MEMS and Combined MEMS/LC Technology for mm-wave Electronic Scanning Reflectarrays

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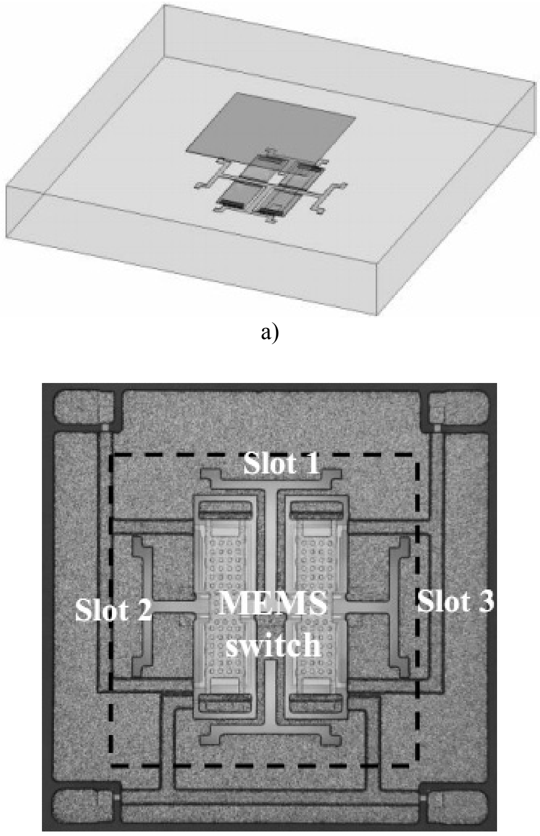
Abstract. This paper presents the most recent advances within ARASCOM project (MEMS & Liquid Crystal based' Agile Reflectarray Antennas for Security & COMmunication). One of the objectives of the project is the exploitation of MEMS and Liquid Crystal (LC) technology in mm-wave electronic scanning reflectarrays. In particular two solutions have been investigated: a MEMS-only approach, where the switches are used to obtain reconfigurable elementary cells with 1-bit of phase resolution - an efficient method applicable in large antennas; and a LC/MEMS combined solution, where the LCs provide a continuous phase-shift up to 180° and a MEMS is used to add another 180° when necessary. Preliminary results validate the proposed approach and give indications for future steps.

1. Introduction

Nowadays there are some emerging applications that would receive a significant benefit from the availability of low-cost mm-waves electronic beam scanning antennas, such as imaging and remote sensing. In such applications the electronic reconfigurability is a fundamental requirement if a reliable and real-time system (such as mm-wave imaging cameras) is to be obtained. However antennas with electronic beam scanning are very complex and costly to realize, especially at mm-waves.

In such a framework, reflectarray antennas represent a very attractive solution, since the quasi-optical feeding eliminates the loss and the parasitic effects associated with conventional RF distribution networks (e.g. phased arrays). In reflectarrays the reconfigurability of radiation pattern is obtained at element level, by varying the phases reflected by the radiating elements (i.e. by the elementary cells) [1-4].

A programme has been launched within the 7th Framework Program funded by the European Commission for the investigation of "MEMS & Liquid Crystal based Agile Reflectarray Antennas for Security & COMmunication" (ARASCOM) [5].


a)

b)

Fig. 1. Sketch of the elementary cell and picture of the phase shifting layer. Dotted line indicates the square patch located on the radiating side of the cell.

One of the major aims is the development of a 77 GHz electronic steerable reflectarray for imaging and security applications. Two solutions have been investigated: the first one is a pure MEMS solution based on the concept of 1-bit scanning antennas. In [6-7] it has been demonstrated that the beam of very large arrays can be steered by using just 1-bit phase shifters, with a loss of only 3 dB directivity and virtually no loss of pointing angle accuracy. This solution is simple yet very effective, and has proved to work in a 16x16 sample board where MEMS have been substituted by short/open connections [8-9]. Meantime the MEMS switching cells have been manufactured and tested, and are ready to be assembled in a first prototype.

