Main achievements to date toward the use of RF MEMS into space satellite payloads

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Abstract **—MEMS (Microelectromechanical Systems) technology plays a key role in the on-going miniaturization of electronic modules for automotive and consumer electronic products. In the microwave field, RF MEMS switches exhibit excellent RF properties as low power consumption, high linearity, low loss and high isolation compared to solid state electronic solutions. Based on these performances, we will present a status of the potentialities of RF-MEMS devices for application to future generation of space satellite payloads through some selected demonstrations achieved within Alcatel Space.**

I. Introduction

MEMS (Microelectromechanical Systems) technology plays a key role in the ongoing miniaturization of electronic modules and systems in future telecommunications, observation and space exploration satellites and probes. While MEMS operating in the low-frequency region are currently being employed in commercial products e. g. as acceleration sensors in automotive applications, the field of RF (radio frequency) MEMS is still in a state of research and early development. RF MEMS switches exhibit excellent RF properties such as low insertion loss, low power consumption and high isolation [1]. Consequently, MEMS can be integrated into satellite payload subsystems to achieve a higher degree of functionality, for example in phase shifting unit, low level routing networks or reflect array antenna.

Space environment is a harsh environment as such, so that packaging constraints are applicable to the RF MEMS components. These constraints can then challenge the overall performance and life time of the device [2]. Compliance with a large temperature range, mechanical vibrations and shocks etc. has to be achieved not only by the single MEMS device but also by the packaged subsystems. Within new generation satellite payloads, the potential applications envisaged by Alcatel Space (AAS) are two-fold. The first application is linked to on-board microwave electronic equipment whereas the second one is related to antenna application.

In this paper, we will show that packaging partitioning is one of the key issues for the application of RF-MEMS technology in the aforementioned fields.

II. RF MEMS application to on-board microwave electronic equipment

If we look at the satellite market trends, we notice an evolution toward higher frequencies (Ka band and upper) and greater functionality [3]. This directly triggers the need for complex redundancy scheme, but also large microwave routing network, and more generally ubiquitous microwave equipment. This increased complexity needs to remain iso performance compared to old generation, because we do not want to have a degraded telecom link toward the user on ground. This results in key advantage of RF MEMS switches over other solutions (waveguide and solid state electronic switches). It combines both the advantages of direct implementation into microwave circuits and high performance (high linearity, power capability, high contrast between On-Off state).

When an emerging technology such as RF-MEMS has a strong potential to be integrated into industrial products, the question that comes first is : should we go for component substitution or new subsystem definition with it ? In one hand, component substitution could be the easiest to implement but can, in the other hand, hide the core advantage of RF-MEMS technology : its intrinsic performances (low insertion loss, reconfigurability, collective process...). For now, AAS approach stands with the substitution scheme and is focused on three main application areas and is illustrated in Fig. 1.

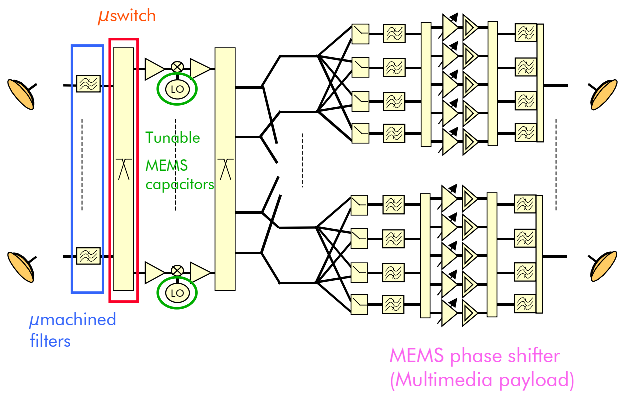

Fig. 1. : Standard transparent telecom repeater with main function that may implement RF MEMS

Example of realization are shown in the following. The first example shows the use of MEMS single pole double throw (SPDT) into low noise factor (NF), Ka band, LNA module. The second example shows some of the work done on variable capacitor for use into VCO for Ku band receivers. Finally, the last example focus on high Q planar filters for application into Ka band receivers.

a) Performance assessment of RF MEMS switches for redundancy within LNA module for Ka band focal array feed reflector (FAFR)

Within the French space agency (CNES) frame program TCS21 which should enable development of next generation of telecom payloads for the 21st century, the possible use of RF MEMS switches is evaluated for redundancy of Ka band LNA chains. This specific study fits with the need of having highly integrated, low noise factor (NF) LNA module (redundancy scheme is 2:1) for use in Ka band FAFR antenna. RF MEMS switches based SPDT are directly competing with PIN diode SPDT (see Fig. 2) which are the baseline solution due to their technological maturity and simplicity. In this project the RF MEMS technology used was from CEA-LETI [4].

