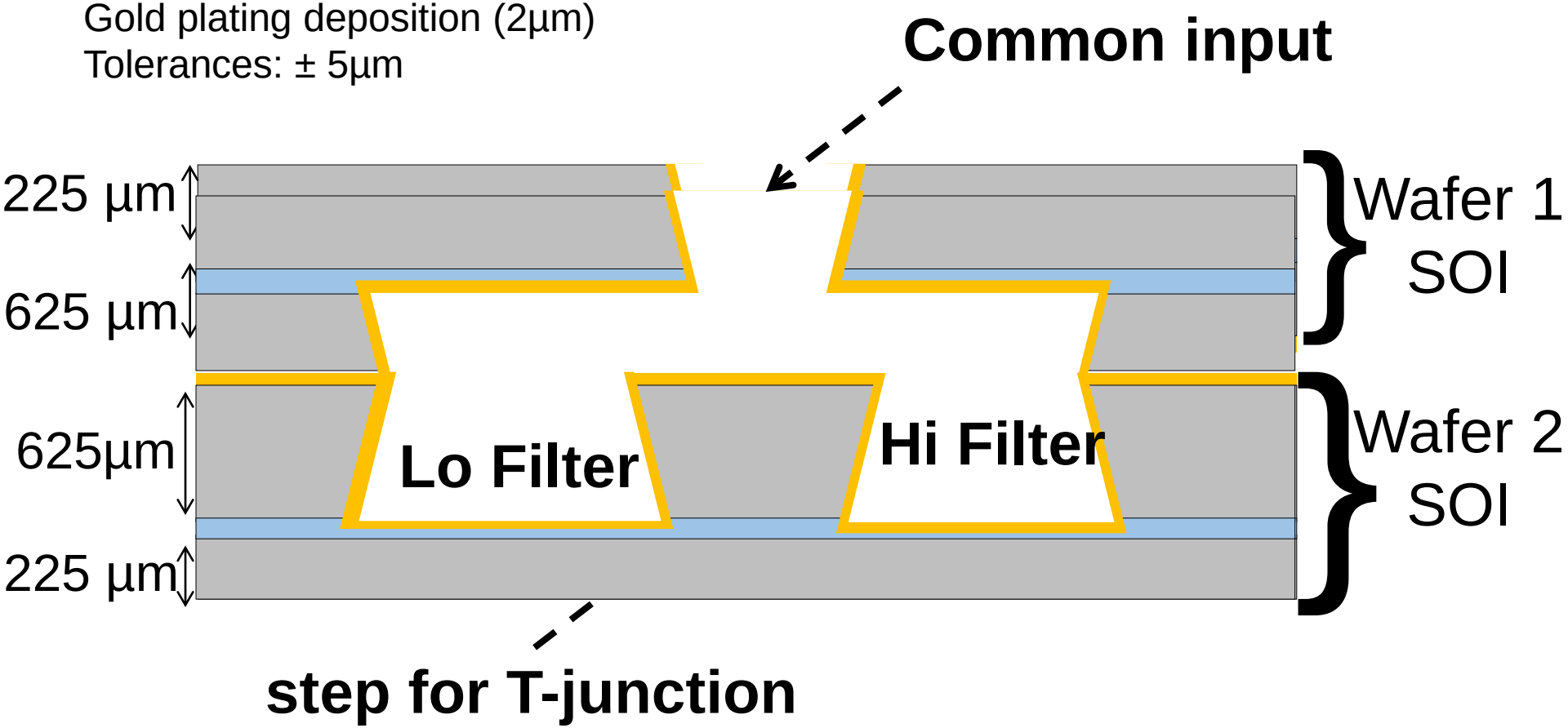
**Filters, Diplexers** (and multiplexer) are key elements in modern multiband and multiservice telecommunications systems

Conventional high Q filters in Ka band and beyond are **based on coaxial TEM mode resonators** allowing for high unloaded Q (>1000). However, they are bulky, heavy in weight and the integration with monolithic circuits is difficult.

# Process & RF design definition

## Process Definition

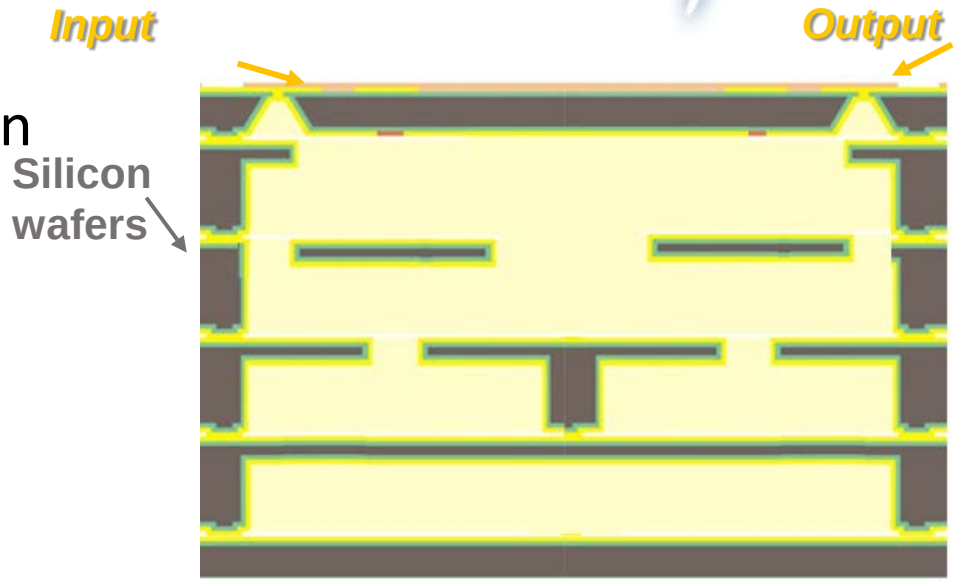
Two Wafer SOI (**S**ilicon **O**n **I**nsulator)
Deep silicon etching
Etching angle: 3 degrees
Gold plating deposition (2µm)
Tolerances: ± 5µm



# Micromachining Technology for RF Filters

Based on resonant cavities and thin membranes that are:

