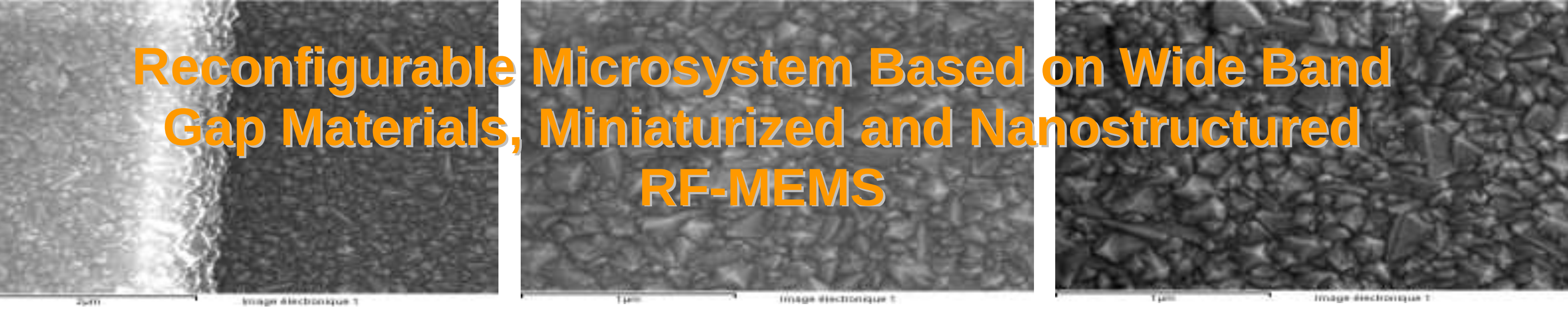
Reconfigurable Microsystem Based on Wide Band Gap Materials, Miniaturized and Nanostructured RF-MEMS



nanocom

NEWSLETTER #4 (FEBRUARY 2015)

Key issues addressed in the project

Several key issues have been addressed within the 4 years of the project namely:

- **III-V semiconductors such as GaN on Silicon**
  - ✓ High frequency, high power density, robustness, low losses
  - ✓ A key technology for high power RF electronics for emitter applications
- **RF-MEMS**
  - ✓ High linearity, low power consumption, low losses, cost effectiveness
  - ✓ A key technology for reconfigurability of smart systems with better switching time
  - ✓ Power handling capabilities & MMIC integration
- **RF MINIMEMS**
  - ✓ Low switching time , lower actuation voltage & power consumption
  - ✓ Future emerging technologies with <1µs switching applications
- **Dielectric materials & reliability**
  - ✓ PZT, Diamond; CNTs in Si_3N_4, TiO_2
  - ✓ Reliability roadmap for each material studied for RF MEMS applications
- **Substrate evaluation**
  - ✓ LCP, GaN/Si, Si/SiO_2, ceramic…
  - ✓ Assessment of RF MEMS technological feasibility
- **Packaging**
  - ✓ Is a key factor for performance and cost-effectiveness

Main demonstrators developed in the project

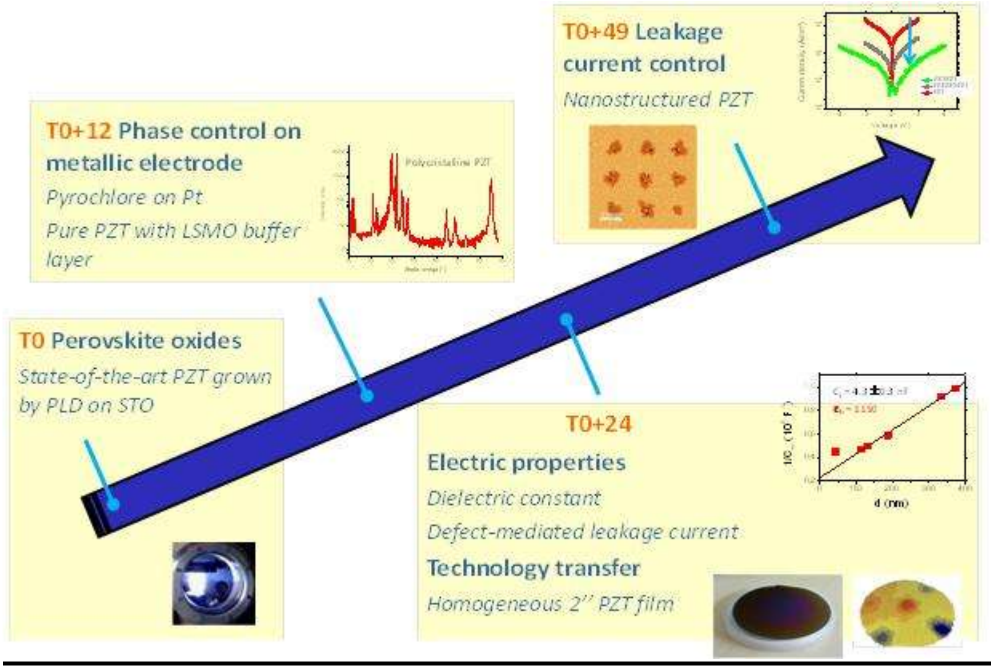
- **Demonstrator # 1** : Reconfigurable smart active antennas with RF-MEMS switches
  - It concerns the development of an active antenna module for wide band applications based on the integration of **RF MEMS (SPDTs)** and **MMICs** for the realization of T/R modules on **GaN/Si substrates for 10-15W power handling capabilities**
- **Demonstrator # 2 :** RF-MEMS based Agile Radio (Tunable filter) for Air Traffic Management Radars
  - It investigates the development of **RF MEMS (SPnTs)** devices for the development of tunable filters for air traffic management with the objective of demonstrating a Reconfigurable front-end based on a tuneable filter using RF MEMS (SPNT RF MEMS) **also ultra-wide band antenna demonstration**