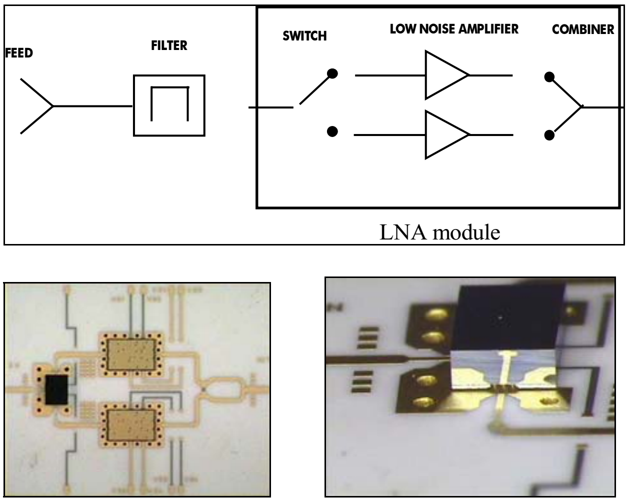

Fig. 2. : Schematics of the LNA FAFR front-end module applicable to PIN diode and RF MEMS (top figure) example of realized LNA module with MEMS SPDT

Because the RF switch is located before the Low Noise Amplifiers (LNA), its insertion losses must be as low as possible. The other main requirement is that the switch must not present any single point failure. That means that if one failure occurs, one way must remain operating. This issue has been solved both for diodes and RF MEMS switches SPDTs (patent pending on the SPDT configuration), which are now compliant with the single failure point criteria.

Because the LNA modules are located just behind the feeds, and the feeds are separated from each other approximately by one wavelength (around 12.8 mm at Ka band), the design constraints are put on LNA module size and LNA NF . When used in cold switching configuration the PIN diode based SPDT remains a strong competitor to its RF MEMS switches counterpart because of their small size, reliability and acceptable insertion losses. We could report 1.2dB insertion losses mesured for packaged diode SPDT at 30GHz.

In the case of MEMS based SPDT compatible with standard flip-chip bonding, we have measured insertion loss of 0.8 dB at 30 GHz for packaged SPDT. In addition at LNA module level, we measured a NF of about 3.95 at 30 GHz with compliant gain and matching at module level as shown in Fig. 3 below.

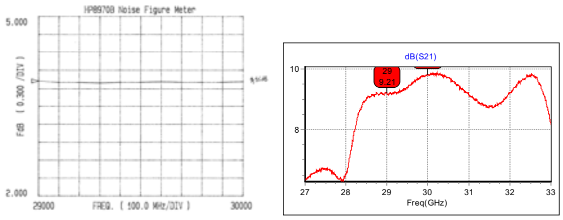

Fig. 3 : NF curve and gain curve module measurement obtained for 2:1 redunded LNA by MEMS SPDT

With improved design and packaging implemented at module level, we envision to further improve the SPDT performance (i.e. lower insertion, losses higher isolation, lower power consumption) thanks to more improved packaging partitioning at the LNA module level which should lead to less direct contribution from the packaging to the module NF.

b) RF MEMS tuning capacitors for use in C, Ku, Ku+ band frequency conversion (frequency generation)

Funded through IST 5th frame program from the European Commission, the MEMS2TUNE (« Development of a metal-based MEMS technology for realising tunable/switchable RF modules for wireless applications ») project aim is to develop a common technology platform that will implement integration of high passive components (capacitors, inductors,…) and metal-based RF MEMS (µswitch, variable capacitors,…) on high resistivity silicon substrate. This will allow to design and fabricate tunable/switchable RF functions with high compactness, extended capability and lower cost. Due to existing integrated passive technology available within one of the partners and the market segment addressed, frequency range is limited up to 6 GHz.

The prototype related to space satellite market is a voltage controlled (VCO) for Ku band receiver frequency conversion (1-4GHz) with MEMS based resonator.

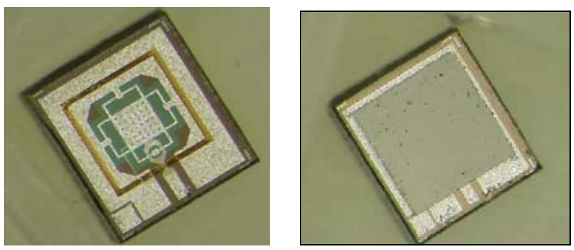

Fig. 4 : Close up of tunable MEMS capacitor before (left) and after (right) wafer level packaging (courtesy of Philips Research)

VCO are roughly constituted of 2 parts: LC resonator and an active part which brings the negative resistance. Our approach is to first go with the substitution of the varactor diode in the LC resonator circuit as it is done in most of the MEMS based prototype VCO elaborated up to now. The technology used to design the MEMS varactor is the one available at Philips Research, developed during the project [5]. In Fig. 4 and Fig. 5 is shown respectively a view of unpackaged and packaged MEMS varactor and typical C-V curves.

