Micro- & Nano-technologies pour applications hyperfréquence à Thales Research &Technology

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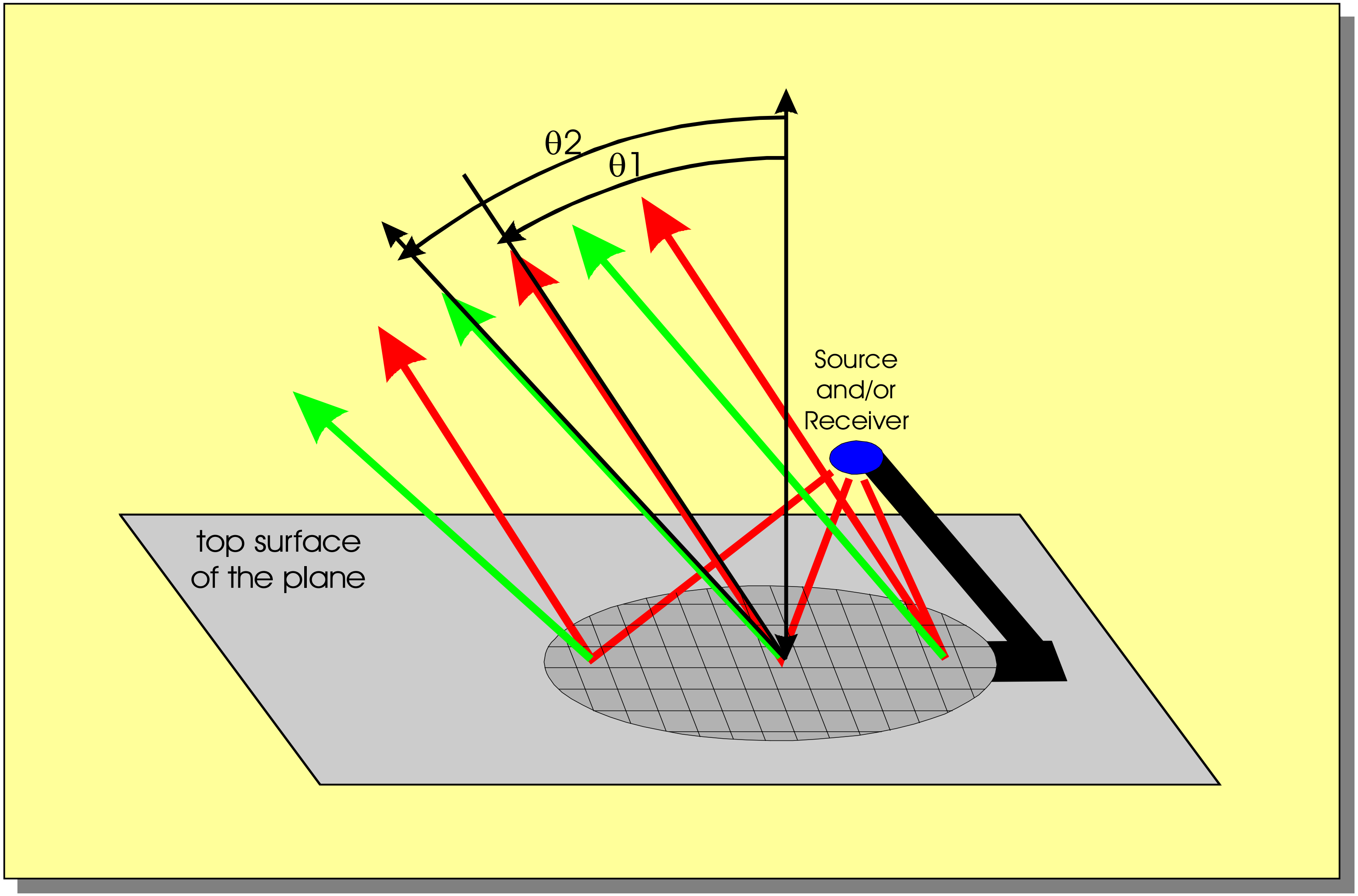
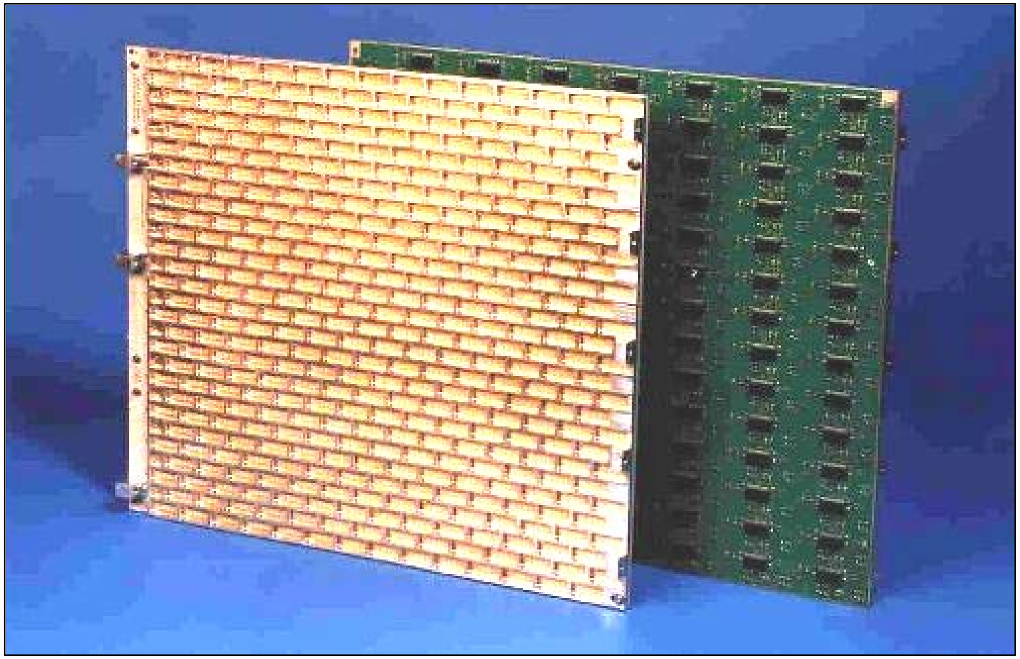
- Application hyperfréquence à THALES:
  Antenne à réseau réflecteur

- Micro-technologies: RF MEMS à THALES Research & Technology
  - Micro-commutateur capacitif
  - ZrO_2-MEMS switch
  - ZrO_2-MEMS SPDT
  - Power Handling and Life-time of PZT RF MEMS

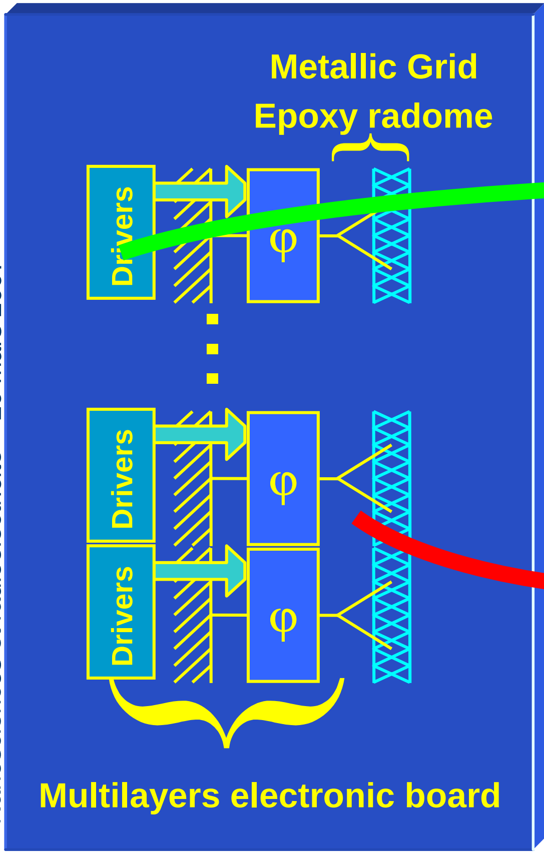
- Nano-technologies for RF applications
  - Nano-commutateurs
  - Nano-antennes

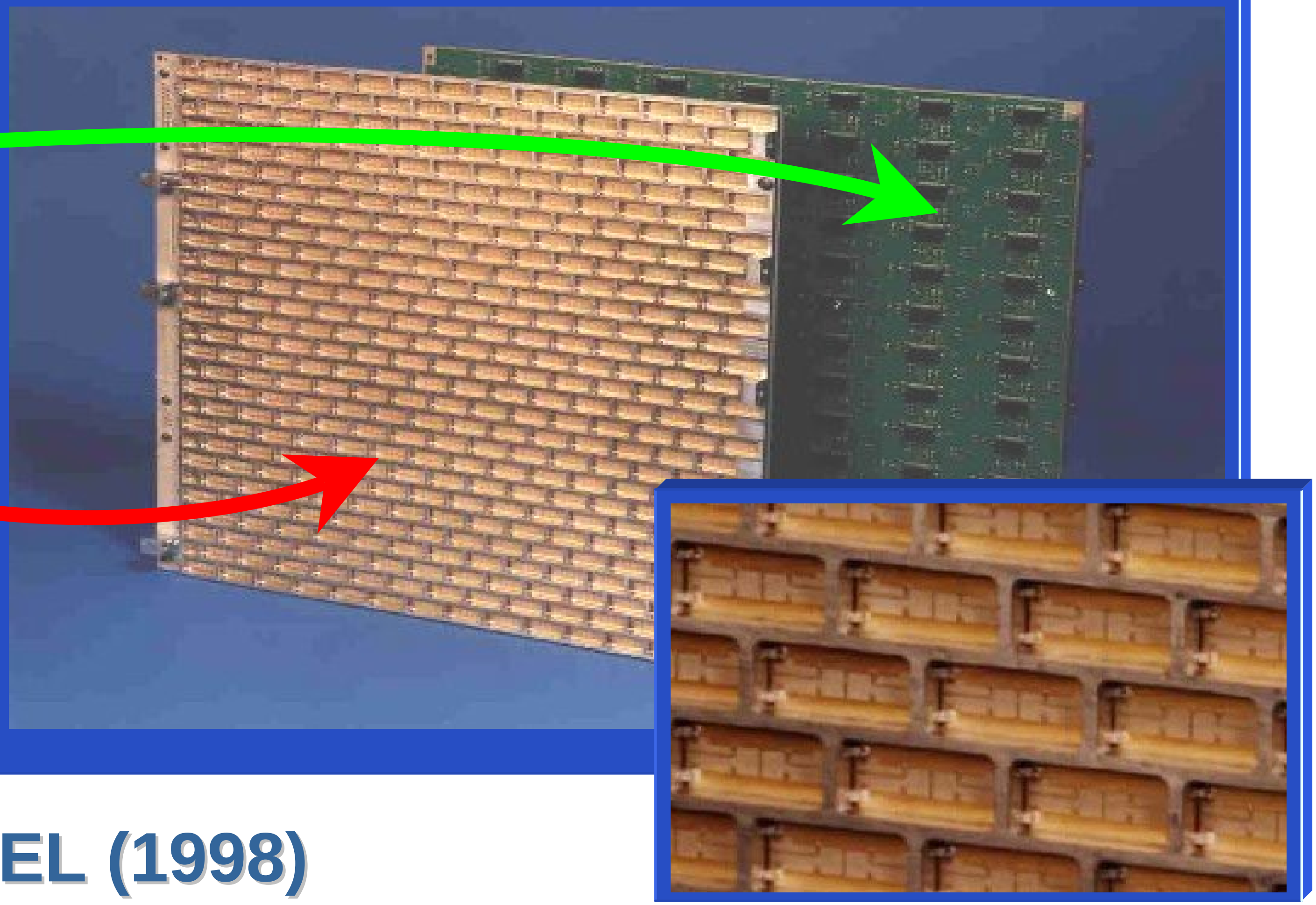

θ2
θ1
Source
and/or
Receiver
top surface
of the plane

THALES Reflect Array Antenna



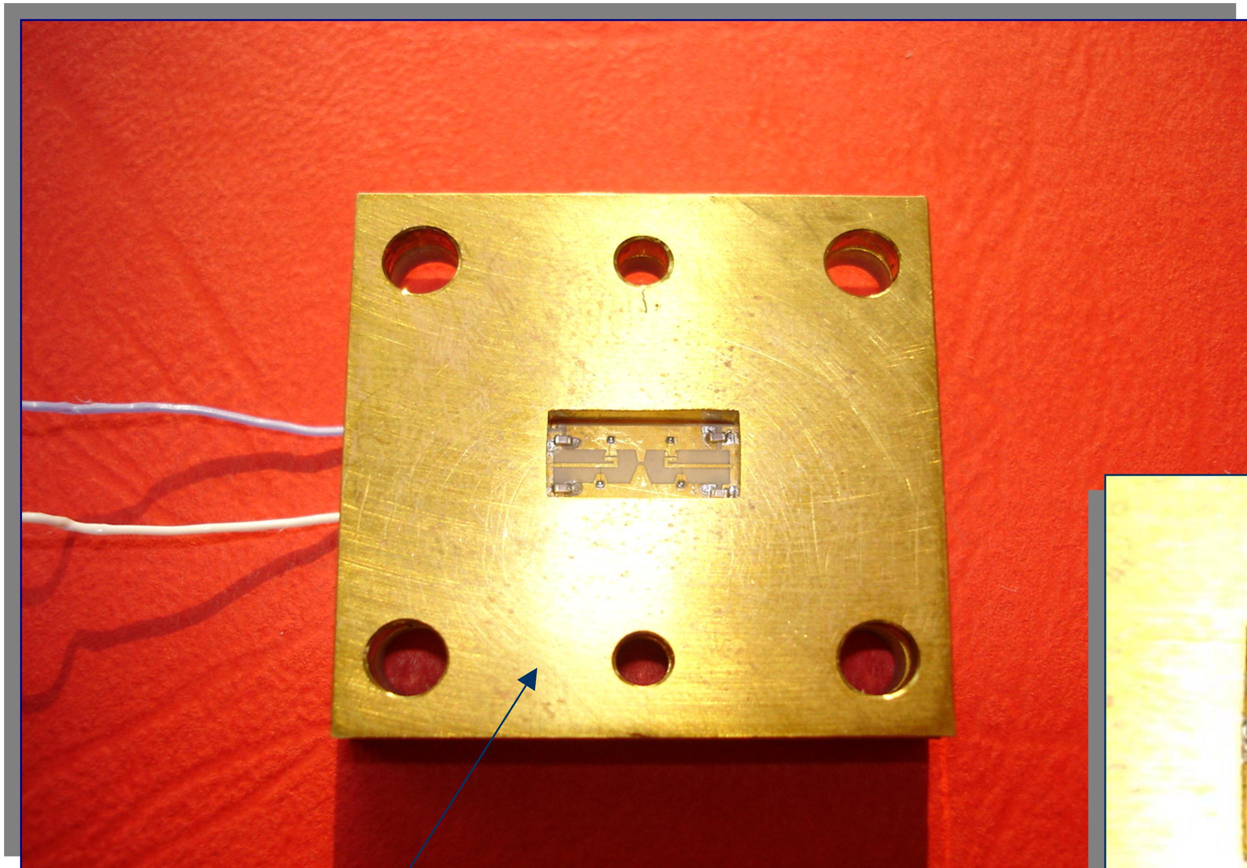
THALES Reflect Array Antenna

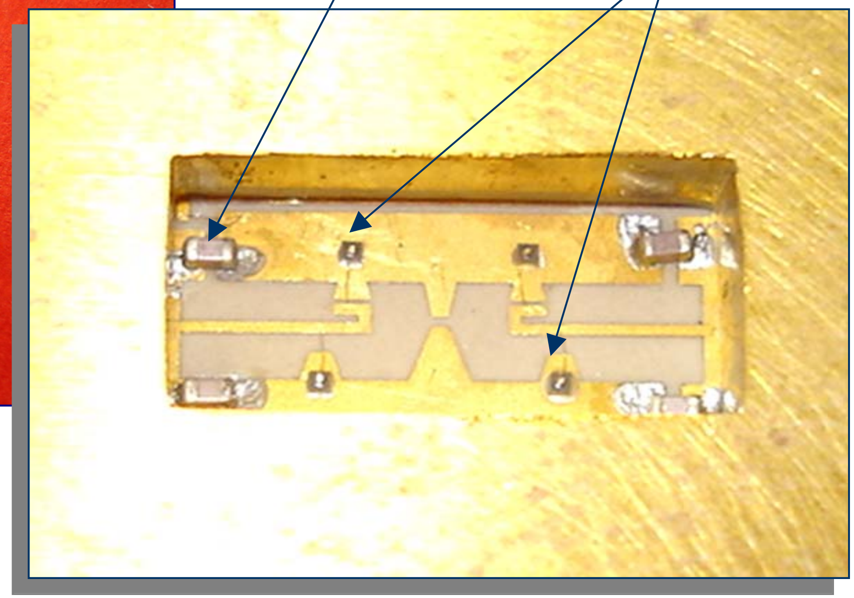




MIRABEL (1998)

Elementary phase shifter

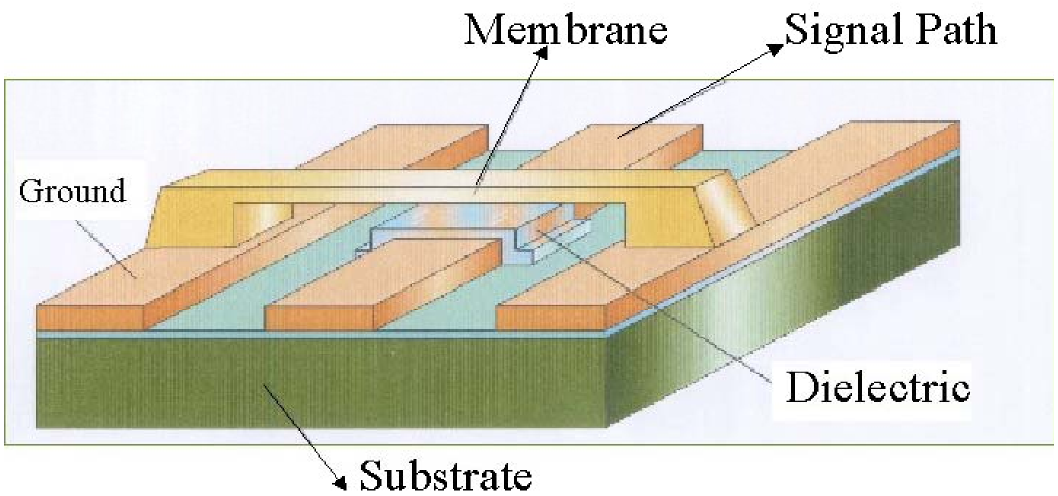


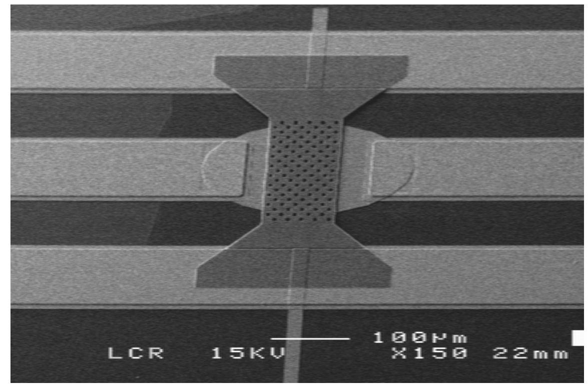


Wave-guide flange

RF-DC decoupling capacitances

PIN-diodes





SEM picture

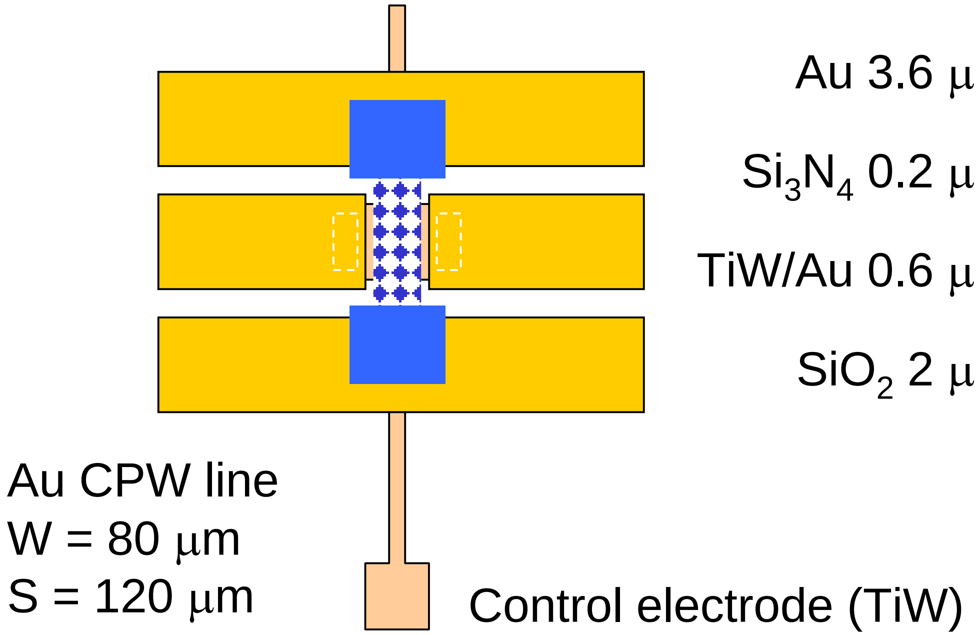
Si micro-machined, metal membrane

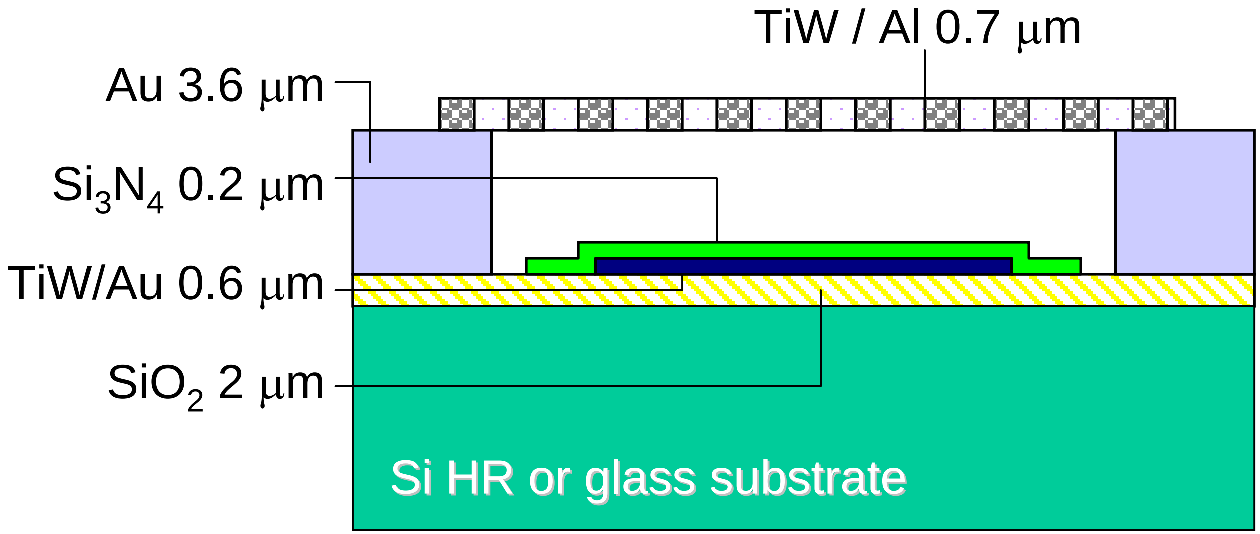
Electrostatic actuation

Capacitive switch using high K dielectric material for high Con/Coff ratio (~150)