Major achievements for the NANOCOM project

- ## Dielectric Material studies

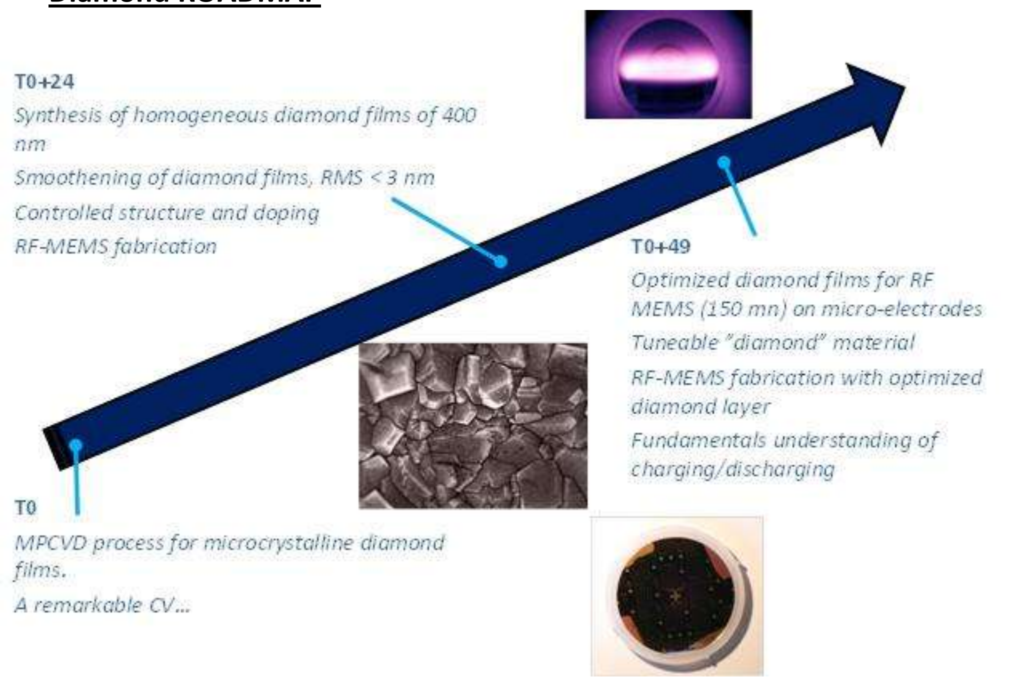
Different dielectric materials have been studied throughout the project and the assessment within the RF MEMS technology has been evaluated for each specific material. A roadmap for each material as developed in the project is illustrated below.