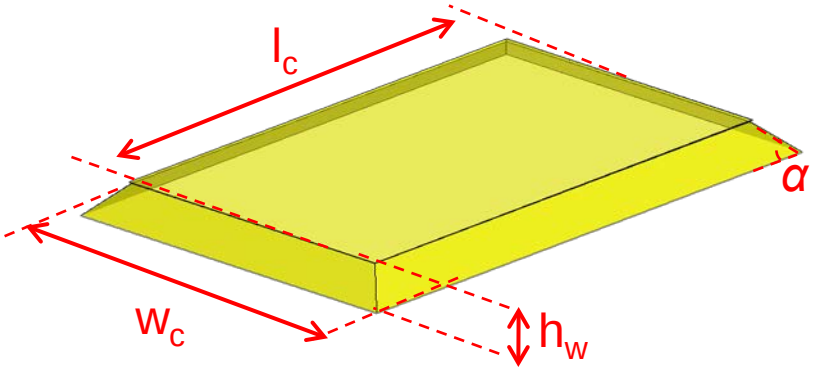
- **etched** in Silicon/Silicon On Insulator wafers
- **gold-plated**
- **stacked** in multilayer structures




- **High miniaturization**
- **High Q**
- **Small footprint (multilayer technology)**
- **Small weight**
- **High integration (Surface Mountable Devices)**
- **Low manufacturing tolerances**

# Ka-band λ/2 TEM Mode Cavity

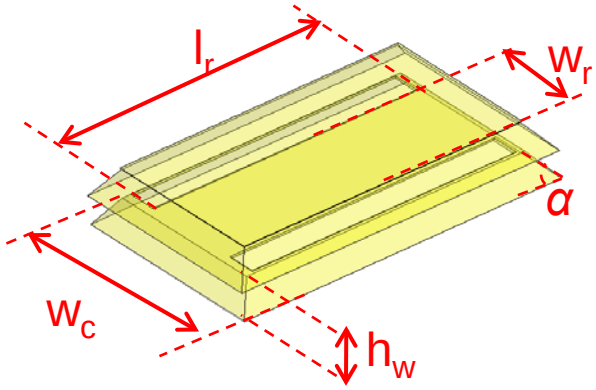
Micromachined cavities are generally realized as **$TE_{101}$ mode cavities**




**$TE_{101}$ mode cavity**

Main critical parameters: $l_c$ and $w_c$

**VS**



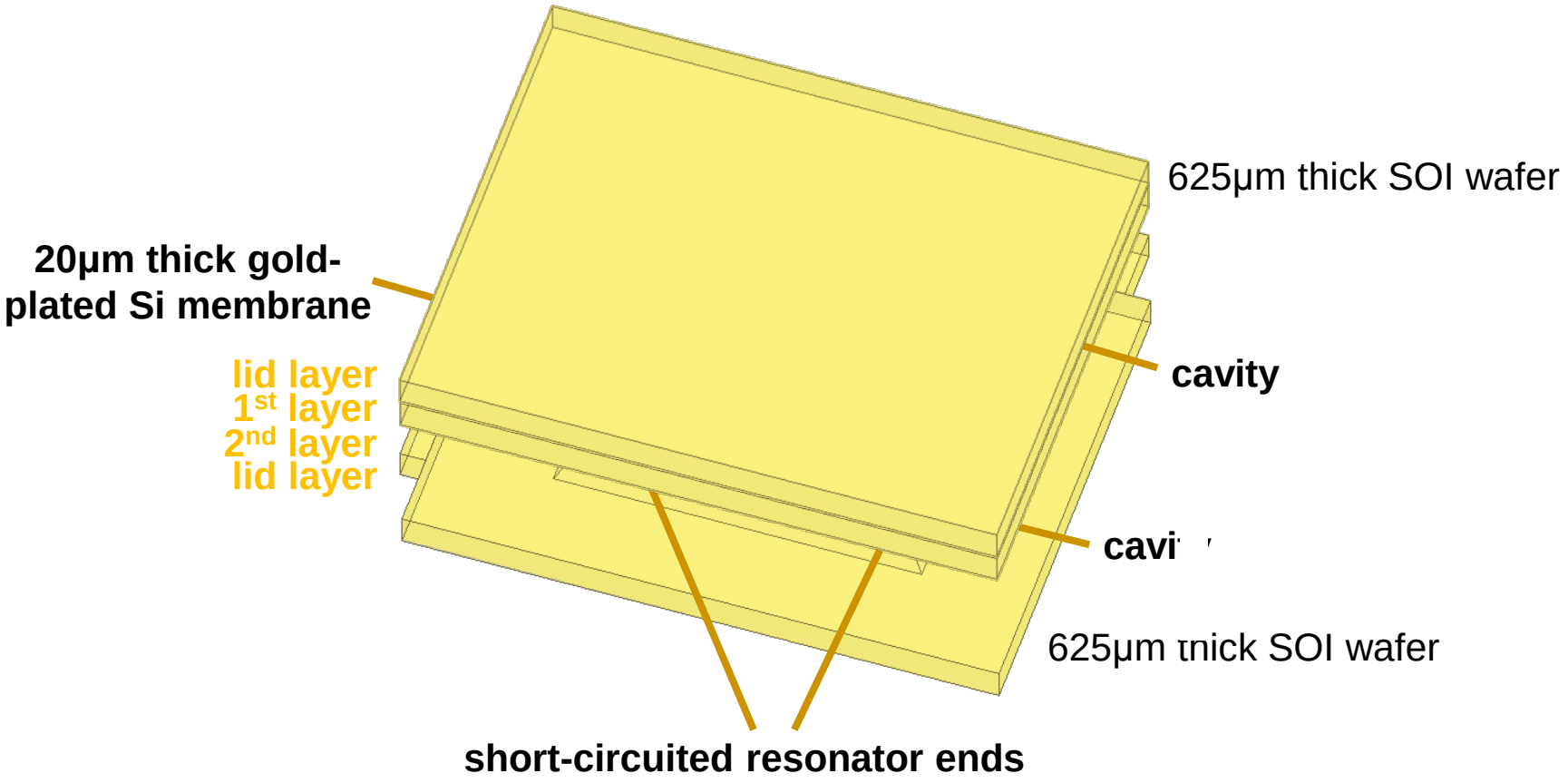

**λ/2 TEM Mode Cavity**

Main critical parameter: $l_r$

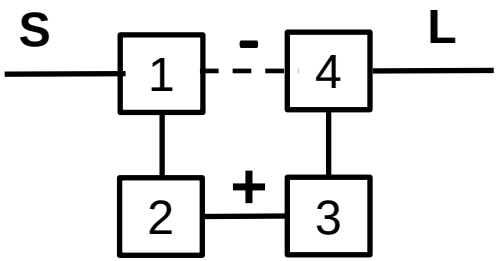
1) Number of geometrical parameters affecting the resonant frequency is minimized
2) Footprint reduction ~ 50%, Q decrease < 25%

