Design and Realization of a MEMS Tuneable Reflectarray for mm-wave Imaging Application

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Abstract — **Electronic beam scanning reflectarrays represent a very interesting solution to obtain reconfigurable antennas at mm-wave frequencies. The potentialities of such systems could be further increased in terms of costs and performance by employing MEMS devices. In this paper we present the design and the simulated results of a two-layer MEMS tuneable reflectarray. This antenna is designed for outdoor passive mm-waves imaging applications (35 GHz). The target is to realize a low cost, fast, small and light antenna system to be implemented in portable devices.**

The manufacturing of the prototype is on the way at the ITC-irst (Trento – IT) laboratories.

I. Introduction

Imaging techniques at millimetre waves offer a number of benefits for many applications, such as airborne and satellite imaging, automotive, medical and security.

The materials show different properties in term of emission and reflection coefficients [1]. At mm-wave frequencies, the imaging systems show a scene according to dielectric and magnetic properties and temperature of the materials.

The working frequency changes depending on applications. In indoor mm-wave imaging, all the frequencies included in 10 ÷ 100 GHz range are allowed. In outdoor applications, the choice of the frequency is more important.

The atmosphere absorption changes dramatically form visible wavelength to microwaves [2]. In addition, weather conditions may affect the attenuation coefficient, depending on wavelength. At the frequencies from 20 to 100 GHz there are two different deeps in the attenuation curve.

In the Fig. 1 the atmospheric attenuation from 10 GHz to 1000 GHz is shown. The noisy line represents the atmospheric loss at different frequencies (20°, 1 Atm, H2O = 7,5g/m^3). Three flat lines represent three different meteorological conditions: drizzle (0,25mm/h), heavy rain (25mm/h), deluge (150mm/h). The last line represents the fog (0,1g/m^3) with visibility 50m. First minima of atmospheric attenuation appear at 35 and 94 GHz.

At these frequency bands, electromagnetic waves may provide high contrast images in unfavourable weather conditions.

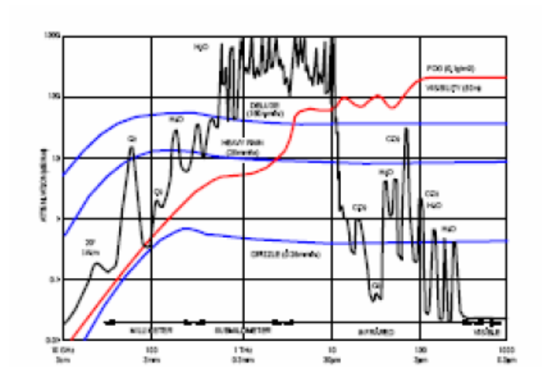


Fig. 1 – Atmospheric attenuation vs frequency.

In this work, an antenna system operating at 35 GHz suitable for outdoor mm-wave imaging devices is presented. The proposed solution is a MEMS tuneable reflectarray antenna with beam scanning capabilities.

An important advantage introduced by the reflectarray architecture, as opposed to classical reflector antennas, is the possibility to electronically scan the scene both in elevation and azimuth, without using complex and high losses feeding networks necessary in phased arrays.

Some authors [3-6] have proposed MEMS tuneable reflectarrays. To our knowledge, none of these antennas have been manufactured with real RF MEMS though, but rather by substituting them with short/open connections. Indeed, one of the most critical issues in the design of such complex systems is the large aspect ratio which makes it difficult to simulate the electromagnetic coupling between radiating elements and RF MEMS switches. In [3-6], the authors have designed MEMS tuneable reflectarray where MEMS are part of the radiating element.

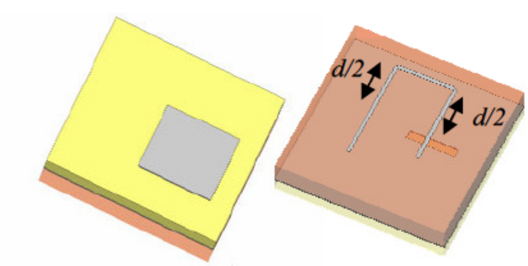
In this paper, we present a very simple design based on a different approach. By placing the radiating elements and the MEMS tuneable loads in separate metal layers, the mutual interaction can be minimized so that they can be designed independently.

