A Low Cost Reflect Array for Near-field Millimeter-Wave Beam Focusing Applications

Ali Molaei*, Jose Martinez-Lorenzo*†
*Electrical & Computer Engineering, Northeastern University, Boston, MA, USA
†Mechanical & Industrial Engineering, Northeastern University, Boston, MA, USA

***Abstract*—A low cost millimeter-wave (mm-wave) electronically reconfigurable Reflect Array (RA) has been presented in this paper. Aperture-Coupled Patch (ACP) elements are used to form a 40×40 element reconfigurable RA operating in the 71-74 GHz range of the mm-wave band. A feeding network, integrated with Single-Pole, Single-Throw (SPST) switches is designed to adjust the phase of the reflected field for the ON/OFF state of the switch. The performance of the reconfigurable RA is evaluated by performing beam focusing at the near-field of the array.**

I. Introduction

Reflect Arrays (RAs) are planar printed surfaces that are excited by an electromagnetic incident field and direct the field in a desired direction or point. RAs have a combined technological features and characteristics of parabolic reflectors and electronically scanned phased array antennas, including the following: low weight, small size, simple feeding system, and low feeding loss [1], [2]. These features make RAs an attractive architecture for both near-field beam focusing and far-field beam steering applications. Dynamically controlled radiation in the RA can be achieved by the use of electronically tunable reflecting elements, such as PIN diodes [3], varactor diodes [4], and MEMS switches [1], [5]. The family of patch antennas is a good candidate for radiating elements of RAs, due to their low cost, light weight, conformability to the host surface, and easy manufacturing process [6]. Among the patch antenna configurations, the Aperture-Coupled Patch (ACP) [7] provides the benefit of isolating spurious feed radiation by adopting a common ground plane.

This paper presents a low cost electronically reconfigurable RA, which employs an 8×1 array of ACPs as its radiating elements. Each 8×1 ACP array is electronically controlled by a Single-Pole, Single-Throw (SPST) switch, to adjust the phase of the reflected field. Near-field beam focusing of an RA consisting of 40×40 reflecting elements is studied in the frequency range of 71-74 GHz.

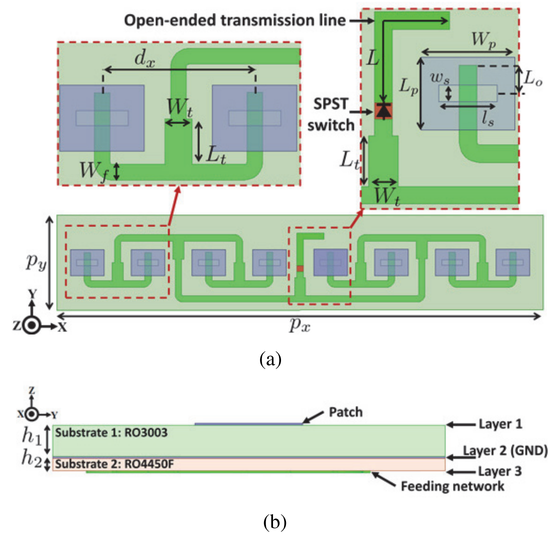

Fig. 1. (a) Top and (b) side view of the 8×1 ACP array used in the reconfigurable RA.

into reflecting elements of the RA to enable dynamic beam focusing for the purpose of this paper. The length of the open-ended transmission line L in the feeding network of the array is adjusted such that the phase of the reflected field changes approximately by π when the diode switches from the ON state to the OFF state, and vice versa.

The 8×1 unit-cell has been simulated using the Ansoft High Frequency Structure Simulator (HFSS). Periodic boundary conditions are defined along the XZ and YZ bounds of the 8×1 array to consider the mutual coupling between adjacent ACP elements. Table I shows the assigned values of the design parameters mentioned in Fig. 1. The RO3003 with dielectric constant of 3 and thickness of $h_1 = 0.254$ mm is used as the top dielectric substrate to support the patches and the RO4450F

TABLE I
OPTIMIZED PARAMETERS OF THE 8×1 ACP ARRAY.

PAR.	VAL. [mm]	PAR.	VAL. [mm]	PAR.	VAL. [mm]
W_p	1.13	W_f	0.21	p_x	16.32
L_p	0.88	W_t	0.36	p_y	3.2
w_s	0.2	L_t	0.6	h_1	0.254
l_s	0.7	L	1.9	h_2	0.1
L_o	0.44	d_x	2.04		

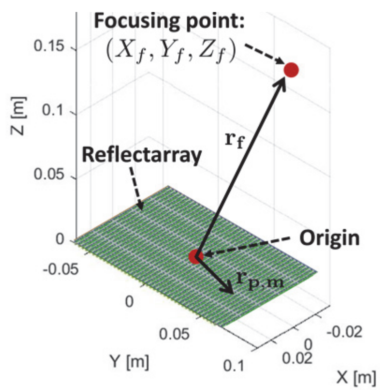

Fig. 2. Schematic representation of the beam focusing system.