# Ka-band λ/2 TEM Mode Cavity

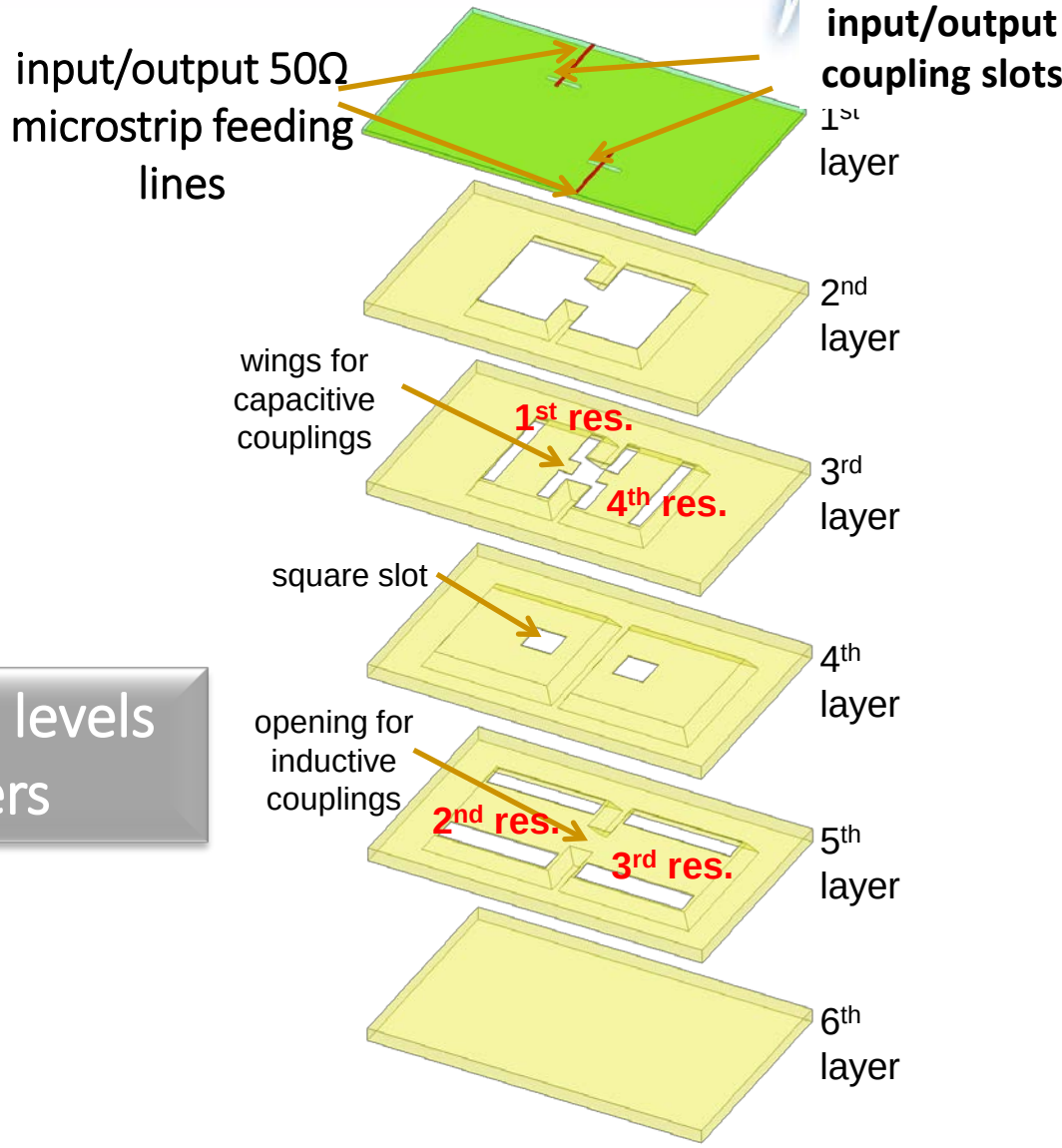
Resonators are realized as short-circuited membranes etched in the Silicon wafers by Deep Reactive Ione Etching, gold electroplated and stacked by thermo-compressive bonding