II. Radiating element

The reflectarray is designed to operate at 35GHz.

Fig.1 depicts the elementary cell. The architecture consists of a two-metal layer where the radiating element is a slot-fed patch connected to a distributed phase shifter, which is open-circuited at the other port. The patch antenna is printed on the top side Rogers substrate 4003C, especially suitable for mm-wave frequencies in term of thickness (h = 0.305 mm), dielectric constant (εr = 3.38) and loss ($\tan\delta$ = 0.0021). The slot is printed on the patch ground plane and the microstrip line is printed on the silicon wafer bottom side, connected to a short-ended 8-states phase shifter, described in the next section.

The elementary cell is simulated in periodic conditions to take into account the mutual coupling effects and the dimensions are performed to be resonant and matched at the centre frequency. The analysis of the elementary cell reflecting properties is performed by assuming the phase shifter as an open circuit stub with variable length. The MEMS tuneable load is then designed in order to produce the same performance.



(a) Radiating (b) Phase shifter

Fig. 2 – Elementary cell dimensions: 4.285X4.285 mm ($\lambda_0/2 \times \lambda_0/2$ @35GHz). Section with length *d* introduced for feed compensation (CST layout).

The external feed is a low gain horn designed to have a 3dB beamwidth equal to 60° at 35 GHz, is placed at 20 cm from the centre of the reflectarray. An important step in the design of a reflectarray consists in the determination of the feed position and orientation. To this purpose some simulation tools must be used in order to evaluate the most important parameters of the antenna, such as the gain and the spillover efficiency. Moreover, the phase distribution of the field on the reflectarray aperture, generated by the feed, has to be evaluated and compensated in order to produce the desired radiation pattern [7]. The length *d* of the line connecting the phase-shifter to the slot (Fig. 2) introduces a delay in each element in such a way as to reflect a plane wave.

In order to determine a relationship between the variable line length and the phase of the scattered field by the radiating element, some full-wave simulations of the elementary cell has been performed, with a plane wave excitation and periodic boundary conditions. In each simulation the microstrip line length varies. In such way, the phase characteristic of the reflectarray element is determined. Fig. 3 shows the phase of the elementary cell scattered field derived for the centre frequency (35GHz) and off-resonance (34.5GHz and 35.5GHz).

As expected, the phase characteristic at the centre frequency is almost ideal, while phase errors become significant for frequencies far from resonance.

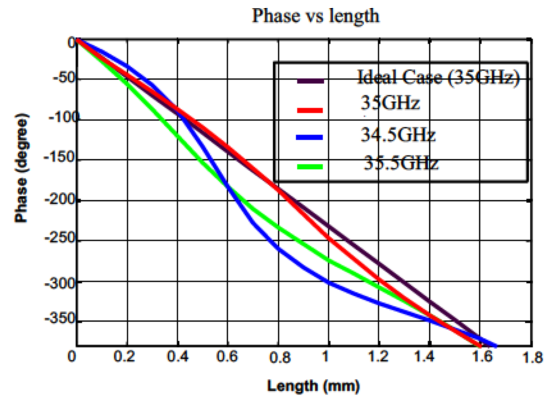


Fig. 3 – Phase versus Length for different frequencies.

III MEMS tuneable reflective load

The tunable reflective load consists of an open circuited microstrip transmission line whose length can be varied by activating ohmic MEMS switches. The line in indeed interrupted in correspondence of the MEMS bridge and the contact between two line sections is provided by the series switch in down position. A 3 bit tunable load is realized by cascading 7 MEMS switches as depicted in Fig. 4.a.

The line is 90µm wide resulting in a characteristic impedance of 67 Ohm. The MEMS switch consists of clamped-clumped gold membrane suspended above the interrupted microstrip line. The switch can be actuated by applying a voltage of about 50V between the membrane and the activation electrode underneath. This electrode as well as the entire bias network is realized by using high resistivity polysilicon in order to minimize the RF signal coupling and leakage through the DC line. When no voltage is applied, the membrane stands 3µm suspended above the interrupted signal line, resulting in a parasitic series capacitance of about 10fF. On the contrary, applying the pull-in voltage, the membrane moves downwards and short-circuits the two microstrip sections. The bridge is 500 µm long and a winged shape was chosen in order to realize a very low resistance contact (~ 2 Ohm) between the bridge and the microstrip line. Coplanar version of similar MEMS switches were indeed already manufactured and tested at ITC-irst showing improved RF and reliability performance ([8]). Fig. 4.b shows the phase shift for the different states computed by using the full wave simulator ADS-Momentum.