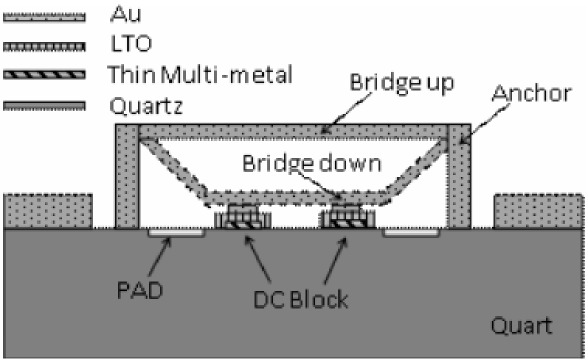


Fig. 2. Schematic side view of the slot line MEMS switch.

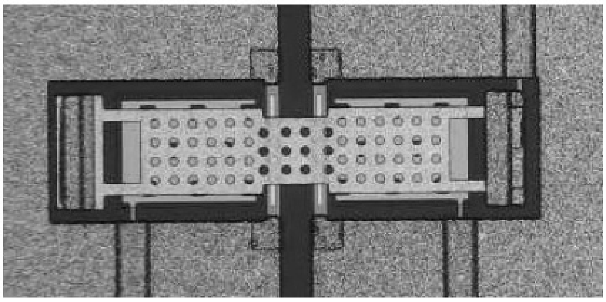


Fig. 3. Photo of SLO switch.

The second solution is based on a combination of LC and MEMS technology. LC, mainly known from display applications, can be used as tunable dielectric layer in structures similar to parallel plate capacitors [10]. By applying a tuning voltage the alignment of the anisotropic LC molecules can be controlled, therefore it is possible to change the effective permittivity of the material. The tuning process works continuously, hence analogue tunable phase shifters can be realized.

The phase shifter presented in this paper is based on a novel technology, which is compatible with a RF-MEMS process. The integration of tunable LC and MEMS components is possible and allows combining the advantages of both technologies, analogue tuning for LC part as well as a low loss design for the MEMS.

A description for both solutions is reported and future developments are discussed.

2. MEMS Slot-Line Solution

The elementary cell developed is depicted in. It is made by a square patch antenna realized on the top layer of a thin quartz substrate (h=300 μm). The patch is slot coupled to the 1-bit phase shifting circuit realized in slot-line technology on the backside of the quartz substrate. Two MEMS switches are placed on the slot-line layer (or phase-shifting layer), consisting of 3 lines connected in T configuration; each line is terminated with an U-shaped slot, so as to be coupled to one of the two linear polarizations that can be radiated by the patch. A fourth dummy slot (not connected) is used to make the layout symmetrical so that the radiation diagram of the elementary cell is identical for both polarizations.

The elementary cell is electronically reconfigured to provide 1-bit of phase resolution (0°/180°). A couple of MEMS switches are integrated in the phase-shifting layer; the MEMS bridges are anchored at the substrate and short-circuit the two metal planes when pulled down. The control of the cell is obtained by activating the switches so as to obtain a SPDT that alternatively connects slot 1 with slot 2 or slot 3. Observe that in order to independently activate each MEMS the actuation pads needs to be electrically separated from the slot-line ground.

When a linearly polarized field, either vertical or horizontal, illuminates the elementary cell theorthogonal polarization is back radiated, independently of the cell state. However, since line 2 and line 3 feed the patch at opposite edges, in the two cases the reflected field has opposite signs, equivalent to 180° phase difference, independent of frequency.

3. MEMS Slot-Line Switch Design & Manufacturing

The MEMS shunt ohmic switch has been designed in slot-line technology on 300μm Quartz substrate. The switch consists of a 410μm × 90 μm thick gold membrane clamped on the substrate at both extremities and 3μm suspended above a 32μm wide slot line. Two windows have been etched away from the slot metallization in order to accommodate the bridge anchors as well as the lateral activation electrodes as shown in Fig. 6. When the switch is in the up position (OFF STATE) the signal can flow along the transmission line; on the contrary when it is activated (ON STATE) it short-circuits the two metallic planes at the two contact points shown in Fig. 2. In order to keep separated the DC and RF signals, two DC-blocks have been integrated in series with the switch contacts, providing a capacitive short circuit at 76.5GHz. Thick Silicon oxide (600nm thick LTO - Low Temperature Oxide) has been used as a dielectric for the MIM capacitors in order to guarantee no break down up to high polarization voltages (>100V).

