Millimeter-Wave Switched-Beam Grid-Array Antenna

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***Abstract*—An electronic switched-beam grid-array antenna (GAA) at 28.0 GHz is investigated. The proposed antenna panel includes of a sixteen-port GAA integrated with RF switching circuit that consists of five RF switches and a separate control panel. The sixteen beams can be electronically switched/steered with a beam coverage of ±22° and measured antenna gain of >14.0 dBi at 28.0 GHz.**

Keywords*—*electronic beam scanning/steering; grid array antenna; multi-port antenna system; RF switch network; switched-beam.

I. Introduction

Millimeter wave or mmWave usually refers to a frequency spectrum from 24GHz to 100GHz, which is a significant role in next generation wireless communications. The mmWave frequency bands offer extensive frequency range accessibility for incredible amount of data transfer with high speed [1]. For wireless mmWave communication systems, a beam-switched/-steering/-forming/-scanning antenna system is the key module. These beam-switched/beamforming/beam-steering antenna systems should have higher gain to enhance the SINR (signal-to-interference/noise-ratio), compensate the higher path loss, and ensure highly consistent communication links at mmWave.

Numerous antenna/array methods were developed for beam steering/switched beam applications. A mechanical-based antenna technique for beam steering [2] is better for wide beam coverage with approximately unaffected radiated beam parameters such as beam shape, gain, beamwidth, sidelobes, etc., however, slow beam-scan speed, antenna system weight, and bulky are the key weaknesses of the mechanical beam scanning/steering technique. The electronic-based phased array (beamforming/-steering) antenna techniques [3] have advantages of faster beam-scan speed, low weight, and low-profile structure, but disadvantages of inadequate beam scan coverage, degrade radiated beam parameters, in specific, at the larger scan angles. Furthermore, these phased array-based electronic beam-steering methods are costly, high-power consumption, and design complexity, particularly when a highly directive beam (high gain) is essential for mmWave satellite link systems [4]. Additional types of electronic-switched-beam methods such as the Rotman lens based fixed multi-beam antennas [5] with larger footprint, multiple feeders/patches-based lens beam-switched/-steering methods [6] with large structure, and the Butler matrix based switched-bean antennas [7, 8] with larger footprint structure are bulky and complex. These types of antennas have limited scan range and scan resolution which is not preferred.

Some other types of multi-beam/switched-beam antennas have been available in the literature such multi-feed patch antenna [9] with limited gain, pillbox architecture [10] with beam scanning leaky wave structure, dual polarized with 2D multi-beam array antenna using differentially fed elements.

In this article, a GAA based switched-beam system is designed at the Ka-band for airborne/5G communication systems. By electronic switch the excitation ports of the 16-port GAA structure, the beam electronically is switched to different angles. The proposed GAA arrangement can be achieved the beam angle coverage of ±22° with measured gain of >14.0 dBi at 28.0 GHz. The electronic switched-beam performance is verified by measurement.

II. Beam Switching GAA System Design

A cross-section view of the planned switched-beam GAA structure is displayed in Fig. 1, wherein the simple outline is presented in [12, 13]. The proposed GAA structure with multiple feeding ports is considered on Rogers RO4003 dielectric layer (ε_r =3.55, tanδ =0.0027) with thickness of 20 mil and a total antenna board size of 78.0 mm × 66.0 mm × 1.0 mm. To improve the impedance matching, small circular ring is added to each feeding probe at a height of 0.2 mm (8 mil) from the ground. The total 16 feeding probes are joined to the outputs of RF switching network respectively.

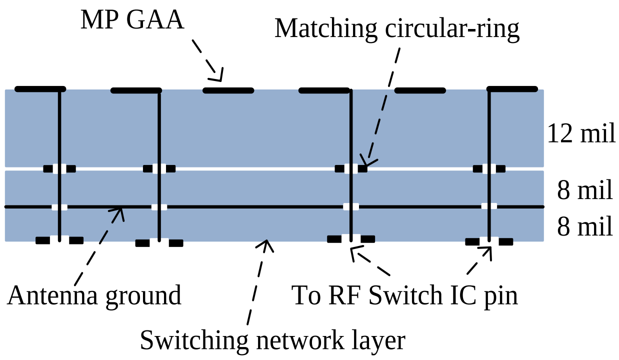


Fig. 1. Cross-sectional view of the proposed switched-beam GAA.

