A High Gain Steerable Millimeter-Wave Antenna Array for 5G Smartphone Applications

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***Abstract*—In this paper, a phased array antenna is designed at millimeter-wave frequency bands for future 5G based smartphone applications. The proposed antenna is a novel open slot-PIFA antenna made on a low cost FR4 board. The antenna array covers a frequency range of 26-32 GHz with a bandwidth of 6 GHz. The antenna exhibits a very good radiation pattern when integrated with the mobile phone chassis. The 8 - element antenna array exhibits a maximum gain around 13 dBi. The pattern can be steered by varying the phase shift at each antenna element.**

***Index Terms*—5G, beamsteering, millimeter wave, phased array antenna, PIFA, smartphone.**

I. INTRODUCTION

Due to the shortage of frequency spectrum below 6 GHz bands and the demand for higher data rate, higher frequencies, e.g., the millimeter-wave (mm-Wave) frequency bands, have been suggested as candidates for future 5G smartphone applications, as the considerably larger bandwidth could be exploited to increase the capacity and enable the users to experience several-gigabits-per-second data rates [1]–[2]. However, shifting from the cellular carrier frequencies used presently up toward the mm-Wave band introduces new problems that need careful consideration. Employing higher frequencies results in an increase in free-space path loss. Commonly referred to as beamforming, a high gain narrow beam radiation pattern synthesized by an array consisting of multiple antenna elements with optimized spacing is a solution to combat the increased path loss at mm-Wave frequencies. Also at mm-Wave frequencies, communication is mostly line of sight. Hence communication links can be disrupted if line of sight is not maintained. This can be solved by varying the phase shift associated with each antenna element, thereby steering the overall radiation pattern of the array.

Recently, several researches are focused on developing mm-Wave arrays at 28 GHz for 5G mobile phone applications. In [3], researchers at Samsung America developed a mesh type patch antenna with dual feeds to achieve polarization around 28 GHz. But the bandwidth achieved was too narrow. In [4], notch antennas based on microstrip feeding and aperture coupled slot antennas were employed to design 1×4 arrays. Even though the antenna was compact, the bandwidth achieved was low. In [5], antenna design utilizing multi-layer PCB and metal cap was demonstrated with a 2 GHz bandwidth around 28 GHz. In [6], off-center dipole elements were used to obtain a 2 GHz bandwidth around 28 GHz. In [7], a 1×4 array using curved dipole antenna elements was designed to achieve a high bandwidth. But the achieved gain was still not sufficient for practical application. A wide beam antenna design was implemented in [8] with a bandwidth of 3.9 GHz using SIW technology, but achieved a low gain. A 1×4 vertical monopole array was used in [9] to obtain a wide beam coverage, but with a low gain and a narrow bandwidth around 28 GHz. For an antenna design to achieve a high bandwidth, high gain and wide beam width at the same time is indeed a challenging task.

In this paper, we demonstrate methodologies to design and selectively utilize up to 8 antenna elements operating around 28 GHz with a wide bandwidth and high gain for futuristic 5G mobile phones. We first discuss the configuration of the antenna array in the mobile phone. Based on this antenna design, a novel but practical mm-Wave phased array is presented in detail using various forms of simulation.

II. CONFIGURATION OF THE ANTENNA ARRAY IN MOBILE PHONE

The 8 element antenna array is located at the bottom edge of the mobile phone chassis as shown in Fig. 1. The mobile phone ground plane of length 130 mm × 74 mm is same size as a 5 inch smartphone. A standard low cost FR4 epoxy of a relative dielectric constant 4.4 and loss tangent 0.25 is used as the substrate for printed circuit board of size 150 mm × 74 mm. The proposed antenna is a simple elliptical PIFA (planar inverted-F antenna) with an open slot on the system ground plane. More details on the antenna design is given in the next section. Since the antenna elements are very compact, it is possible to add even more antenna elements to the array. But due to the lack of measurement capabilities, only 8 elements are considered. It is possible to implement this array on all sides of the chassis thus creating 4 sets of 1×8 antenna arrays providing more coverage.

