# RF-MEMS Switches Reliability for Long Term Spatial Applications

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# Purpose

- Radio Frequency Micro-Electro-Mechanical Systems (RF-MEMS) are becoming more and more interesting for future wireless and wired RF applications
- Light and small redundancy switches in satellite applications
- The reliability of electrostatically actuated MEM switches has been mainly tested only in term of RF performances and cycling, neglecting other reliability issues: ESD, radiation, long term actuation
- We have tested the behaviour of four kinds of MEMS switches under long actuation times, showing how the anchors geometry can impact on the reliability of such devices

# Outline

- Introduction
- Devices Description
- Electro Static Discharge sensitivity
- X Ray – Total Ionizing Dose effect
- Long term stress characterization

    ➔ Meanders shape impact on the reliability

- Conclusions

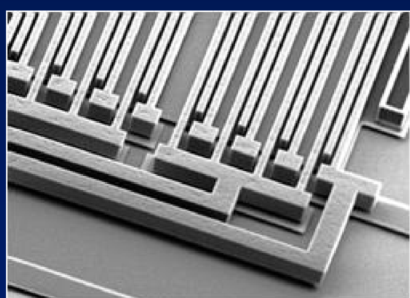
# Introduction

## Micro-Electro-Mechanical-System Application

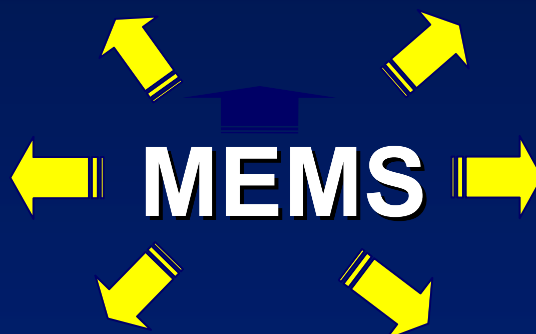
Micro-motors

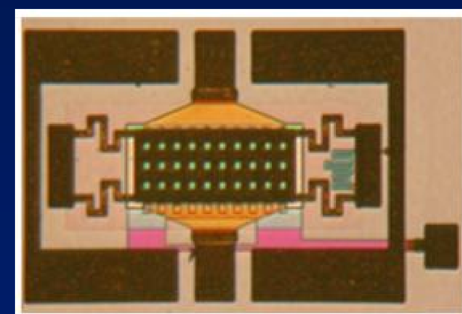
Micro-lenses

Telecoms, BS / Mobile equipment, Defense

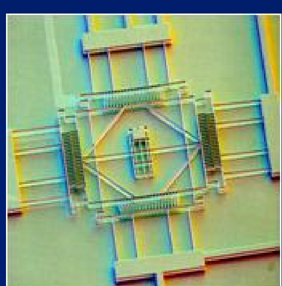


Accelerometers



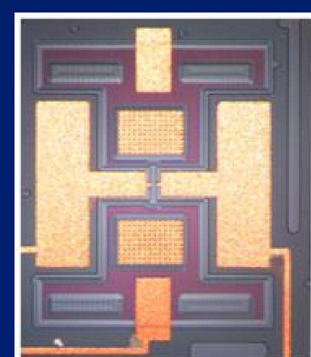



RF Switches

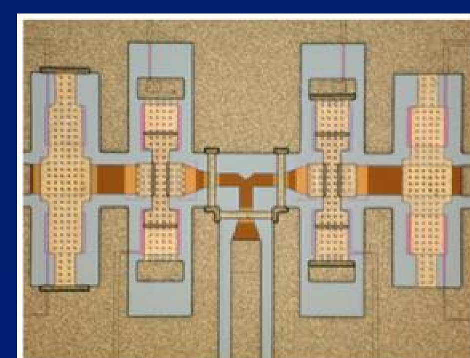


BIO-MEMS
“lab on a chip”