As illustrated in Figs. 2 and 3, exciting port (P41 or P34) at the antenna's center will generate the boresight beam. The beam steering in ±*x* directions can be generated by exciting P51, P52, P33, and P32. The steering beams in ±*y* directions can be achieved by exciting P22 and P44, the beams along 45° diagonal line by P21, P24, P42 and P43, the beams along 135° diagonal line by P23, P31, P53 and P54, respectively.

III. Switched-beam GAA Protype and Measurement

The radiation beam of the proposed GAA system can be electronic switched manually by switching the excitation "ON/OFF" of the feeding ports, which is designed using RF switch ICs. The used switch IC chip SP4T (ADRF5046/7) with four channels can work up to 44.0 GHz with around 2.0 dB insertion loss at 30.0 GHz. The switching network consists of five IC-ADRF5046 / 7 chips as illustrated in Fig. 2. The RF switch sw1 controls the four switches (sw2, sw3, sw4, and sw5) which are connected to 16 ports of the GAA structure to control manually the feed excitation ports located at different locations.

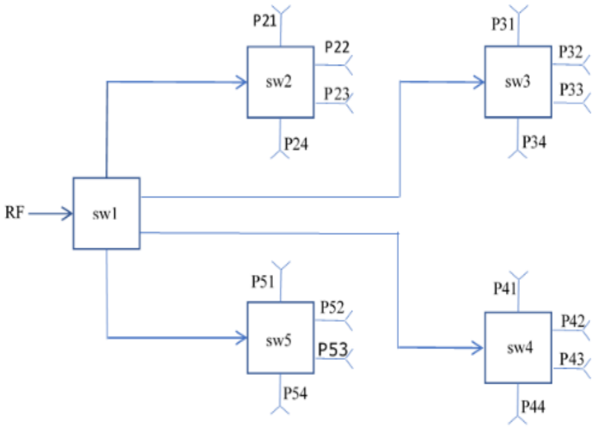
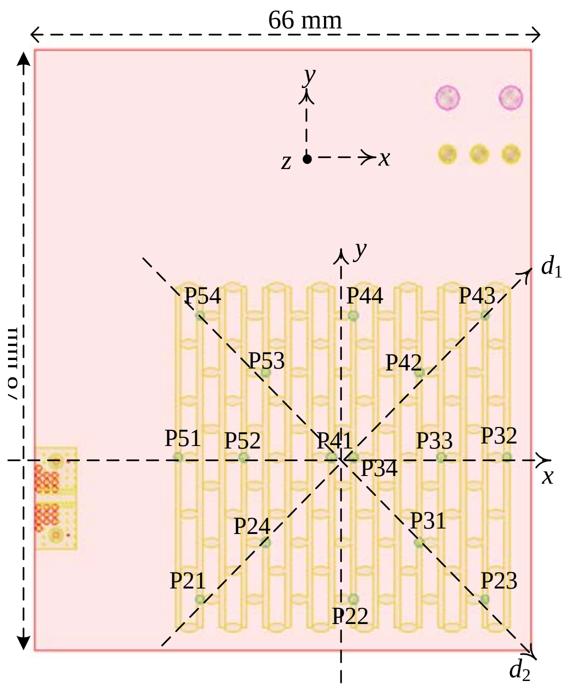


Fig. 2. The switching network block diagram.