✓ **PZT ROADMAP**



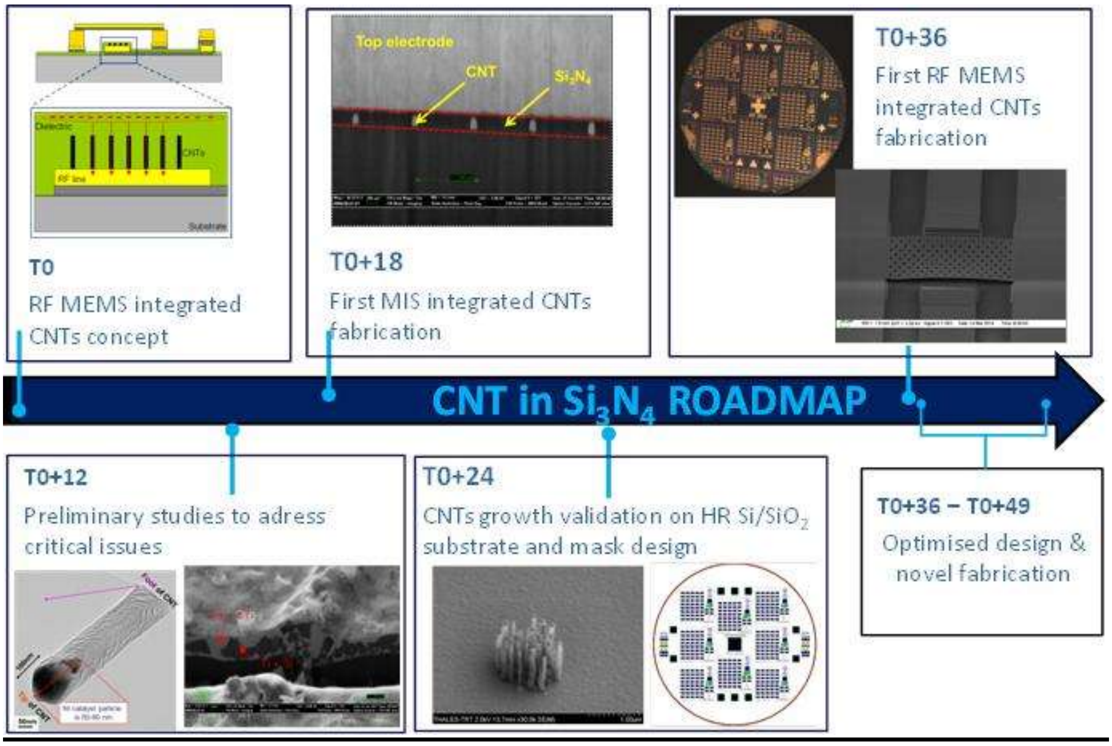
PZT roadmap

✓ **Diamond ROADMAP**



Diamond Roadmap

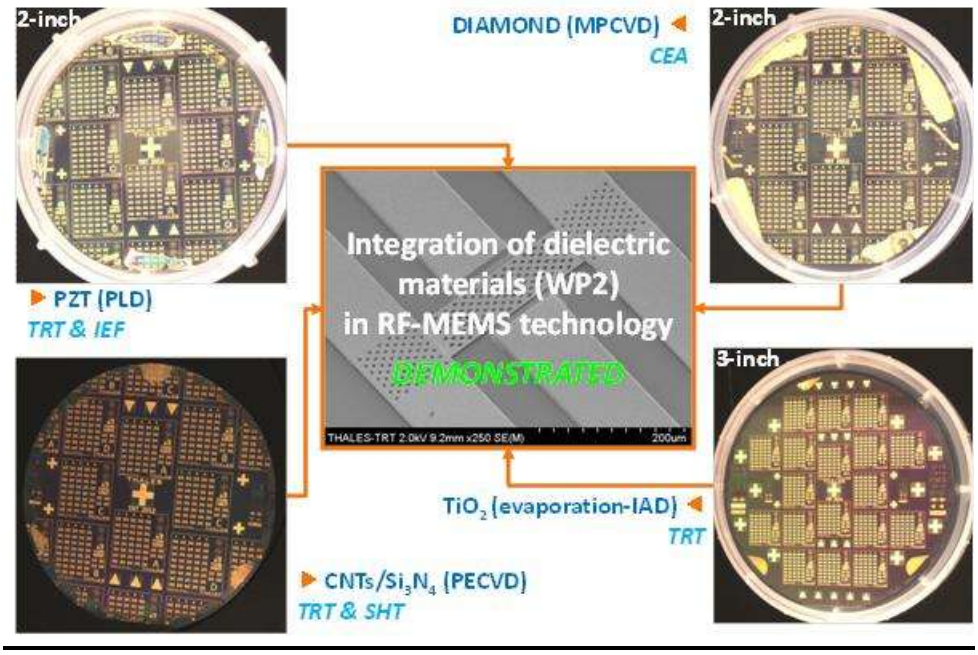
✓ **CNTs in Si_3N_4**



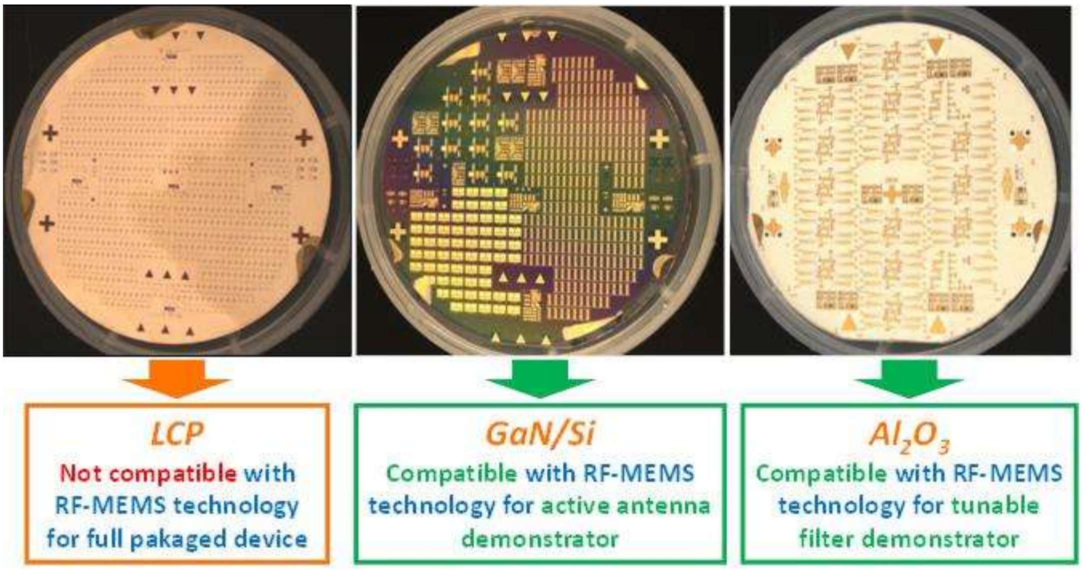
Integration of carbon nanotubes in dielectric material (CNTs in Si_3N_4)

- **RF MEMS technology**

Within the project, the RF MEMS technology has been demonstrated on various substrates and on each of the identified dielectric material.



Summary of RF MEMS technology demonstrated with different dielectric materials



Demonstration of RF MEMS technology on various substrates

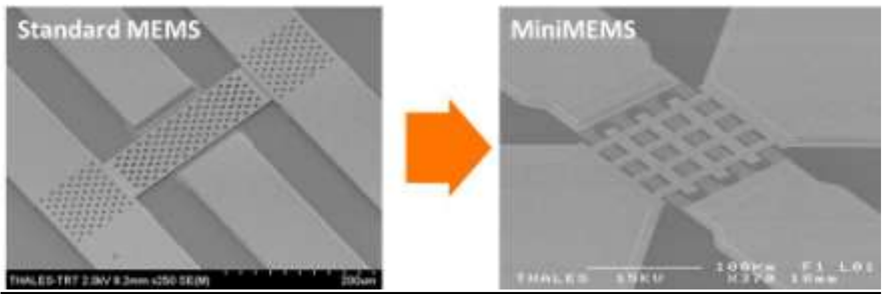
Using TiO_2 as dielectric material the average insertion losses (lines & MEMS) of 0.2dB and isolation of the order of 15-20dB were demonstrated compared to the other dielectric materials.