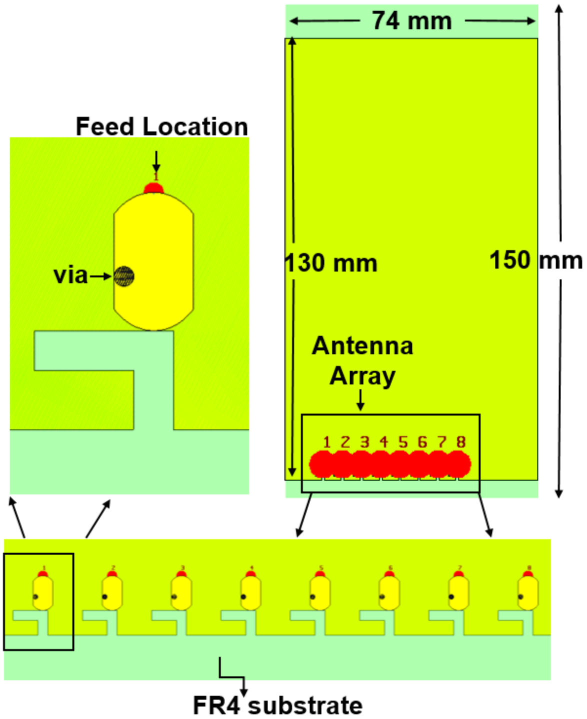

Fig. 1. Proposed antenna design and array location in mobile phone.

III. ANTENNA DESIGN AND PERFORMANCE

A. Single Antenna Design

The proposed antenna is a simple elliptical shaped PIFA antenna with an open slot cut in the ground plane near to the PIFA as shown in Fig.2. The elliptical shape helps to achieve high bandwidth. The location of the shorting point is critical in impedance matching and helps to minimize the antenna size. The open slot is also an important part of the design. The width of the open slot has a significant role in wideband impedance matching. The radiation pattern also has a major effect from the slot width and the position of the slot below the elliptical patch. If the overlap between the elliptical patch and the open slot is increased, the radiation pattern becomes distorted.

The PIFA has a length of approximately λ/4 at 27 GHz. The open slot also has a length of λ/4 at 27 GHz. Both structures together contribute to the 6 GHz bandwidth.

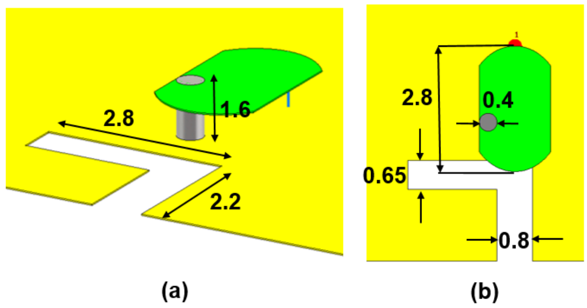

Fig. 2. Proposed antenna design with substrate hidden (a) Perspective view; (b) Top view.

B. Single Antenna Performance

The simulated reflection coefficient of the antenna is shown in Fig. 3. It can be seen that more than 10 dB return loss has been achieved over a 6 GHz bandwidth from 26-32 GHz.

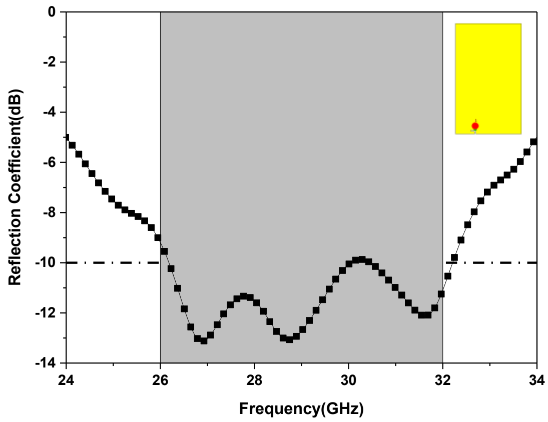

Fig. 3. Simulated reflection coefficient of antenna.

The simulated 3D radiation pattern of the proposed antenna element can be seen in Fig. 4. It can be seen that the radiation pattern is stable throughout the bands of interest and offers a stable gain of at least 4.8 dBi.

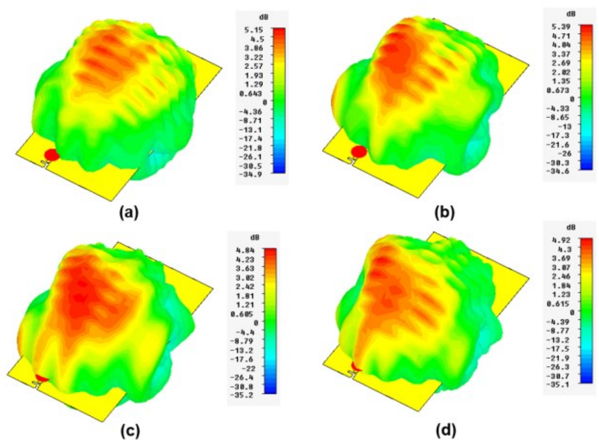

Fig. 4. Simulated 3D far field pattern for proposed antenna at frequencies of (a) 26 GHz; (b) 28 GHz; (c) 30 GHz; (d) 32 GHz.