Series or shunt switch designs

MEMS technology used : ‘ Surface micro-machining ’

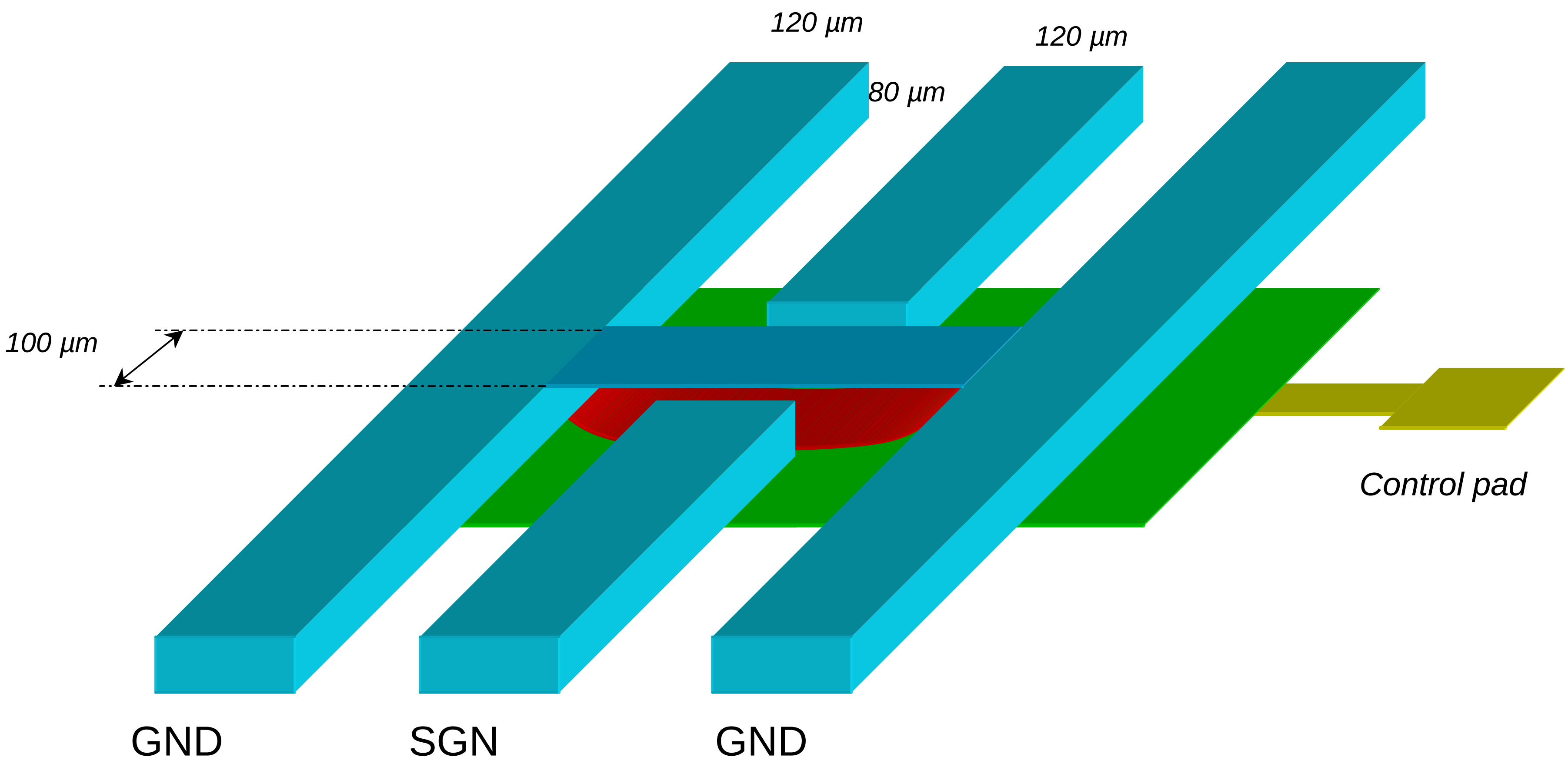




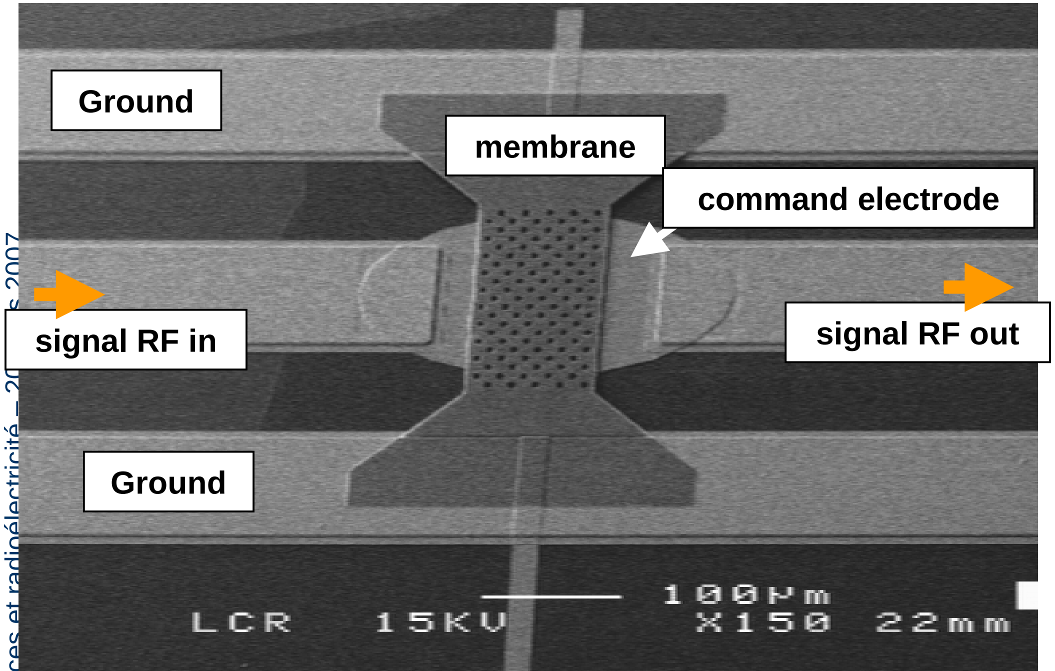
Schematic of cross section (Shunt Switch)

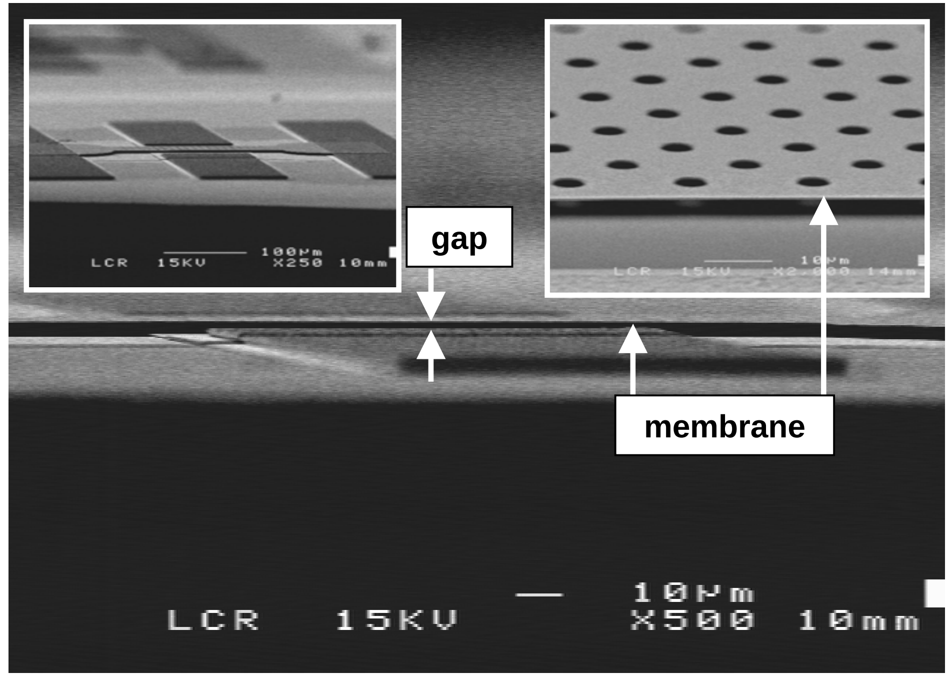
Holes are etched into the membrane in order to facilitate the membrane ‘ delivery ’

MEMS for Power Switching



SEM pictures of fabricated switches

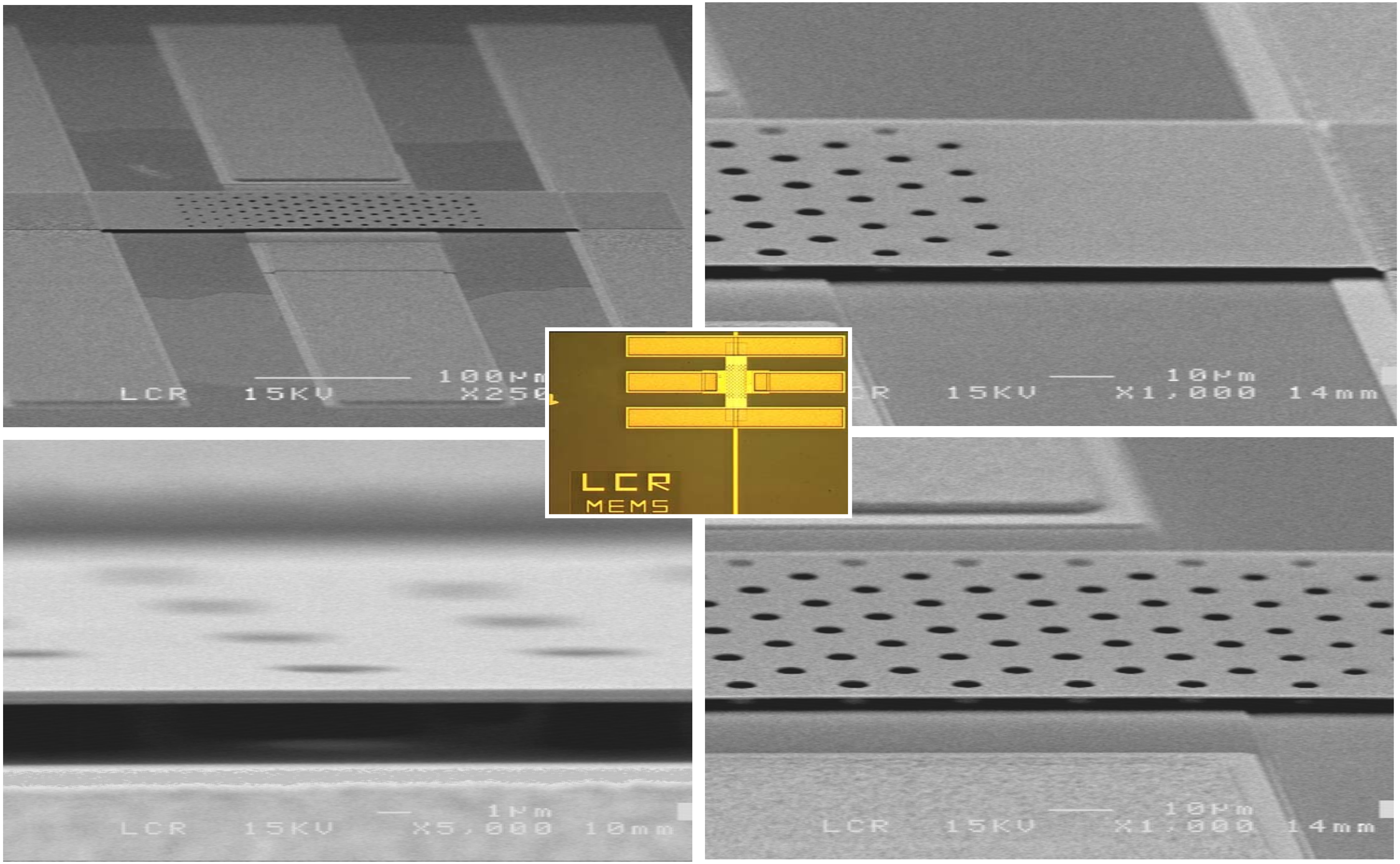




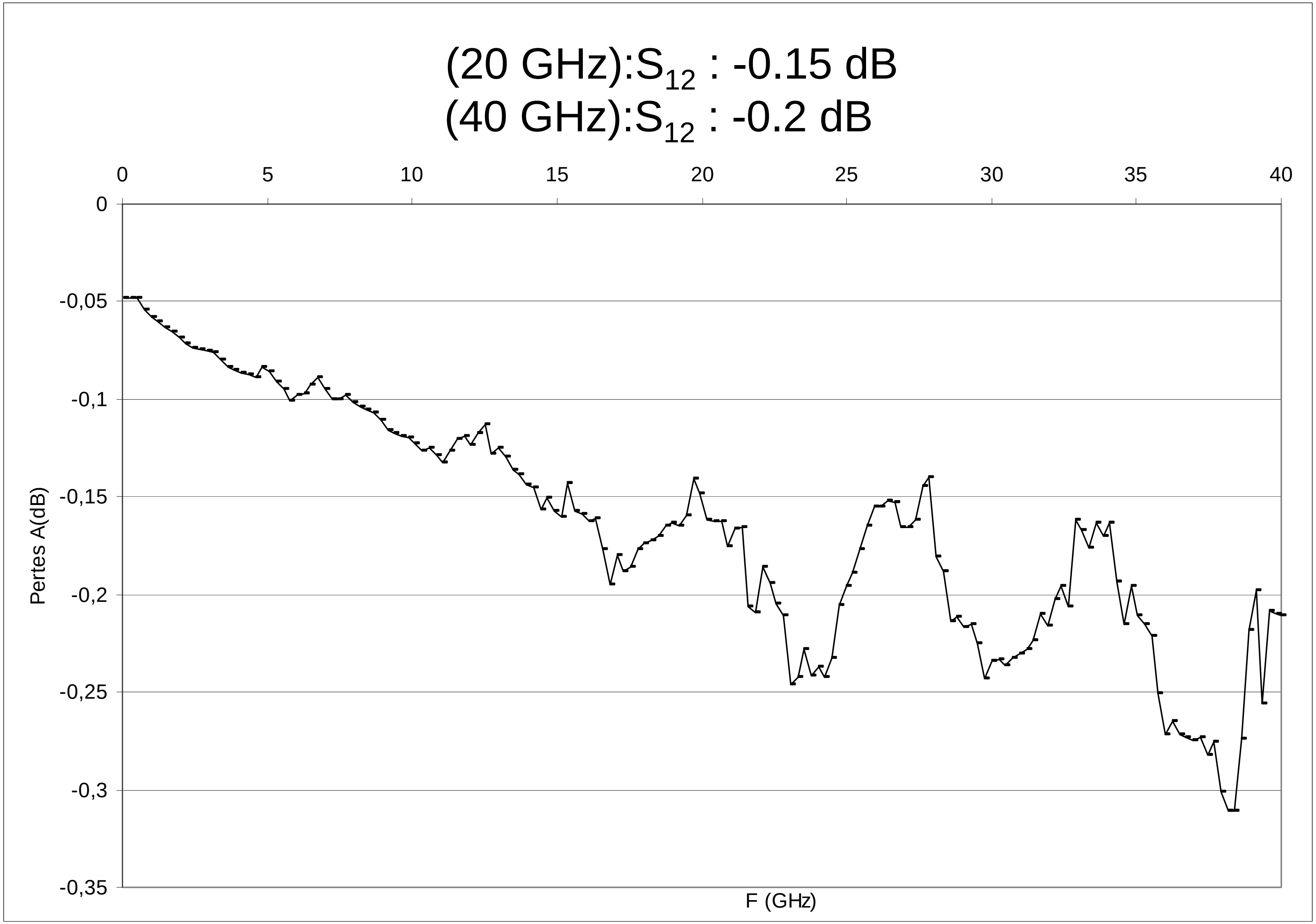
Gap : g = 3 μm
Membrane width : 100 μm

Dielectric thickness : g_0 = 0.2 μm

SEM pictures of fabricated switches

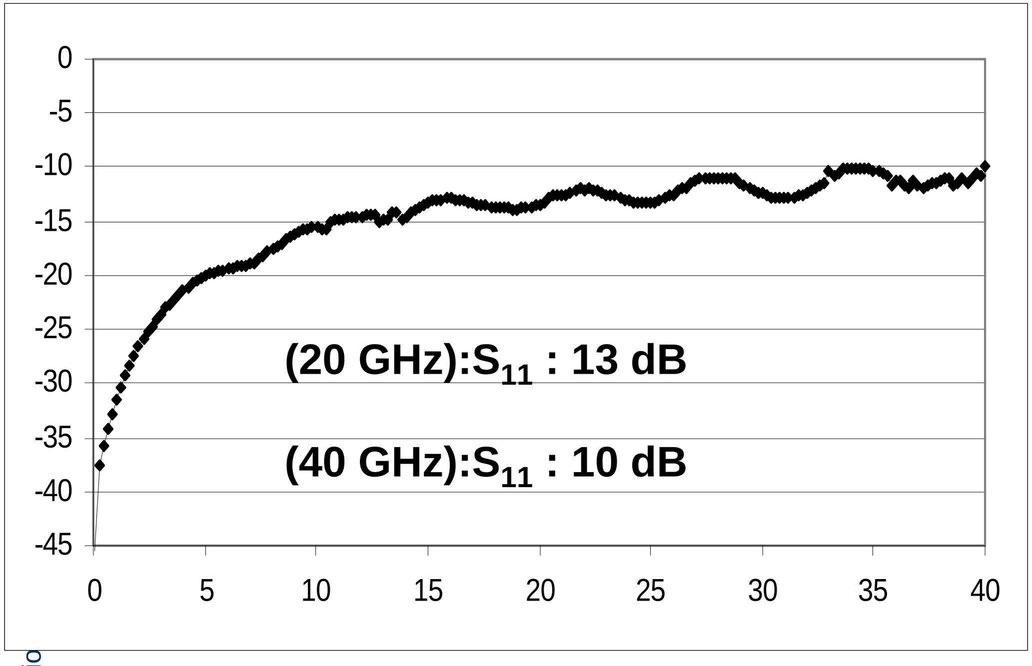


Insertion losses (Membrane in up position)