# 4th-order Filter: RF Design



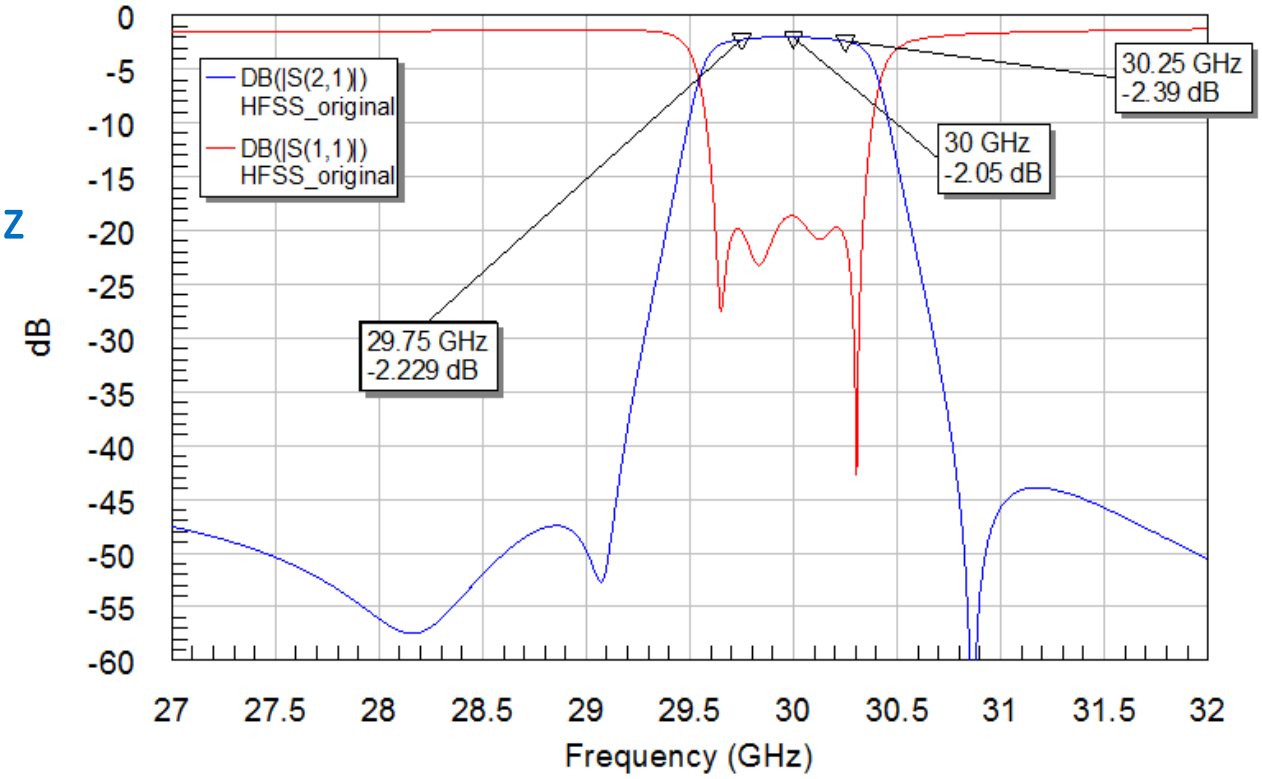

Filter Topology




The 4 cavities are placed on 2 levels
→ stacking #6 silicon layers

# 4th-order Filter: Simulated performance

Centre Frequency: 30GHz
Fract. Bandwidth: 1.8%
Insertion Loss < 2.5 dB
Q ~ 600



# Filter Manufacturing

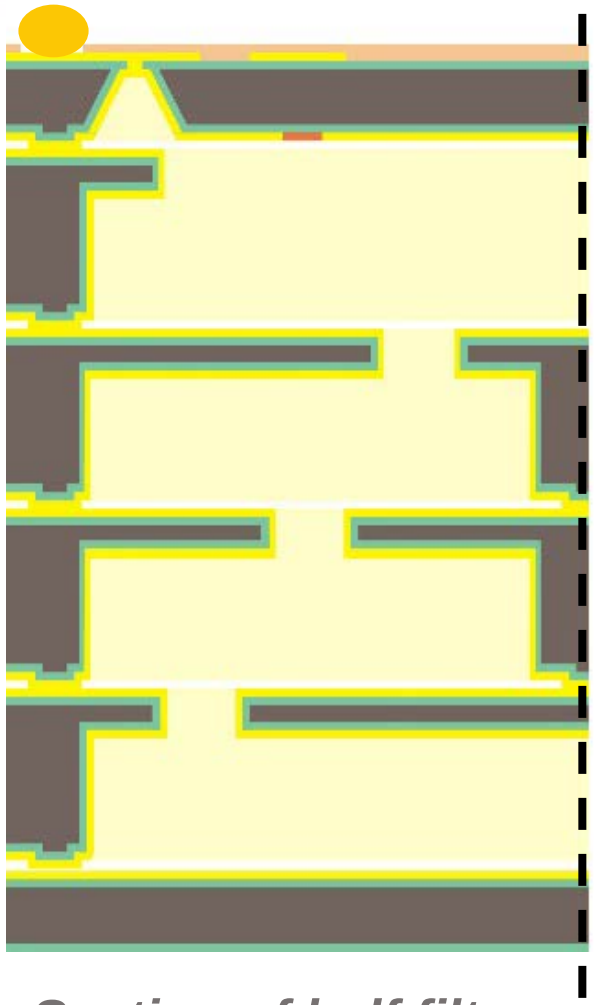
Stacking:

- 1 HR Silicon wafer, 200µm thick (top plate)
- 4 SOI wafers, 625µm thick each
- 1 supporting wafer

Basic Technological Processes:

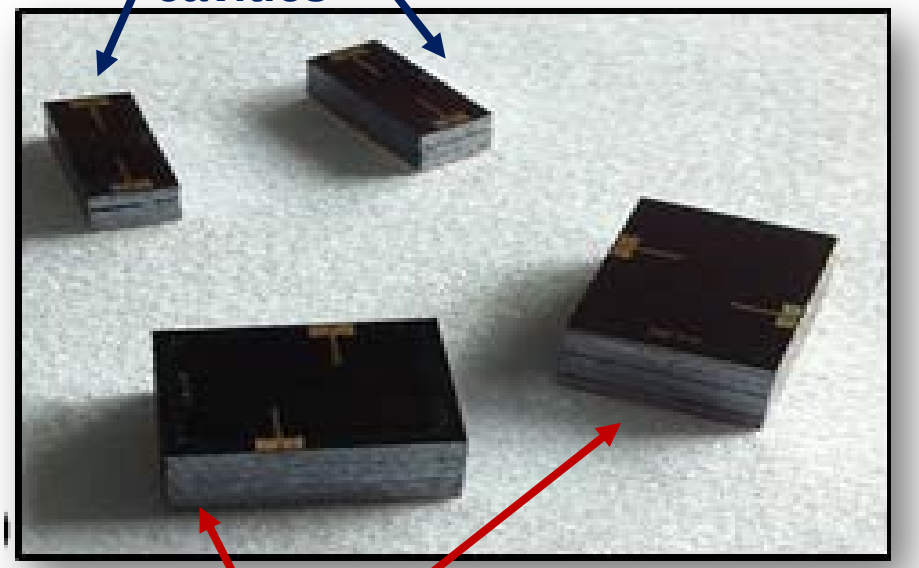
- Deep Reactive Ion Etching (DRIE)
- Gold Electroplating
- Anisotropic Etching (TMAH) for Conductive via's
- Thermo-compressive Wafer Bonding

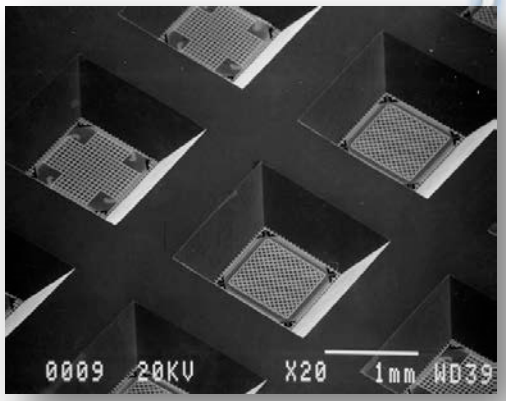
**Manufactured and assembled in FBK - Italy**



