

A 60 GHz Beam-Steering Reconfigurable Antenna

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Abstract—We present the design, microfabrication, and characterization of a multifunctional reconfigurable antenna (MRA) with beam steering capability operating at 60 GHz band (59-66 GHz). The MRA provides 3 different beam directions pertaining to: $\theta \in \{-30^\circ, 0^\circ, 30^\circ\}$; $\phi = 90^\circ$ based on reconfigurable parasitic layer approach. The structure consists of three layers namely, feed, driven antenna and reconfigurable parasitic layers. The first two layers use RF and microfabrication process compatible quartz ($\epsilon_r = 3.9$, $\tan\delta = 0.0002$) substrate while parasitic layer is formed on a low-cost pyrex ($\epsilon_r = 4.9$, $\tan\delta = 0.01$) material with air cavities formed underneath. The upper surface of pyrex has 3x3 rectangular shaped metallic pixels, four of which are interconnected by means of switching. By judiciously controlling the switch status the beam-steering is accomplished. The simulated impedance and gain characteristics show $\sim 15\%$ bandwidth over which the maximum realized gain remains relatively flat around ~ 7.2 dB for all modes of operation.

I. INTRODUCTION

The demand of high data rate has been frantically increasing in the recent years due to expansion of smart devices and cloud-based applications. In response, the development of wireless communication systems operating at higher frequencies such as mm-Waves (WiGig, 60GHz) has become a popular research area of interest for both academy and industry [1]. While this mm-Wave frequency range is excellent in offering very broad bandwidth (BW) and high data rates, the associated propagation losses are too severe to ignore. This makes necessary to develop antenna systems with high gain and beam-steering capability. Phased array antennas with excellent beam-steering capability and high gain can provide the desired antenna properties [2]. This, however, comes with high cost and complexity, which may be prohibitive for some commercial wireless communication applications. The MRA with beam-steering capability presented in this paper has the potential to be the main building block of a new class of mm-Wave antenna array with low-cost and complexity [3]. The main novelty of such a reconfigurable antenna array is its variable element factor which is fixed for legacy phased array antennas. This work presents the design, manufacturing and initial characterization of a single element MRA. This MRA structure takes advantage of a low-cost and microfabrication process compatible pyrex material, which is used to create reconfigurable parasitic layer.

II. ANTENNA DESIGN AND FABRICATION

The MRA structure as shown in Fig. 1 and Fig. 2, is designed to reconfigure the main beam direction of the ra-

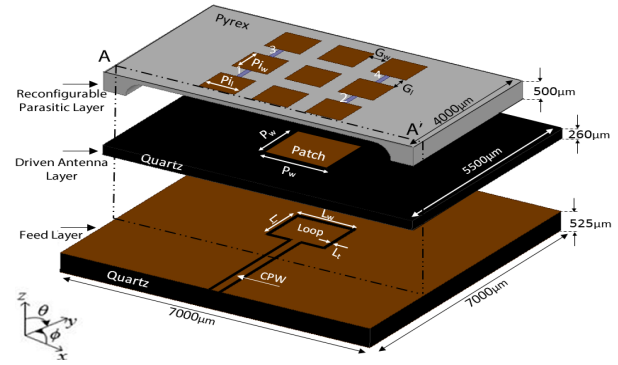


Fig. 1. 3-D Schematic of the designed MRA (for illustration purpose the layers are suspended on top of each other), (1, 2, 3, 4 denote switches location)

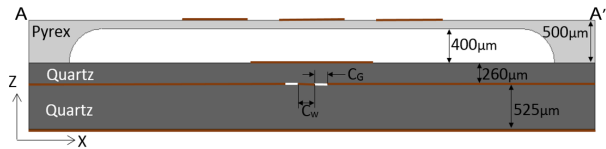


Fig. 2. A-A' Cross section view of the pattern reconfigurable antenna.

diation pattern into three different directions pertaining to: $\theta \in \{-30^\circ, 0^\circ, 30^\circ\}$; $\phi = 90^\circ$ over 59 - 66 GHz band. The antenna structure consists of three layers namely, the feed, driven antenna and reconfigurable parasitic layers with respective thicknesses of $525\mu\text{m}$, $260\mu\text{m}$ and $500\mu\text{m}$. The bottom and middle layers which house the CPW-fed loop and driven patch antenna, respectively, are formed on quartz substrates which provides good RF properties and micro-fabrication process compatibility. The CPW-fed loop couples the EM energy to the patch antenna, which results in broad BW. The formation of copper metalization for both layers are implemented by basic microfabrication processes of thin layer metal deposition via electron-beam and lift-off techniques. The top layer is made out of low cost pyrex material which is thinned down to $100\mu\text{m}$ by using standard chemical wet-etch process. The upper surface of this layer has 3x3 metallic rectangular shaped pixels, which are connected or disconnected by means of switching, where for the sake of simplicity these interconnections are employed as perfect short and open circuits in this work. Among the total of twelve interconnections between adjacent pixels only four need to

be controlled to accomplish the targeted three different beam-steering directions. This layer is solely used for mechanical support for reconfigurable pixel surface and the air cavity formed underneath with a thickness of $400\mu m$ serves as low dielectric constant and low loss medium. The design parameters are jointly optimized to simultaneously yield broad impedance BW, high gain and desired beam steering capability. The optimized design parameters of the patch element, CPW-fed loop, and the reconfigurable parasitic layer which are obtained by full-wave EM simulations are provided in Table I.