As can be seen in Fig.5, tuning ratio (Cmax/Cmin) up to 4 has been achieved with very good reproducibility on MEMS tunable capacitors.

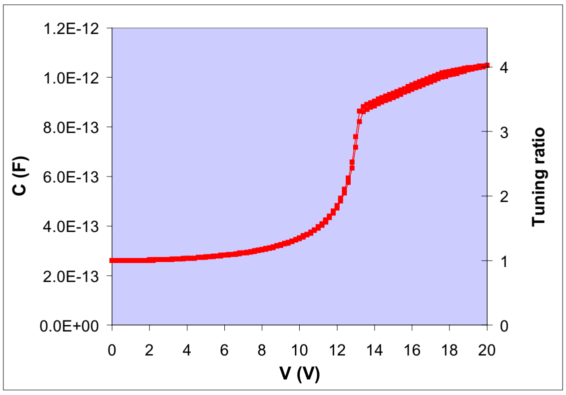

Fig. 5 : typical measured tuning ratio of MEMS capacitor

The same packaged device have been implemented into standard hybrid VCO and characterized. First tests have shown functionality (pure spectrum with expected VCO ray) and a tuning range of about 40 MHz for MEMS actuation voltage ranging from 10 to 25 V. Further tests are currently on-going.

c) High Q membrane supported planar filters

RF MEMS filters, when based on Si bulk micromachining technologies, merge advantages of both standard planar filter technology and waveguide filter technology which are miniaturization, cost reduction and high quality factor as far as Ka and Q/V band receivers are concerned. At these frequencies, waveguide components are widely used and offer good electrical performances. However, they result in high production cost and bulky components. Standard planar technologie suffer from radiation from the resonators into the substrate and from high resonator ohmic loss.

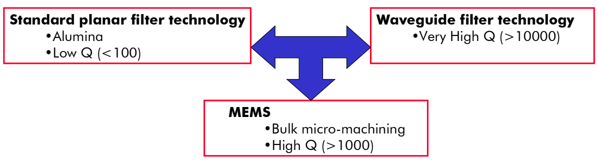

Fig. 6 : Principle of bulk micromachined Si filters compared to existing filter technologies

Basic idea is then put the resonator on a membrane into a shielded cavity. As a result, MEMS filters allow to combine both high Q and miniaturization as well as batch fabrication as illustrated in Fig. 6.

As shown in Fig. 7 below, the filter is constituted from three different wafers : The upper cavity, the dielectric membrane and the lower cavity. All of the cavities are micromachined using well known KoH wet etching of silicon. The three wafer are then stacked together and and glue with conductive epoxy to form a completely shielded self packaged circuit.

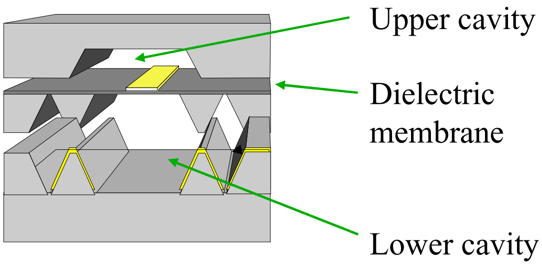

Fig. 7 : Illustration of typical membrane supported filter

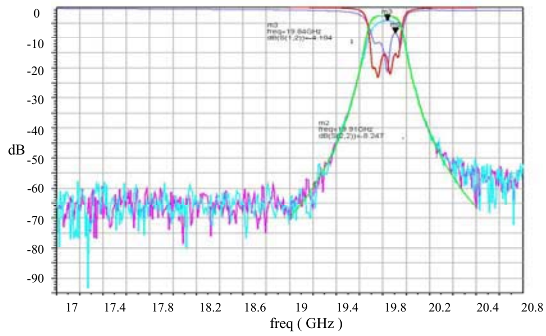

Fig. 8 : Comparison of test results with simulation obtained on a 4 poles, Ka band filter (-50 dB rejection obtained in 500 MHz frequency band)

In Fig. 8 is shown the comparison of simulated filter response with measured response. This filter was realized using IRCOM technology [6] with impressive results : –50dB rejection is exhibited at 20 GHz with less than 500 MHz bandwidth. This is what is specified to reject the spurious 2OL from RFout in Ka band down-converter (30/20 GHz). The shift in insertion loss is explained by the fact that the models has been done using HP momentum which does not account for the transition from bulk material to the membrane.