to focus the main beam in the focusing point (X_f, Y_f, Z_f), as shown in Fig. 2. Considering a Uniform-Plane-Wave (UPW) normally incident on the RA, the phase variation associated with the reflected field from the m-th 8×1 array traveling to the focusing point is given by $\Delta\Phi_m = k_0(|\mathbf{r_{p,m}} - \mathbf{r_f}|)$, with k_0 being the wavenumber of the incident UPW. Therefore, to produce a focused beam at point $\mathbf{r_f}$, the ON/OFF state of the SPST switch at the m-th 8×1 array is dynamically assigned to introduce the following phase correction term

$$F(\Delta\Phi_m) = \begin{cases} \pi \text{ if } \Delta\phi_m \bmod 2\pi < \frac{\pi}{2}, \\ \pi \text{ if } \Delta\phi_m \bmod 2\pi > \frac{3\pi}{2}, \\ 0 \quad \text{otherwise.} \end{cases} \tag{1}$$

Figure 3 shows the reflected fields of the designed RA, when it is focused at the point (0 cm, 10 cm, 20 cm), for 71 GHz, 72.5 GHz, and 77 GHz.

IV. CONCLUSION

This paper presents the design of a low cost electronically reconfigurable RA for near-field beam focusing applications. An ideal SPST switch is integrated to a microstrip feeding network to adjust the reflected phase from an 8×1 ACP array (unit-cells of the reconfigurable RA). Near-field beam focusing

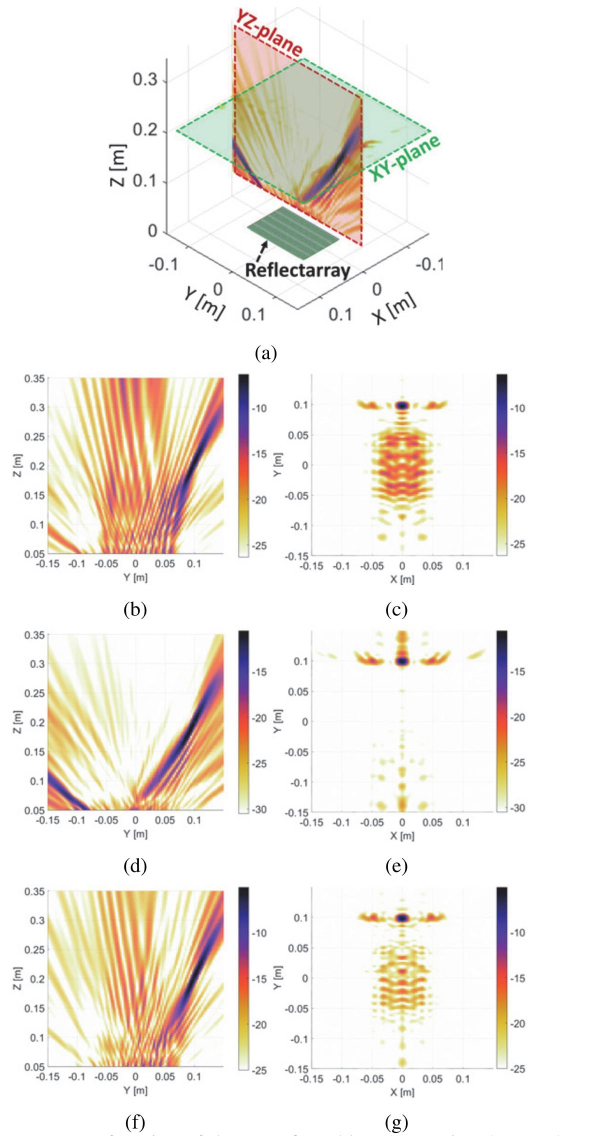

Fig. 3. (a) Beam focusing of the reconfigurable RA at point (0 cm, 10 cm, 20 cm): reflected E-field at (b,c) 71 GHz, (d,e) 72.5 GHz, and (f,g) 74 GHz.

[2] H. Gomez-Sousa and J. A. Martinez-Lorenzo, "Modeling and imaging security threats using a single-frequency adaptable reflect-array," in *Technologies for Homeland Security (HST), 2017 IEEE International Symposium on*. IEEE, 2017, pp. 1–7.

[3] H. Tanaka and T. Ohira, "Beam-steerable planar array antennas using varactor diodes for 60-ghz-band applications," in *Microwave Conference, 2003. 33rd European*, vol. 3. IEEE, 2003, pp. 1067–1070.

[4] R. B. Waterhouse and N. Shuley, "Scan performance of infinite arrays of microstrip patch elements loaded with varactor diodes," *IEEE transactions*