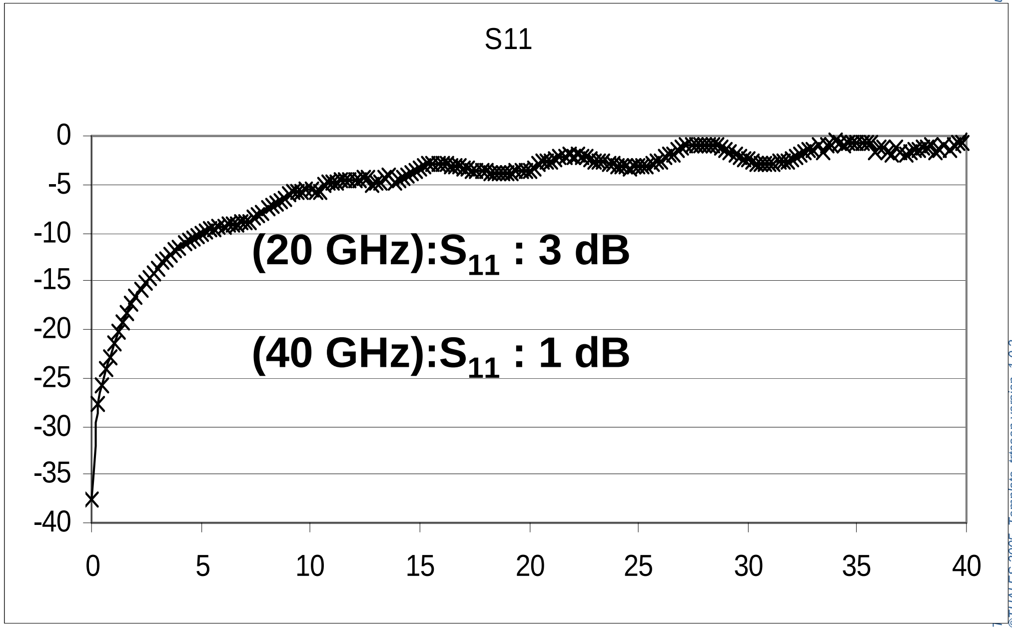


25 dB à 40 GHz

S_{11} Membrane in up position (The membrane is unactuated)



S_{11} Membrane in down position (The membrane is actuated)

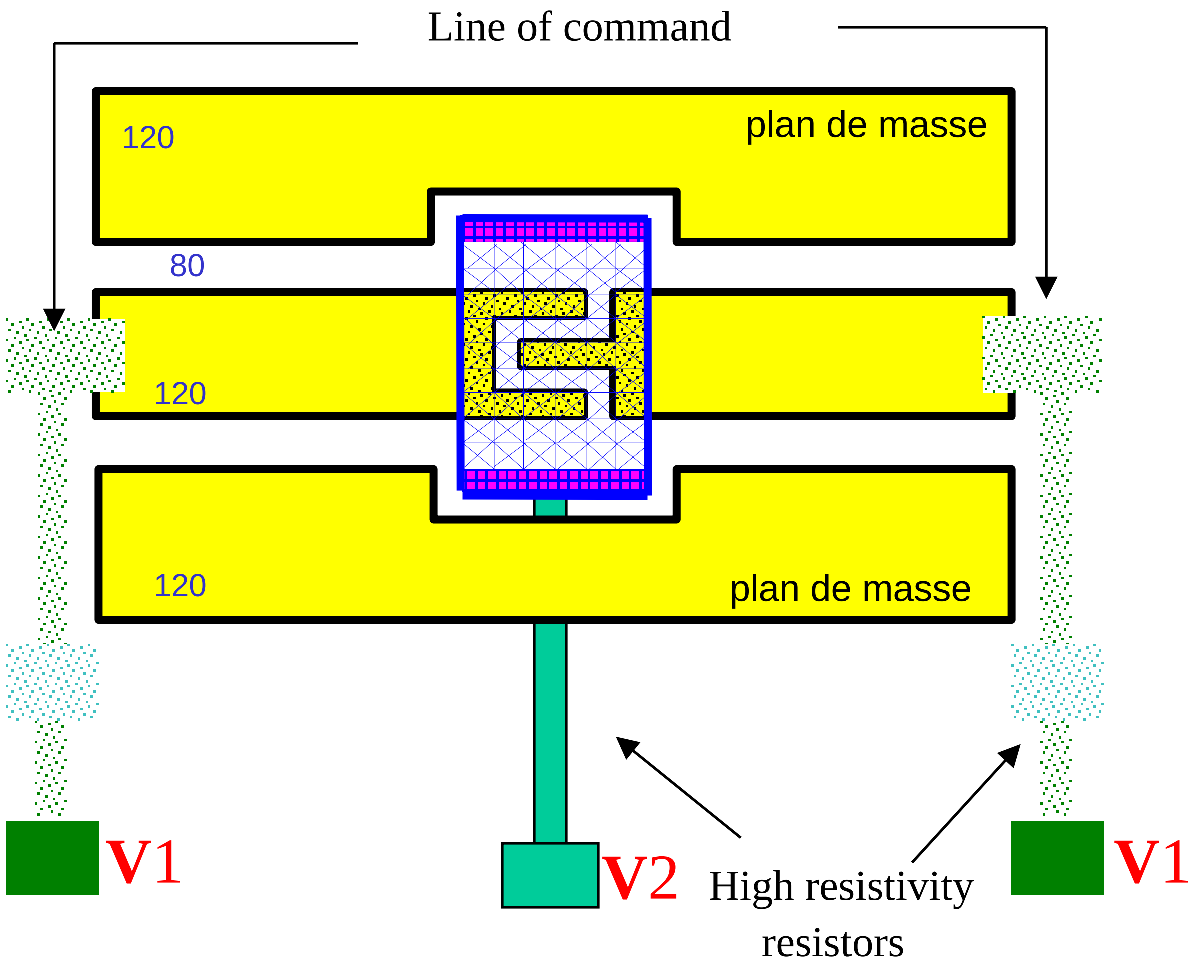


0-40 GHz measurements

Results under 0dBm

Key characteristics of TRT MEMS RF Switch

Isolation	32 dB (40 GHz) – 18 dB (20 GHz)
Insertion losses	0.2 dB (40 GHz) – 0.1 dB (20 GHz)
Driving voltage	32-38 V
$\mathbf{C_{on}}$	2-3 pF
$\mathbf{C_{off}}$	30-40 fF
$\mathbf{R_{on}}$	< 2 Ohms
Switching time	< 5 µs
K	81 N/m
Mechanical resonance	214 kHz



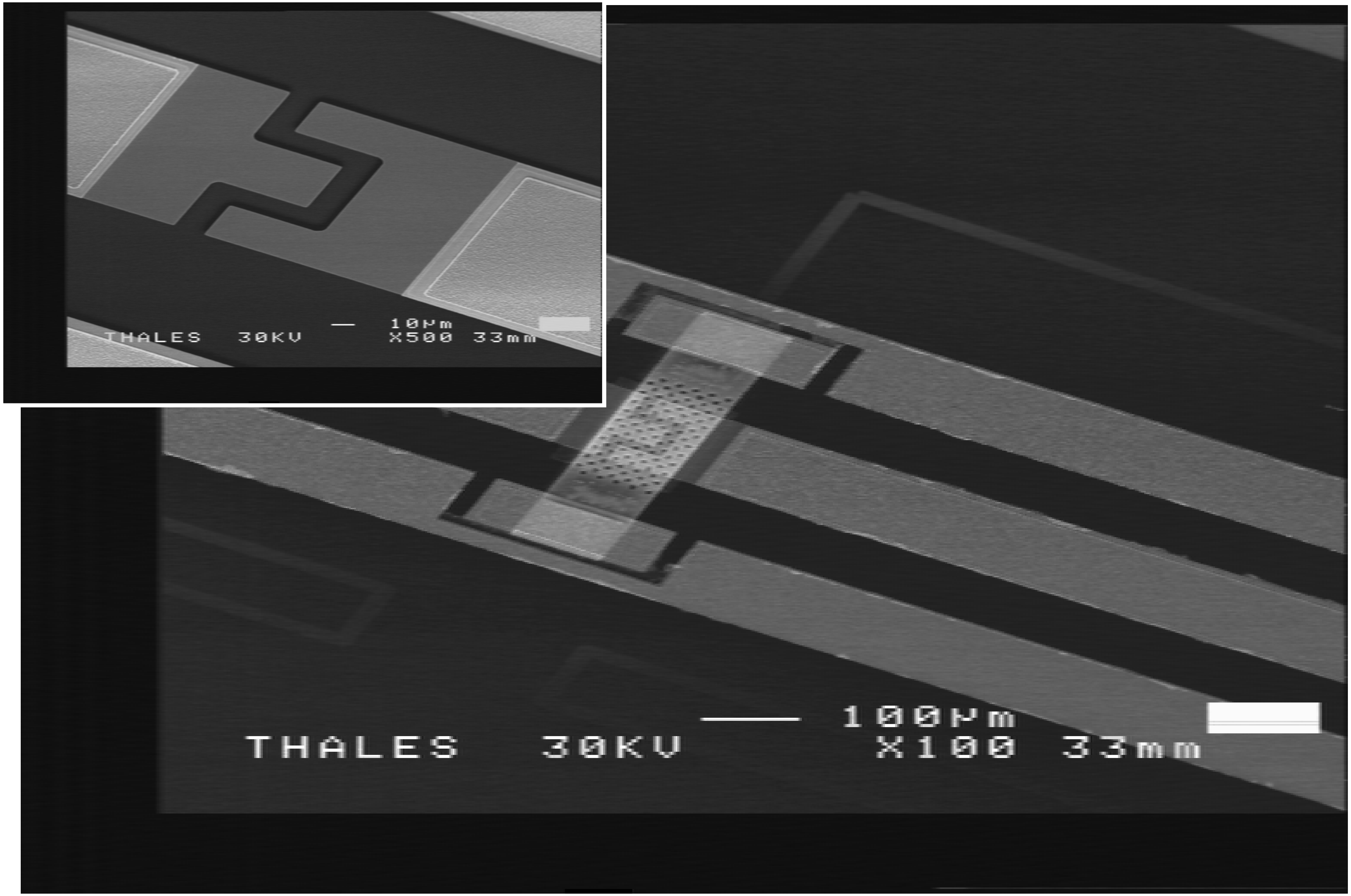
Conception

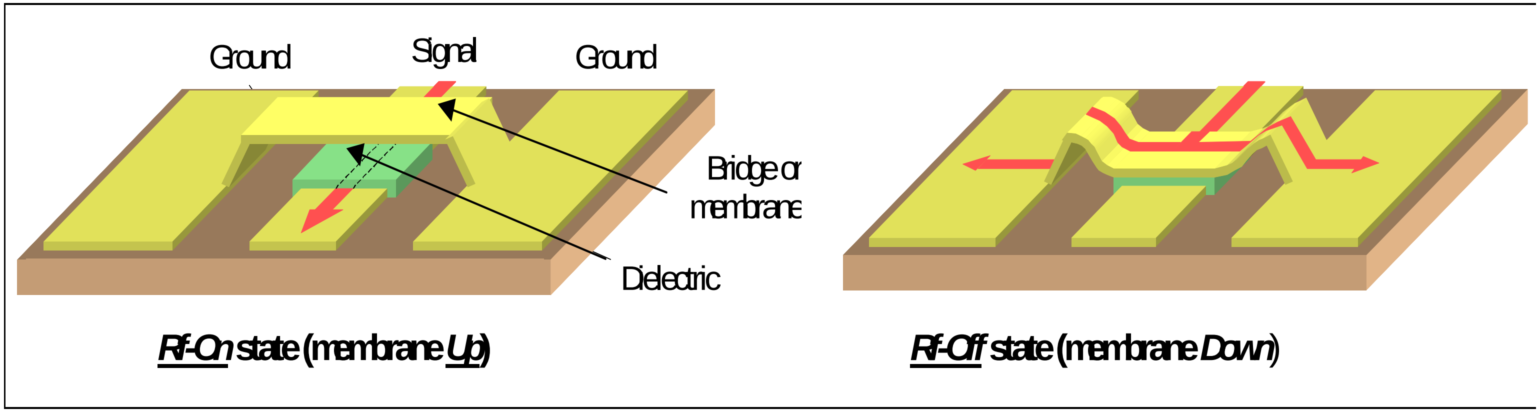
ON state : Membrane in down position

OFF state : Membrane in up position

$$\frac{C_{on}}{C_{off}} = 109$$

SEM pictures of fabricated switches



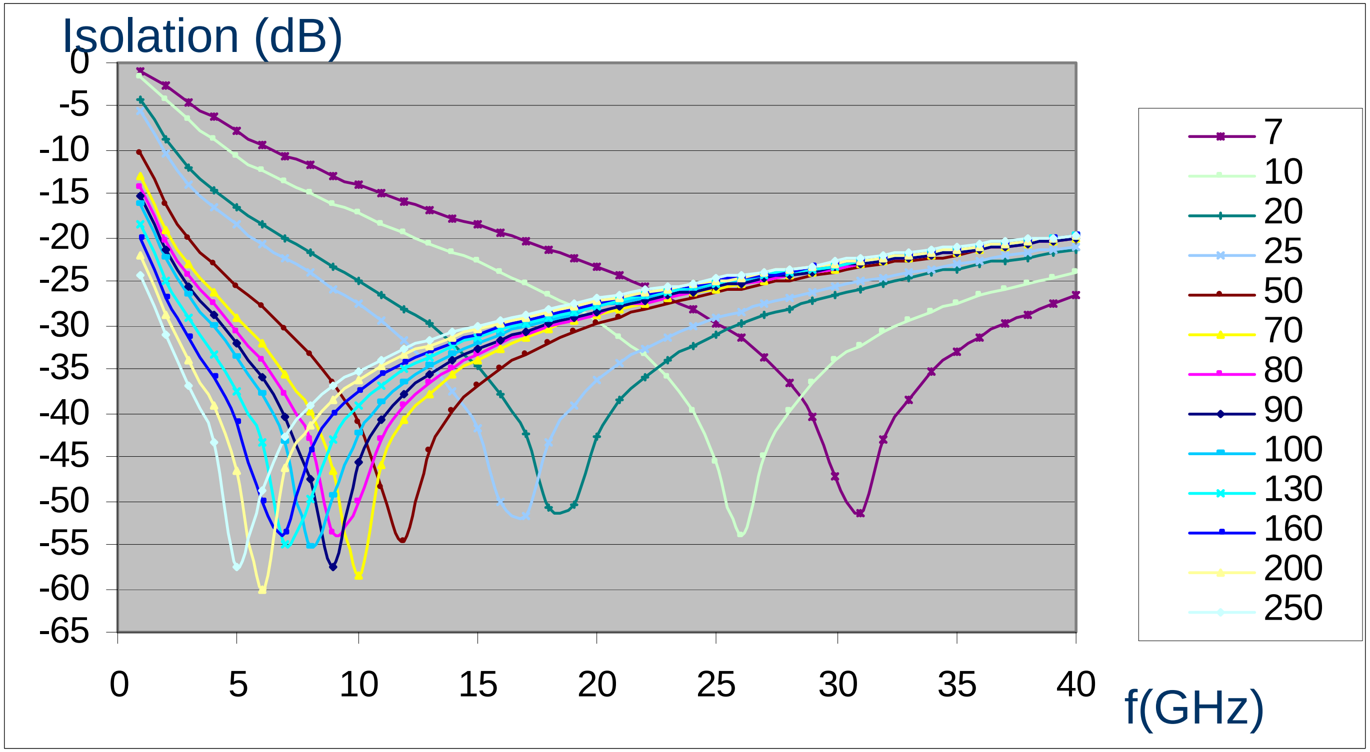


Increasing switching ratio ($\frac{C_{on}}{C_{off}}$)

↓

Increasing C_{down} for a given C_{up}

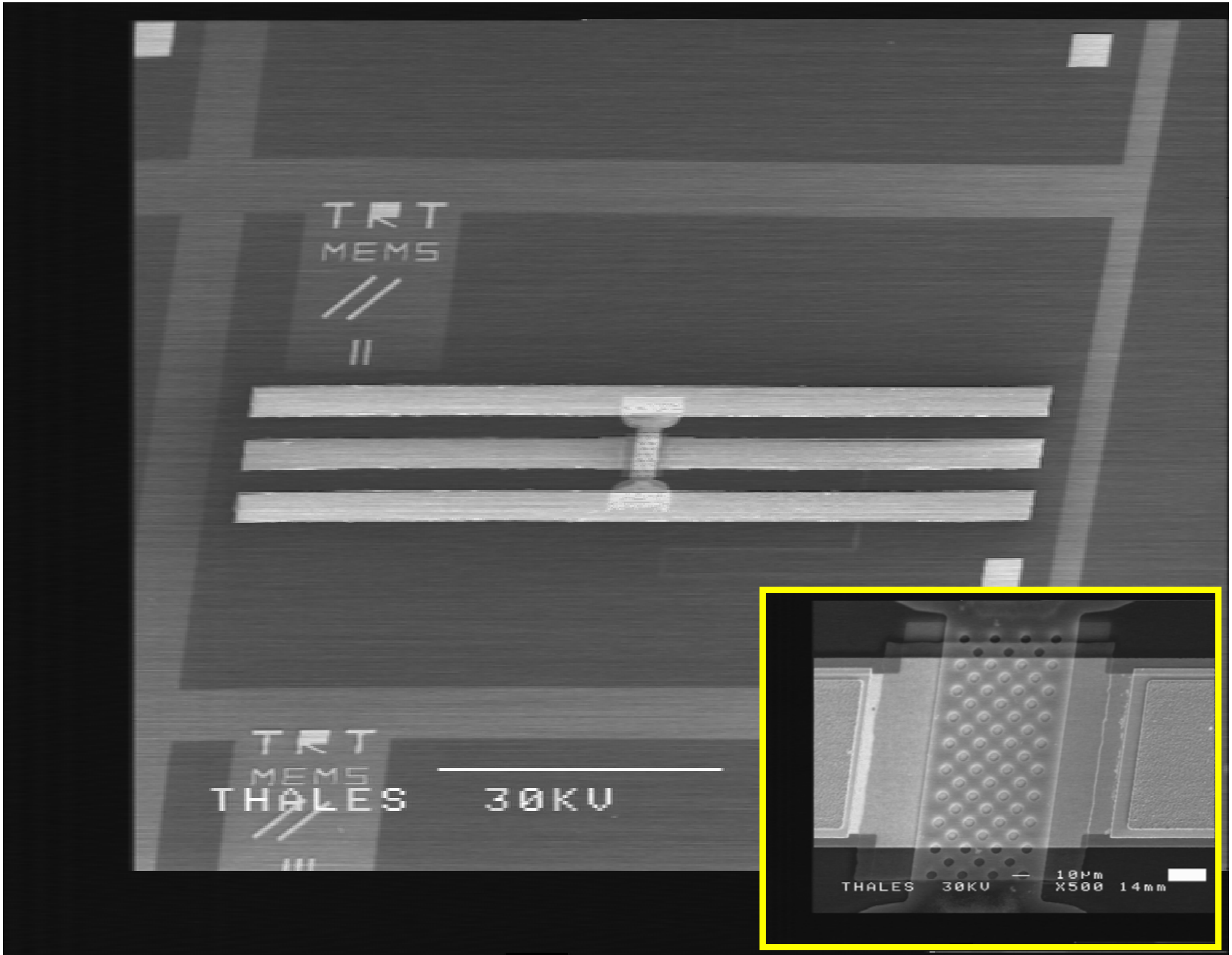
Simulations HFSS



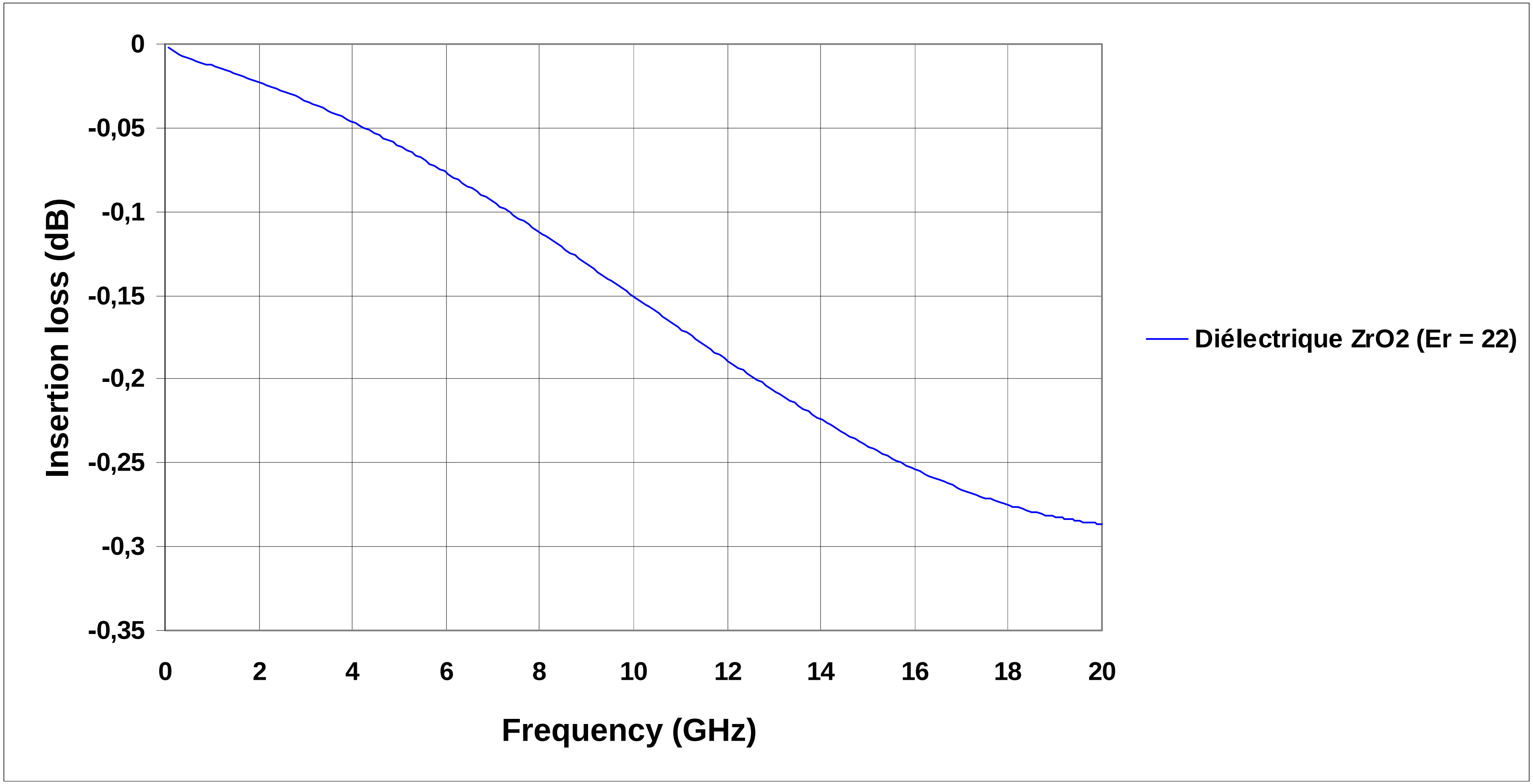
Much higher isolation in DOWN state than previous design