	DIAMOND	PZT/PLD	CNTs/Si_3N_4	TiO_2
Temperature deposition (C)	High	High	High	Low
Homogeneity	2-inch	< 2-inch	2/3-inch	3-inch
Insertion Loss @ 10 GHz	<0.2dB	<0.2dB	<0.2dB	<0.2dB
Isolation @ 10 GHz	< 5 dB	< 5 dB	< 5dB	Up to 20 dB

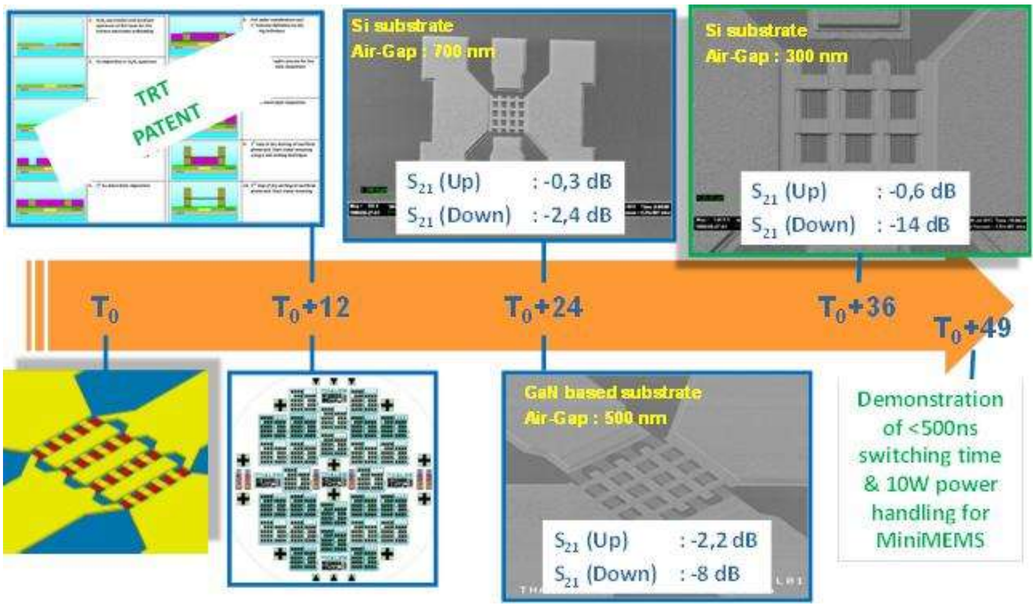
Summary of the [s] parameters results obtained on each dielectric material for the RF MEMS technologies

- **<u>RF MINIMEMS technology</u>**

A novel process flow has also been realised in order to demonstrate the feasibility of RF MiniMEMS devices. The main objective of the MiniMEMS technology was to achieve sub µs switching time while maintaining good [s]parameters and power handling characteristics.



Typical difference between RF MEMS & RF MINIMEMS devices with the dimensions of the membrane reduced by a factor of 10, the gap reduced by a factor of 4

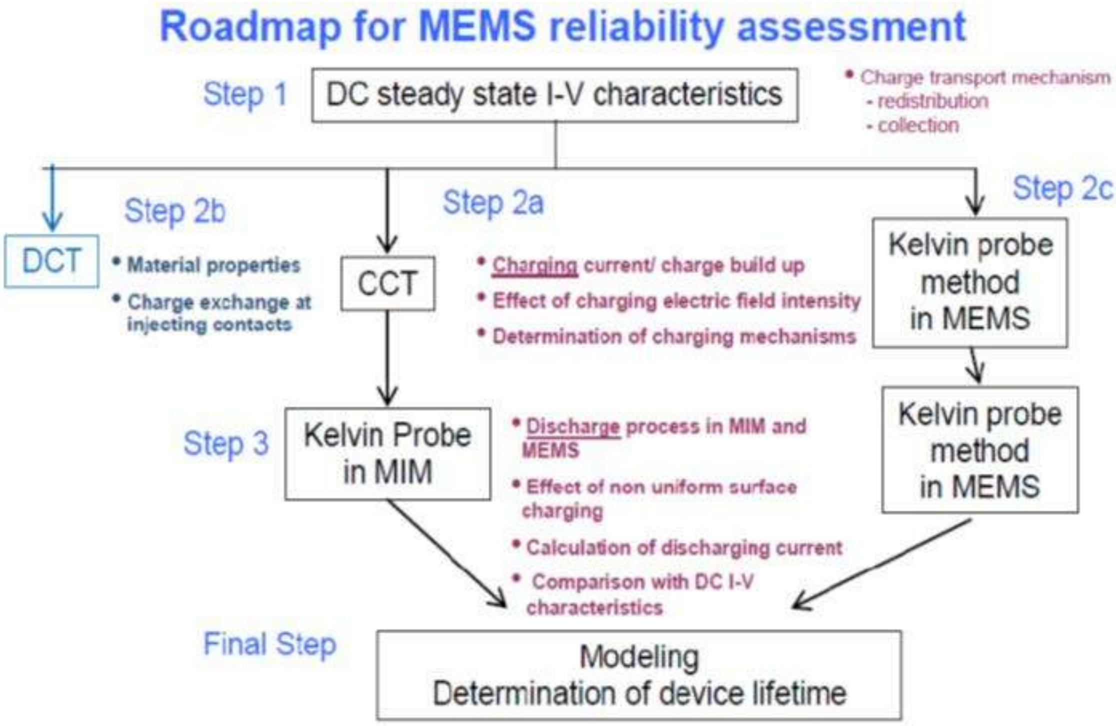


Summary of the RF MINIMEMs device technology

The major results obtained from this technology demonstrated a switching time of **<1µs** for the RF MiniMEMS, with a power handling capability of up to **10W**.

- **Reliability issues**

Within the project, the reliability aspects have also been investigated. As a major highlight, a typical reliability roadmap was established in order to assess the various dielectric materials used in the RF MEMS technologies.