Gyroscopes



HF Resonators

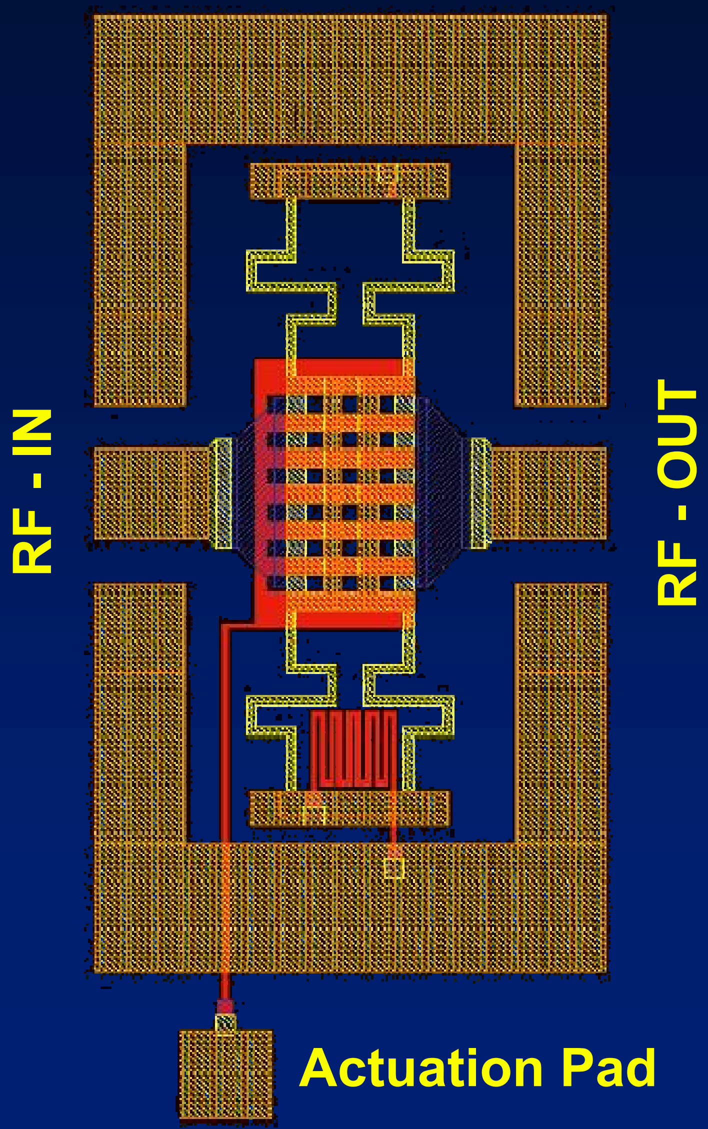


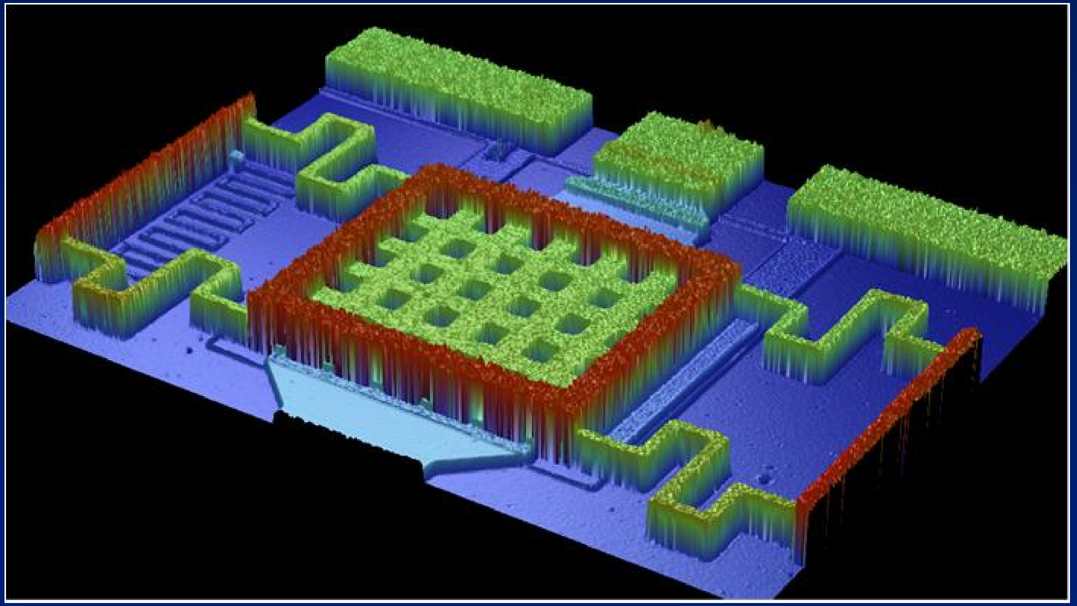
SPDT - Switches

# Devices Description

**Meander based suspensions – Ohmic series / shunt switch**

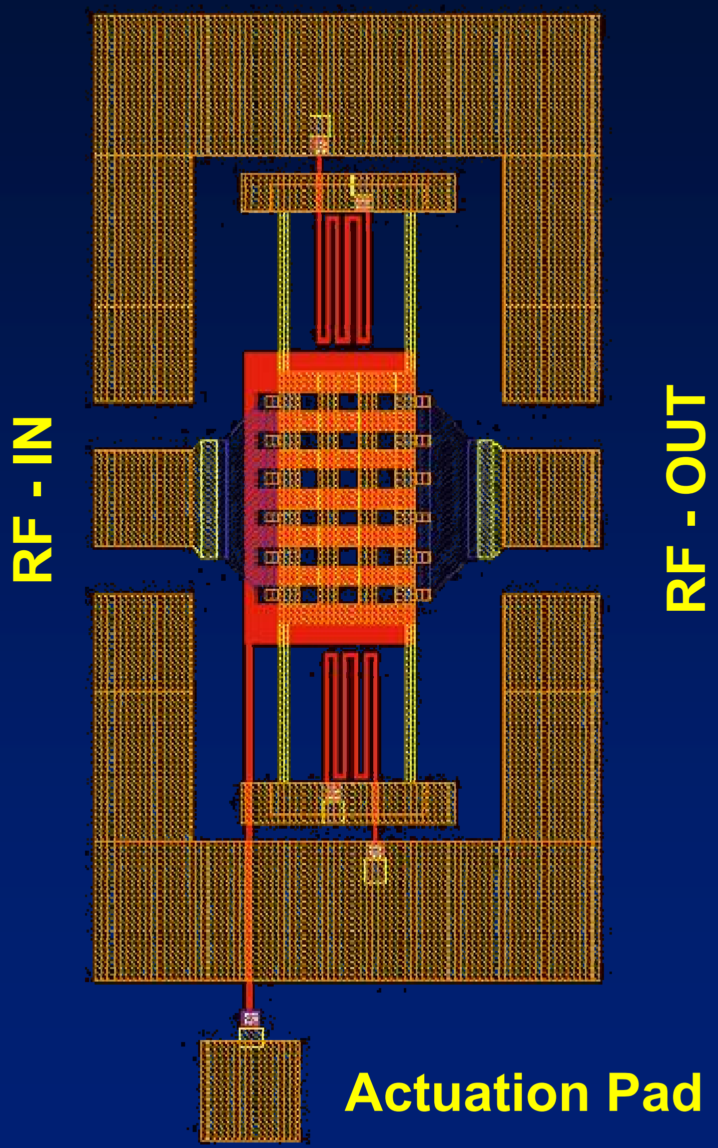
- Surface micromachining process based on electrodeposited suspended gold (membrane layer)
- Low-losses RF signal path (gold layer)
- 1.5µm / 5µm thick beam springs
- Perforated plate structure with 20x20µm holes with 20µm separation
- Interdigitated topology for actuation electrodes



# Devices Description

**Straight beam suspensions – Ohmic series / shunt switch**

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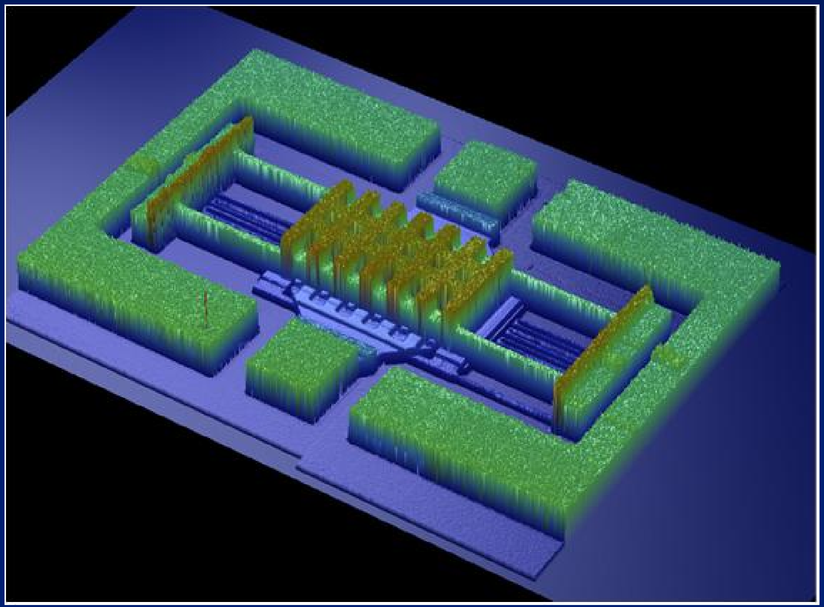
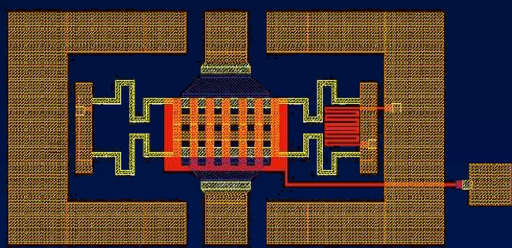
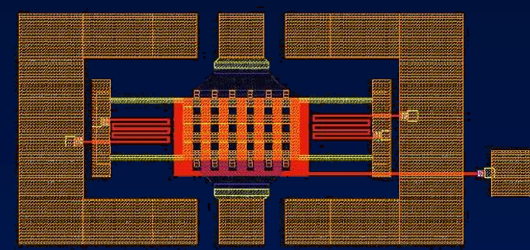