Replace Si_3N_4 with high dielectric constant ZrO_2 film

SEM pictures of fabricated ZrO_2 capacitive switch

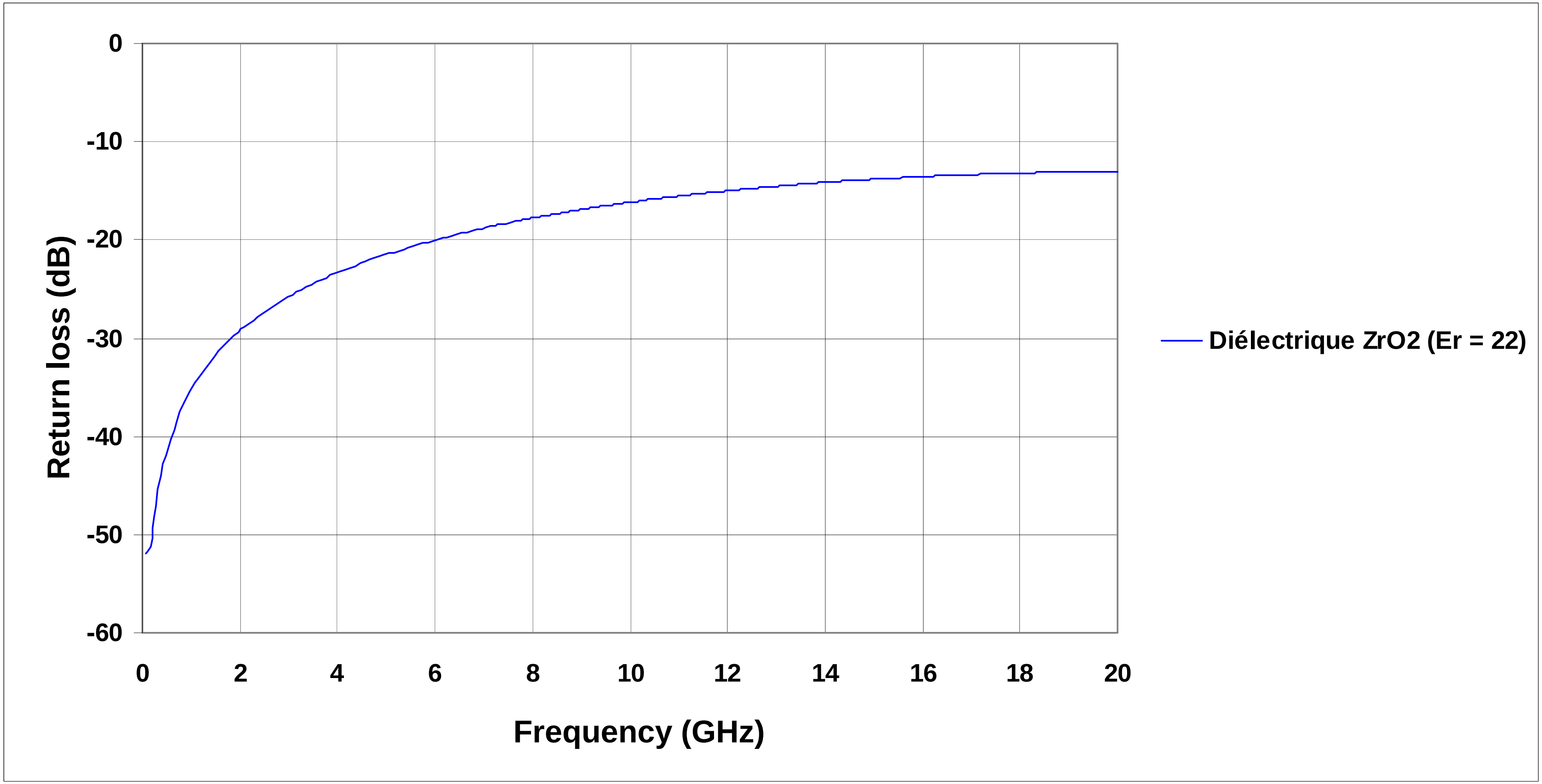


Shunt ZrO_2 switch characteristics in the UP state



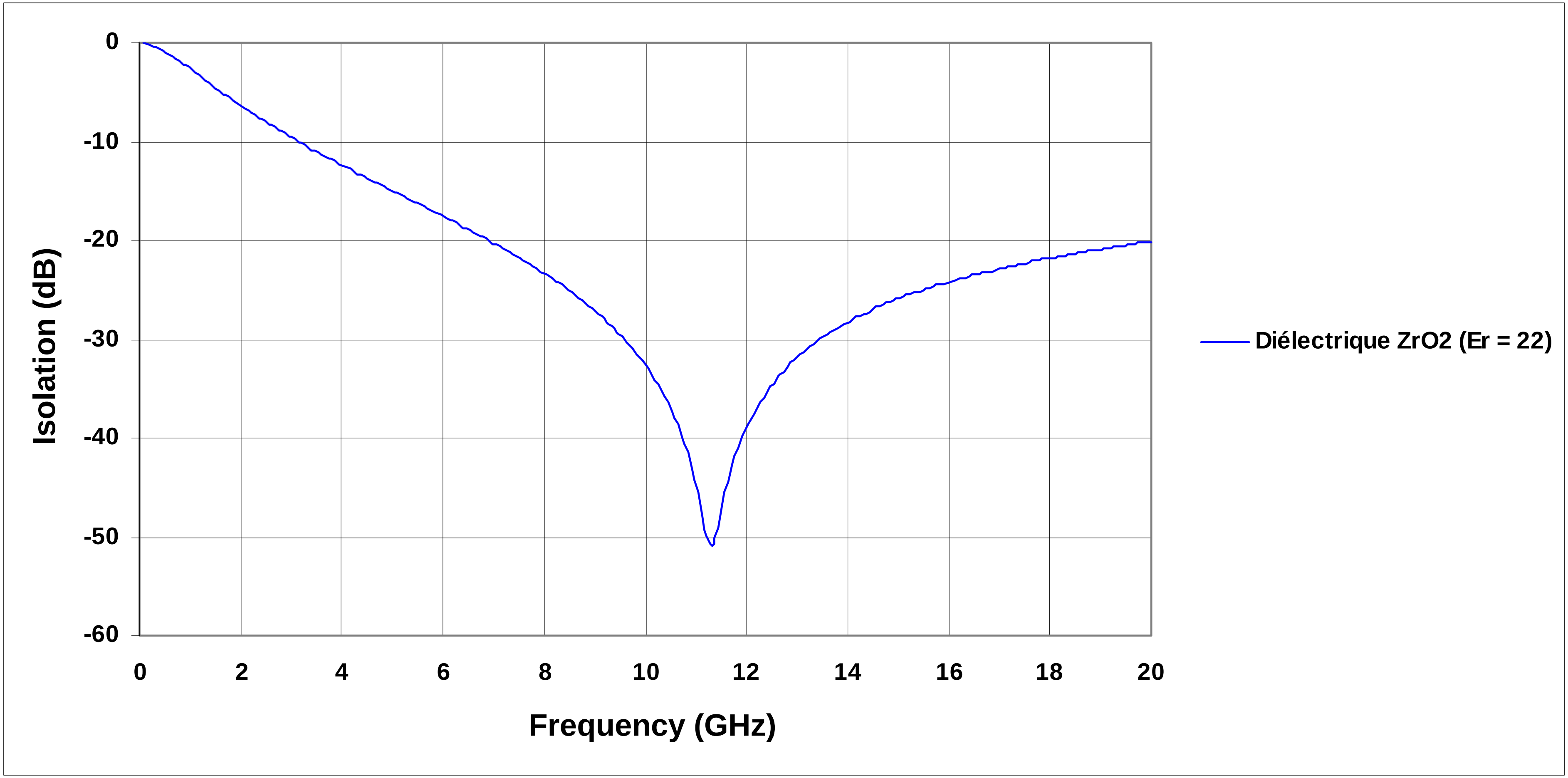
THALES

Shunt ZrO_2 switch characteristics in the UP state



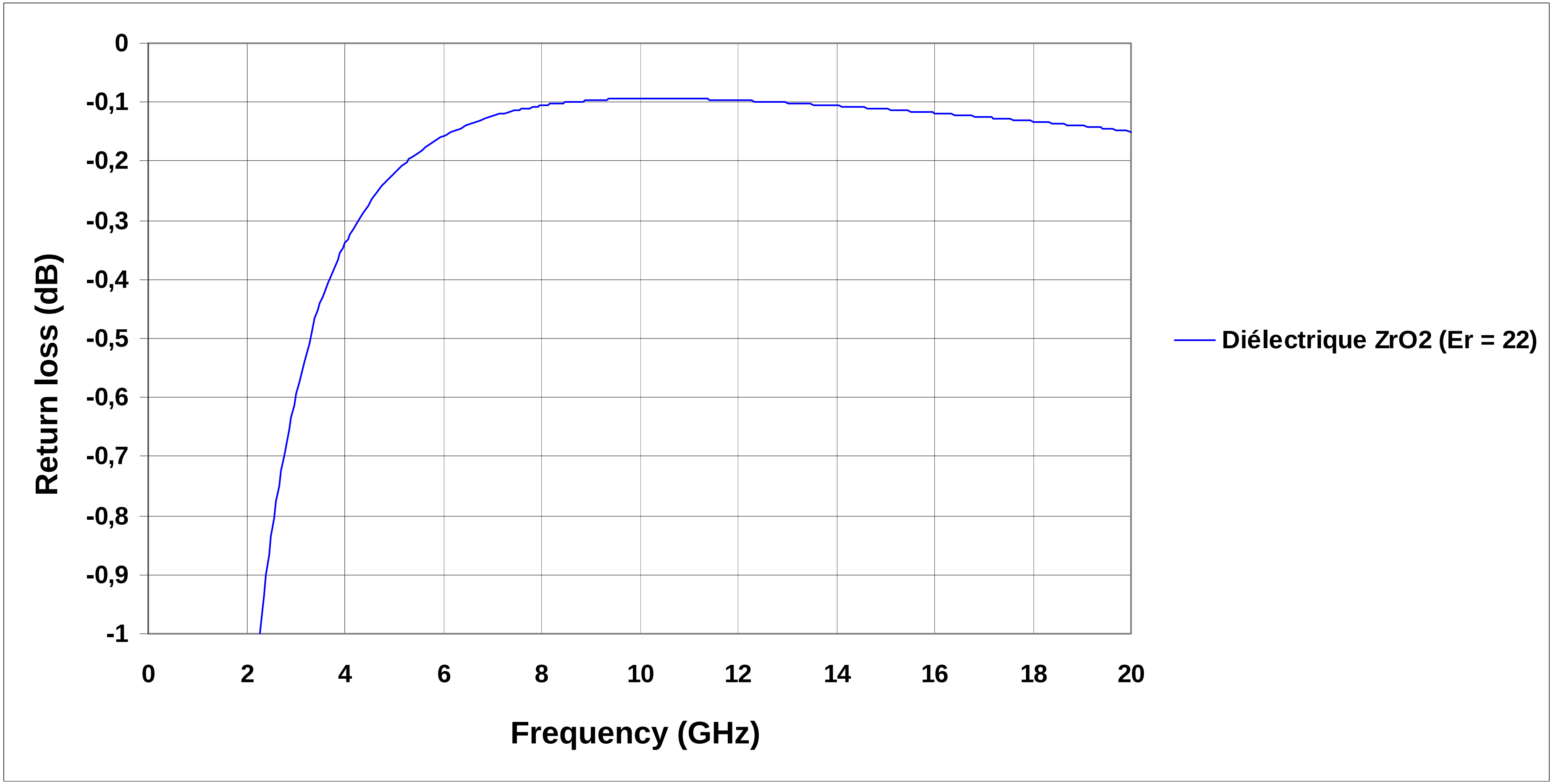
Switch measured characteristics: Isolation

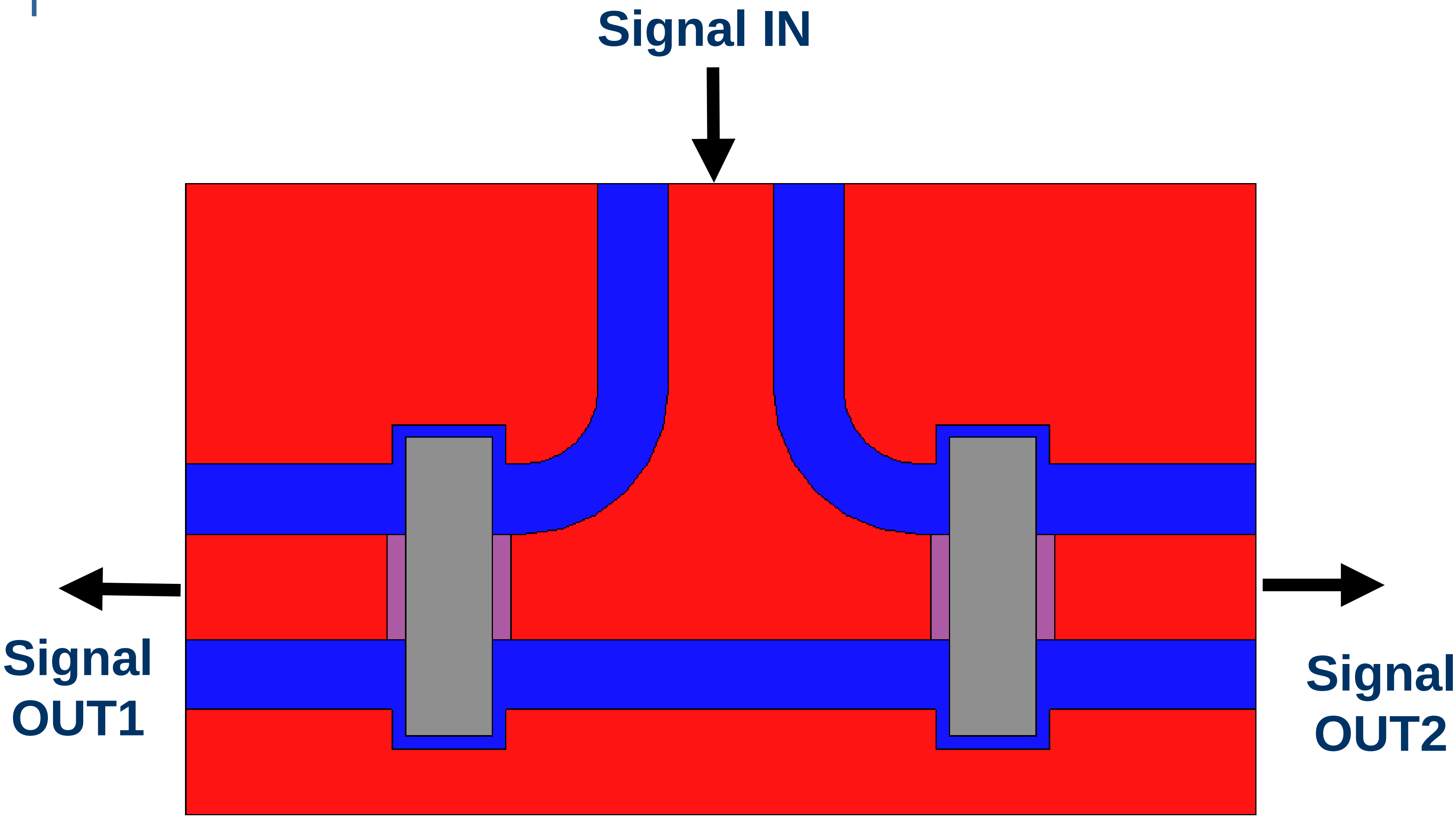
Shunt ZrO_2 switch characteristics in the DOWN state



Switch measured characteristics: Return loss

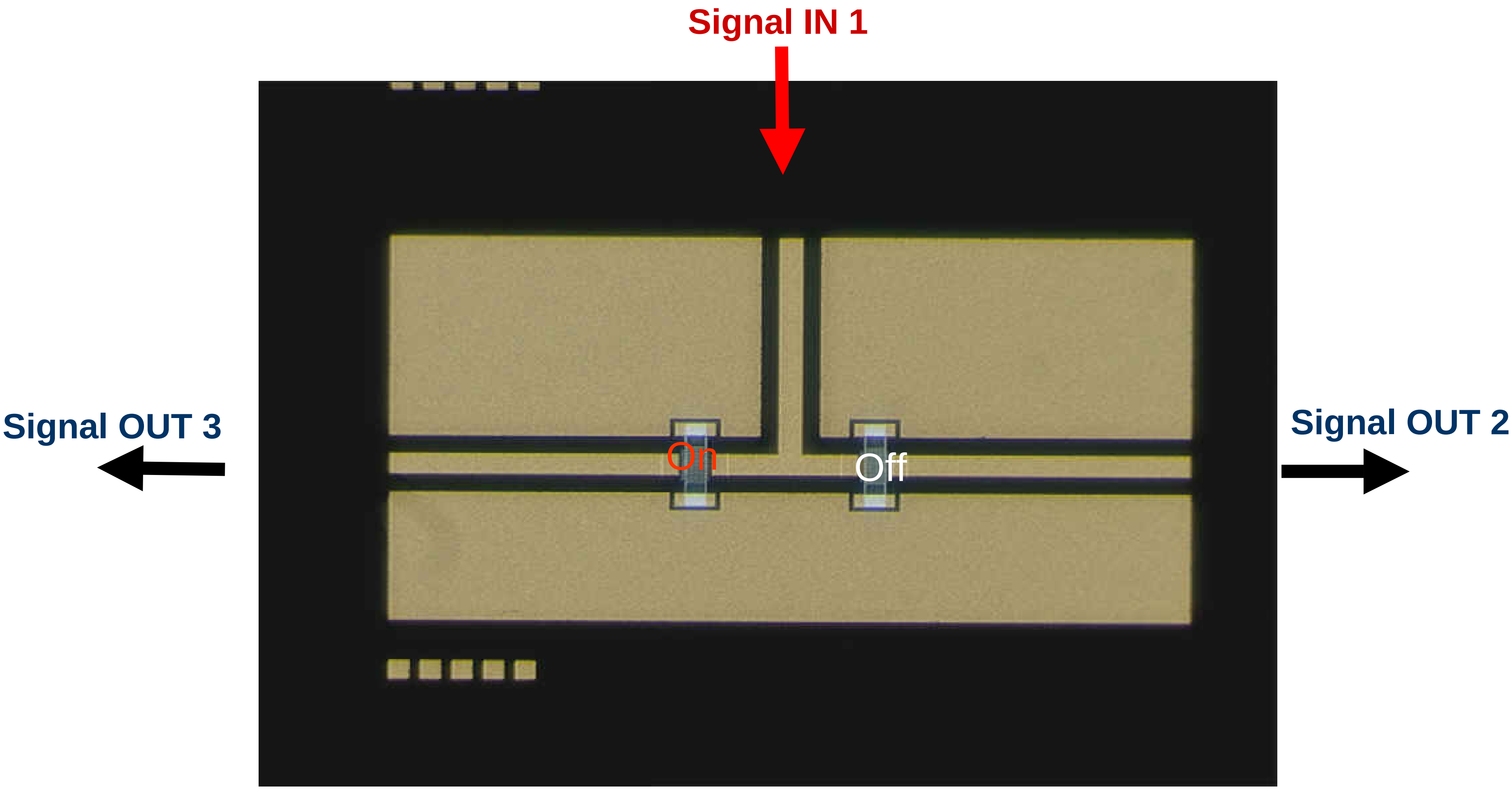
Shunt ZrO_2 switch characteristics in the DOWN state