In order to mitigate dielectric charging phenomena, the dielectric has been removed from the surface of the activation pads. Mechanical stoppers have been patterned in the pads to prevent the contact between the down-state bridge and the dielectric-less pads.

The slot line 76.5 GHz MEMS switches and the MEMS-based radiating cell unit have been monolithically manufactured on 300µm thick Quartz substrate (4”) by using the 8 mask FBK RF MEMS process. A photo of the manufactured test switch is presented in Fig. 3.

DC measurement have been performed in order to characterize the behavior of the slot-line switches. The measurement set up consists of a Agilent 4156c Parameter Analyzer and 4284A LCR Meter. The variation of the capacitance between the grounded metal underpass and the bridge is recorded for increased positive bias voltage as shown in Fig 4. Actuation and de-actuation voltages of about 65V and 50V have been recorded. The monitoring of the pull-in and pull-out voltage under repeated and long term actuation show low charging effect thanks to the dielectric-less electrodes. Reliability tests are on-going.

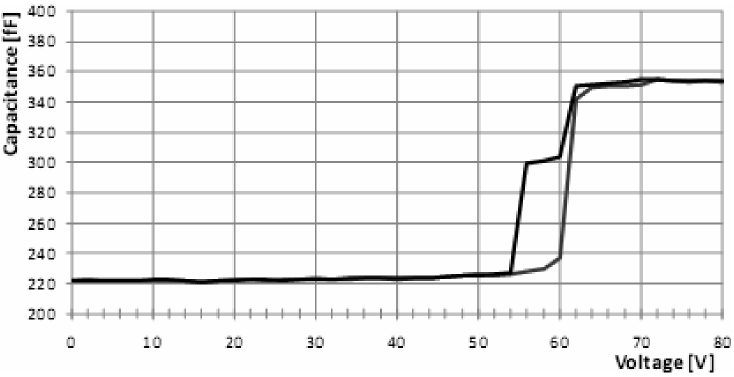


Fig. 4. CV measure of a switch.

4. LC/MEMS Solution

The combined LC and MEMS device is realized in a reflection type phase shifter (Fig. 5), where a 0…90° continuously tunable LC based phase shifter is terminated by a 0°/180° MEMS phase shifter.

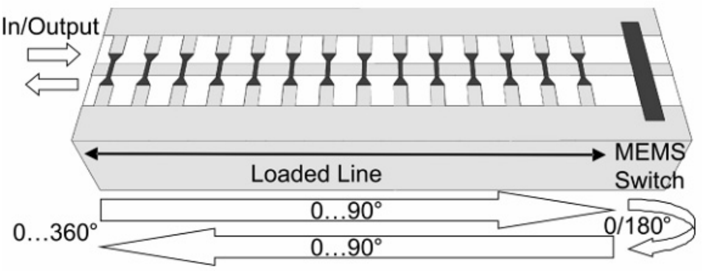


Fig. 5. LC MEMS combined reflection type phase shifter.

The incoming wave travels through the LC phase shifter, is delayed up to 90°, gets reflected at the MEMS phase shifter with 0° or 180° and is delayed on the way back by up to another 90°. Hence, the complete phase range of 360° can be tuned continuously.

In order to test and optimize the design process as well as the fabrication technology, a large number of variations of separate MEMS and LC parts as well as the combination have been fabricated and measured.

A photograph of the loaded line is shown in Fig. 6. The line consists of 14 unit cells, depicted in Fig. 7. Each of them contains a varactor, formed by a suspended MEMS bridge spanning over the inner conductor of the CPW line. The cavity between the MEMS bridge and the conductor is around 1.6 µm height. Filling of the LC cavity is performed with a micropipette, as a small drop of LC is placed close to the MEMS bridge and pulled underneath the bridge by capillary forces.