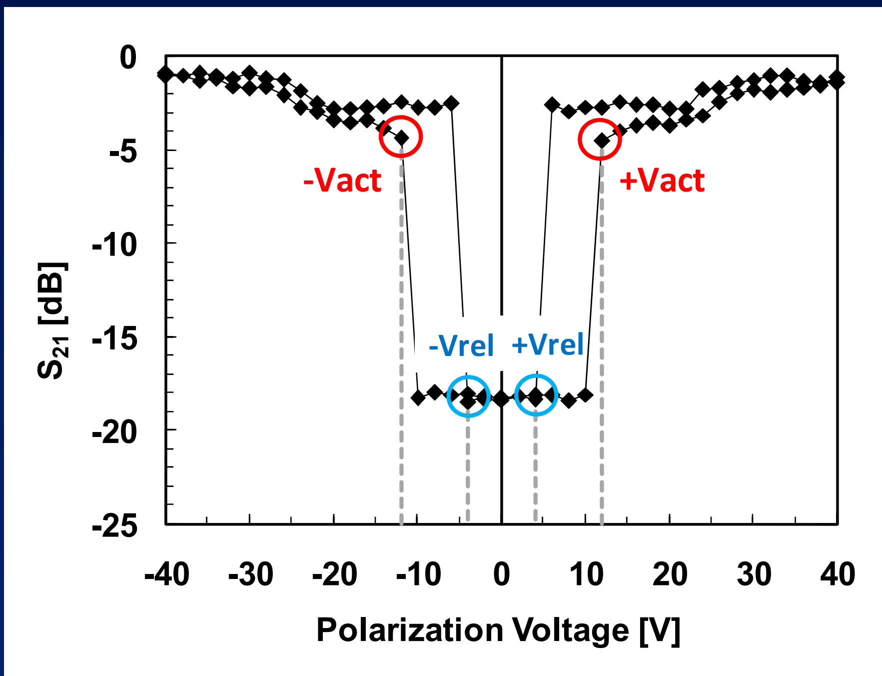
# Ohmic devices DC characterization

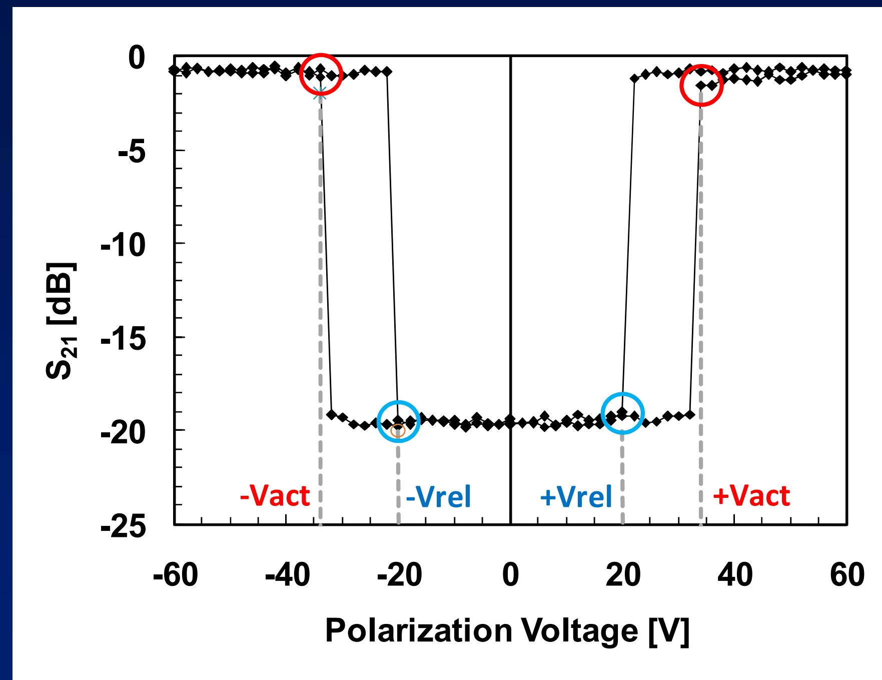
**Meander based anchors**



**Straight beams anchorage**






$|V_{ACT}| \approx 12V$

$|V_{REL}| \approx 4V$

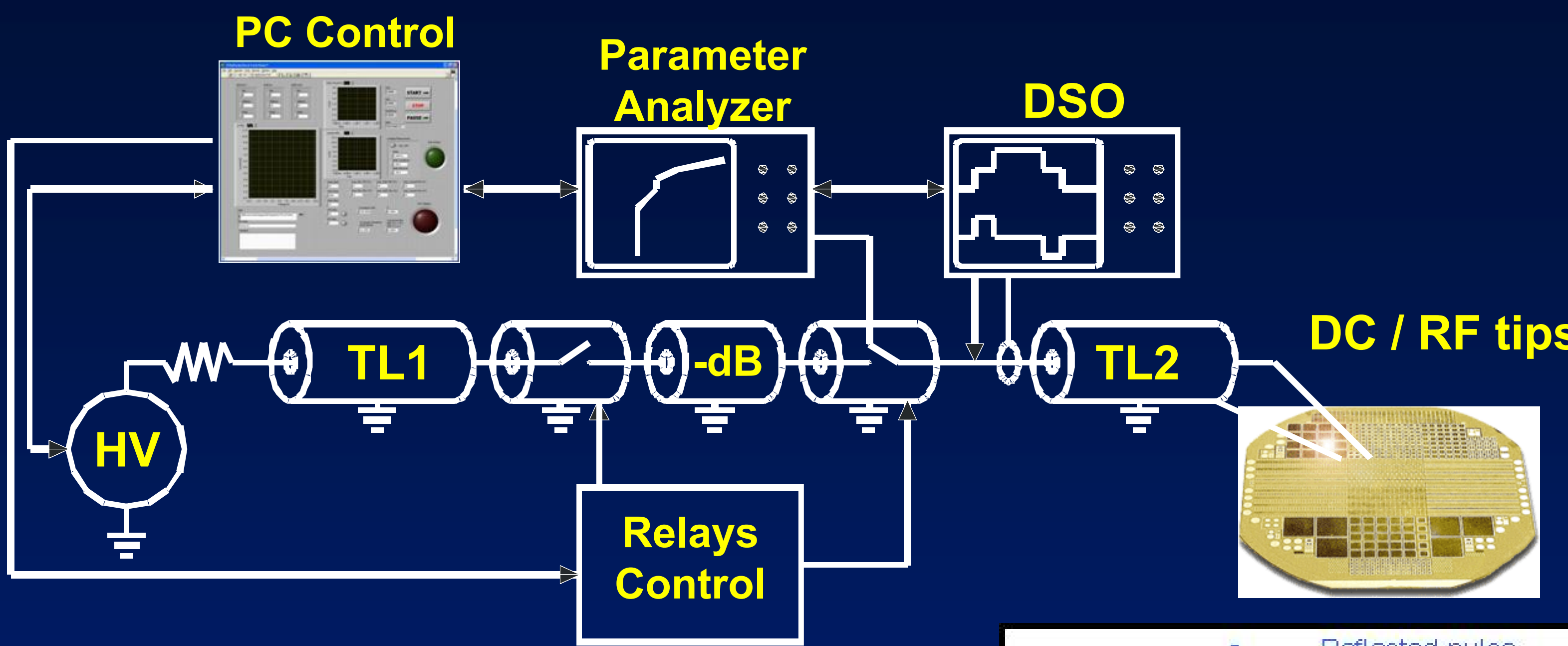
$P_{RF} = 0$ dBm, $f_{RF} = 6GHz$

$|V_{ACT}| \approx 34V$

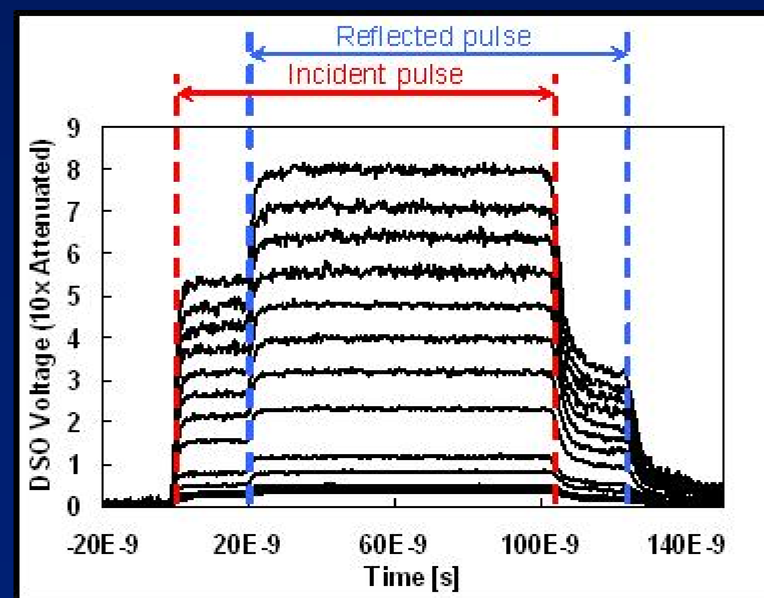
$|V_{REL}| \approx 20V$

# Electro Static Discharge

## Transmission Line Pulser

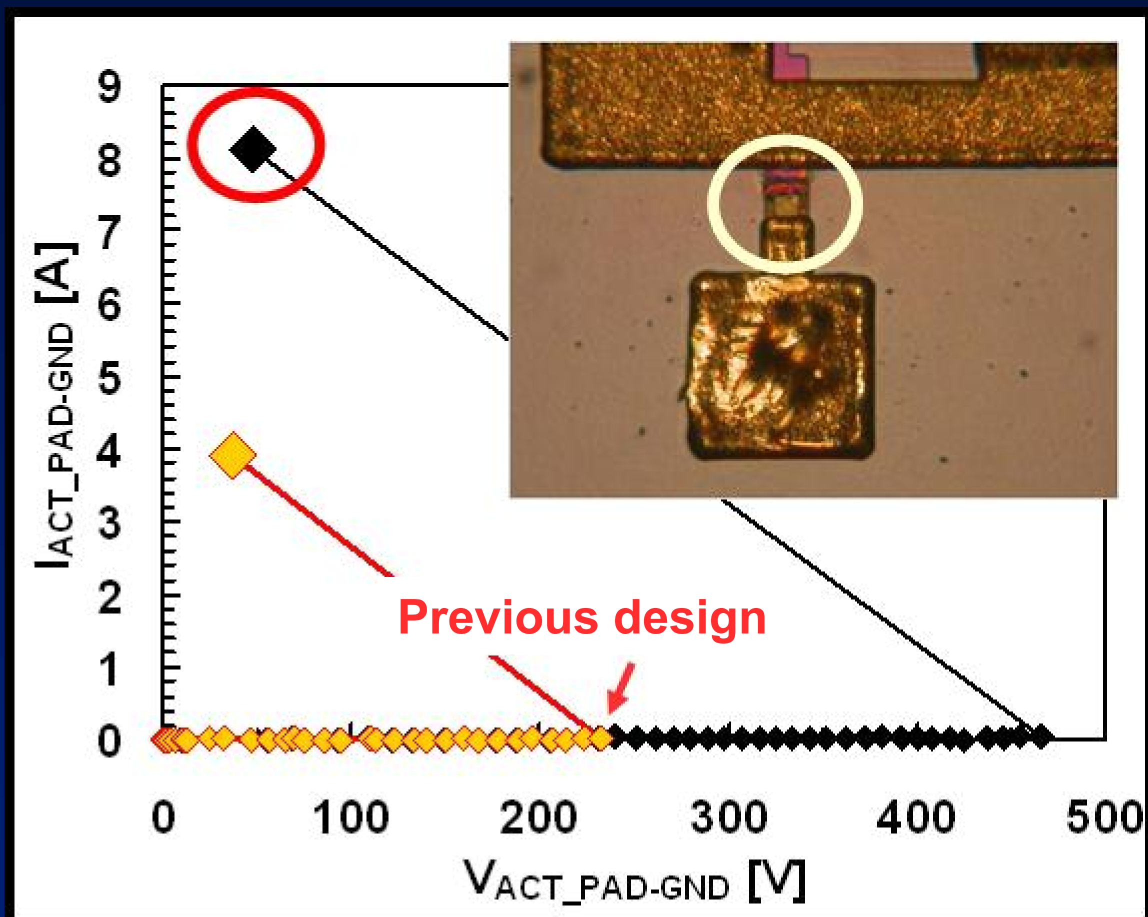


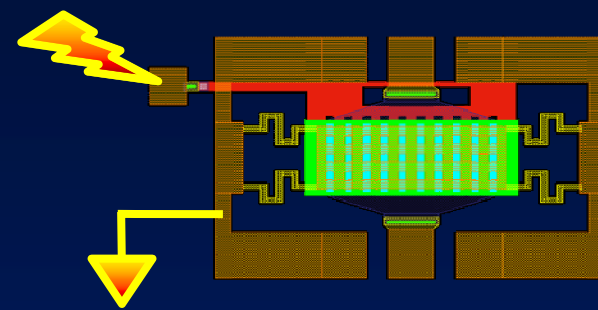

- Sub-nanosecond rise time
- TL1 length = 10m -> 100ns pulse width
- Time Domain Reflectometer technique