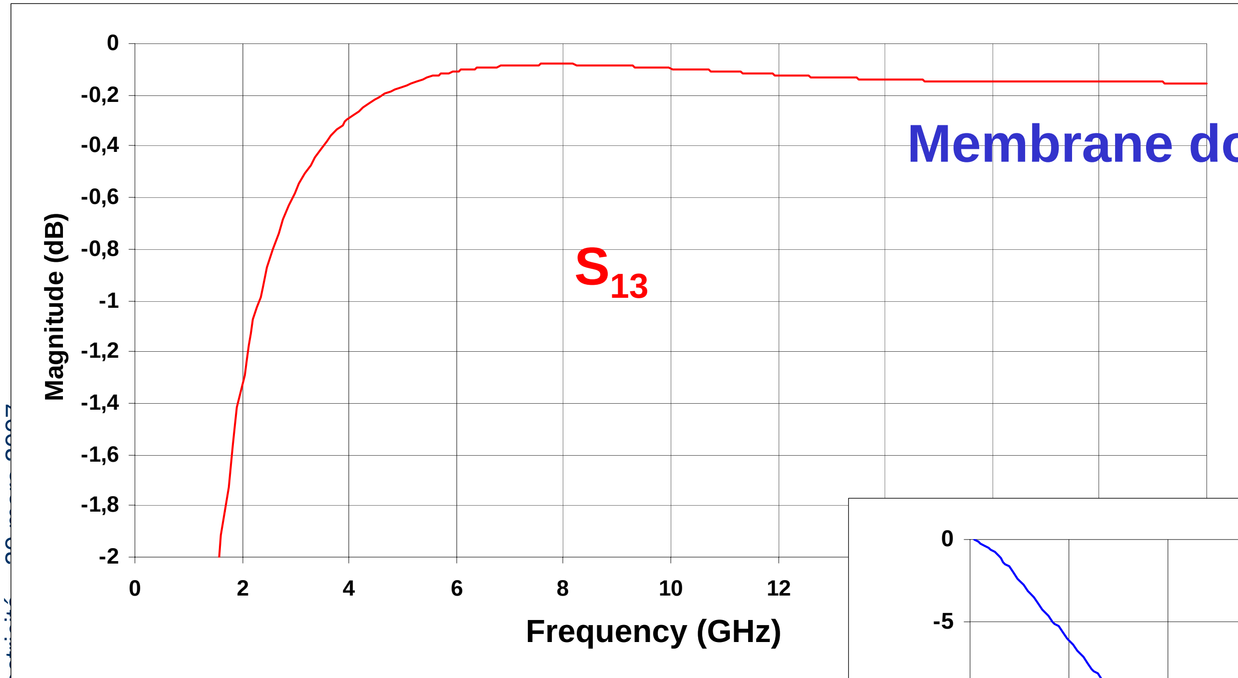
Coplanar Waveguide

MEMS SPDT Switch (ZrO2)

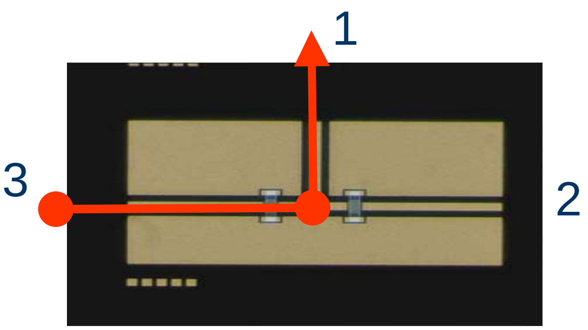


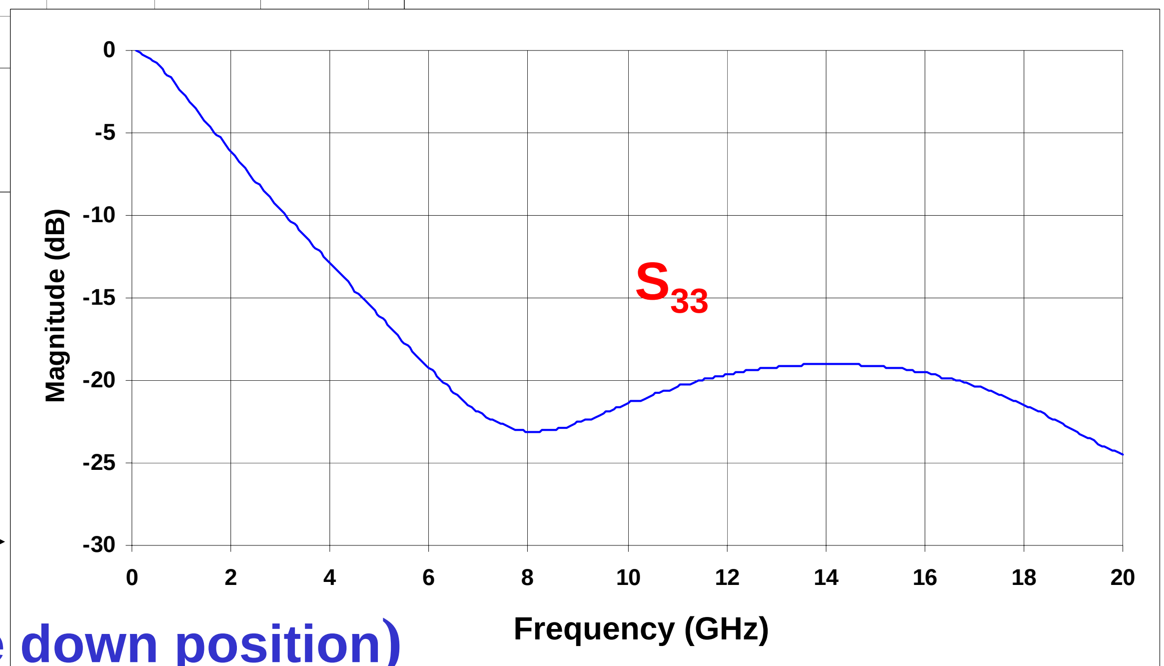
THALES design,
Serial-serial PZT-PZT

MEMS SPDT Switch (ZrO_2) without packaging (X band)



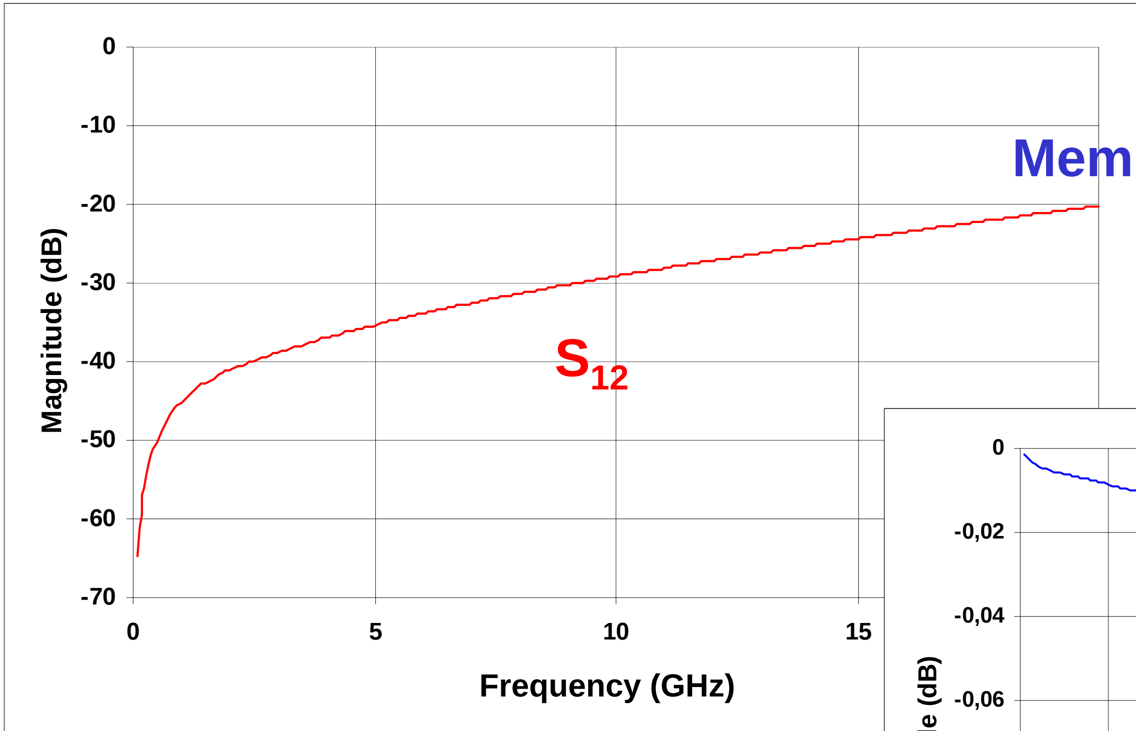
Membrane down position (S_{13} in the on state)



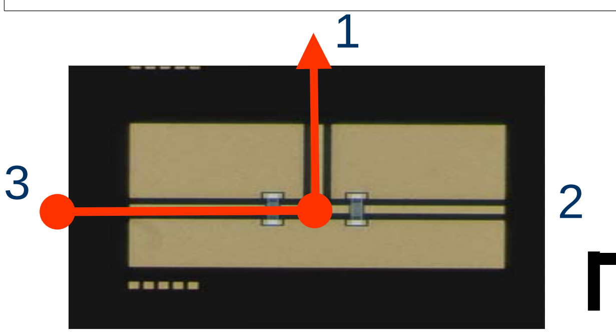


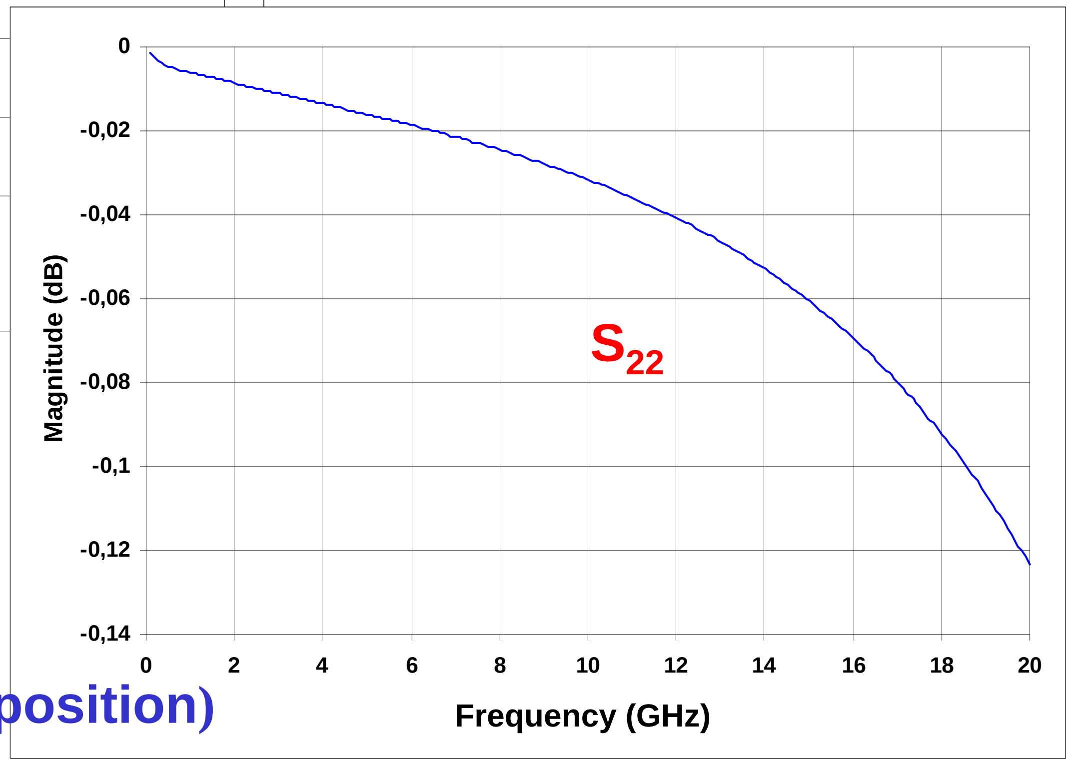
S_{33} in the on state (Membrane down position)

MEMS SPDT Switch (ZrO2) without packaging (X band)



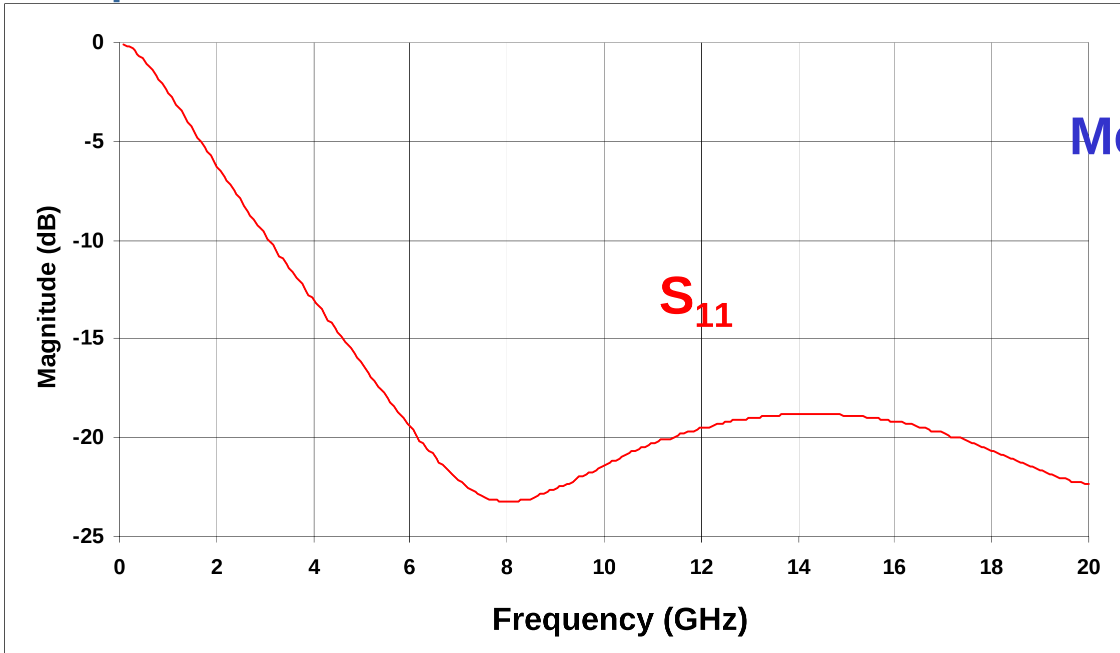
Membrane up position (in the off state)



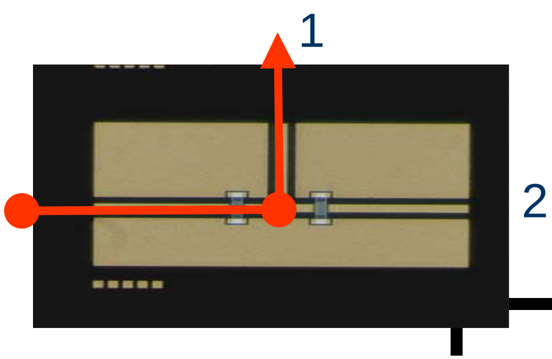


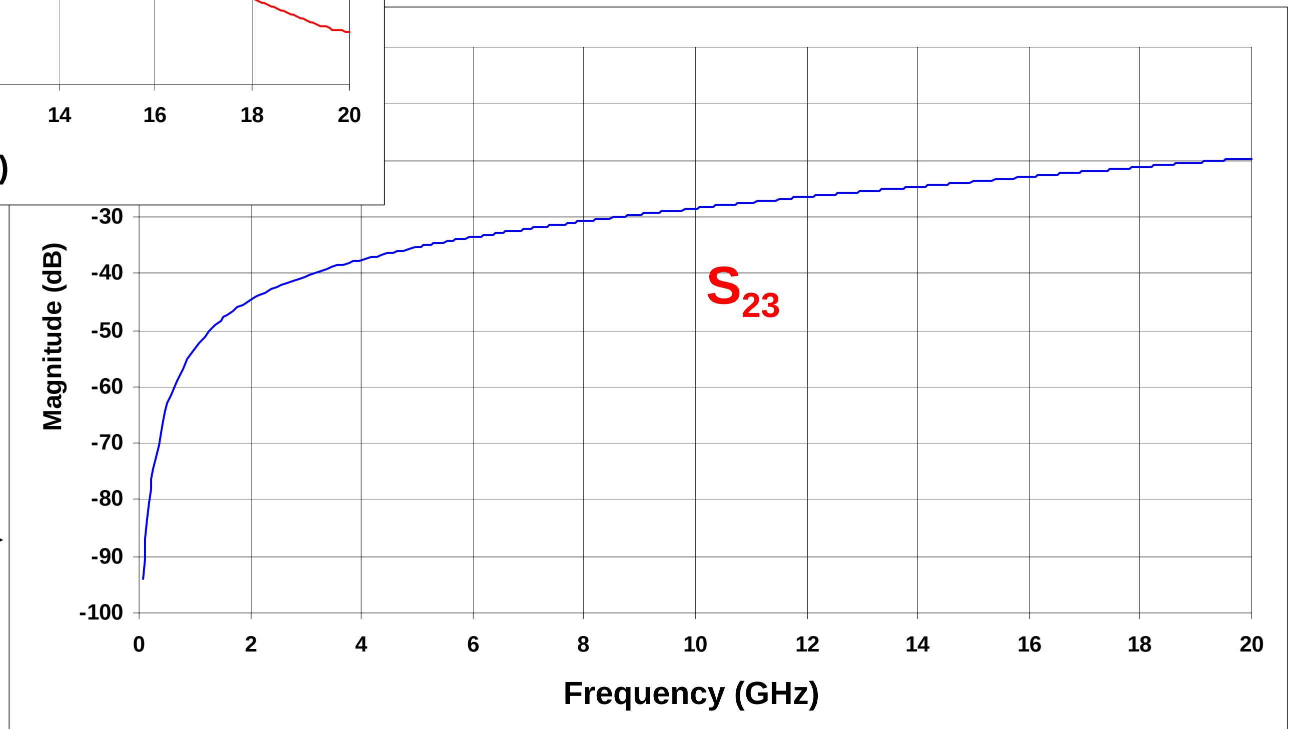
S_{22} in the off state (Membrane up position)

MEMS SPDT Switch (ZrO2) without packaging (X band)

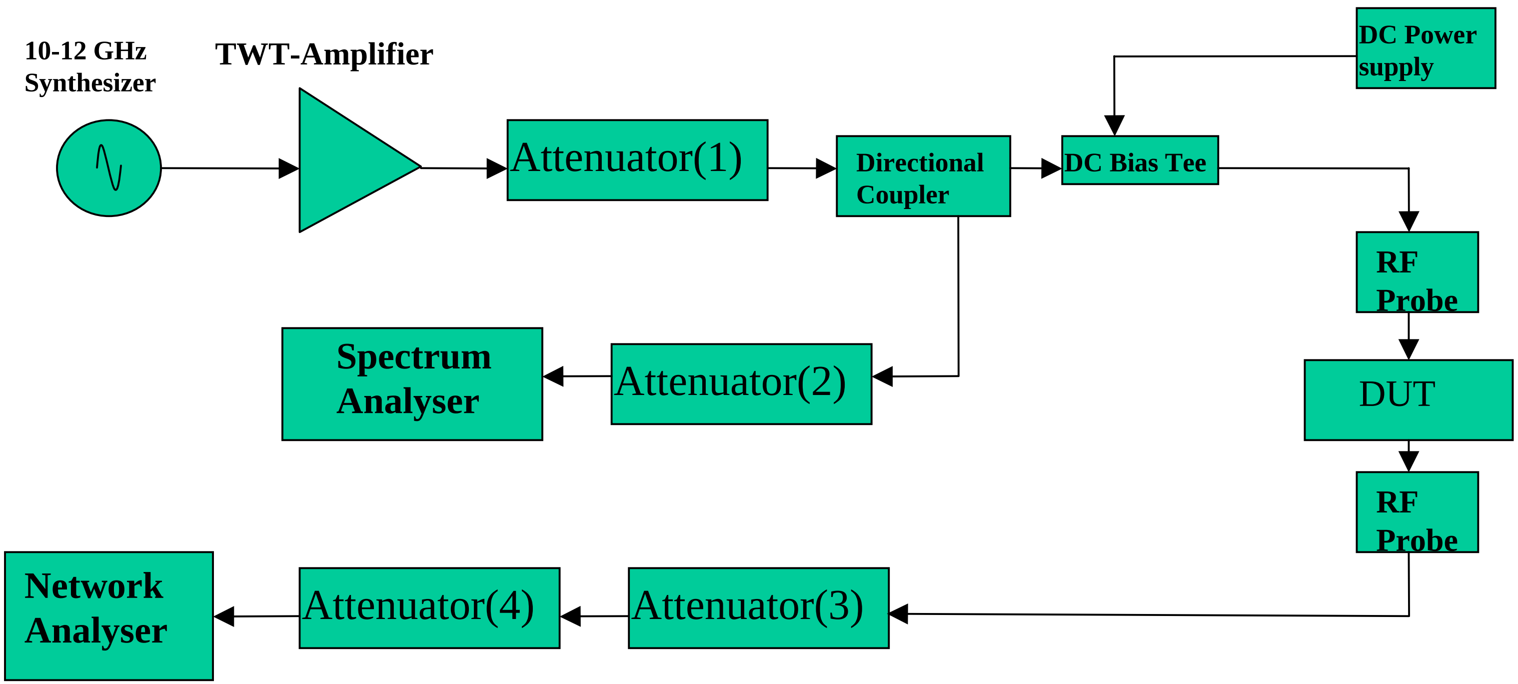


Membrane up position (**in the off state**)