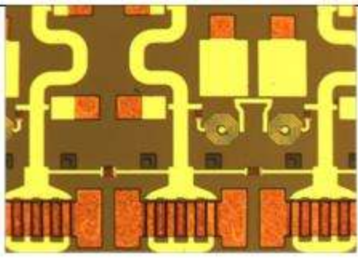
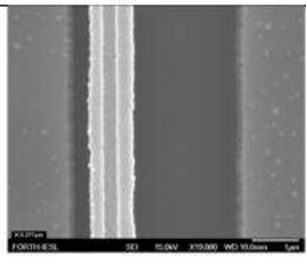
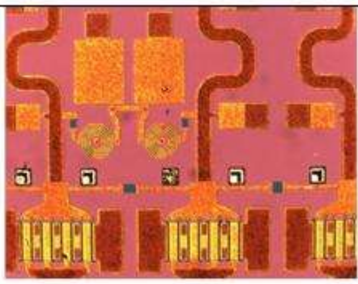
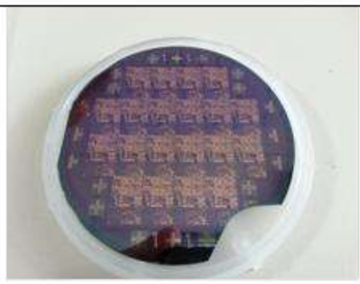


Roadmap for RF MEMS reliability assessment as established within the project

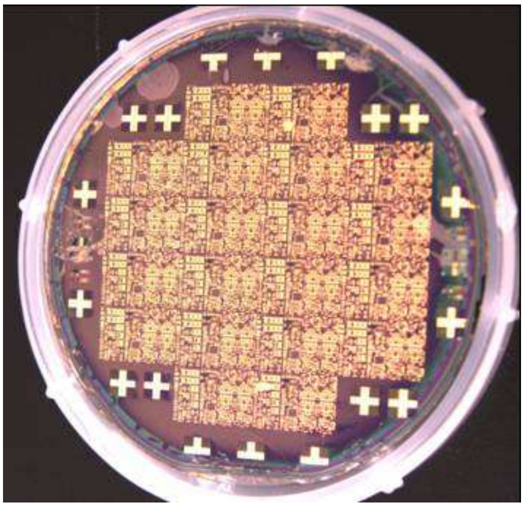
- **Demonstrator # 1 : Smart Active antenna based on T/R module**

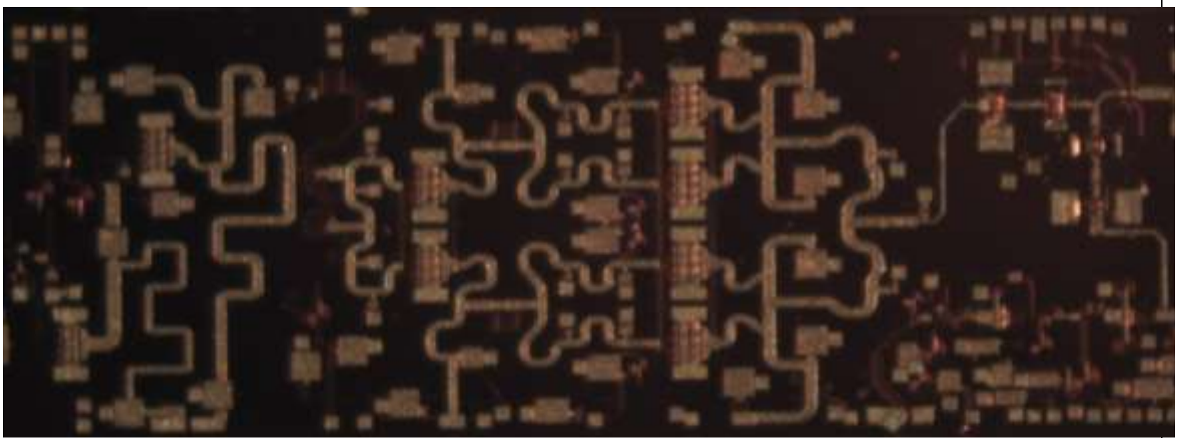
Based on the simulation characteristics, a process flow has been developed between TRT & FORTH in order to realise a monolithic integration of **RF MEMS** and **HPA/LNA/driver** devices onto the same **GaN/Si** substrate. For this purpose, this technology is based on a typical **MMIC technology** for an industrial approach and hence has been adapted on a micro-strip configuration. The fabrication towards the final demonstrator has been carried out in different phases during the course of the project in order to develop a mature and robust industrial approach. The phases were defined as follows:

- ✓ Analysis and validation of key critical steps : choice of dielectric material, thinning process, membrane and air bridge definition, definition of dry etching requirements, choice of glue
- ✓ Validation of the established design and the process flow on a dummy substrate
- ✓ Development of the fabrication of MMICs by FORTH in order to validate the key passivation techniques, contact metallisation and choice of dielectric materials
- ✓ Demonstration of the technological feasibility on thinned GaN/Si substrates with vias

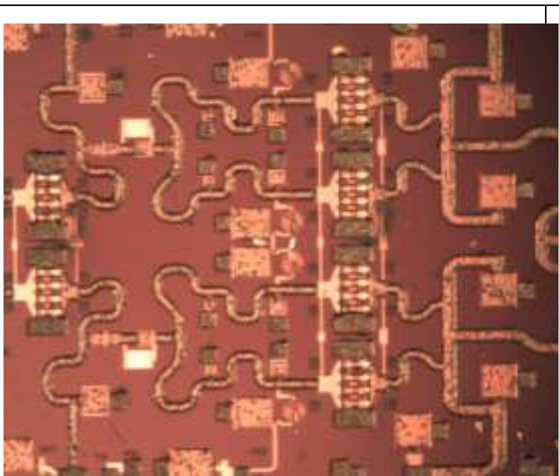
	
Circuit details prior to 3rd SiN deposition	SEM image of the gate head detail
	
Circuit details following 3rd SiN deposition	Finalised device

Key mask development and 1st fabrication run of the monolithic integration of MMICs & RF MEMS on GaN/Si substrate

