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Title	Investigation of a Reconfigurable Pixel Antenna for Millimeter Wave Bands
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Source	2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting, IEEECONF 2020 - Proceedings, / IEEE. Piscataway, NJ : IEEE, 2020, p. 295-296, Article number 9330090
Version	Accepted Version
DOI	10.1109/IEEECONF35879.2020.9330090
Publisher	IEEE
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Investigation of a Reconfigurable Pixel Antenna for Millimeter Wave Bands

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Abstract—The performance of a reconfigurable pixel antenna operating at 27 GHz is investigated in this paper. With different states of hardwired connection, the proposed pixel antenna can achieve a beam scanning range of 240° in the azimuth plane with 6.6-8.9 dBi realized gain. When all hardwired connections are replaced by PIN diode switching, the scanning range and realized gain reduce to 120° and 4.5-7.5 dBi respectively. The antenna efficiency is also decreased to around 65% from over 90%. It is concluded that, more efficient RF switches should be studied for use in future millimeter-wave reconfigurable pixel antennas.

Index Terms—beam-steering, millimeter-wave (mm-wave) antenna, pixel antenna

I. INTRODUCTION

In 2016, the Federal Communication Commission (FCC) announced millimeter-wave (mm-wave) bands for fifth generation (5G) wireless communications. Although the wide bandwidths available in mm-wave bands can support higher data throughputs [1], the larger propagation path loss and the complicated antenna fabrication process need to be considered. Therefore, the investigation of mm-wave antennas, particularly with reconfigurability, is important.

In this paper, we provide a design for an endfire reconfigurable pixel antenna operating at 27 GHz and investigate its performance. The proposed antenna resembles a Yagi antenna in which the dipole acts as a radiator while a parasitic pixel array acts as directors. The connection state between pixels is optimized for maximum gain and beam steering range [2]. It is shown that a steering range of 240° in the azimuth plane with 6.6-8.9 dBi realized gain can be achieved when hardwired connections are utilized. Radio frequency (RF) switches constructed from 52 PIN diodes, MA4AGFCP910 manufactured by Macom, are then used to replace the hardwired connections in the antenna design. Due to the loss of the PIN diodes, the antenna efficiency is decreased to around 65% from over 90%. In addition, the PIN diode version of reconfigurable pixel antenna can only achieve 120° steering range with 4.5-7.5 dBi realized gain.

II. ANTENNA DESIGN

Figure 1 illustrates the geometry of the proposed reconfigurable pixel antenna, which is based on the structure from [3]. The antenna consists of a half-wavelength dipole, a rectangular

ground plane at the back side of the substrate, and a 4×8 parasitic pixel array located at the front of the dipole. The substrate used is 0.787 mm-thick Rogers RT5880, in which the permittivity and loss tangent are 2.2 and 0.0009 at 10 GHz respectively.

Fig. 1. Geometry of proposed reconfigurable pixel antenna.

The PIN diode MA4AGFCP910 is selected as an RF switch and the equivalent circuit models of the OFF- and ON-states in the frequency band of interest (26-29 GHz) are shown in Fig. 2.

Fig. 2. RF equivalent circuit models of PIN diode used.

III. SIMULATION RESULTS

The reflection coefficient (S_{11}) and radiation pattern results of the proposed antenna when all pixels are isolated ideally and connected with PIN diodes in the OFF-state are shown in Fig. 3. The -10 dB bandwidth of the two arrangements are 5.3 GHz (from 25.2 to 30.5 GHz) and 3.8 GHz (from 26.2

to 30 GHz) as shown in Fig. 3(a). Figure 3(b) also compares their radiation patterns in the xy plane at 27 GHz. It can be perceived that the directivity of the antenna with PIN diodes is higher while its realized gain is lower. This indicates that the loss in the diodes causes the reduction in antenna efficiency.

Fig. 3. Simulation results when all pixels are ideally open and all pixels are connected with diodes in the OFF-state. (a) S_{11} . (b) Directivity and realized gain in xy plane at 27 GHz.

The radiation patterns with hardwired connections and PIN diode switching optimized for different angles are shown in Figs. 4(a) and (b) respectively. The reconfigurable pixel antenna using hardwired connection can achieve a range of 240° beam-steering range with peak gains of 8.91 dBi, 8.97 dBi, 7.71 dBi, 6.69 dBi, and 6.93 dBi at $\phi = 0^\circ, \pm 30^\circ, \pm 60^\circ, \pm 90^\circ$, and $\pm 120^\circ$ respectively. On the other hand, the reconfigurable pixel antenna using PIN diode switching can only achieve a steering range of 120° with peak gains of 7.49 dBi, 6.21 dBi, and 4.55 dBi at $\phi = 0^\circ, \pm 30^\circ$, and $\pm 60^\circ$ respectively. The narrower steering range and lower realized gain are caused by the loss of the PIN diodes. Table. I lists the simulated reconfigurable antenna efficiencies with different beam-steering angles. The reconfigurable pixel antenna connected by hardwires exhibits much higher efficiency and is larger than 95% for all states. However, the efficiency becomes less than 69% when PIN diodes are used. Thus, the properties of the diodes affect the antenna efficiency severely which explains the degradation in radiation performance.

IV. CONCLUSIONS

An endfire beam-steering pixel antenna operating at 27 GHz mm-wave band is proposed. The connections between pixels using both hardwires and PIN diodes are studied. A drop of

Fig. 4. Realized gains optimized for different angles in xy plane. (a) With hardwired connection. (b) With PIN diode switching.

TABLE I
EFFICIENCY COMPARISON OF PROPOSED ANTENNA USING
HARDWIRED CONNECTION AND PIN DIODE SWITCHING

	0°	$\pm 30^\circ$	$\pm 60^\circ$	$\pm 90^\circ$
Hardwired connection	98%	97%	97%	95%
PIN diode switching	62%	68%	69%	-

120° steering range in the azimuth plane and a 2 dB realized gain loss occur when PIN diode switching is used. Moreover, the antenna efficiency is reduced to around 65% compared to over 95% for hardwired connections. Thus, a more efficient RF switch at mm-wave bands is needed for enhancing the gain and steering angle of reconfigurable pixel antennas in mm-wave bands.

ACKNOWLEDGMENT

We gratefully acknowledge the support of grant GRF 16209019 from the Hong Kong Research Grants Council.

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