TABLE I
THE CRITICAL DESIGN PARAMETERS OF THE MMWAVE MRA (ALL DIMENSIONS ARE IN mm).

P_{il}	0.8	P_{iw}	0.8	G_l	0.4	G_w	0.4
P_w	1	L_l	1	C_G	0.02	C_w	0.191
P_l	1	L_w	1.2	L_t	0.02	S_t	0.1

III. RESULTS AND CHARACTERIZATION

The top view of the MRA showing switch locations is depicted in Fig. 1. A multi-objective genetic algorithm optimization [4] in conjunction with full-wave analysis is used to design the reconfigurable parasitic surface. Results indicate that only four out of twelve interconnections need to be controlled in order to achieve targeted three beam steering directions pertaining to: $\theta \in \{-30^\circ, 0^\circ, 30^\circ\}$; $\phi = 90^\circ$ over 59- 66 GHz band. The corresponding optimized switch configurations are given in Table II.

The simulated reflection coefficients for all the three modes of operation are given in Fig. 3. The intersection of three individual reflection coefficients indicate a common BW of 6 GHz covering 59-65 GHz band. The total realized gain patterns in Y-Z plane corresponding to each mode of operation at 60 GHz are shown in Fig. 4. The maximum realized gain

TABLE II
THE SWITCH STATUS CORRESPONDING TO THREE BEAM STEERING DIRECTIONS (0 = OFF, 1 = ON).

SwitchNumber	1	2	3	4
$\phi = 90^\circ, \theta = 0^\circ$	0	0	0	0
$\phi = 90^\circ, \theta = -30^\circ$	1	1	0	0
$\phi = 90^\circ, \theta = 30^\circ$	0	0	1	1

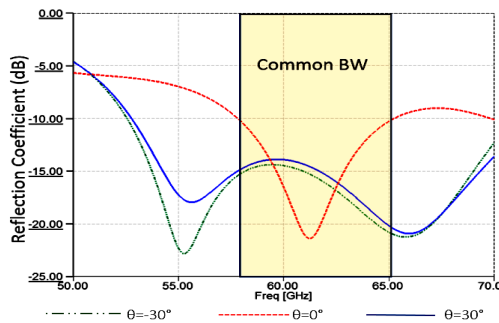


Fig. 3. Simulated reflection coefficient of the MRA.

values in the steered beam directions are all above ~ 7 dBi. The realized gain values for all modes of operation over the entire 59 - 64 GHz band are in the range $\sim 6.5 - 7.9$ dB as shown in Fig. 5.

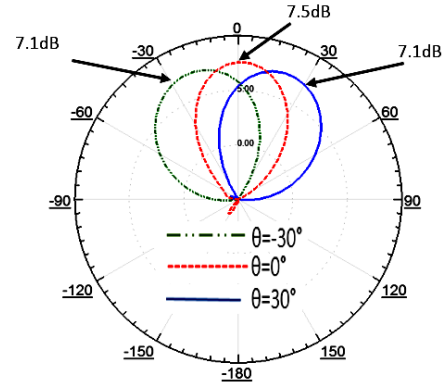


Fig. 4. Simulated total realized gain plots of the MRA in $\phi = 90^\circ$ (Y-Z) plane.

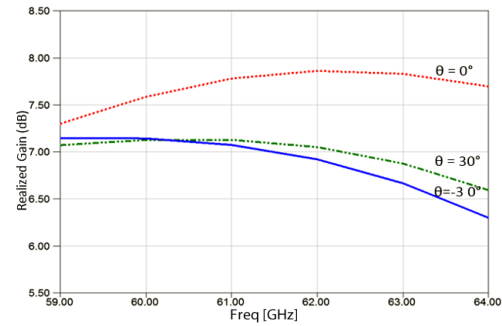


Fig. 5. Simulated realized gain values over 59-64 GHz band for three beam-steering directions $\theta \in \{-30^\circ, 0^\circ, 30^\circ\}$; $\phi = 90^\circ$ (Y-Z) plane.

IV. CONCLUSION

In this paper, an MRA with beam steering capability operating at mm-Wave range is designed and simulated. The simulation results for different operational modes indicates a realized gain around 7 dBi covering 59-64 GHz band. The low-cost and microfabrication compatibility of this MRA makes it a useful candidate for mm-Wave application. Our current efforts are concentration on replacing perfect short/open connections with p-i-n diodes and performing measurements.

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