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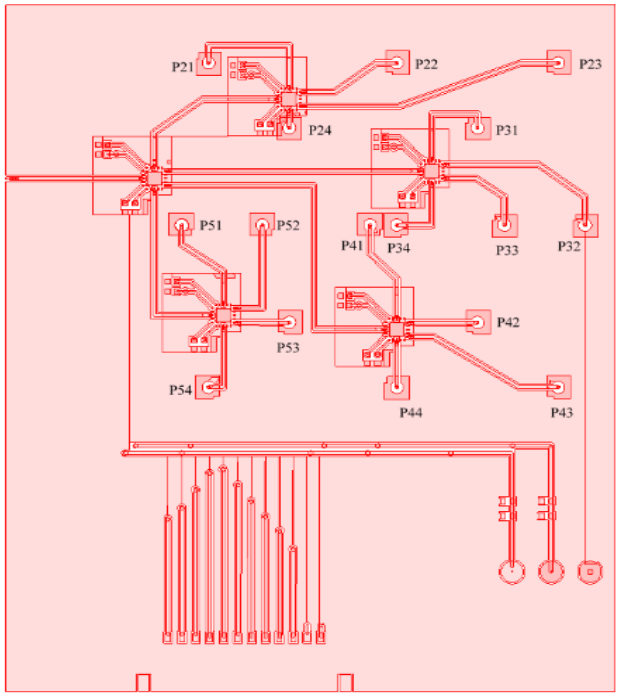
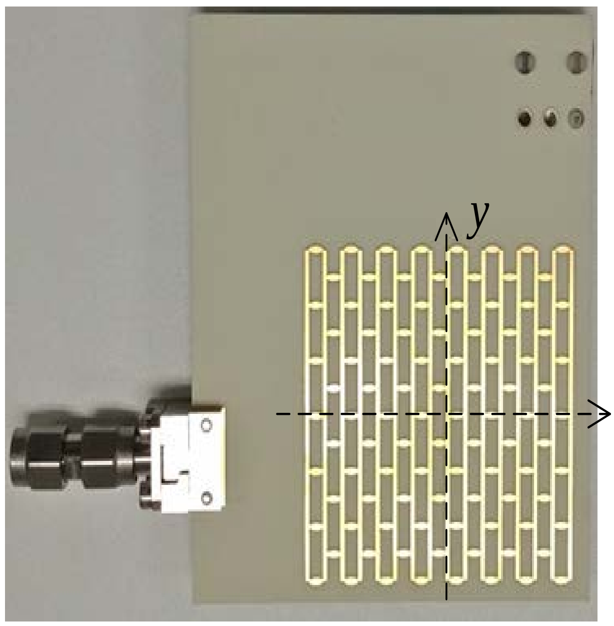


(b)

Fig. 3. Switched-beam GAA system configuration, (a) top view of the GAA locations of the 16 feeding ports and (b) layout of the RF switching network.

Fig. 3 shows the designed 16-port GAA structure (top and bottom views) with five RF switches. Fig. 4 shows the fabricated prototype (top view and bottom view). The switching control board for controlling the RF switches is illustrated in Fig. 5



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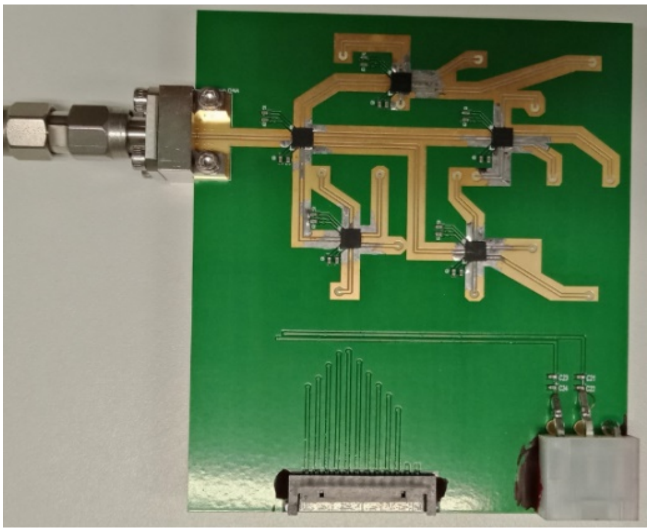


(b)

Fig. 4. Photograph of 16-port GAA system with switching network board; (a) top view (GAA) and (b) switching network.

Fig. 5. Manual RF switching control board.