The phase shift and return loss amplitude for the 8 phase shifter states are summarised in Table1 at the antenna operating frequency (35 GHz). Note that the parasitic upstate capacitance and the downstate contact resistance have been taken into account in the full wave simulation.

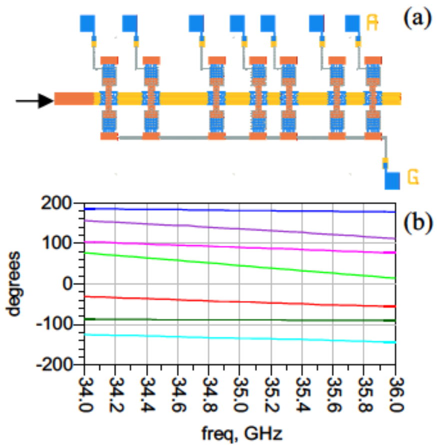


Fig. 4 – MEMS tunable reflective load: (a) layout; (b) phase shift @ 35GHz for the 8 states.

MEMS	*Phase-shift*	*S11[dB]*
***0* – state 0**	*0°*	*0,1*
***1* - state 2**	*-89.57°*	*0,14*
***2* - state 4**	*-179.92°*	*0,32*
***3* - state 6**	*-270.01°*	*0,72*
***4* - state 1**	*-44.87*	*0,56*
***5* - state 3**	*-134.24°*	*0,49*
***6* - state 5**	*135.64°*	*1,13*
***7* - state 7**	*44.91°*	*1,49*

Table 1 – The phase shift and return loss amplitude for the 8 phase shifter states @35GHz

IV. Reflectarray prototype: simulated results

The proposed 12x12 (6x6 cm^2) beam scanning reflectarray is designed at 35 GHz.

In order to reduce the number of the control signals, the beam scanning is allowed only in the E-plane of the antenna. Consequently, the tuneable loads in the same row are controlled by the same signal. The phase shifting device is a 3 bit MEMS tuneable load (7 MEMS), resulting in 84 biasing lines that control the beam steering in one plane.

The manufacturing is under fabrication at ITC-irst: the Silicon wafer will be assembled with the Roger 4003C substrate through an adhesive film. The control network integration and the RF circuitry packaging will be carried out at OPTOI laboratories (Trento, IT).

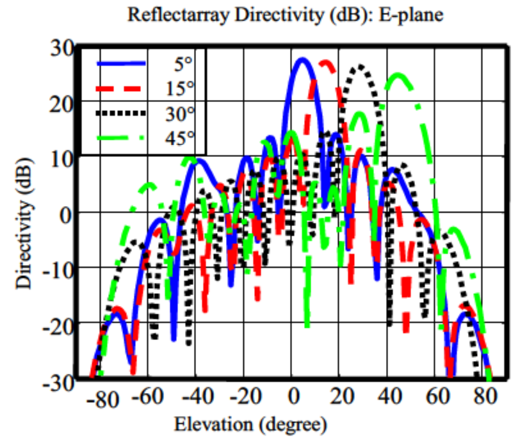


Fig. 5 – Simulated radiation pattern for different scanning angles: 0°, 15°, 30° e 45°.

Fig.5 shows the simulated results of the 12x12 reflectarray radiation pattern for different scanning angles in elevation region: 0°, 15°, 30° e 45°.

The phase distribution on the reflectarray surface has been quantized by using the simulated values of the phase shifter in term of the phase and losses. As shown in Fig. 5, the phase-quantization produces some rising of the side-lobe level that becomes significant only at 45°.

V. Conclusions

This work is the result of a collaboration between University of Perugia and ITC-irst Trento, in the framework of the European Network of Excellence in the MEMS device AMICOM (www.amicom.info). We propose an electronic beam scanning reflectarray for mm-wave imaging applications at 35 GHz. The beam reconfigurability is obtained by employing MEMS tuneable loads. The antenna is a three-metal layers in microstrip technology, the elementary cell being a slot-coupled patch connected to an open-ended MEMS phase shifter. The manufactory of the first prototype is on the way.

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