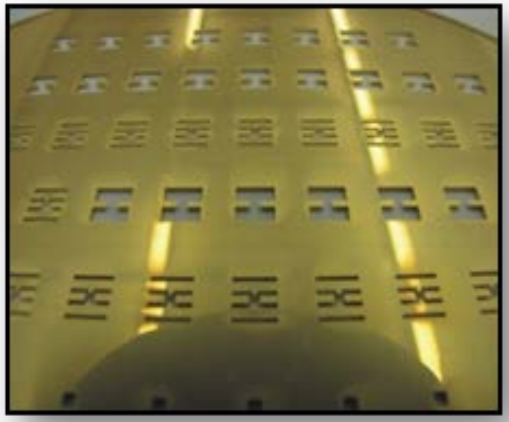

*Section of half filter*

# Filter Manufactured



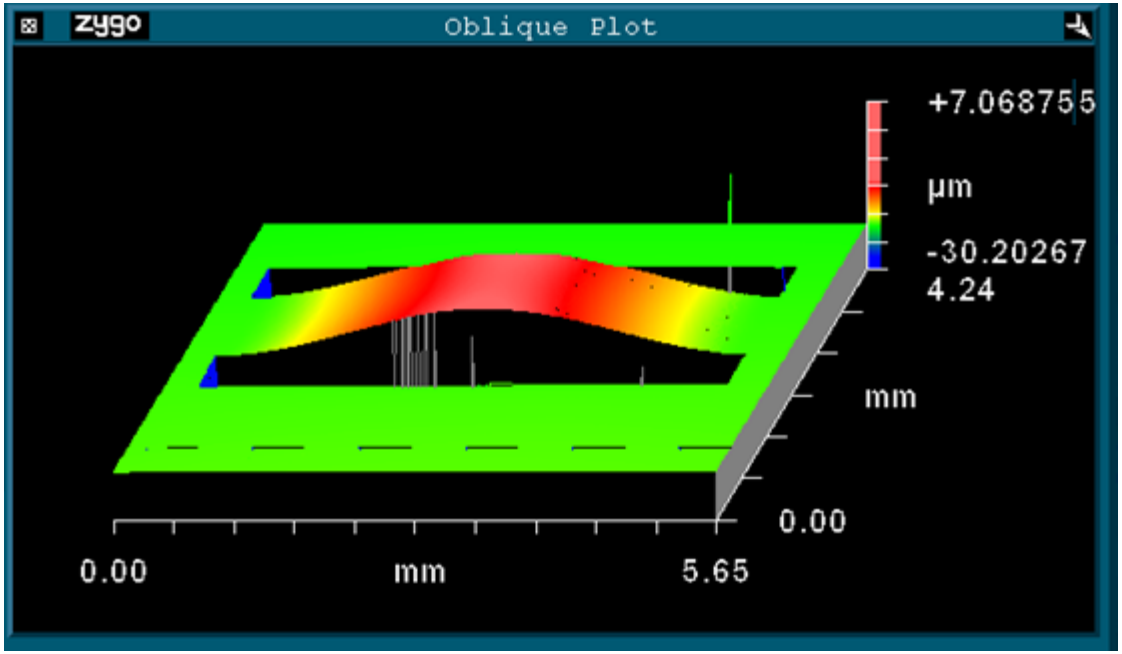

conductive vias



wafer details

# Inspections on Membrane flatness

- The final membranes are almost flat (buckling < 3µm).

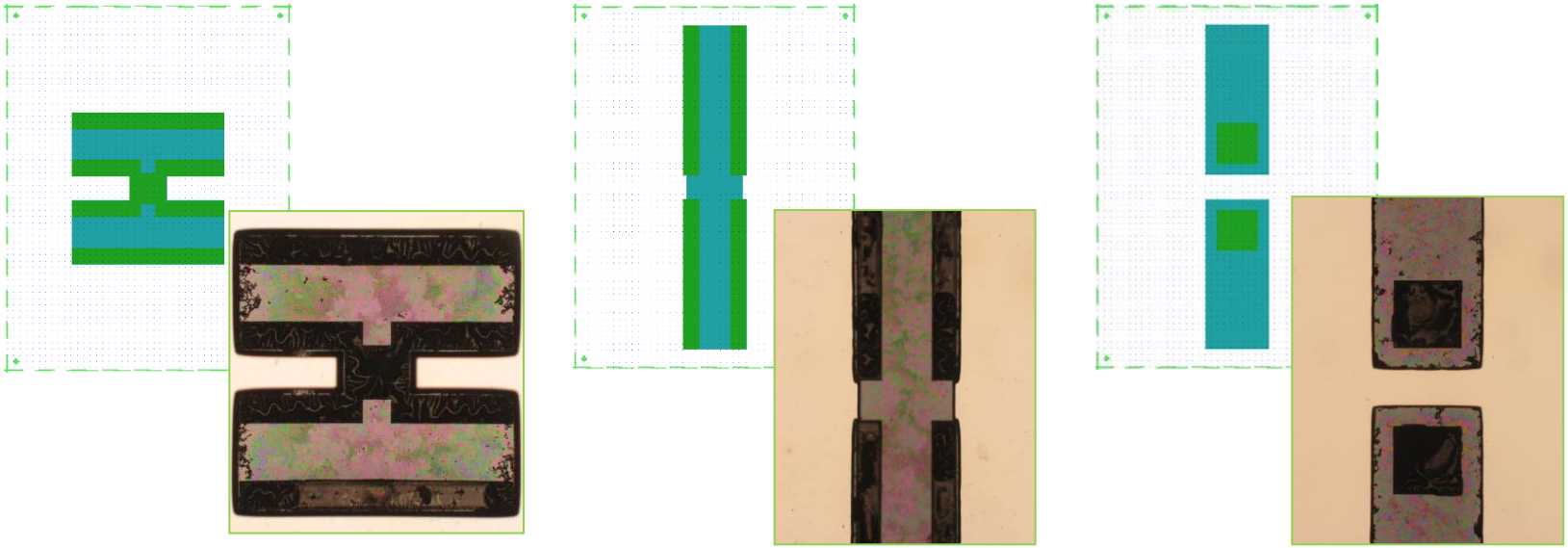


# Dimensional Inspections

All membranes were longer than designed, because of a non-optimized etching time that caused an over-etching of the cavity side walls (about 60-80 µm for each side). This problem caused:

1. longer λ/2 membranes → down-shift of the filter centre frequency (about 600-900 MHz)
2. Larger couplings between cavities that → higher RL

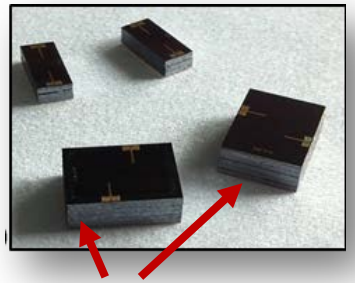
In the second run this error will be compensated for by undersizing the masks