- DC & RF tips configuration
- High Current (up to 48 A)
- Easy to use with on package devices

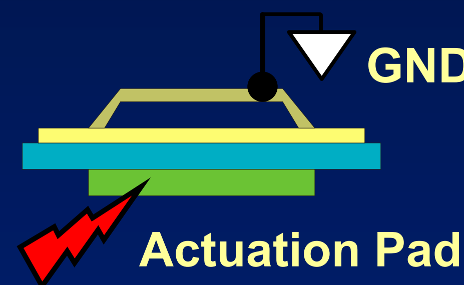


# Sensitivity to Electro-Static Discharge

## TLP between the ACTUATION PAD and GND



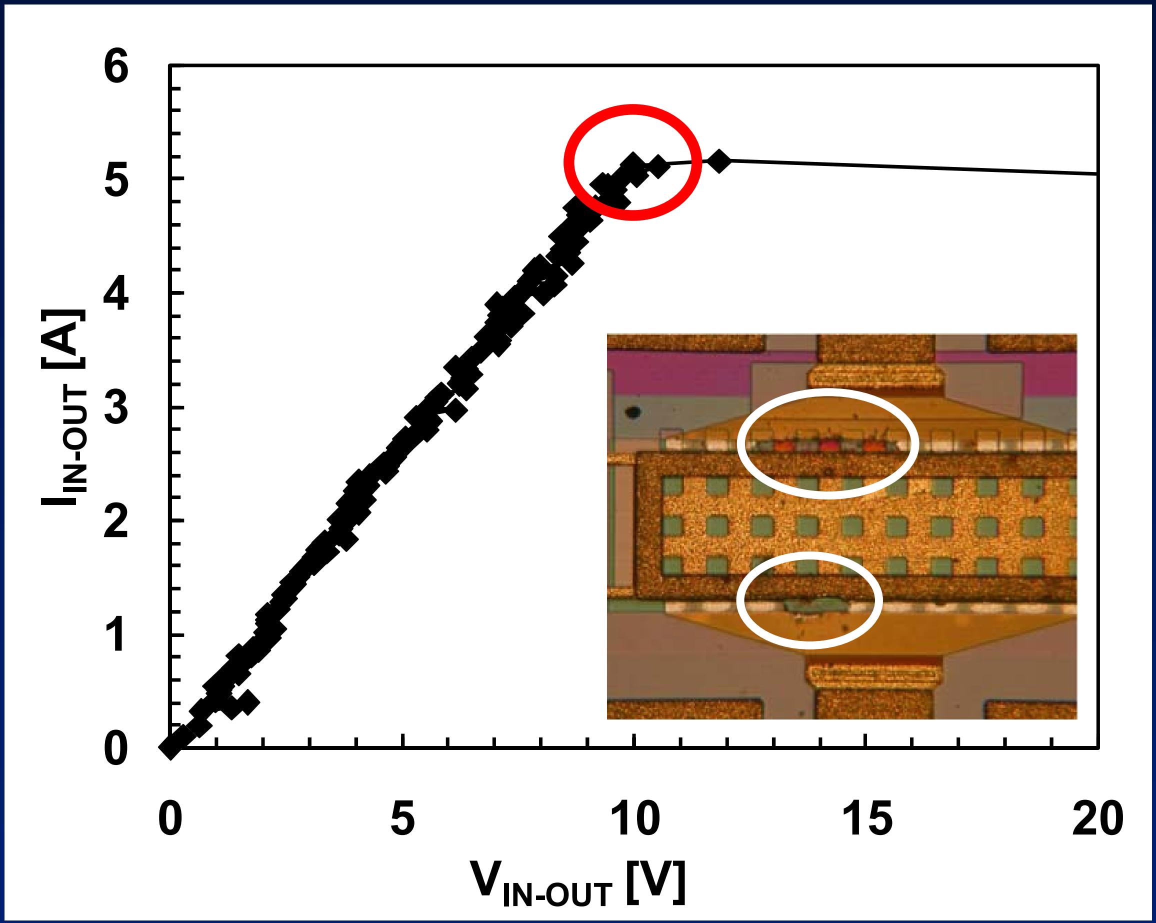


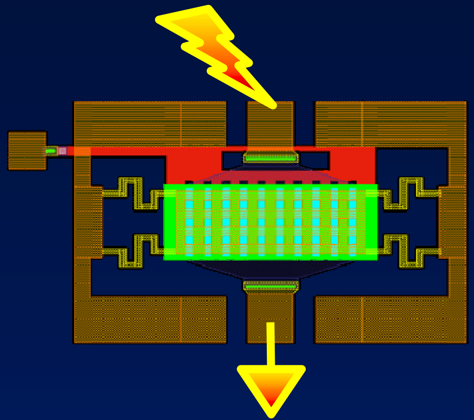

**Dielectric breakdown observed at low discharge voltage (compared to HBM)**

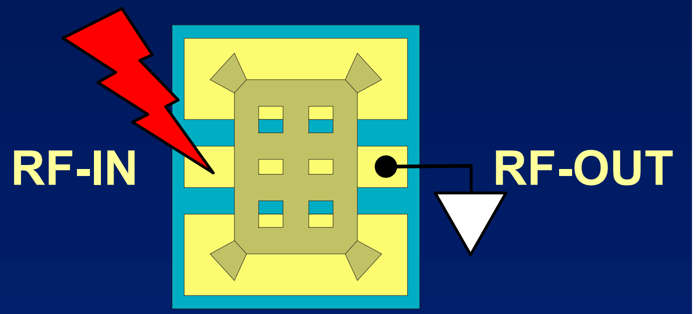
Ref: A. Tazzoli, V. Peretti et al., "Transmission Line Pulse (TLP) Testing of Radio Frequency (RF) Micro-machined Micro-Electro-Mechanical-Systems (MEMS) Switches", EOS/ESD Symp. 2006, Tucson, AZ, USA