Power Handling of RF MEMS Capacitive shunt switches

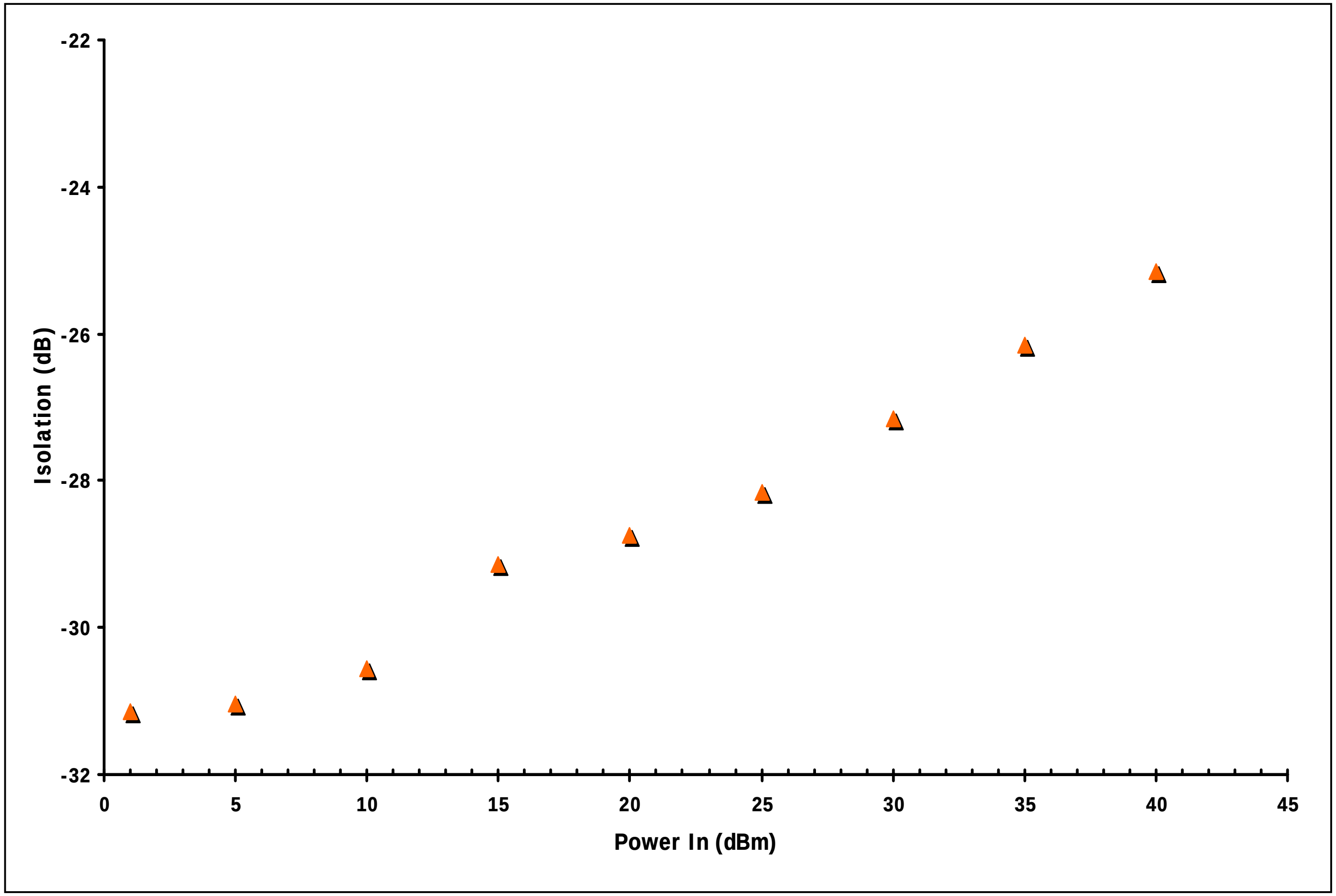


PZT Shunt capacitive switch

ISOLATION	30 dB (10GHz)
PERTES INSERTION	0.1dB (10GHz)
TENSION D'ACTIVATION	25~30Volts
RAPPORT Con/Coff	150
GAP D'AIR (entre membrane et diélectrique)	2~2.5µm
MEMBRANE	240µm x 100µm
Cpw	80µm/120µm/80µm
METALLISATION DE LA MEMBRANE	0.5 µm Al, 0.2µm TiW
CONSTANTE DIELECTRIQUE UTILISEE (PZT)	160~170
VSWR	1.2
Switching time	4 µs

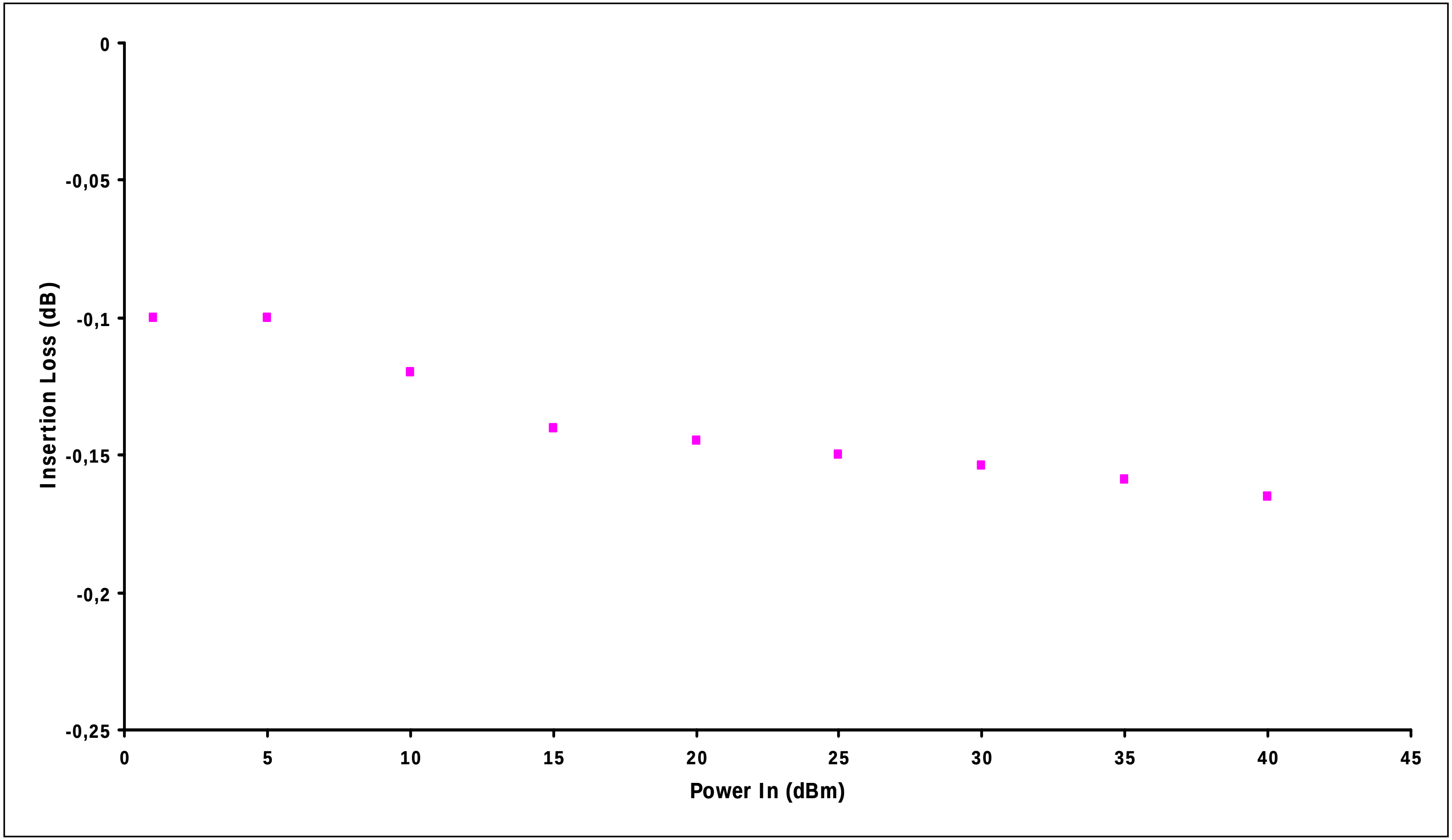
under 0dBm (10 GHz)

Measured down-state isolation versus input power at 10GHz



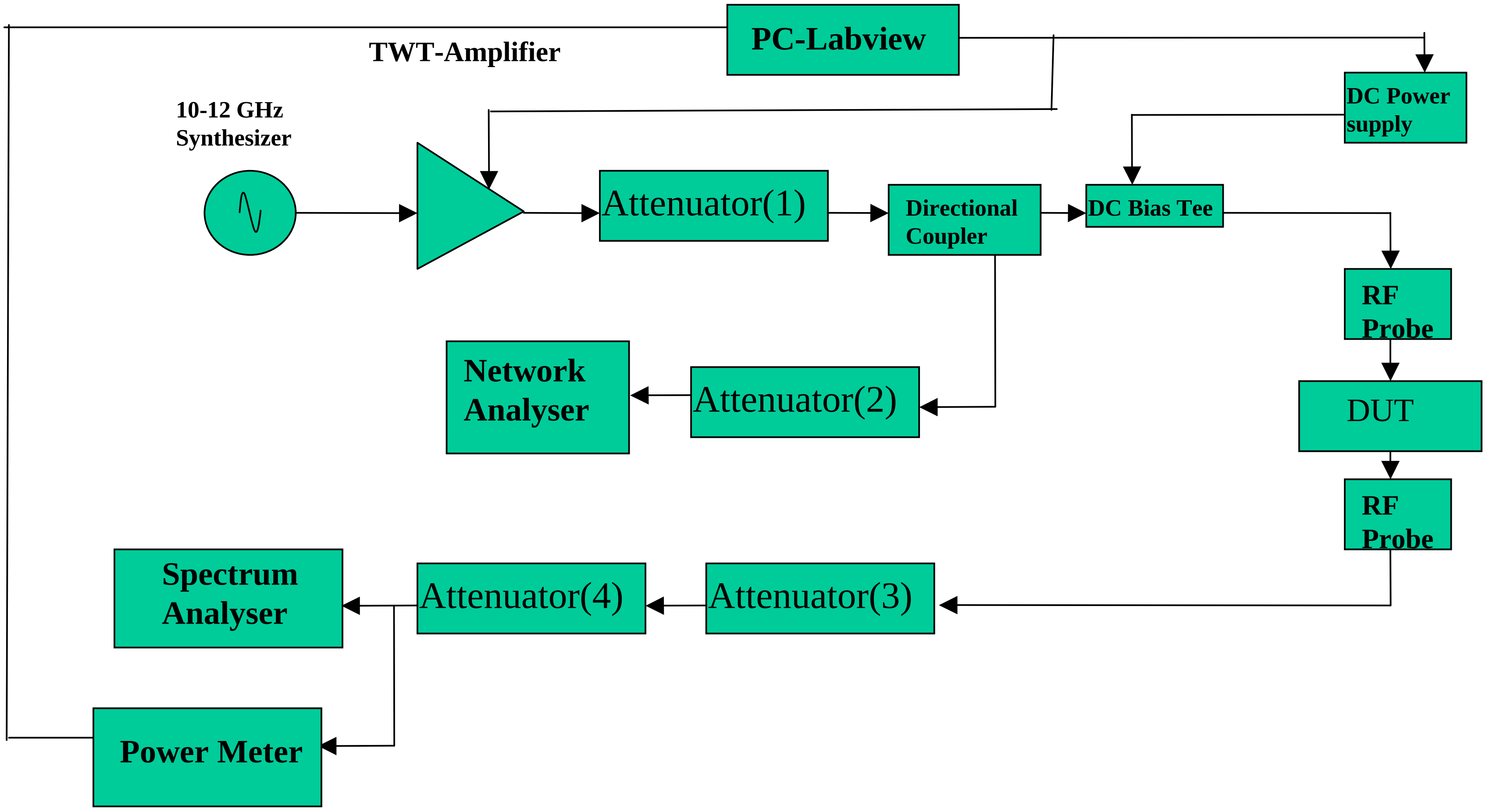
Power Handling of RF MEMS Capacitive shunt switch

Measured up-state Insertion Loss versus input power at 10GHz



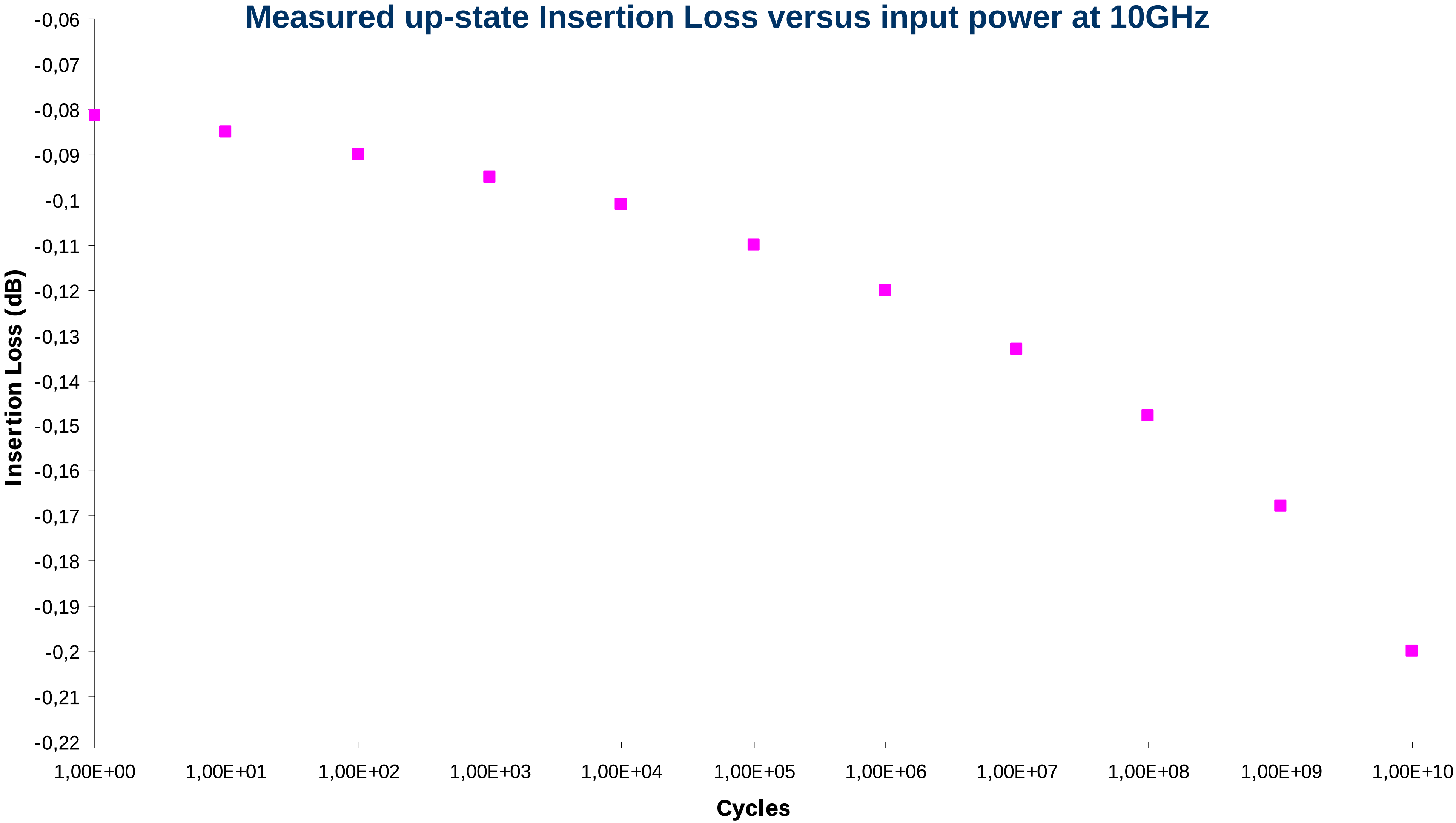
Lifetime measurements (10 GHz)

High power RF lifetime of THALES MEMS switch at 10GHz



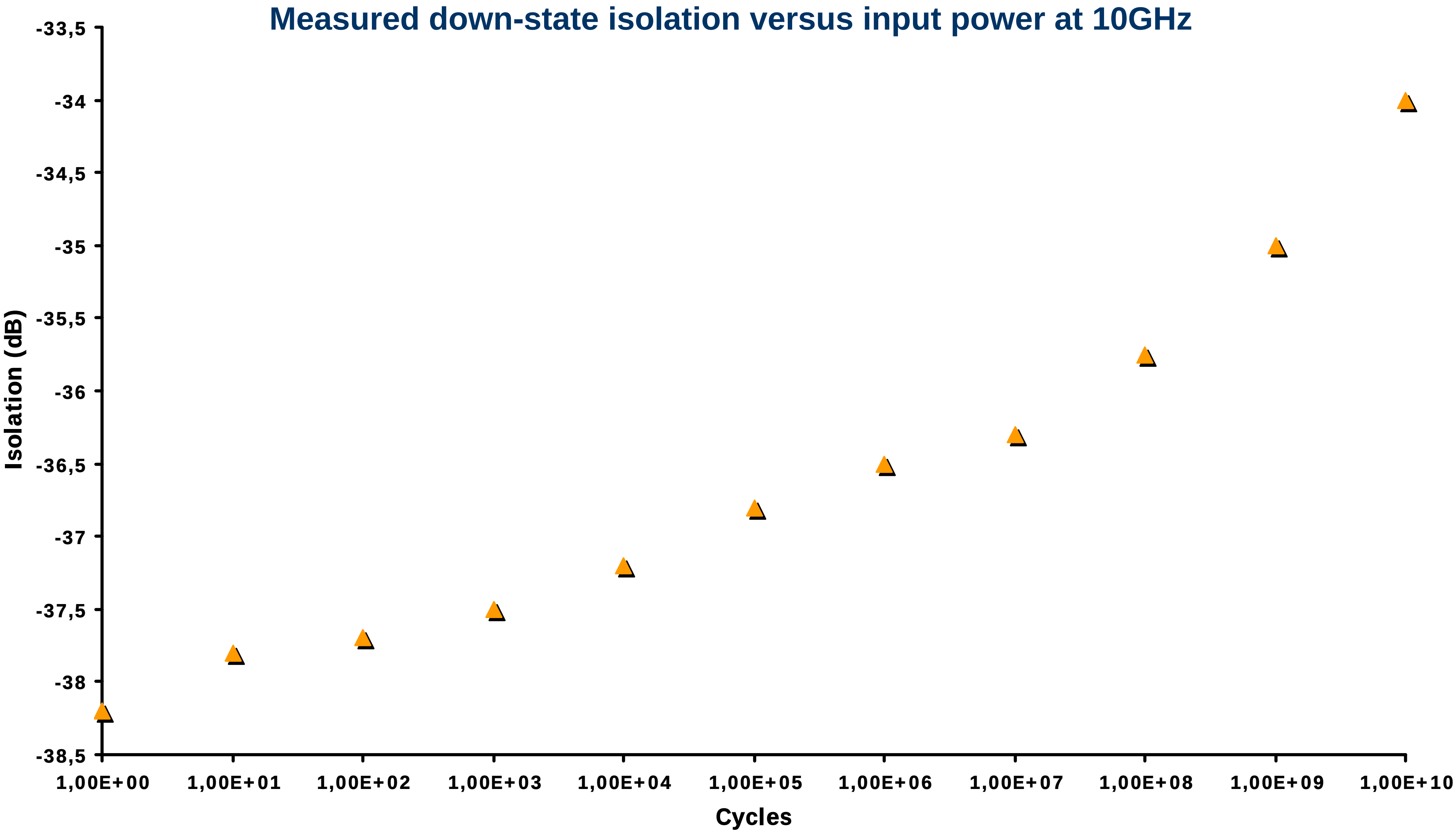
RF lifetime of THALES MEMS switch at 10GHz

Cold switching (37 dBm)



RF lifetime of THALES MEMS switch at 10GHz

Cold switching (37 dBm)



RF Lifetime at 10 GHz
10 Billion Cycles at 37 dBm

32 Devices Tested at 36 dBm and Room Temp.

25 Devices Completed 10 Billion Cycles (Stopped Test)

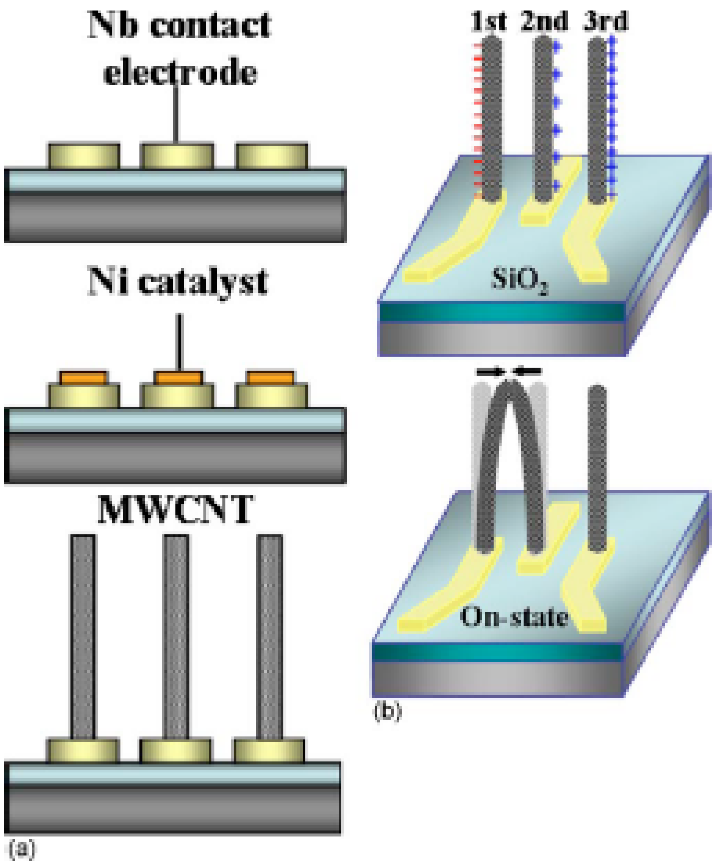
6 Devices Completed 1 Billion Cycles (Stopped Test)