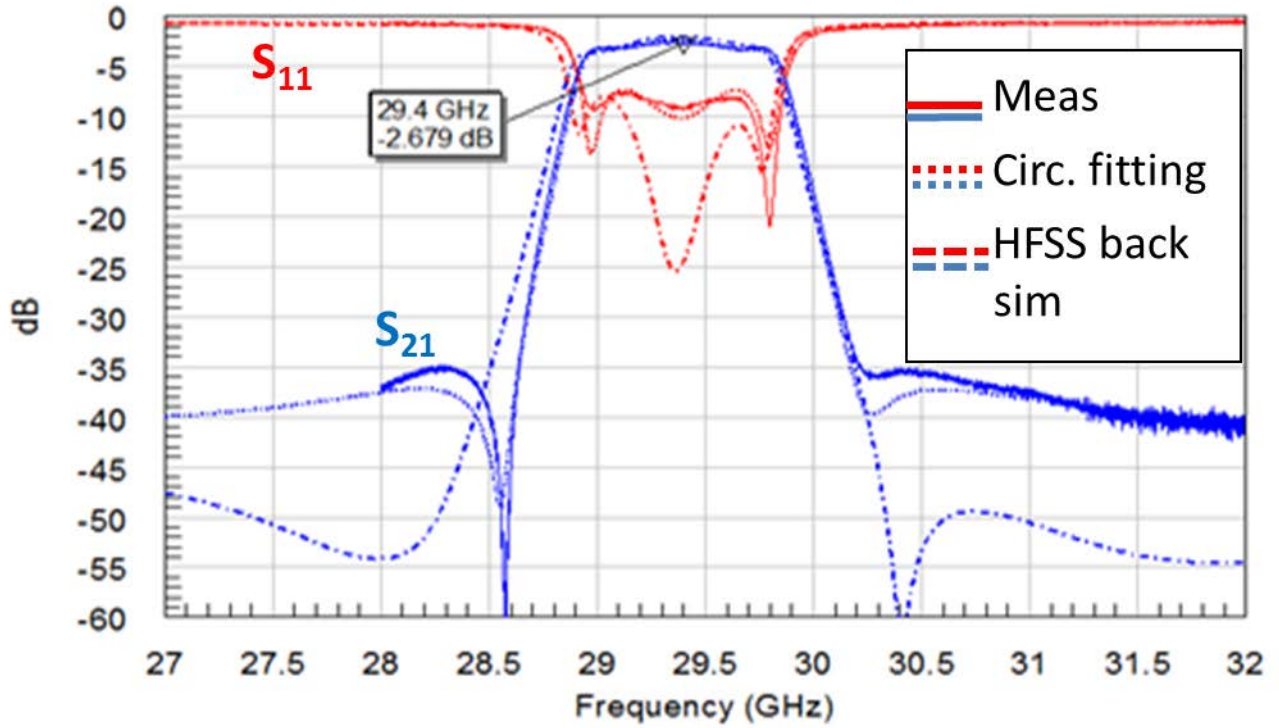
# RF Measurements

Comparison among measurements, circuital (AWR) and HFSS back simulations, accounting for the actual cavity dimensions

Frequency: 29.4 GHz
Fract. Bandwidth: 2.6
Insertion Loss < 3 dB
Simulated Q ~ 500

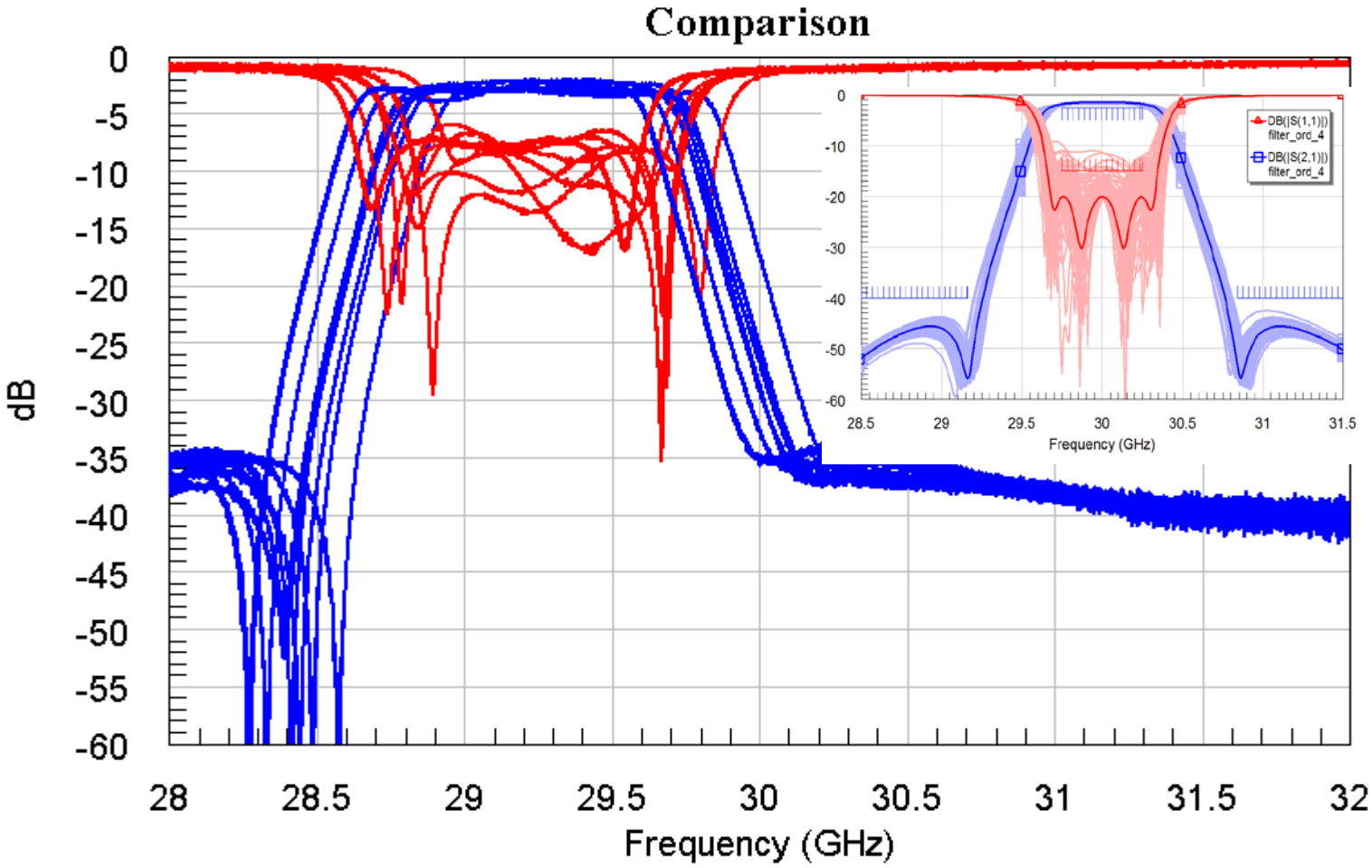


4th order Ka-band Filters




Frequency down-shift by about 600MHz and poor S11 due to the over-etching problem