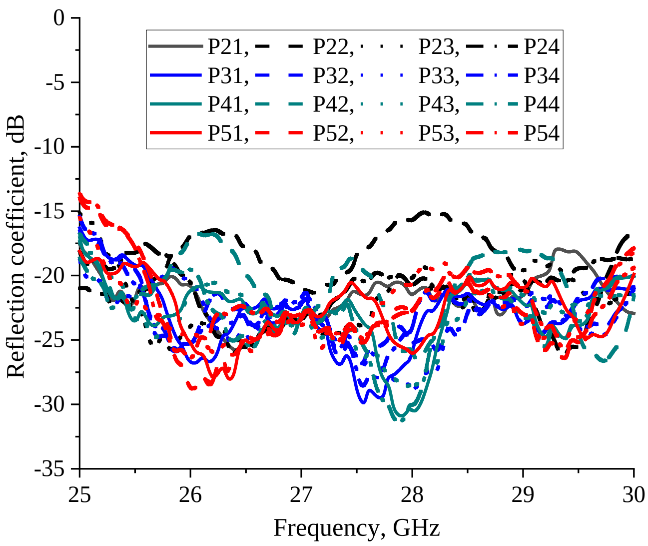
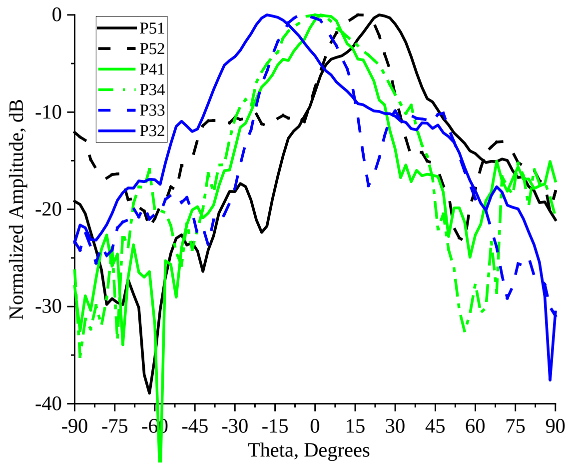


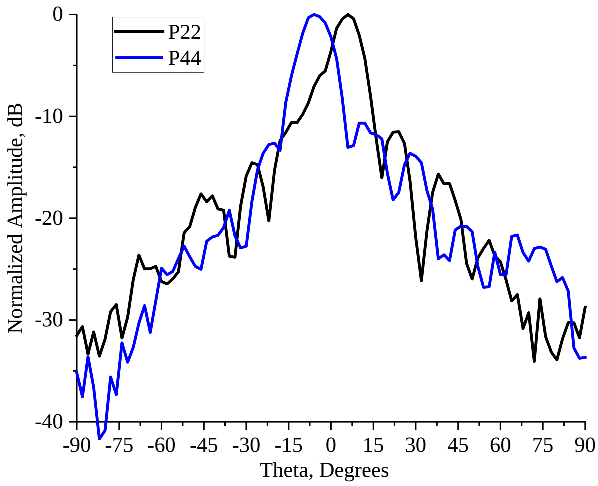
Fig. 6. Measured reflection coefficient of the switched-beam GAA system.

Fig. 6 shows the reflection coefficient in dB of the 16-port GAA with switching network structure. The reflection coefficients were measured by manually switched the antenna ports using switching control board.

The radiation parameters of the switched-beam GAA were measured in a full antenna measurement chamber. The measured radiation patterns for different feeding ports are plotted in Figs. 7(a)-7(d). Fig. 7(a) displays the beams along *x*-axis are directed to 24°, 16°, 0°, 0°, -6°, and -18° when the ports of P51, P52, P41, P34, P33, and P32 are excited respectively, all the beams are with gain of around 16 dBi. When ports of P22 and P44 are switched “ON”, the beams along *y*-axis point to 6° and -6°, respectively, with measured gain of ~14 dBi, as presented in Fig. 7(b). Similarly, the beams along 135° diagonal line with gain of around 16 dBi and scan angle of 18°, 10°, -8°, and -18° are fed by ports of P23, P31, P53, and P54; the beams along 45° diagonal line with gain of around 16 dBi and scan angle of 22°, 14°, -12°, and -18° are fed by ports of P21, P24, P42, respectively, as shown in Figs. 7(c) and (d). The measured beam steering angle and main beam gain values at different ports are also summarized in Table 1. The largest beam scan-angle of 24 degrees can be achieved with gain of around 16 dBi. The antenna efficiency is more than 70% for all ports.