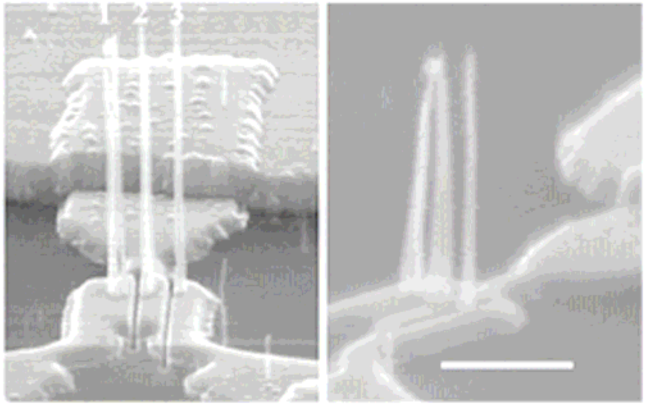
1 Device Failed at 0.72 Billion Cycles

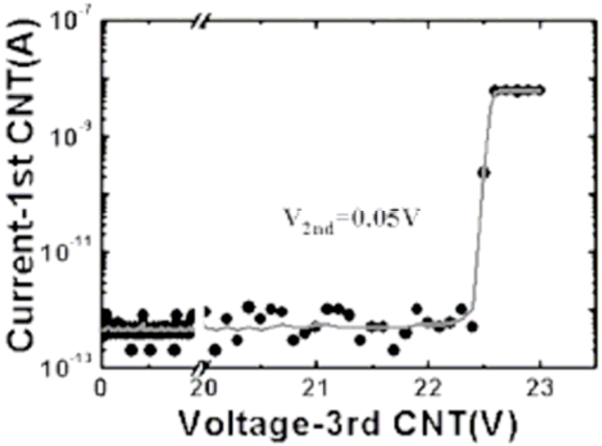
8 KHz Cycle Rate

0.69 Billion Cycles/Day

10 Billion Cycles in 15 Days

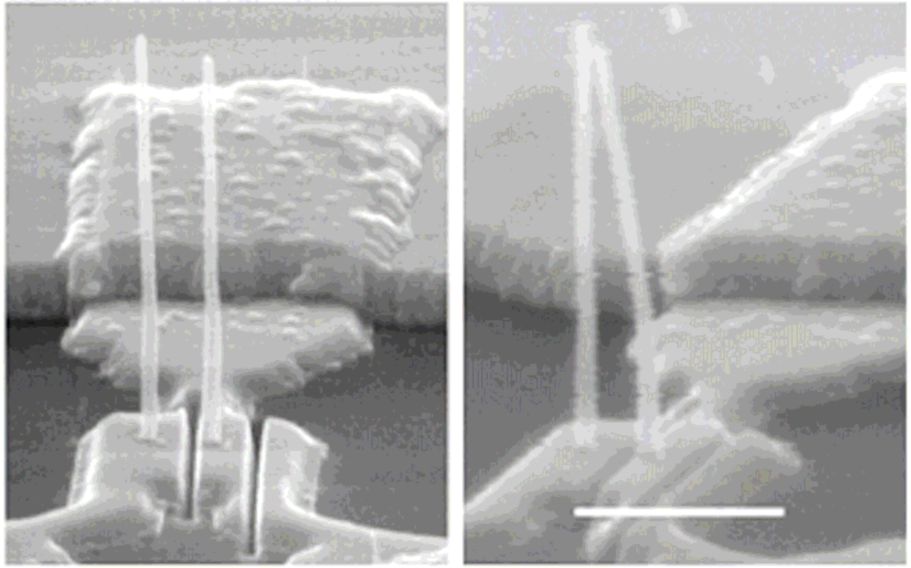


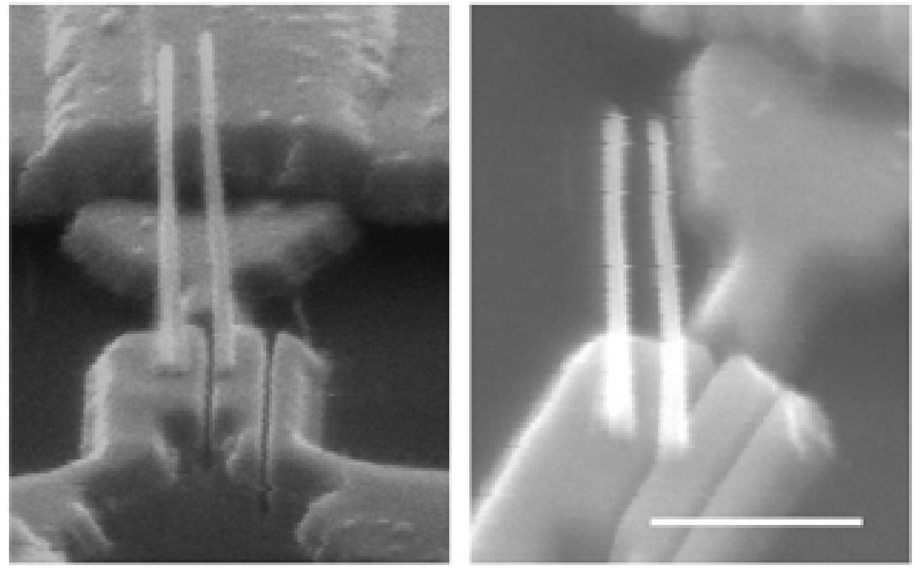


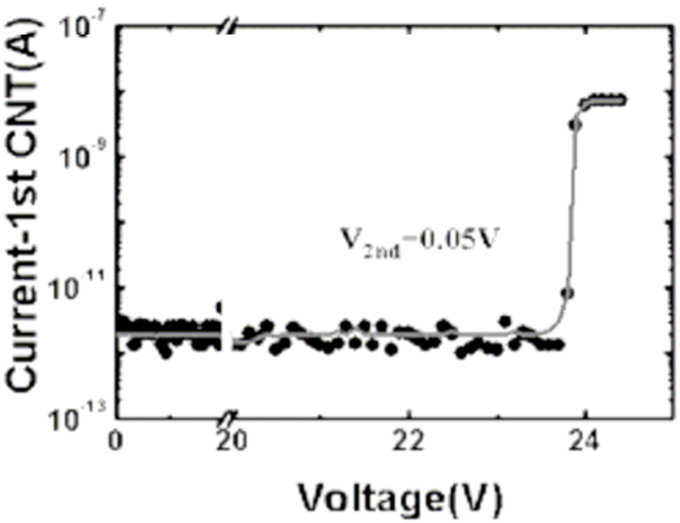


J. E. Jang *et al.*, Appl. Phys. Lett. **87**, 163114 (2005)
"Nanoelectromechanical switches with vertically aligned carbon nanotubes"
Department of engineering, University of Cambridge

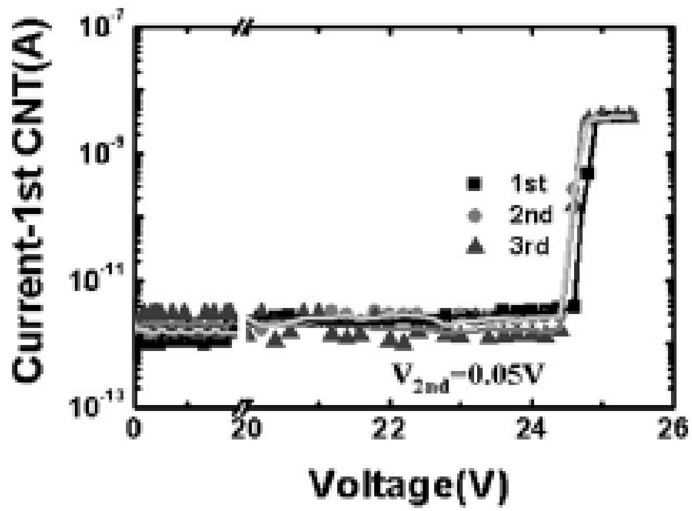
CNs switch







Current-1st CNT(A)
10^-7
10^-9
10^-11
10^-13
V2nd=0.05V
0
20
22
24
Voltage(V)



Current-1st CNT(A)
10^-7
10^-9
10^-11
10^-13
1st
2nd
3rd
V2nd=0.05V
0
20
22
24
26
Voltage(V)

Why carbon nanotube based NEMS?

- High isolation, low losses → from MEMS properties

- Low actuation voltage → < 10 V
- High switching speed → ~ a few ns

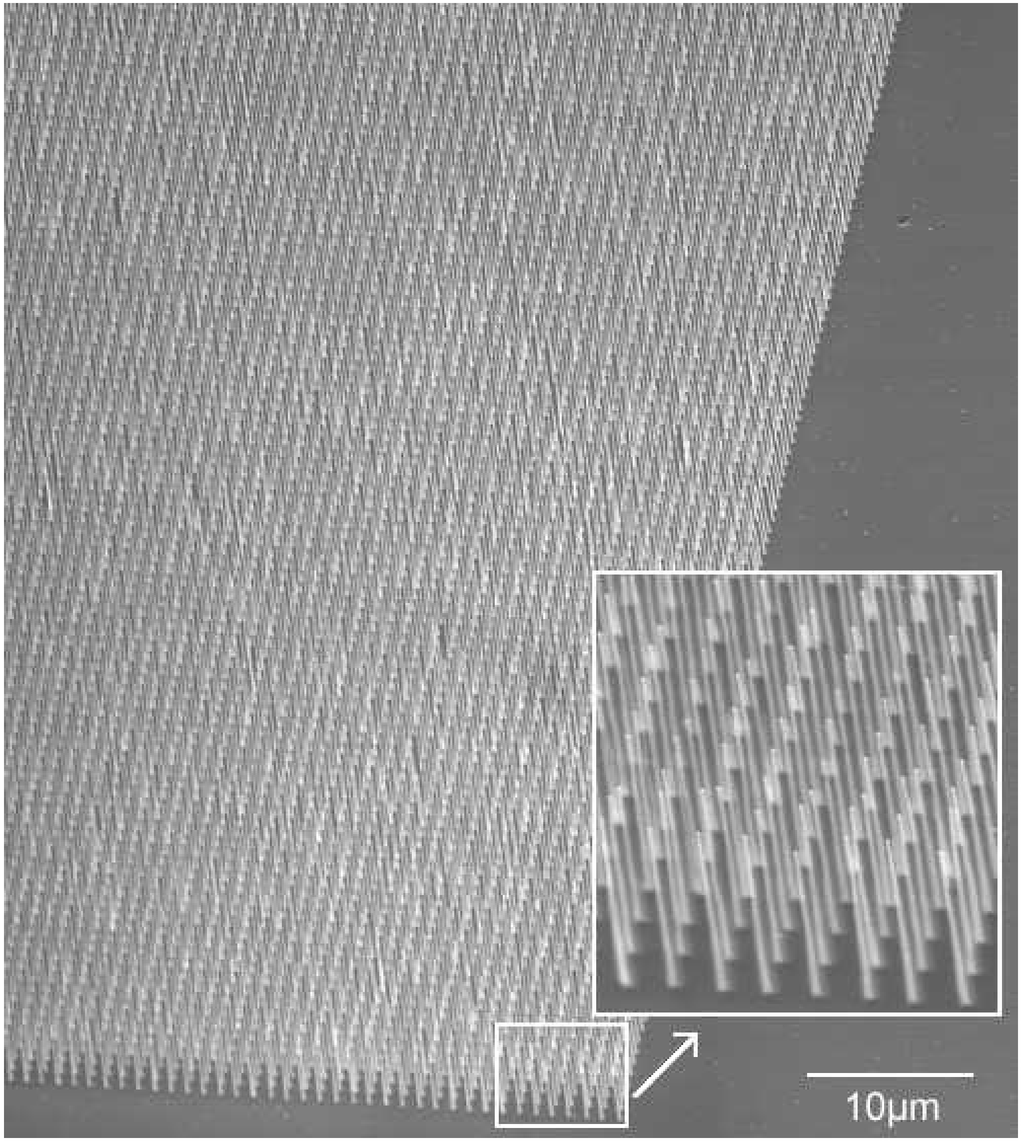
  } From nanometer size of CNs

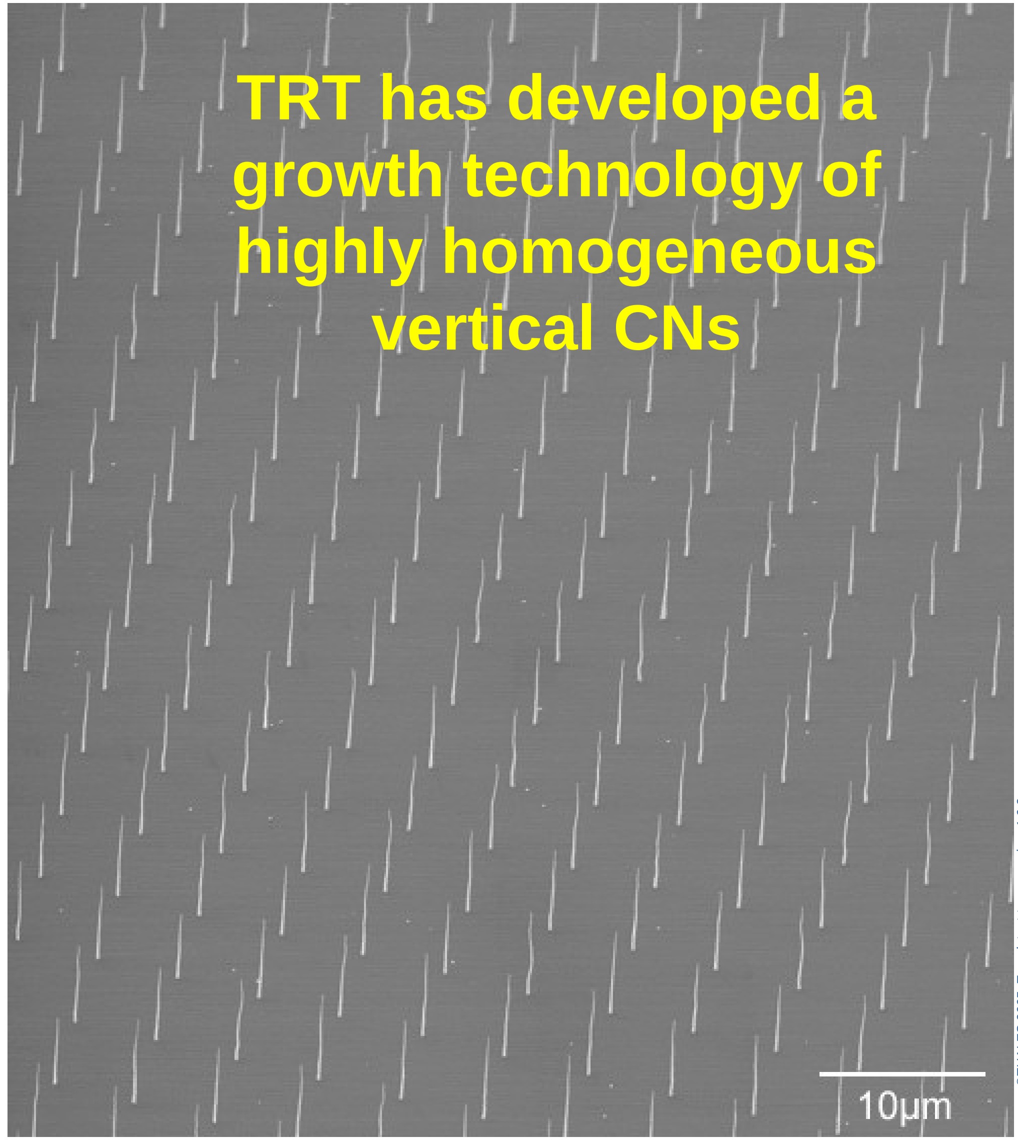
- High power handling → exceptional electrical and mechnical properties of CNs

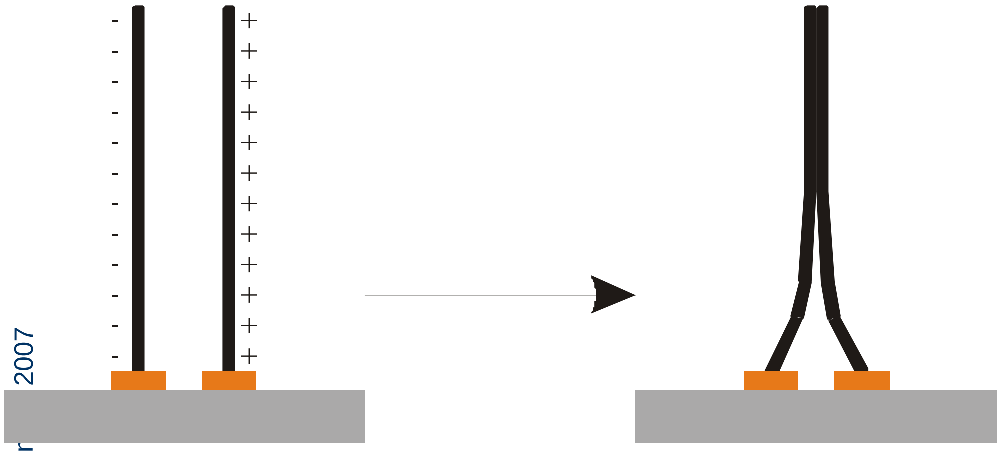
- High integration density
- Low cost
- Low consumption

Main difficulty

• Achieving reproducible and routinely fabrication process of CN switches

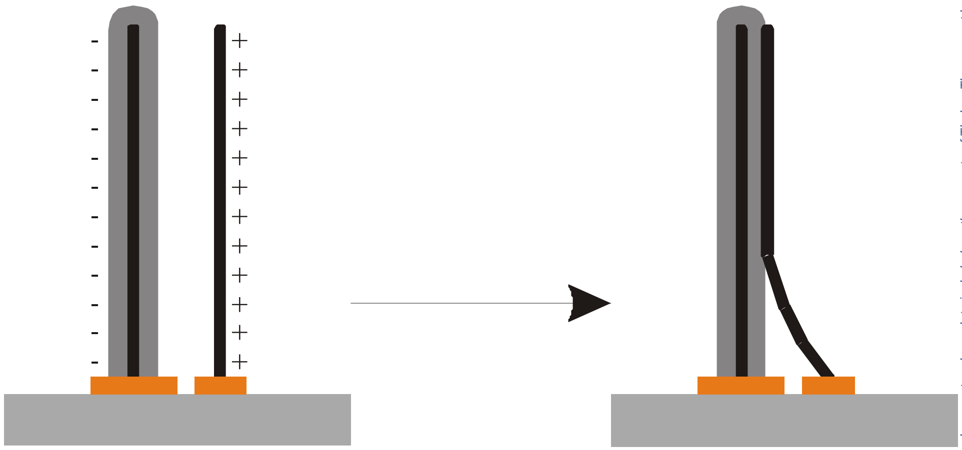

10µm


TRT has developed a growth technology of highly homogeneous vertical CNs
10µm

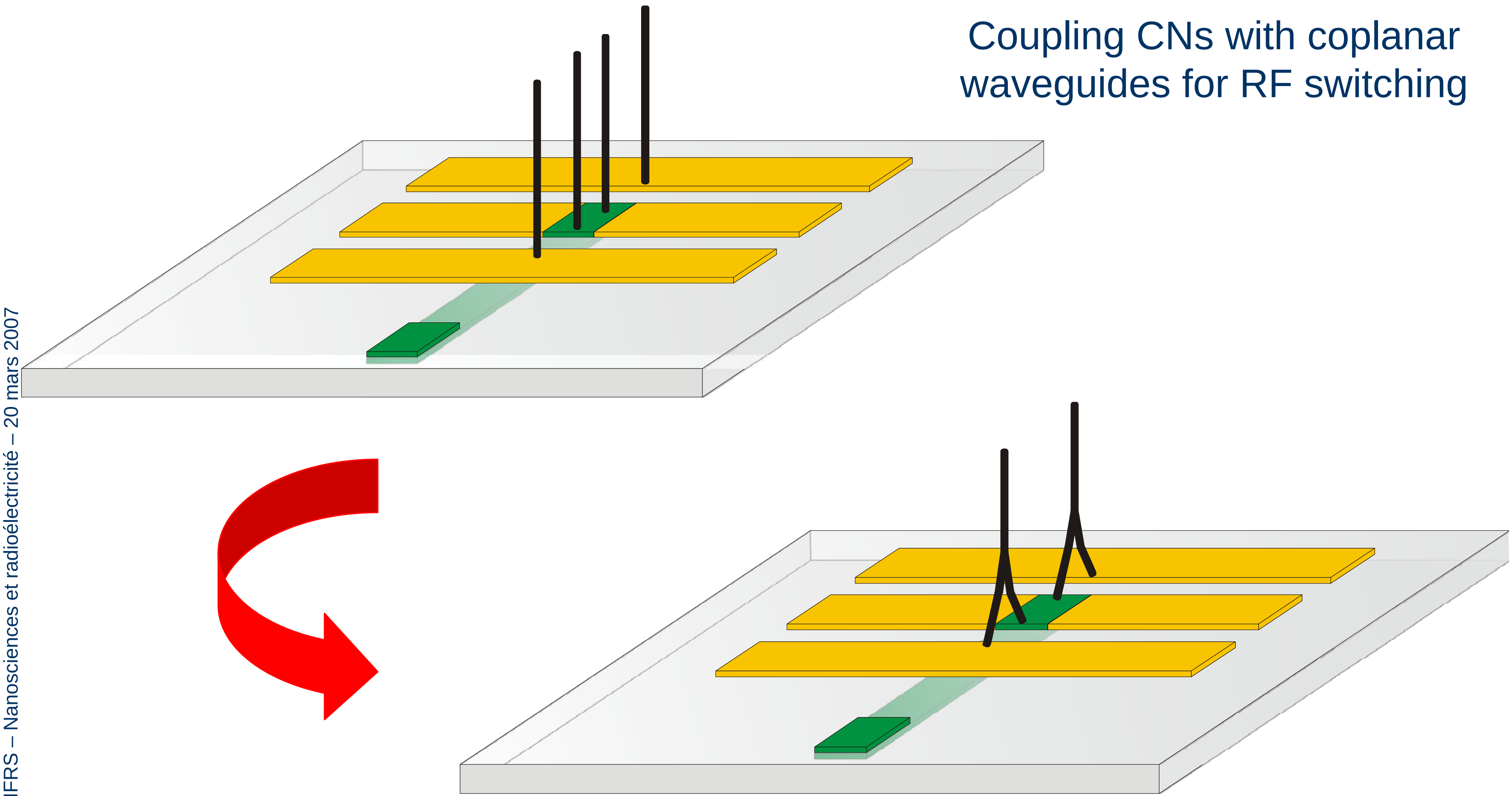


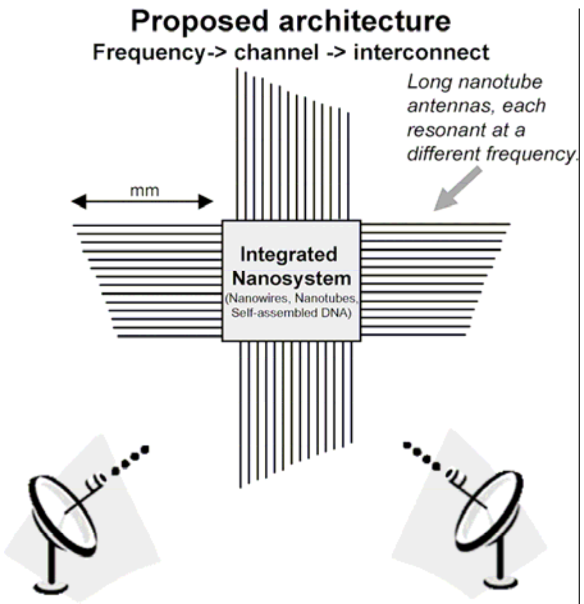
Ohmic switch
(metal/metal contact)