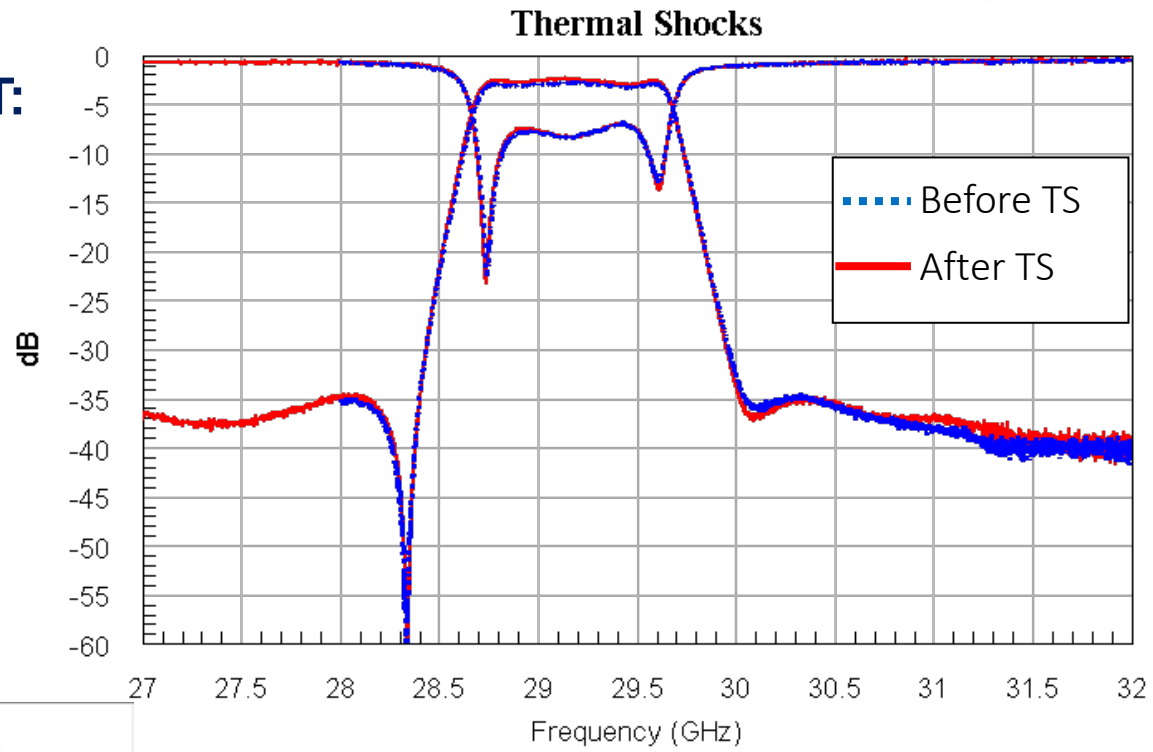
# Performance repeatability



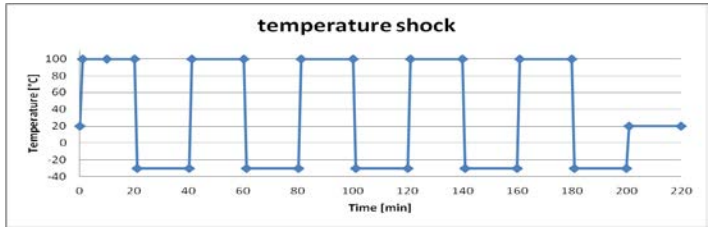

**Good agreement between measured performance of #8 samples and Montecarlo analysis, accounting for manufacturing and assembly tolerances**