(a)



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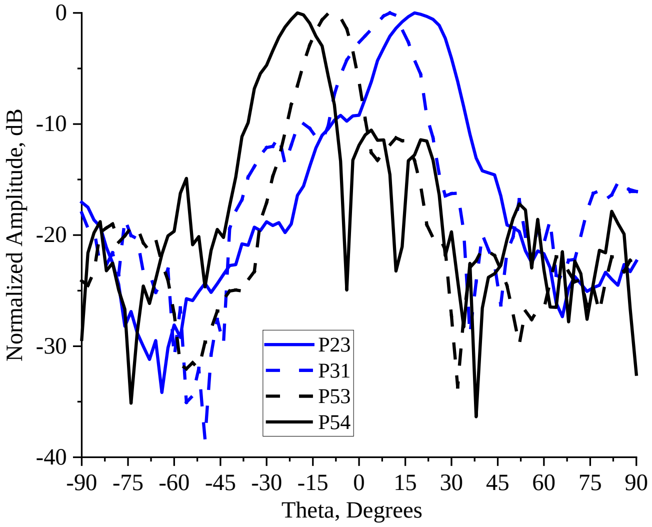

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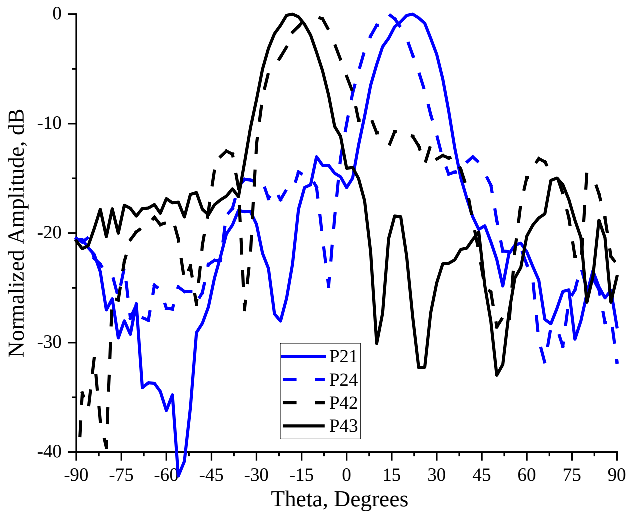

(d)

Fig. 7. Measured-normalized patterns for 16 ports: (a) along *x*-axis, P51, P52, P41, P34, P33, and P32, (b) along *y*-axis, P22, P41, P34, and P44, (c) along 135° diagonal line, P23, P31, P53, and P54, and (d) along 45° diagonal line P21, P24, P42, and P43.

Table I. Measured scan-angel and gain of electronic switched beams

Electronic-switch port	Scan-angle (°)	Gain (dBi)
P21	22.0	16.1
P22	6.0	15.6
P23	18.0	16.2
P24	14.0	15.5
P31	10.0	15.6
P32	-24.0	16.2
P33	-6.0	14.1
P34	2.0	15.7
P41	0.0	15.8
P42	-12.0	15.5
P43	-18.0	16.3
P44	-6.0	14.2
P51	18.0	16.1
P52	16.0	15.6
P53	-8.0	15.5
P54	-18.0	16.1

IV. CONCLUSION

An electronic switched-beam GAA has been verified experimentally at the Ka-band. By utilization of 16-port GAA with integrated RF switches, the antenna system has achieved a scan range of around ±22°. The designed GAA is low profile and light weight, it is a promising cost efficient mmWave electronic beam-scanning/-steering solutions for connectivity and 5G applications.

ACKNOWLEDGMENT

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