III. RF MEMS Application antenna : interest of MEMS based reconfigurable reflect array

Controllable reflect array antenna is also an important domain that can take advantages of RF MEMS. A reflect array is a planar array illuminated by a primary feed. This array is composed of planar elements reflecting the incident wave with a phase shift controlled through either by diodes or by MEMS, as described in the following figure. It is consequently possible to steer and form a beam by controlling the phase shift of the elements.

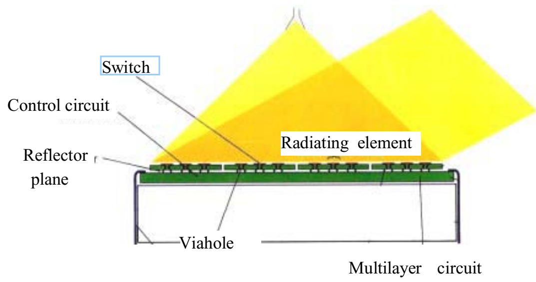

Fig. 9 : Principle of the reflectarray

A reflect array antenna is an attractive solution for reconfigurable antennas, for it has both advantages of arrays – beam shaping with fixed antenna - and reflectors

– high efficiency single feed. The reflect array is also very attractive for low profile antennas (passive or active), easy to stow in the launcher. AAS has a strong heritage on reflect arrays, and conducted different studies in order to build competitive products. The focus is put one study funded by the French government Department of Industry under acronym ARRESAT. This project, headed by AAS and in connection with Thales Research, academic partners and SMEs, was the first study on reconfigurable reflect arrays. The main objectives were to demonstrate the feasibility of low loss active phase shift elements with MEMS control and to demonstrate the high radiating performances of a reflectarray. The following specifications were selected for the phase shift element :

- Ka band ;
- Circular polarization ;
- Large bandwidth;
    - Low loss and integrates MEMS switches to monitor its phase ;
- Compact ,

The aimed application was satellite antennas of a telecommunication system using Low Earth Orbit satellites. Innovating phase shift elements, providing phase control thanks to Micro MEMS were designed and built. Special attention was given within the design process, to include the MEMS characteristics, expressed as a C_{down}/C_{up} ratio, where C_{down} refers to the capacity with the membrane down, and C_{up} to the capacity with the membrane up. These phase shift elements operated in circular polarisation over a very large band (17.8-19.3GHz), with a 2.5 bits resolution.

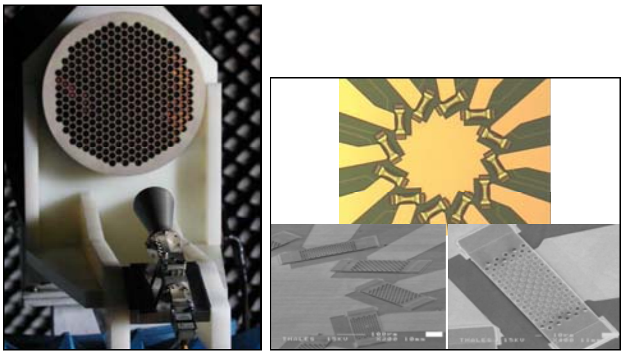

Fig. 10 : overall picture and detail of the phase shifting element of the manufactured reflect array.

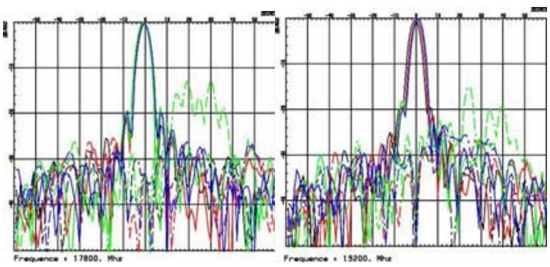

Fig. 11 : Results obtained on the overall bandwidth (17.8-19.2 GHz) for MEMS in fixed state.

A reflect array antenna was designed, fabricated, and measured. It has demonstrated excellent results over a wide band : Radiation efficiency > 60% over this band, and very low cross polarization (<-35 dB) ; as shown in Fig. 11 and [7].

The results will be further discussed at the conference together with application of other antenna configuration like a novel concept of phase shifter element with MEMS devices operating on linear polarisation [8].

IV. Conclusion

First attempts of direct implementation of RF MEMS based device into space satellite payload (Electronic microwave product and passive antenna) have been presented. Most of the work presented here have underlined Alcatel Space approach for now limited to solid state electronic devices substitution by MEMS based devices.

It has shown the potentialities of RF MEMS switches and varactors, but also the elements that could limit their introduction into actual space products such as suitable packaging partitioning and reliability concerns.

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