IV. ARRAY PERFORMANCE

The proposed antenna is arranged as an 8 element array with a separation of $\lambda/2$ between each element to ensure good isolation between the antenna elements and minimize the grating lobes. The array is integrated into mobile phone chassis at the bottom location as shown in Fig. 1. The reflection coefficient of antenna elements is shown in Fig. 5. The results indicate a 10 dB return loss over a 6 GHz bandwidth from 26-32 GHz. A worst case isolation of 18 dB is achieved between the antenna elements.

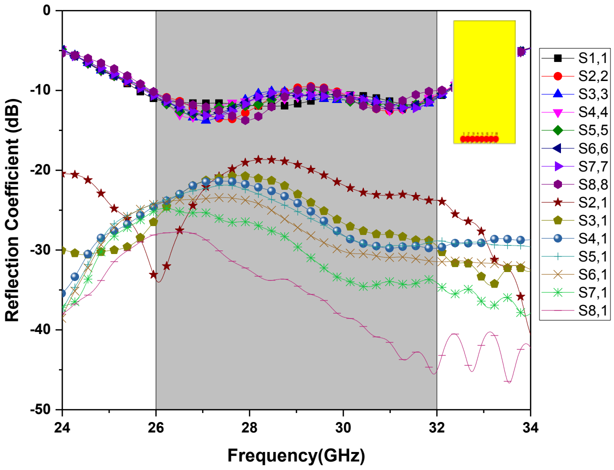

Fig. 5. Simulated reflection coefficient of antenna elements.

Simulated total efficiency is shown in Fig. 6. The total efficiency is above 70% throughout the 26-32 GHz band and is stable. The total efficiency can be improved by using Rogers RT5880 which is relatively expensive. The antenna dimensions need to be re-optimized if Rogers RT5880 is used.

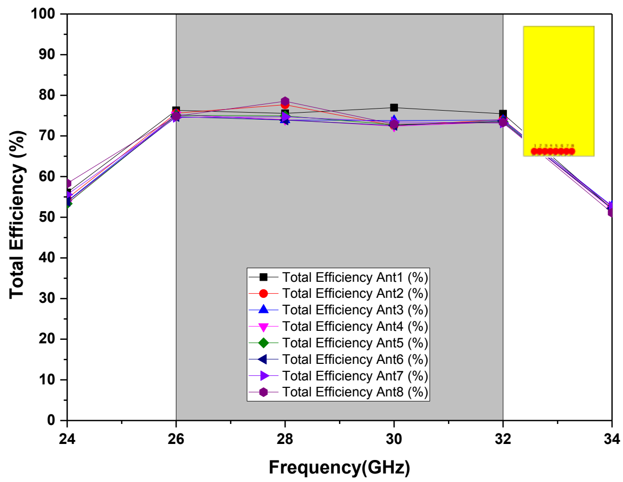

Fig. 6. Simulated total efficiency of antenna elements.

The simulated current distribution for the antenna array is shown in Fig.7. Note that Fig. 7 is obtained under the condition that port 1 is excited while the remaining ports are terminated to a 50-Ω match load and vice-versa. It is clearly seen that the induced current in remaining ports are weak when port 1 is excited and vice-versa. This explains the achieved isolation of around 18 dB.

The antenna array scanning is simulated in CST MWS 2014 using the simulation setup shown in Fig.8. The signal is fed to an 8-way power divider. It is then fed to individual phase shifter for each antenna element where various phase progression is made to enable beam steering. The phase shifter output is finally connected to the antenna array. Various phase progressions of 0°, 20°, 40°, 80°, 120° and 160° are provided to generate the steered radiation pattern.

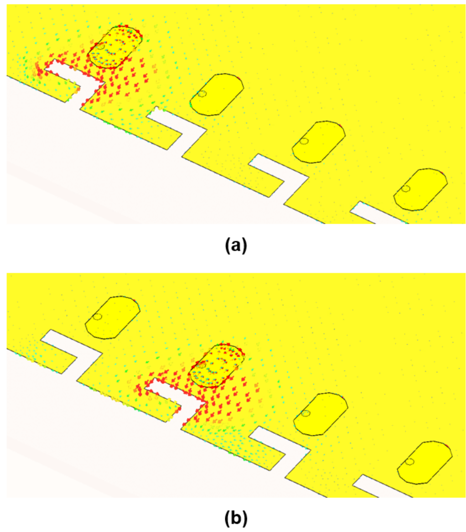

Fig. 7. Simulated current distribution (a) Port 1 is fed; (b) Port 2 is fed.