# Sensitivity to Electro-Static Discharge

## TLP between the RF-INPUT and RF-OUTPUT






**Open circuit observed after the failure point**

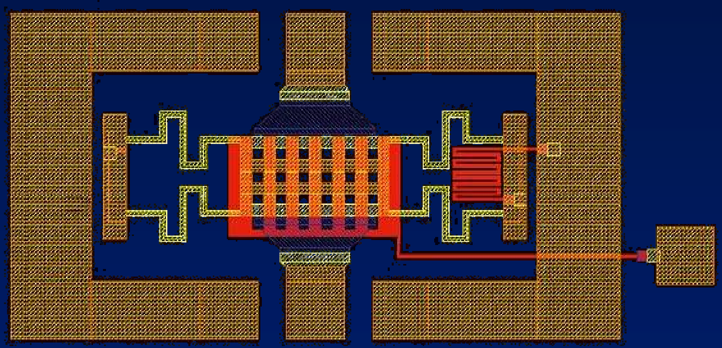
Ref: A. Tazzoli, V. Peretti et al., "Transmission Line Pulse (TLP) Testing of Radio Frequency (RF) Micro-machined Micro-Electro-Mechanical-Systems (MEMS) Switches", EOS/ESD Symp. 2006, Tucson, AZ, USA

# Total Ionizing Dose – X-rays

**The sensitivity to 1Mrad(SiO2) Total Ionizing Dose has been evaluated using a 50keV, 500rad/s, X-ray source available at INFN-LNL (Legnaro, Italy).**

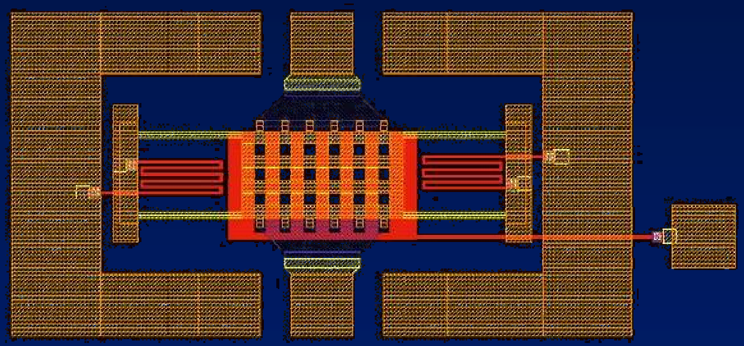
**Tested devices: 30 m.b. + 40 s.b. ohmic switches**

**Meander-based**



| | | |
|---|---|---|
| Stiction | → | 50% |
| S-parameters degradation | → | 42% |
| Negligible variations | → | 8% |
| Actuation line damage | → | 0% |

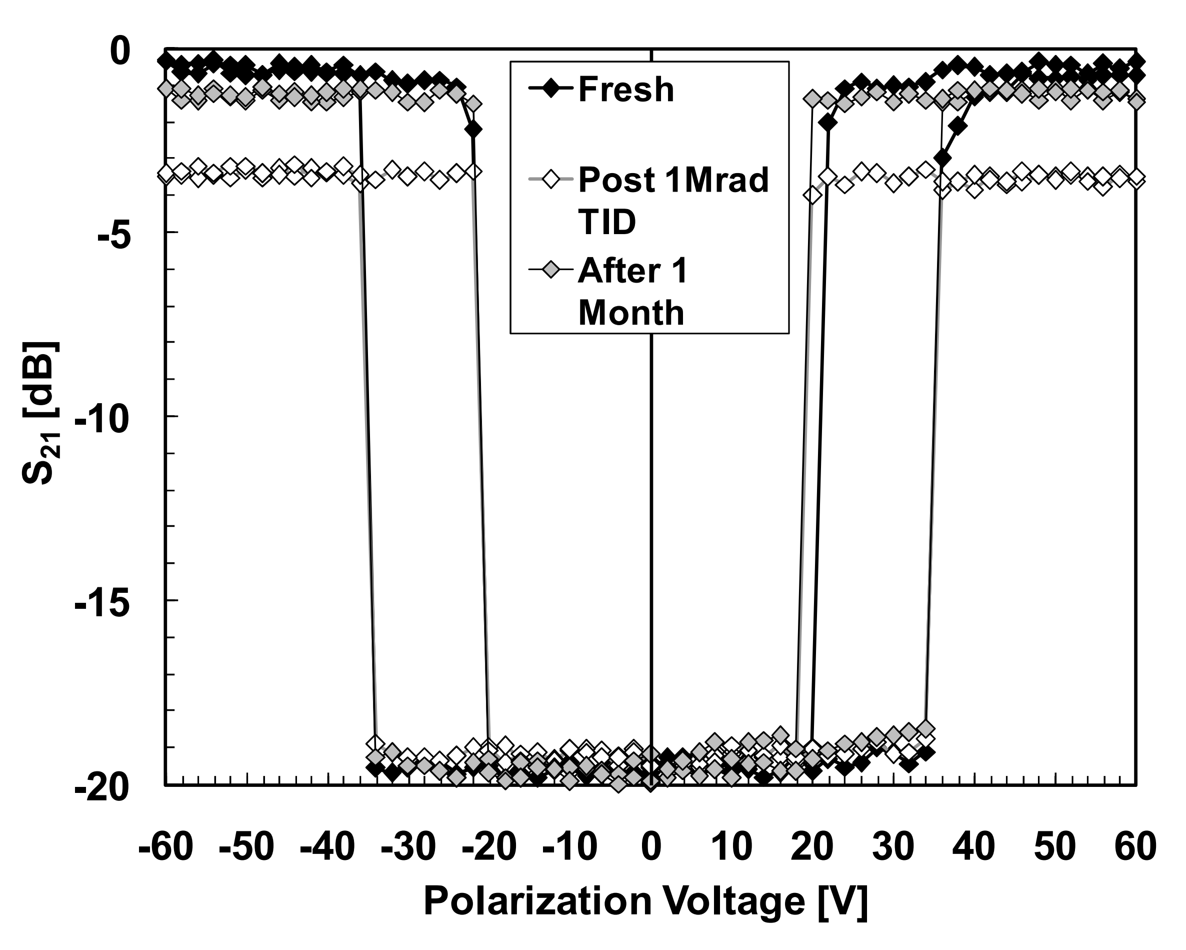
**Straight beams**



| | | |
|---|---|---|
| Stiction | → | 6% |
| S-parameters degradation | → | 24% |
| Negligible variations | → | 66% |
| Actuation line damage | → | 4% |

# Total Ionizing Dose – X-rays

**The sensitivity to 1Mrad(SiO2) Total Ionizing Dose has been evaluated using a 50keV, 500rad/s, X-ray source available at INFN-LNL (Legnaro, Italy).**