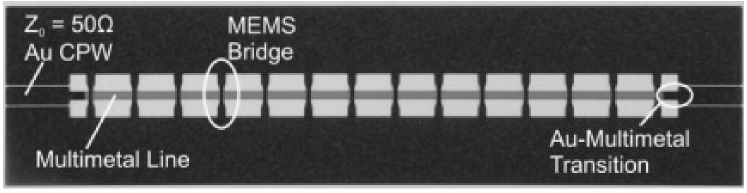


Fig. 6. Photograph of loaded line.

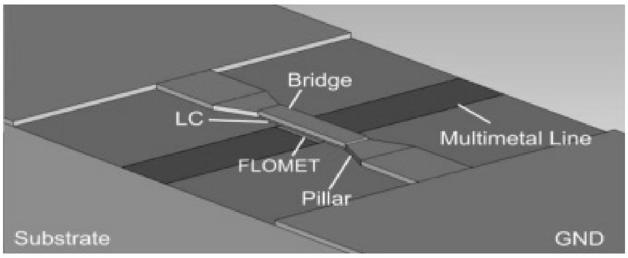


Fig. 7. LC based varactor.

The fabrication process is compatible with the RF MEMS process described in previous section. The structure is biased by applying a bias voltage between the inner conductor and the outer ground planes through the CPW measurement probes. By sweeping the bias voltage from 0V to 30 V, the differential phase delay can be set to values from 0 to 90° (Fig. 8).

The input matching of the LC loaded line phase shifter is below -15 dB for the frequency range from 65 to 97 GHz. The insertion loss is measured to be 2.4 dB at 76 GHz.

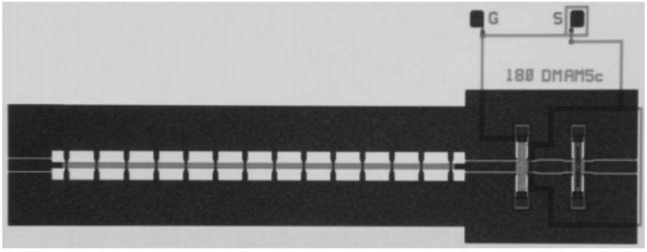


Fig. 8. Combined MEMS and LC phase shifter.

The complete combined LC/MEMS phase shifter is shown in Fig. 9. The MEMS is connected to the loaded line at the right side. Measurements of the 0/180° MEMS reflection-type phase shifter alone (not connected to the LC loaded line) have shown a differential phase shift of 198°.

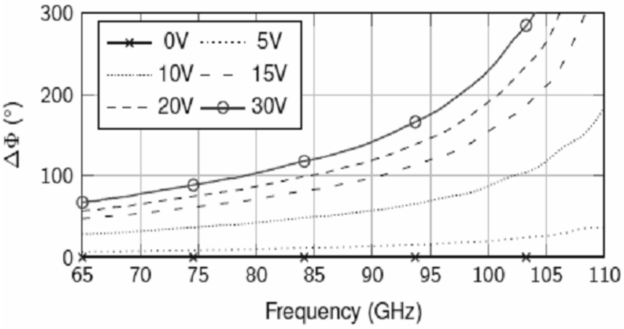


Fig. 9. Measured differential phase shift.

During the filling process of the combined phase shifter, it was observed that the LC is not only being pulled underneath the nearest MEMS bridge, but it also creeps along the CPW line towards the MEMS switch. The switch is therefore filled accidently by LC as well, measurements have shown that the phase shift of the MEMS termination is graduated to around 30°.

To overcome this problem, current work includes experiments on a barrier that will prevent the LC from flooding the MEMS switch as well as a capping solution for the MEMS.

5. Conclusions

Recent advances on reconfigurable reflectarrays operating at 77GHz investigated within the ARASCOM project are presented in this paper. Two approaches are proposed: the first one is suitable for very large reflectarrays and it is based on a MEMS elementary cell with 1 bit of phase resolution. The second approach uses analogue phase shifters obtained with a combined use of RF-MEMS and LC technology. Preliminary results are very promising; a first full working reflectarray is scheduled by September 2011.

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