Capacitive switch
(metal/dielectric/metal contact)



Coupling CNs with coplanar waveguides for RF switching

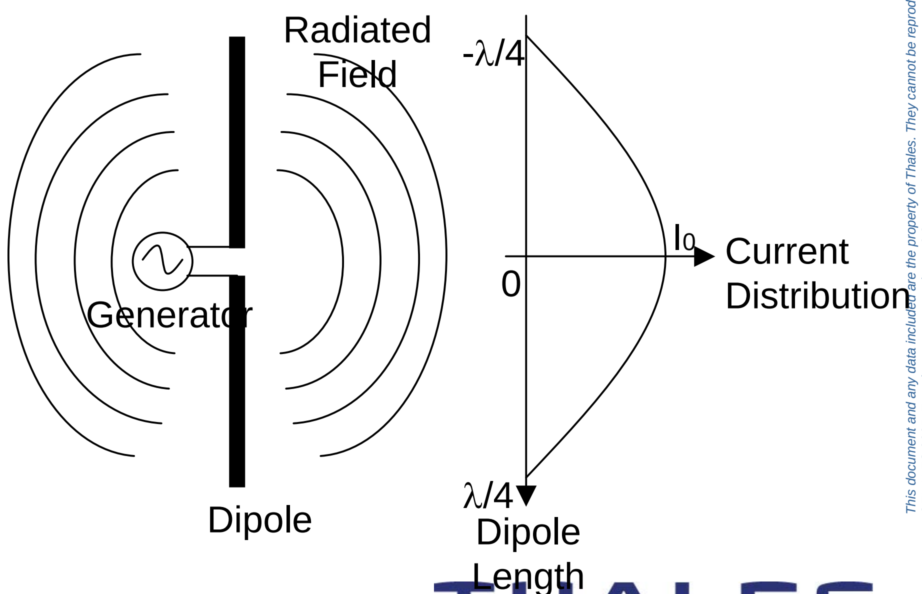


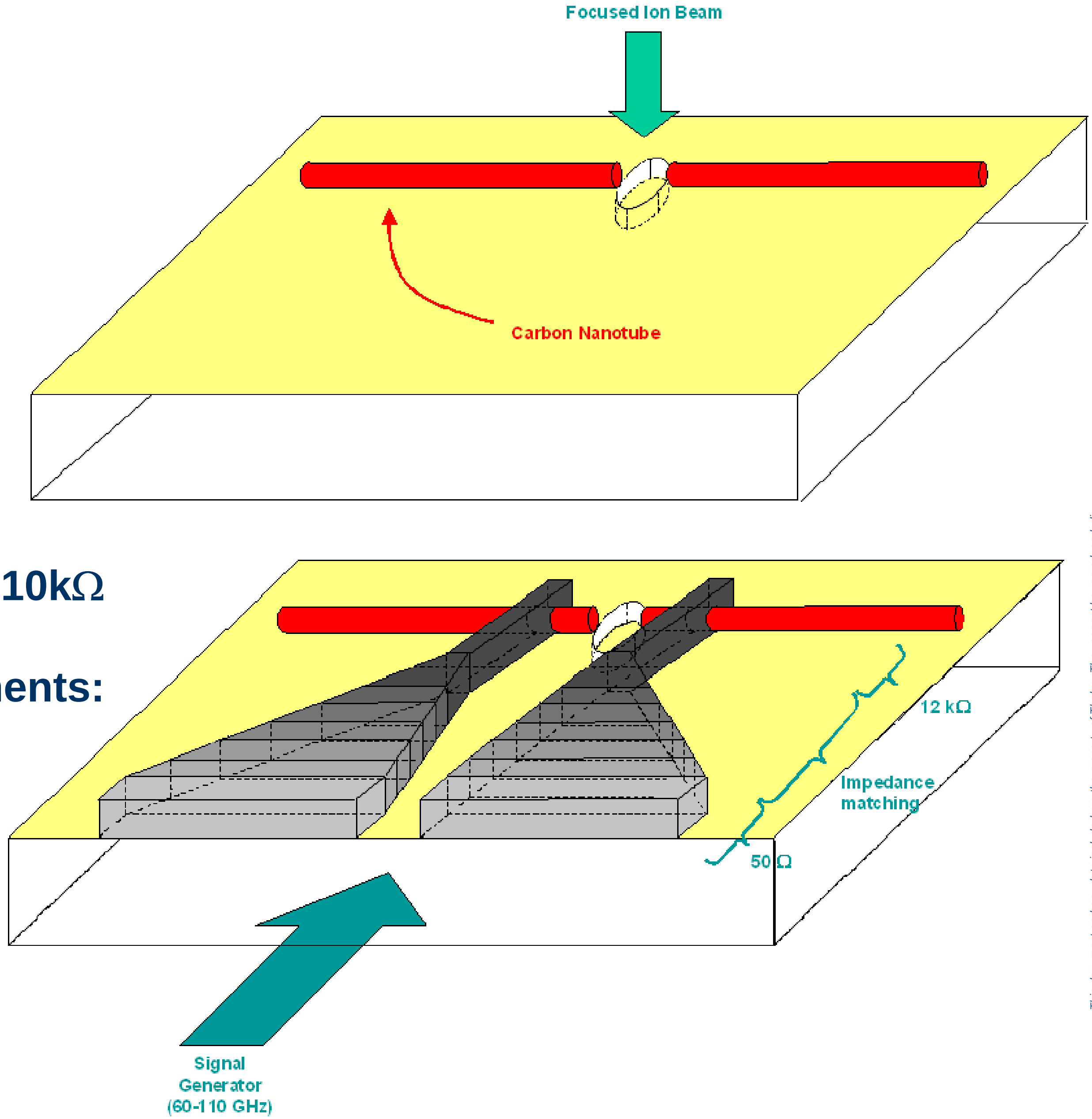


Advantages of CN antennas:
- High integration
- High density circuits
- High frequency resonators

Applications of CN antennas:
- Wireless communications between nano-sized devices/organisms and macroscopic world
- Antenna arrays at high frequencies
- Thales: 60-110 GHz

Particular electrical properties:
- High characteristic impedance & high losses
- High relaxation frequency (>50GHz)
- High wave velocity ($\lambda/50$ - $\lambda/100$)





Technical issues:

- Dipole fabrication: FIB
- Impedance matching: 50Ω - 10kΩ
- Emission pattern measurements: Radiation efficiency – 60 dB

Conclusion

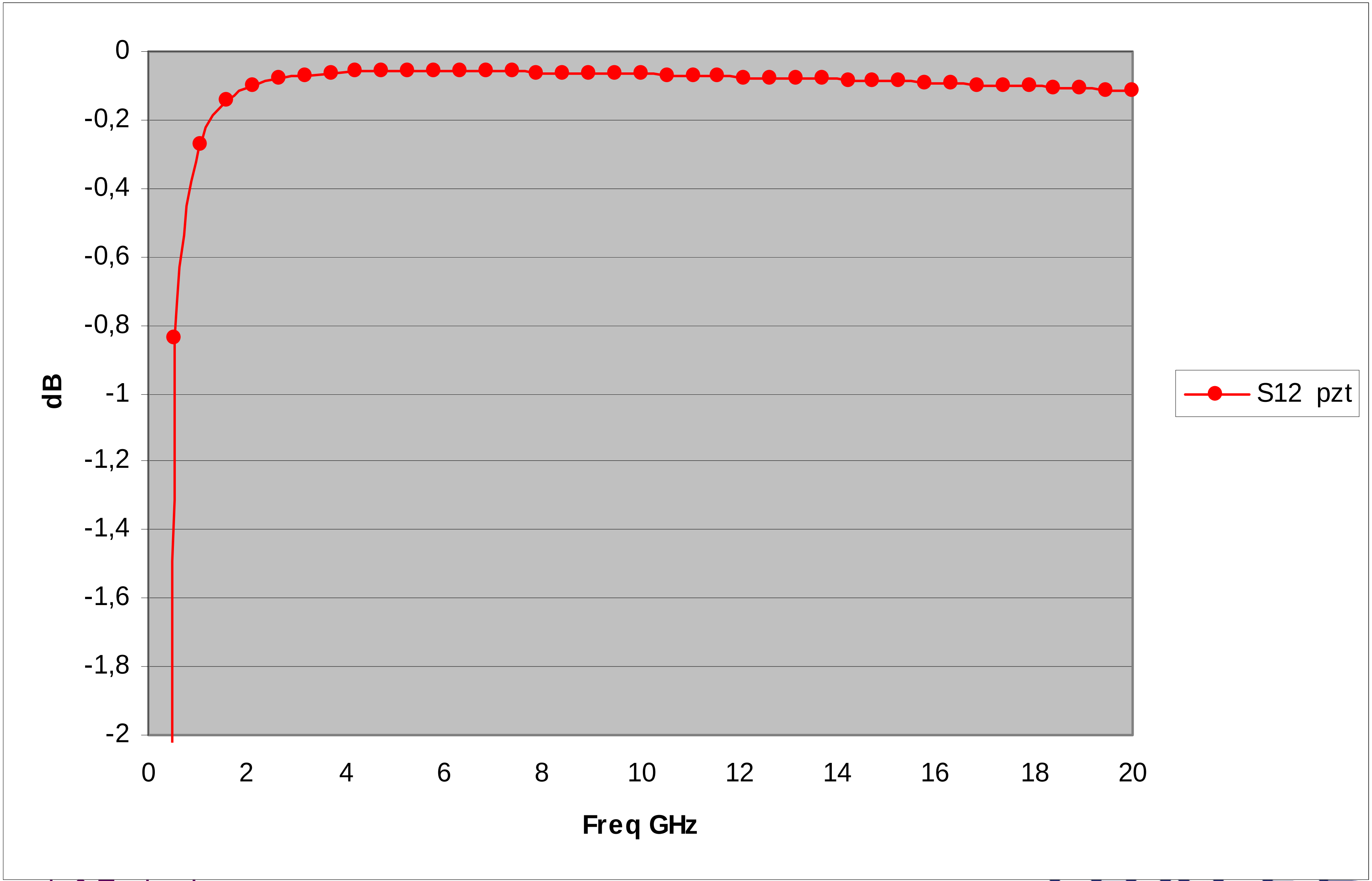
- Key RF performance characteristics for a ZrO_2-SPDT switch are at 10 Ghz: insertion loss of 0.15 dB and isolation of 28 dB .

- RF lifetimes exceeding 10^{10} cycles achieved at input Power level of 36 dBm

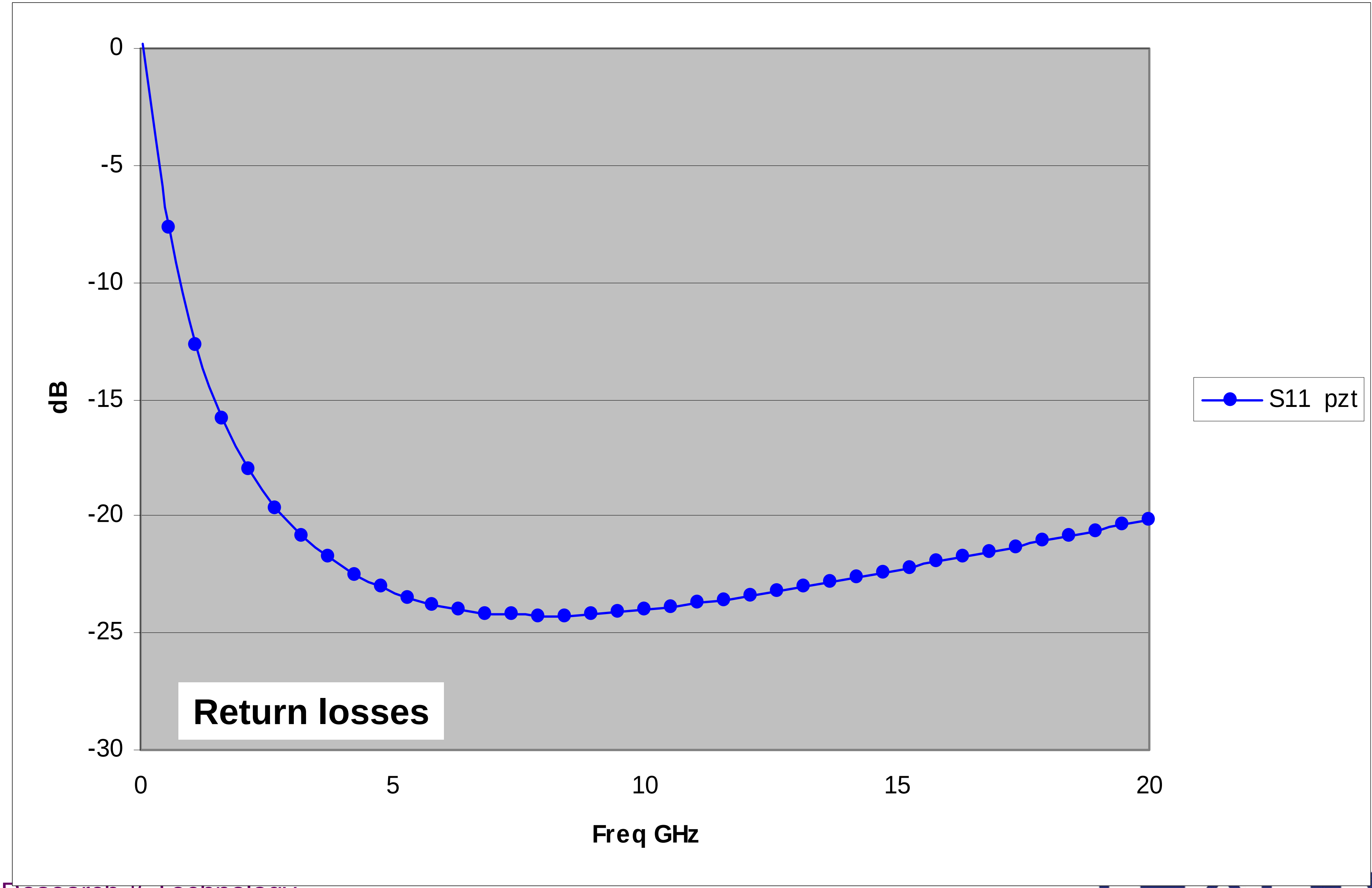
- Research on nanotubes RF NEMS is underway at Thales Research & Technology

Thank you for your attention

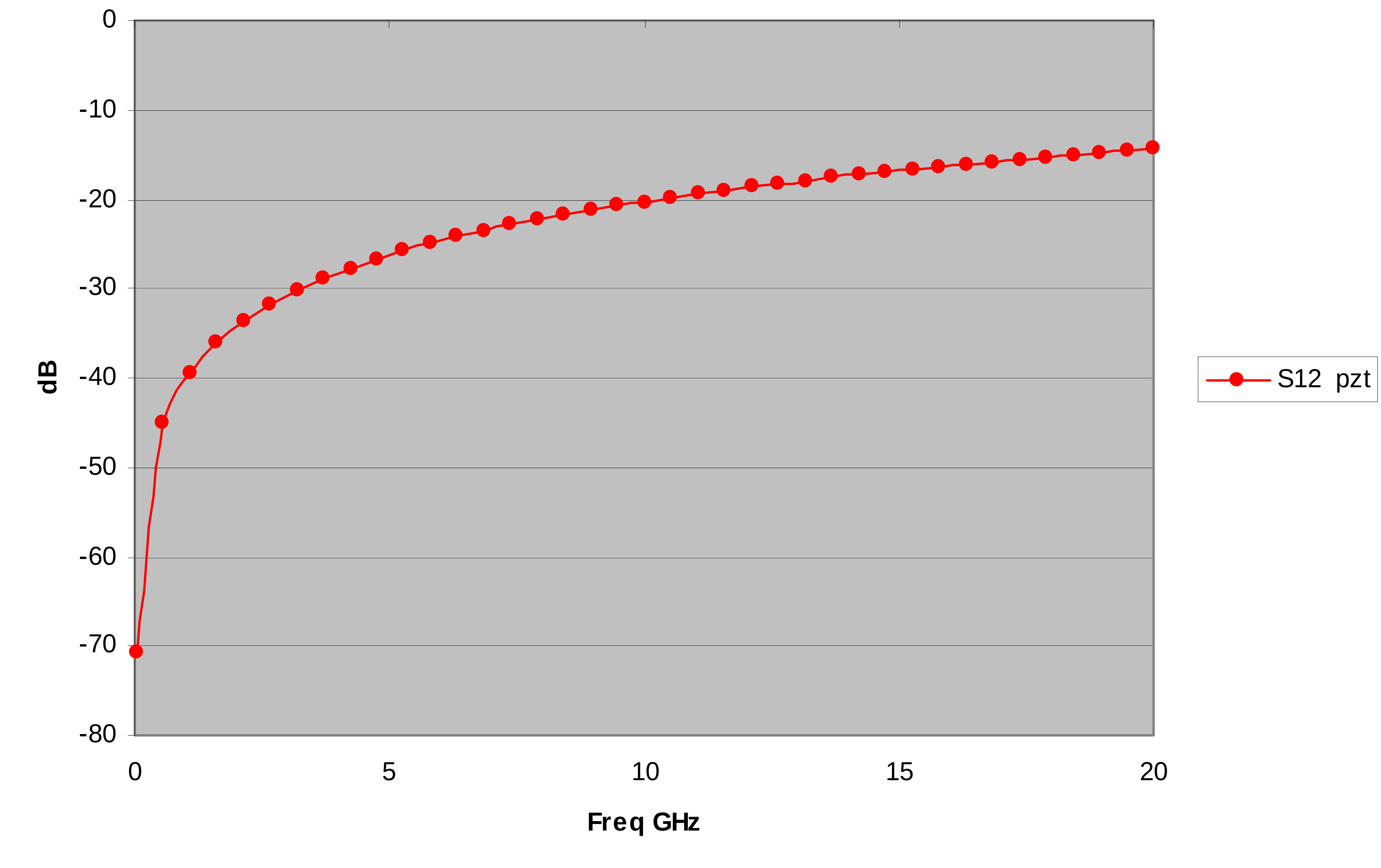
Bare chip Characteristics: Insertion losses
Membrane in up position



0.04-20 GHz measurements



Bare chip Characteristics: Isolation (0.4-40 GHz)
Membrane in down position



0.04-20 GHz measurements