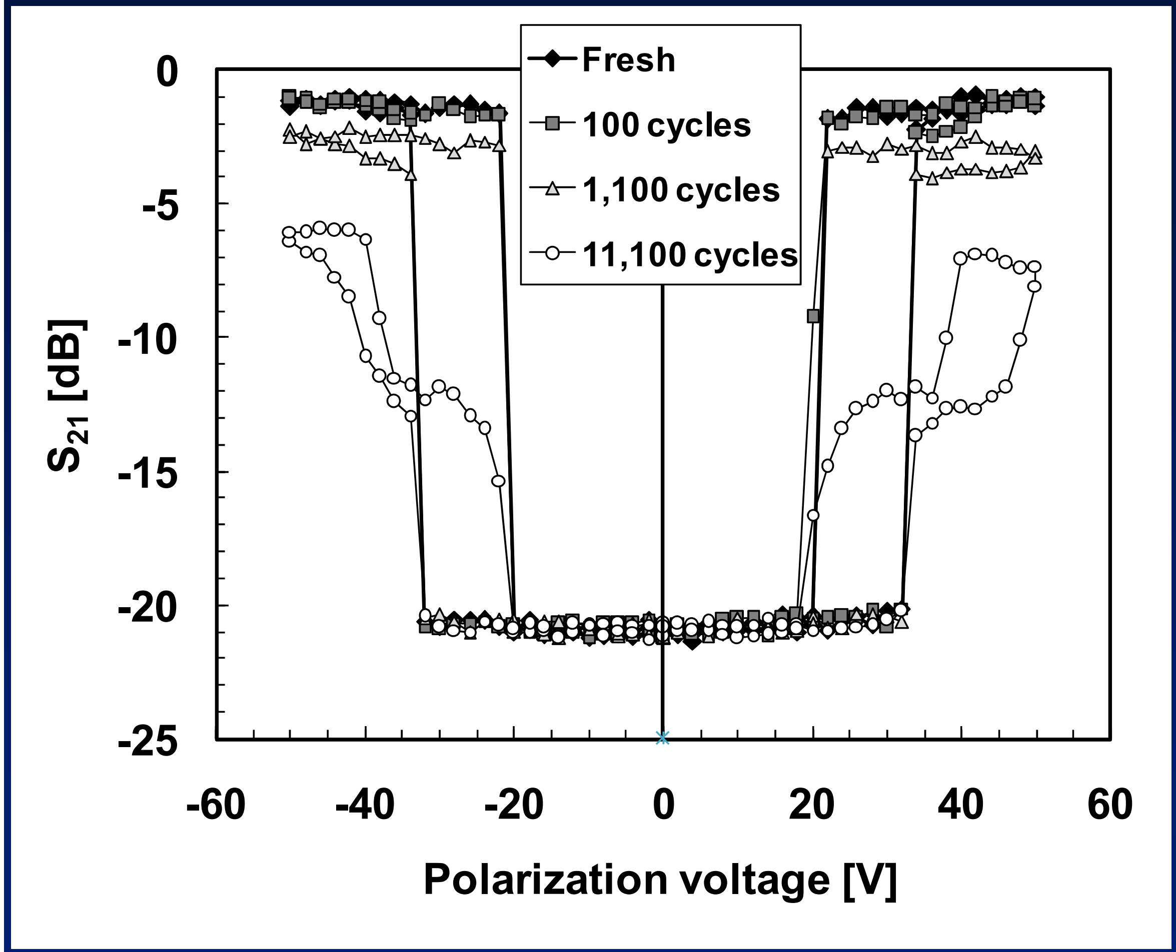



**Ohmic switch – Straight beams - $f_{RF}$ = 6 GHz**

- **Degradation of the S-Parameters when actuated (series resistance increase)**
- **No changes in the actuation voltage**
- **Recovery after 1 month ➔ charge entrapment / redistribution ??**
- **<u>Extra studies are needed!!</u>**

# TID – Cycling correlation ?

**TID induced degradation is very similar to the degradation caused by low voltage cycling**




- Similar degradation of the S-Parameters (series resistance increase)
- Almost no changes in the actuation voltage

**Bias conditions**

DC sweep:

$f_{RF}$ = 6 GHz

Cycling:

$V_{ACT}$ = 40 V

$T_{ACT}$ = 250 μs

$F_{ACT}$ = 1 kHz

$P_{RF}$ = 0 dBm

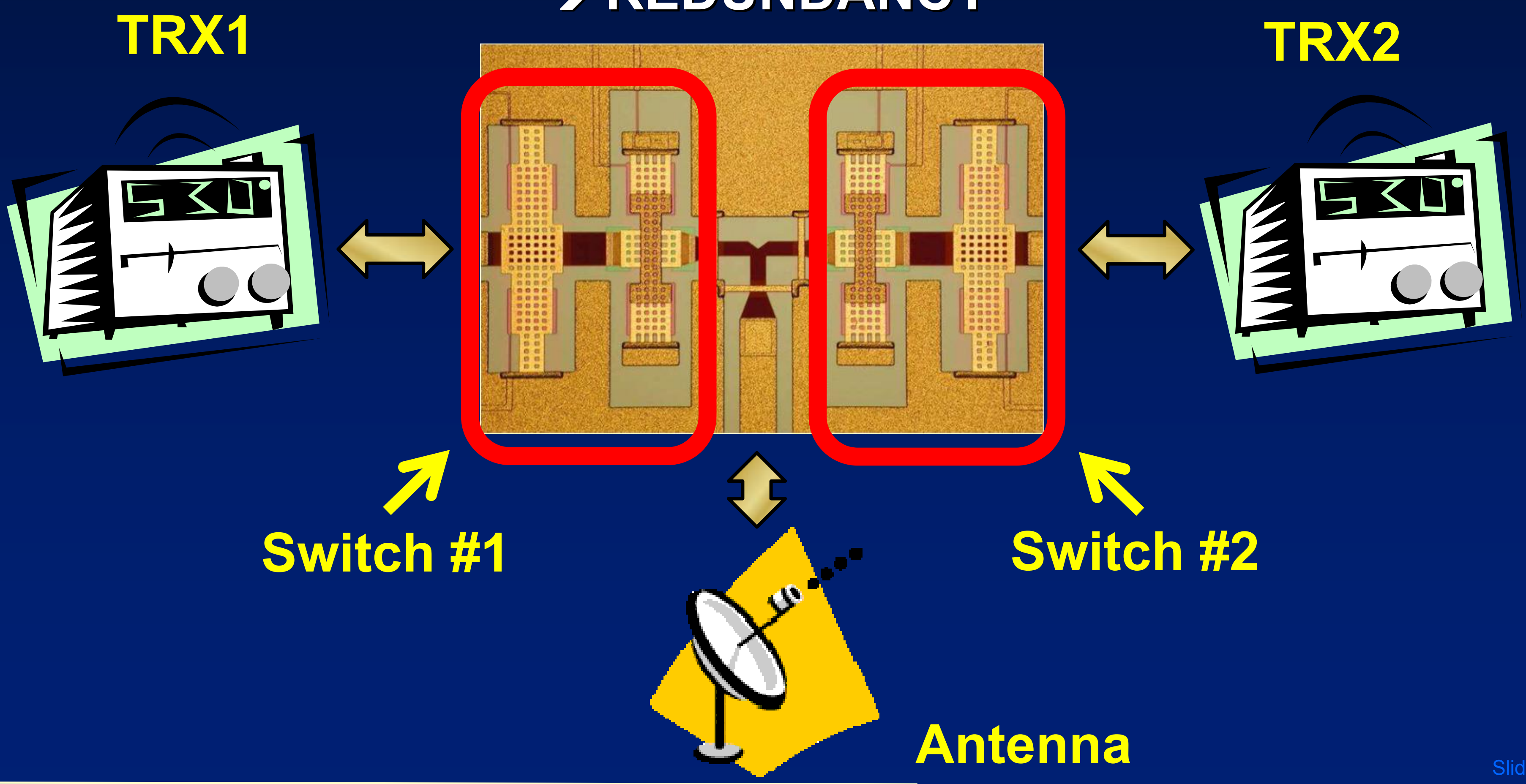
$f_{RF}$ = 6 GHz

**Could radiation be studied as a new accelerating factor?**

# Application: Redundancy Switch

**Reliability** is a major issue for any satellite, since it is almost impossible to foresee any repair work once the spacecraft has been launched. This approach is often not sufficient to meet the required mission lifetime (15 years) for today's telecommunications satellites