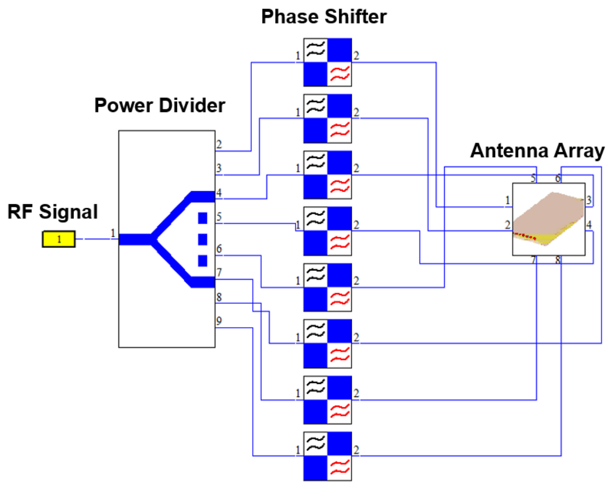

Fig. 8. Antenna array scanning simulation setup.

The steered pattern in the Phi-plane is shown in Fig. 9. A gain of 10 dBi is maintained for about 60° in the Phi-plane. Thereafter, the realized gain reduces drastically. The 3D radiation pattern of the antenna array after scanning operation is shown in Fig. 10. In the simulation, insertion loss in the power divider and phase shifter are neglected.

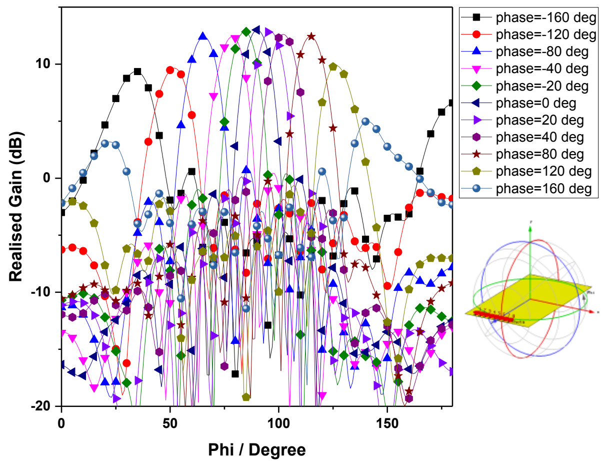

Fig. 9. Realized gain for scanned pattern in the Phi-plane.

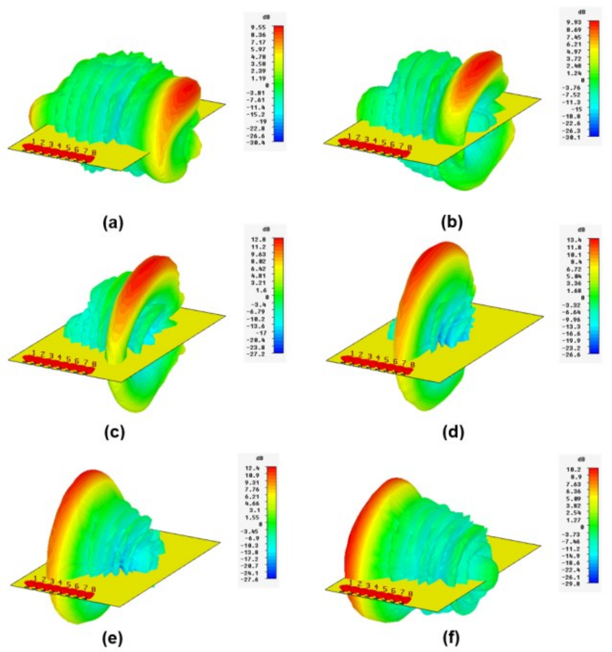

Fig. 10. Simulated scanned pattern for proposed antenna at various tilt (a) -60°; (b) -45°; (c) -30°; (d) 0°; (e) 15°; (f) 45°.

V. CONCLUSION

A novel low cost open slot-PIFA antenna design has been proposed for 5G millimeter-wave applications. The proposed antenna achieves a 6 GHz bandwidth for S11 < -10 dB to cover 26-32 GHz frequency band which is intended for future millimeter wave communications. Moreover, the proposed antenna has been arranged as an 8-element array at the bottom location of the mobile phone. The antenna array achieved a maximum gain of 13 dBi in the boresight direction. The antenna array could be utilized as a phased array and hence could be used to steer the radiation beam. The antenna exhibited a very good radiation pattern and stable gain throughout the frequency band of interest when integrated with the mobile phone chassis. The next step is to fabricate the antenna and verify the simulation results which will be reported at the conference.

ACKNOWLEDGMENT

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