# Thermal Shocks

**DEVICES UNDER TEST:**
**#10 single cavities**
**#10 4th pole filters**



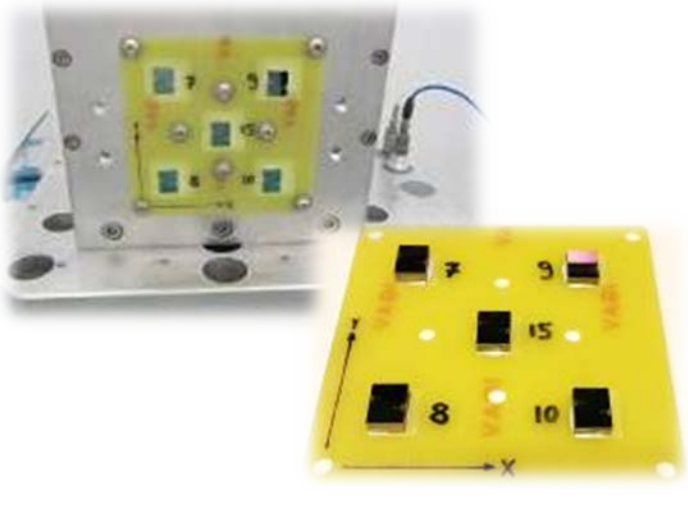

**TEST CONDITIONs**
**#10 cycles -30°/100°**
**MIL –STD – 202G ; Method 107 G ,test condition A-1**



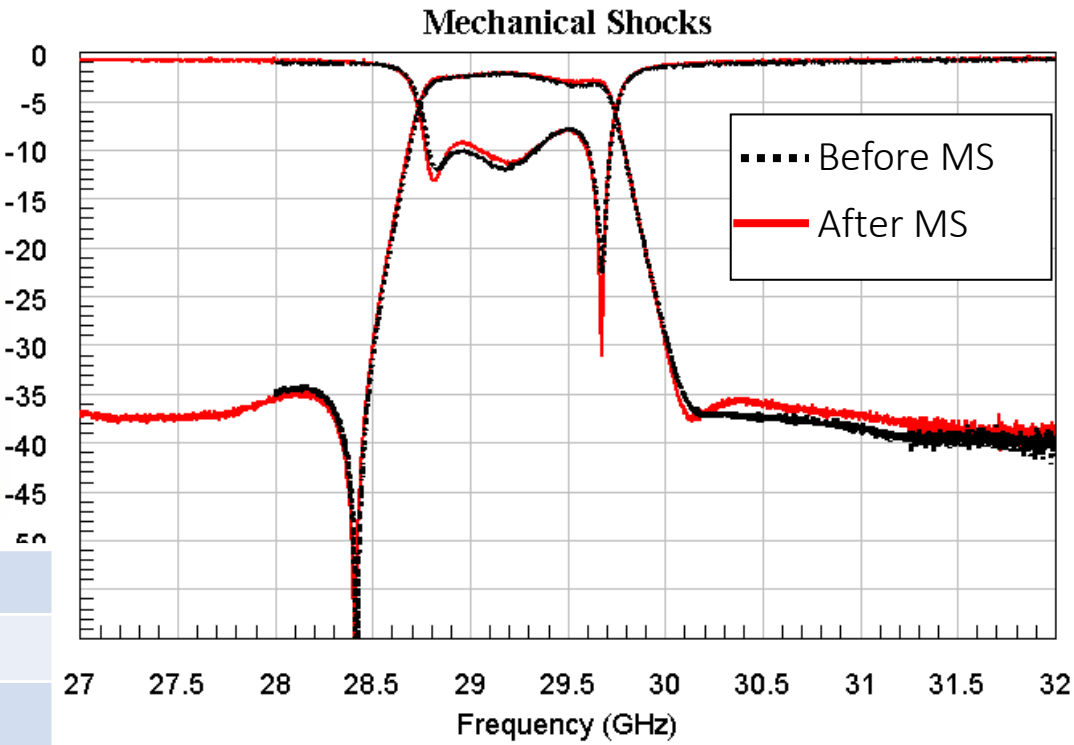

**No failure or change in S parameters for the #20 samples**

# Mechanical Shocks

**#5 4th order filters were glued on a test board and stressed with mechanical shocks**



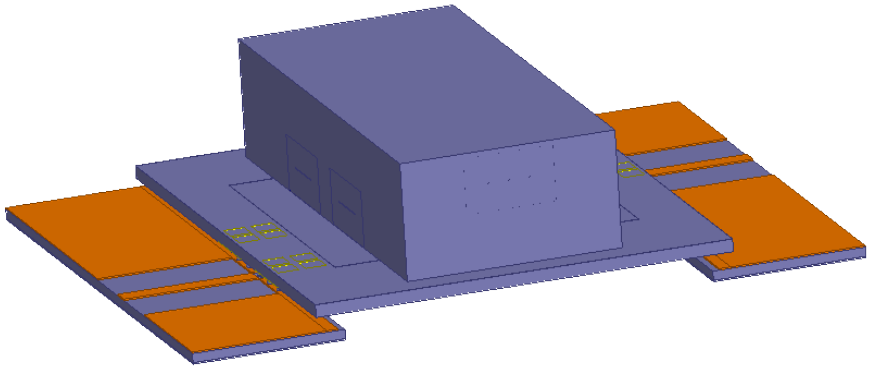

| | |
|---|---|
| **Shape of shock pulse** | Half-sine |
| **Peak acceleration** | 1500 g |
| **Duration of pulse** | 0.3ms |
| **Number of shocks** | 9 (3 shocks in each axis) |

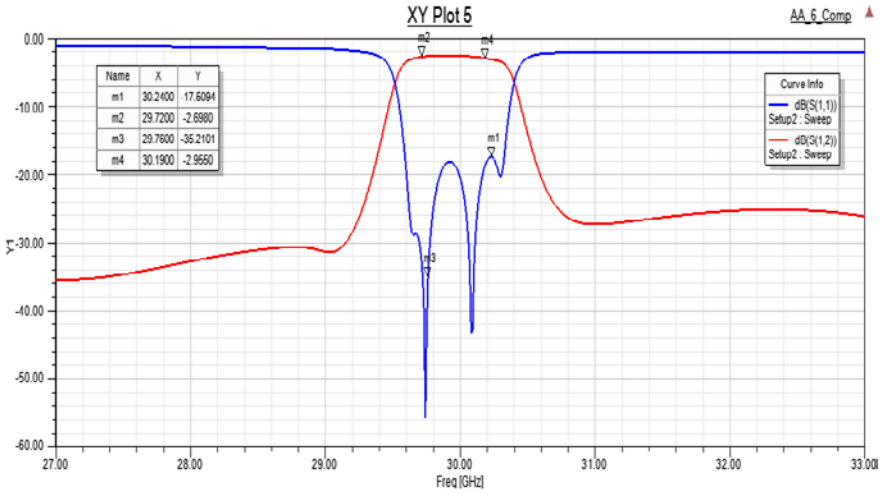



**No failure or change in S parameters for the #5 samples**

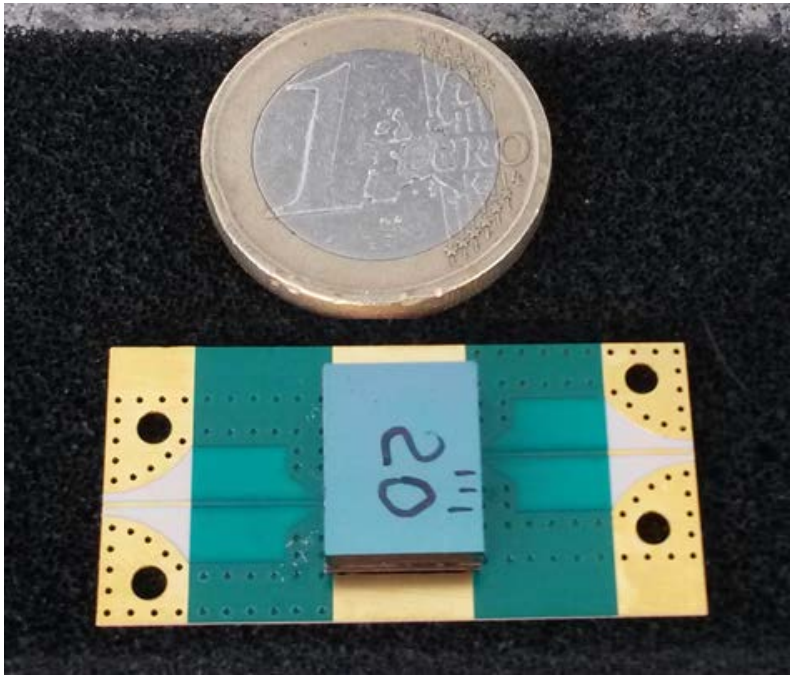
# Surface Mounting

- The filter will soldered on a test board to measure the performance of the integrated device.
- The test board has been modeled and design to ensure good matching and minimize the interconnection loss.





# Surface Mounting



***Measurements and thermal shocks are on-going***

# Conclusions

- A new micromachined resonator has been proposed for Ka–band filters for space applications
- 4th order micromachined surface mountable filters have been designed, fabricated and tested
- Volume occupation is less than 12x9x3mm, weight is 0.75g
- Unloaded Q around 500 and good reproducibility were demonstrated
- Q up to 1000 is expected by increasing the cavity height, i.e. by using thicker wafers
- Good robustness to both thermal and mechanical shocks
- The filter has been integrated in a test board by using standard surface mounting techniques.

# Acknowledgements

**ARTES 5.1** project "**MIGNON**"

"**MI**cromachined filters in multi-layer technolo**G**y for satellite **ON**-board communication systems"

Special thanks to Dr Francois Deborgies and Dr Christoph Ernst from ESA/ESTEC for their support and suggestions.

***Thank you for your kind attention***