➔ REDUNDANCY



# Redundancy Switch

## Excerpt from ESA tender

## "High Reliability MEMS Redundancy Switch" (2006):

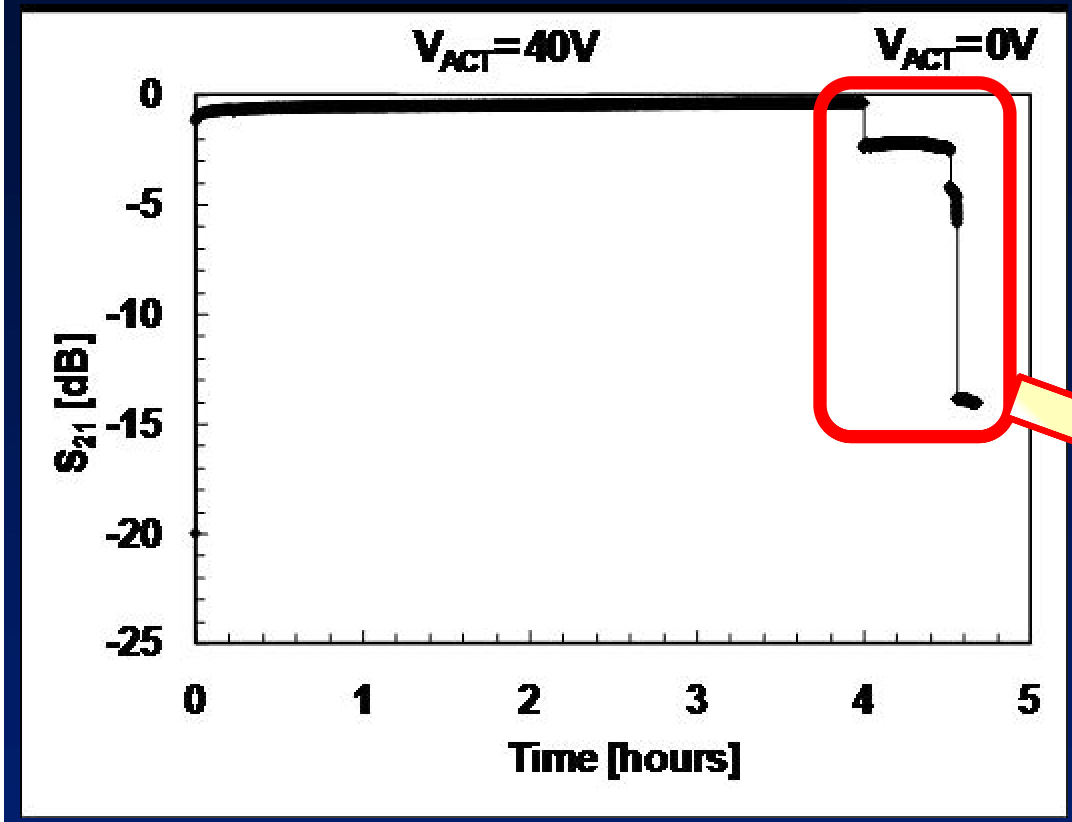
The MEMS Redundancy Switch shall fulfil the following specifications:

| Parameter | Specification |
|---|---|
| Frequency band | Ku-band |
| Bandwidth | Covering whole frequency band |
| Input match (50 Ohms) | -15 dB max |
| Output match (50 Ohms) | -15 dB max |
| Insertion losses | 0.5 dB max (unpackaged) |
| Isolation between channels | 50 dB min |
| Maximum input power | 10 dBm |
| Reconfiguration time | 1 s max |
| Operating temperature range | -20°C / +55°C |
| Storage temperature range | -50°C / +125°C |
| Lifetime (predicted) | 15 years min (with 1000 actuation max) |

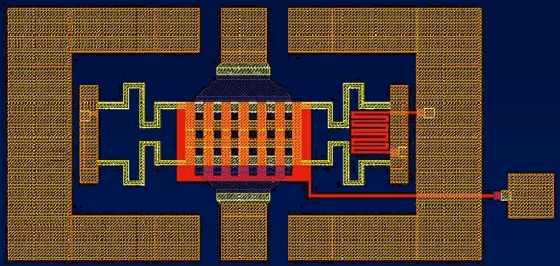
Lifetime shall not be affected by "hot switching" which happens when the switching is done while the RF power is still applied (0 dBm max).