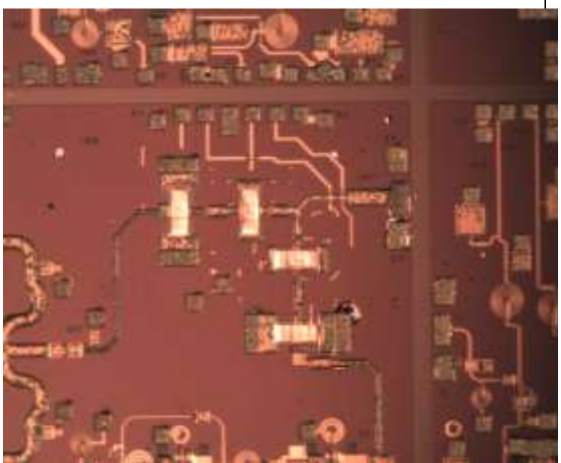




Overview of a T/R module



HPA element of the T/R module

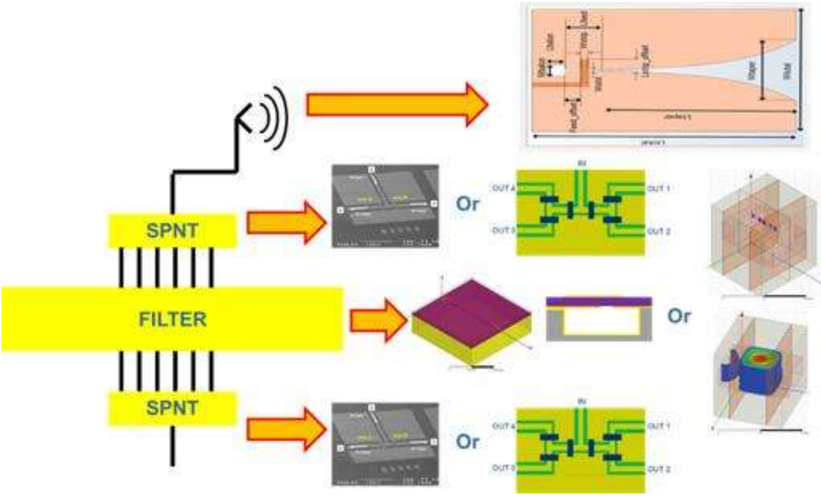


SPDT MEMS element of the T/R module

Completed full wafer 2nd fabrication on thinned GaN/Si substrate with TRT & FORTH merged technology

- **<u>Demonstrator # 2 : Reconfigurable front-end demonstrator</u>**

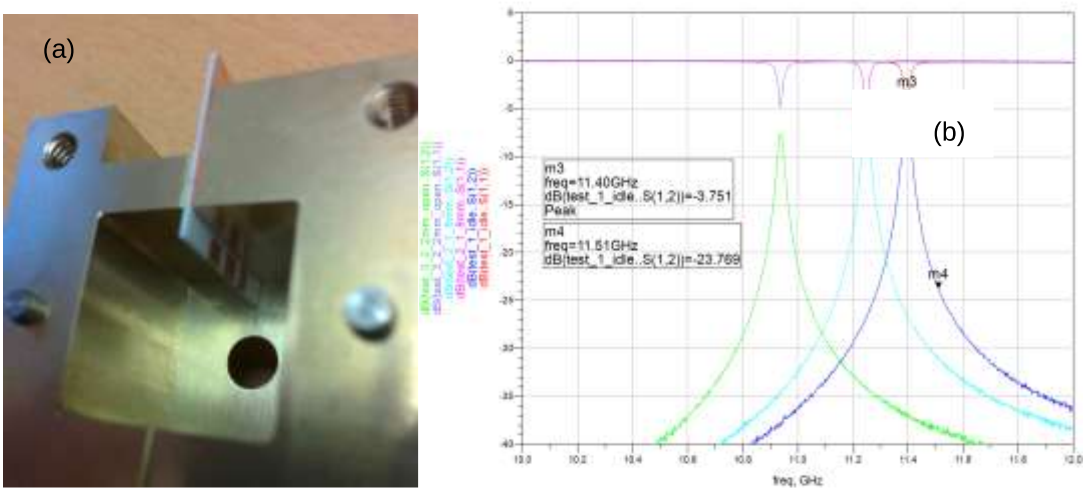
The design, manufacturing and characterization of the "**<u>high-Q" filter</u>** for the reconfigurable front-end of project NANOCOM have been successfully undergone. The measurements are close to the specifications: bandwidth (BW) 40 v.s. 10 MHz, insertion loss 2.5 v.s. 3-5 dB and selectivity of 20 dB at 125 v.s. 28 MHz from the carrier frequency. The key factor in improving filter's performance is increasing the Q-factor. There are several ways to increase the Q-factor such as gold or silver plating the inner filter enclosure, increased contact pressure on Ohmic contacts, reduce roughness of the metallic walls, etc... The Q-factor evaluate from post-measurements simulations is about Q_0=800, which is relatively high compared to the state of the art, but lower than initially simulated. The filter with the tuning RF-MEMS substrate in place is optimised for a high Q-factor of the TE_{101} mode. Tunability was demonstrated by measuring fixed stubs on the MEMS die, resulting in a maximal frequency shift of 800 MHz for a stub of 3 mm long and 2 width pla²ced in the centre of the resonant cavity.