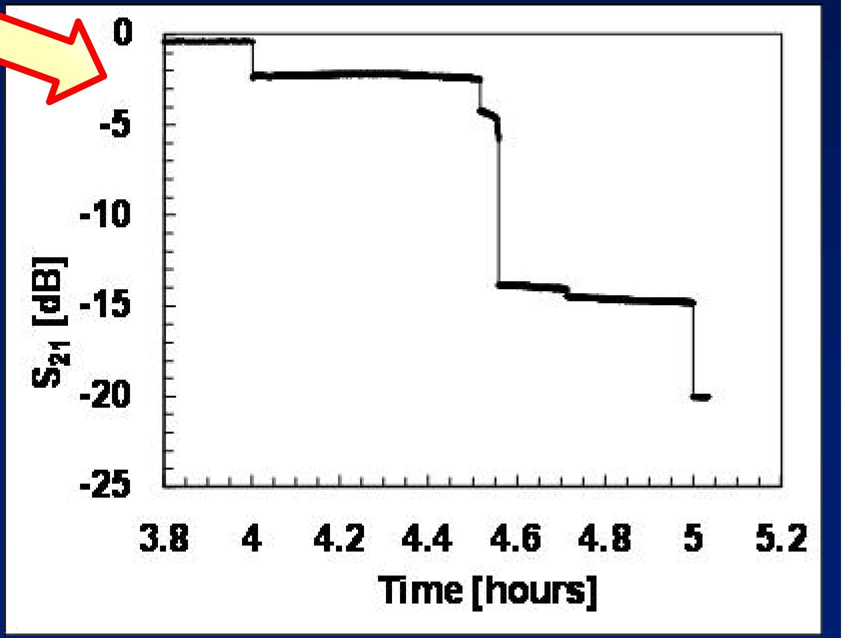
# Long Term Actuation

## DC Stress




**Meander-based anchors**



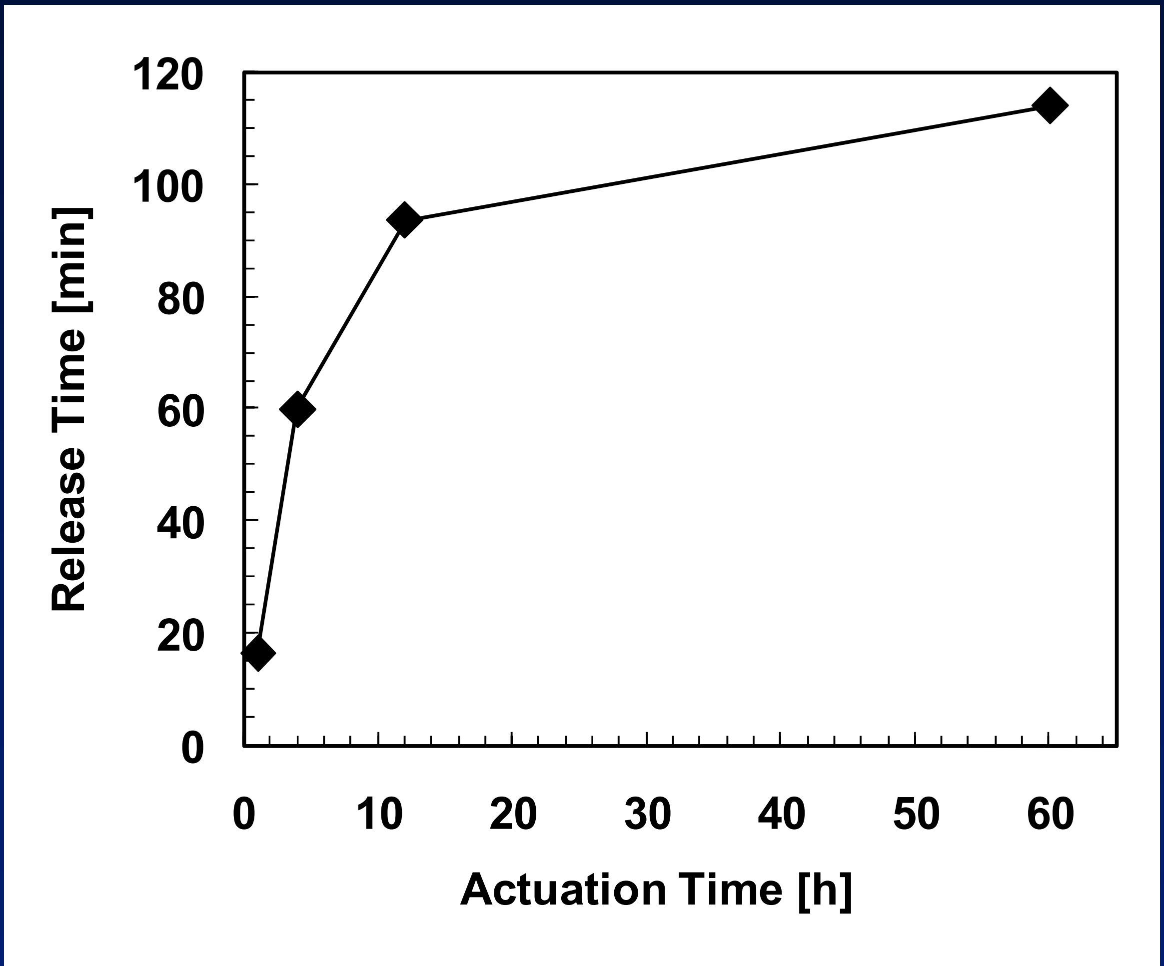



**$V_{ACT}$ = 40 V, $T_{ACT}$ = 4 hours**
**$P_{RF}$ = 0 dBm, $f_{RF}$ = 6GHz**

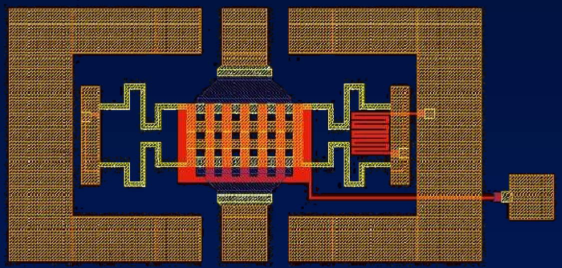
**After 4 hours of DC actuation, meander-based devices take up to 1 hour (and beyond) to de-actuate!!**

# Long Term Actuation

## DC Stress




**Meander-based anchors**



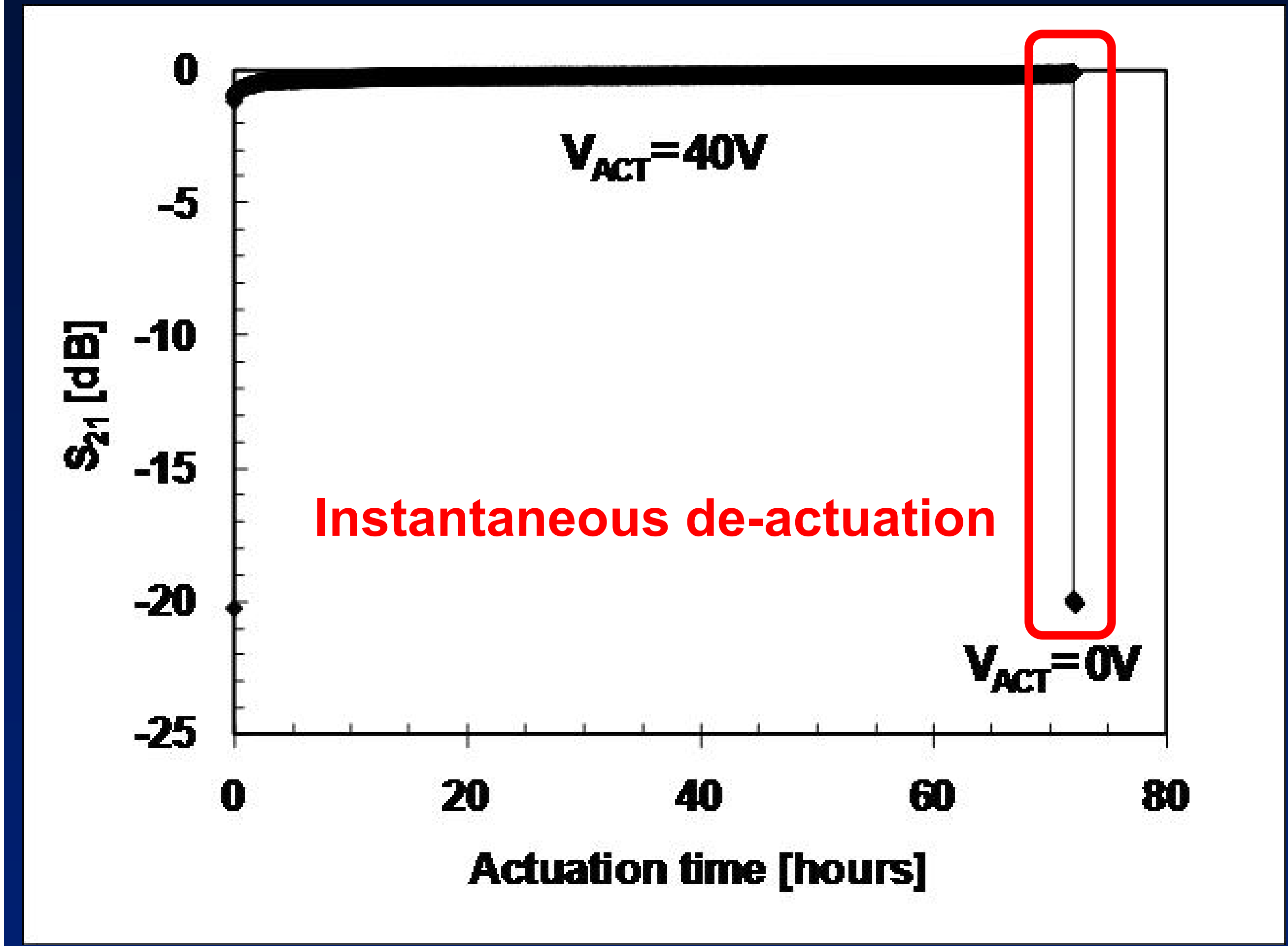
$V_{ACT}$ = 40 V
$P_{RF}$ = 0 dBm
$f_{RF}$ = 6GHz

Similar behaviour also with low RF power applied (-10dBm, -30dBm)

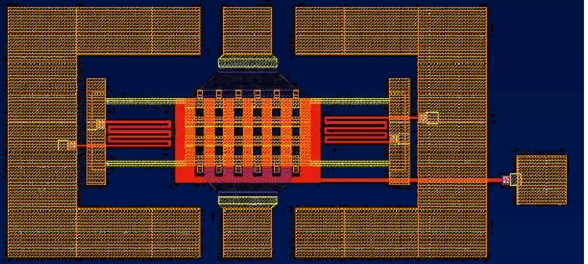
**Good RF performances, but these devices are completely useless as redundancy switches!**

# Long Term Actuation

## DC Stress




**Straight beams anchorage**



$V_{ACT}$ = 40 V
$P_{RF}$ = 0 dBm
$f_{RF}$ = 6GHz

**After 72 hours of continuous actuation, the switch suddenly releases itself**

**Very promising for redundancy applications!**

# Conclusions

- **RF-MEMS switches: very good performances, but a "true" complete characterization is needed for spatial applications / future commercialization**
- **The sensitivity to 1Mrad (500rad/s) X-rays TID could be extremely critical for RF-MEMS switches**
- **TID ←→ Cycling correlation??**
- **De-actuation time could be a critical factor, especially for redundancy switch applications**
- **Straight beams anchors offer better behaviour than meander-based anchorage (improved TID robustness, cycling, and de-actuation time)**