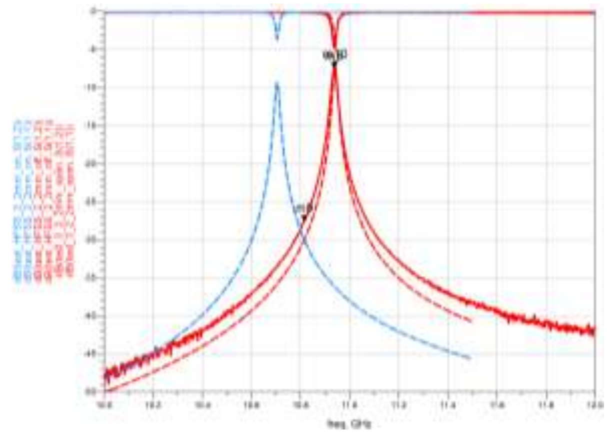
Reconfigurable front-end approach in the NANOCOM project

<u>Demo 2 - Filter Version 1</u>

A die of 18 x 18mm, 500µm tick Al_2O_3 has been inserted in the band pass filter. The die is provided with three metallic stubs, as can be seen in figure below. Several measurements were performed among which a successive commutation of the three stubs and a variation of the length of one tuning stub. The latest measurement is reported in figure below.



Tunable filter a) demonstration with fixed stubs on MEMS die and b) measurements



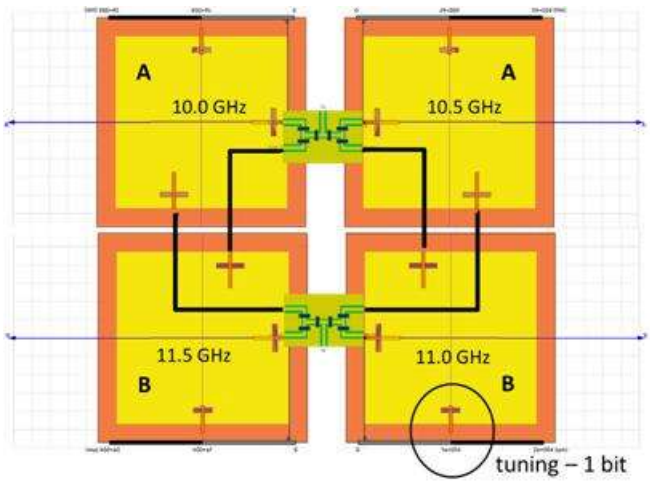
Adapted HFSS model after RF measurements with improved performance

Demo 2 – Filter Version 2

The second tunable filter realised in NANOCOM is the "**medium Q-factor" filter**. The specifications of this latest are little relaxed with a BW of 100 to 1000 MHz and a selectivity of 20 dB at 0.3-1 GHz from the carrier frequency. However, the integration is increased as this filter is fully integrated into a MEMS process as composed of the assembly of two wafers by thermocompression bonding. The top part is a standard high resistivity substrate (HRSi) of 325-400 µm thickness and permittivity epsr = 11.9 and resistivity 5000 Ωcm. The tuning concept of the medium filter is depicted in figure below.

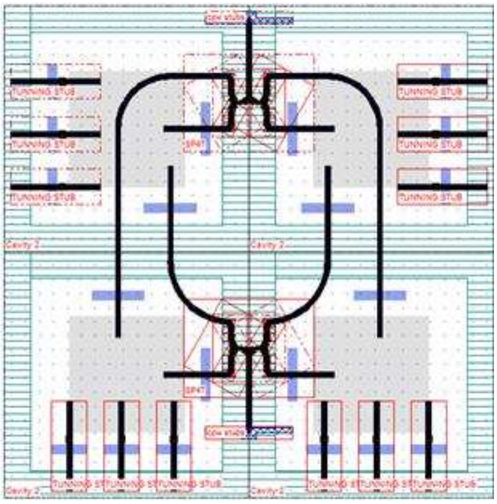
The filter is based on a rectangular cavity resonator, excited in its fundamental resonance mode TE_{101}.

As to fulfil the specifications, (5 bits filter) the concept is to use four cavity resonator filters, designed for 10 GHz, 10.5 GHz, 11 GHz and 11.5 GHz, respectively. The four cavities are connected with a SP4T. In addition, each filter is provided with a 1 bit fine tuning that could easily be increased to 3 bits and more.



Concept of the medium Q-factor filter: 4 cavity resonators connected with a SP4T and each provided with additional fine tuning up to 3 bits

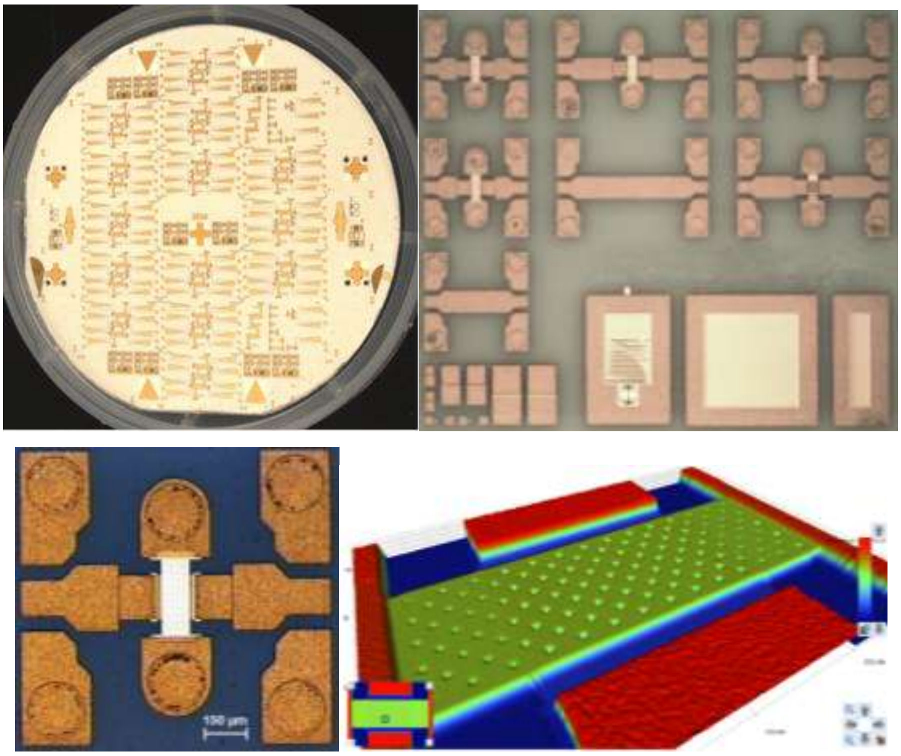
The final RF-MEMS layout of the medium Q-factor filter is presented in figure below. The medium Q-factor filter is composed of four resonant cavities with TE_{101} resonances at 10 GHz, 10.5 GHz, 11 GHz and 11.5 GHz, respectively. Overall, this demonstrator is incorporating all elements previously detailed in the previous Sections, such as detuning slots for the 3 bits fine tuning per cavity, SP4T and IN and OUT coupling slots. The overall foot print is 30 x 30 x 2 mm^3. Fabrication is in progress for this second design.



Final RF-MEMS layouts of the medium Q-factor filter

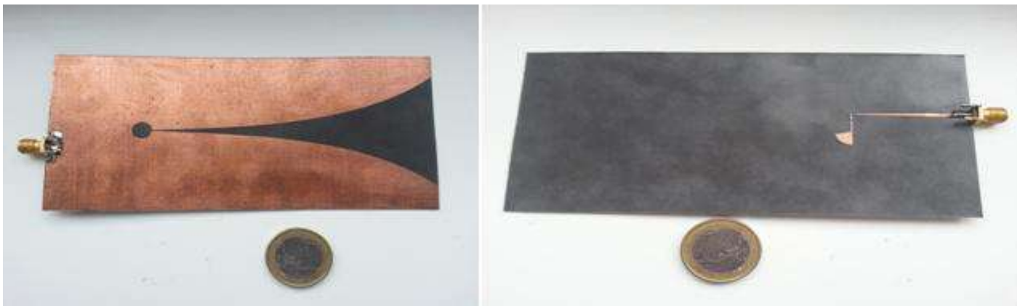
<u>Demo 2 - Filter Version 3</u>

In parallel, TRT has also developed a 10GHz design for filter applications based on a ceramic substrate with the selected dielectric material from the NANOCOM project.



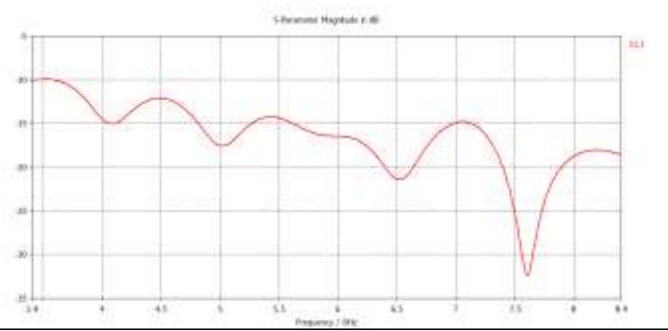
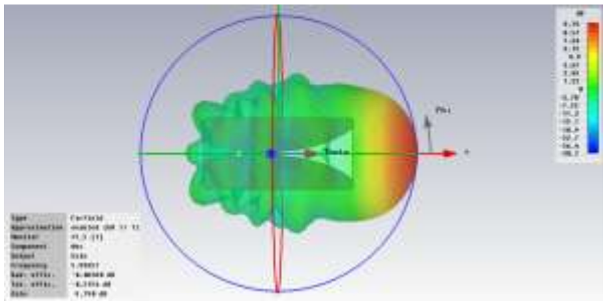
Development of a filter design on ceramic with a novel design

Concerning the **UWB antenna**, to attain ultra-wide band characteristics a Vivaldi structure has been chosen. The antenna was fabricated using chemical etching technique. Figure below shows front and back side of the fabricated antenna. An off set of 20 mm is given from the feeding edge to facilitate conductive gluing of the ground plane so that it will be easy to be integrated on to other module.

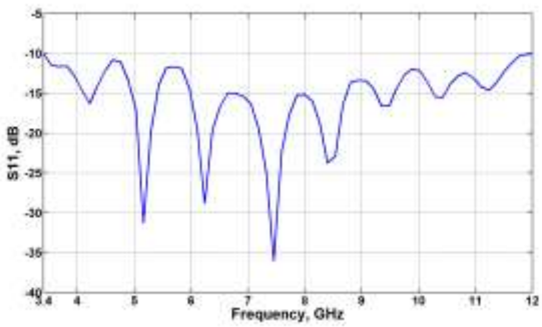


Front and back side image of fabricated antenna

Figure below left shows the simulated m-10dB band width of the antenna. It can be seen that the Vivaldi maintains good matching throughout frequencies ranging from 3.4 GHz to 11 GHz. Figure below right shows the radiation pattern of the antenna. The antenna is highly directive with almost 10dB simulated gain.

	
Simulated -10dB return loss of the Vivaldi antenna	**Simulated radiation pattern of the antenna**

S-parameters of the antenna is measured besides the radiation pattern and efficiency of the antenna. **Erreur ! Source du renvoi introuvable.** Figure below shows the measured S11 of the antenna and it can be seen that the antenna has very good matching over 3.4 – 12 GHz range. The antenna will perform well until 20 GHz but the due to the limitation of cable it is not shown in the result. The efficiency is measured efficiency is 98% around center frequency at 8 GHz. The antenna has a gain of 9 dB.



Measured -10dB return loss of the Vivaldi antenna

DISSEMINATION - Forum poster:

European Nano electronic Forum – November 2014, Cannes, France.