# 5G Base Station Antenna Design for IoT Applications

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***Abstract*—Base station antenna requirements for 5G demand high gain, wide beamwidth and low reflection coefficient antenna structures. A slot-fed waveguide antenna with stepped opening is proposed to satisfy all these requirements. The design and simulations of the antenna are carried out in CST Microwave Studio and impedance bandwidth (RL< -15 dB) and element gain greater than 14 dBi are obtained. The structure, although inspired from open-ended waveguide, exhibits low gain variation and stable beamwidth over 24.5 GHz to 28.5 GHz. The antenna has slant polarization with +45° or -45°. Theoretical analysis and simulation details are discussed.**

***Keywords— 5G, IoT, base-station antenna, slot-waveguide antenna, array antenna***

## I. INTRODUCTION

The fifth generation (5G) mobile communications is envisioned as the key enabler of internet of things (IoT) applications ranging from machine-to-machine communications to smart devices and infrastructures [1]. To support exponentially growing demand of data traffic, more bandwidth, especially at millimeter waves, has emerged as a requirement. To combat with high path loss at mm-wave frequencies, the antenna gain, hence the signal-to-noise ratio (SNR) of the system, must be quite high compared to traditional wireless system counterparts [2]. Antenna size, efficiency, polarization reconfigurability play a vital role in antenna array design.

Unlike conventional phased antenna arrays where the required phase shift from element to element is achieved either by analog phase shifter or through time delay, digital beamforming at the baseband provides greater flexibility especially at mm-wave frequencies with bandwidth as much as 2 GHz. All digital beamforming also enables the realization of multiple-input-multiple-output (MIMO) antenna systems where highest antenna gain can be achieved through appropriate combination schemes such as maximal-ratio-combining [3-4]. MIMO antenna systems beyond 8 antenna elements mostly require excessive resources and computational time which renders them almost impractical for handset or power-limited applications. On the other hand, tower mounted MIMO antenna systems with relatively low dependency on battery power can be more appropriate to utilize massive MIMO systems. Therefore, there is definitely a need for a scalable antenna element that would be best suited for massive MIMO applications. In this study, we propose low-loss, hence high efficiency, antenna element that would be a potential candidate to meet this requirement.

The antenna element presented in this study is specifically targeted for base-station applications. First, requirements summary for such antenna element is discussed, then, the antenna design is detailed and simulation results are presented.

## II. REQUIREMENTS

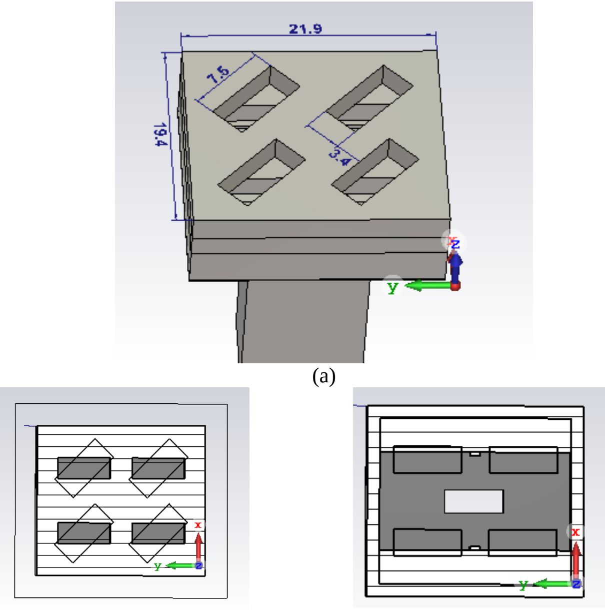
Base station antenna requirements for 2G/3G and 4G communication systems are well established from user and service provider coverage scenarios [5]. At mm-wave band, the antenna gain must be even larger earlier standards to combat high path loss and still within the effective isotropically radited power (EIRP) limit of the regulations, which is taken as 60 dBm. Overall target antenna requirements are shown in Table I. The antenna array is thought to be a hybrid digital and analog beam forming where analog phase shifters are implemented on sub-arrays. Therefore, antenna element is chosen as a sub-array and gain of the subarray is chosen as minimum of 13 dBi with less than 35 degrees half-power beamwidth (HPBW). The polarization of the antenna element is chosen as 45 degrees slant polarization with opposite polarizations on receive and transmit to increase transmit-receive isolation and to combat multi-path fading with mixed horizontal and vertical polarizations. Hence, we assume separate antenna structures for transmit and receive of the remote radio head (RRH) of the base station system. Although the power input to the antenna element is thought to be less maximum +10 dBm, a return loss value of greater than 15 dB is more than enough for minimum signal loss due to antenna mismatch.

TABLE I. ANTENNA ELEMENT SPECIFICATIONS

| Feature | Value |
|---|---|
| Frequency Band | 24-28.5 GHz |
| Gain | > 13 dBi |
| HPBW | < 35° |
| Polarization | +45° or -45° |
| Scan Angle | +/- 60° |
| Return Loss | > 15 dB |
| Efficiency | > 90% |
| Sidelobe level | < -10 dB |

## III. ANTENNA DESIGN

The antenna structure is shown in Fig. 1. It is essentially waveguide fed, stepped-cavity, slot antenna with four radiating elements forming the target subarray [6-7]. There is a feed-waveguide whose cross sectional dimensions are optimized for single mode operation covering the target bandwidth. The feed waveguide opens to a stepped cavity and this cavity is loaded with slant slots to provide +45 degrees polarization. This subarray configuration is optimized for performance and no grating lobes are introduced within the target scan angles.



(a)

(b) (c)

Figure 1 Subarray antenna, a) slot-radiator on top plate, b) cross-section of waveguide cavity coupling, c) cross-section of feed waveguide.

## IV. SIMULATION RESULTS

The antenna is simulated with CST, Microwave Studio [8]. The reflection coefficient of the antenna reveals quite large bandwidth starting from 23.75 GHz and ending at 29 GHz with RL > 15 dB. This bandwidth corresponds to approximately 20% fractional bandwidth. Considering relatively low power antenna transmit levels, RL >10 dB can also be utilized, which in this case, larger bandwidth (FBW > 30%) can be obtained.

Broadside antenna gain is displayed in Fig. 3. Within target band, the antenna achieves 13.75 dBi gain and gain fluctuation remains less than 0.25 dB with highly stable gain performance. This particular feature of antenna gain becomes quite useful in wideband array antenna design and its array calibration thereafter.

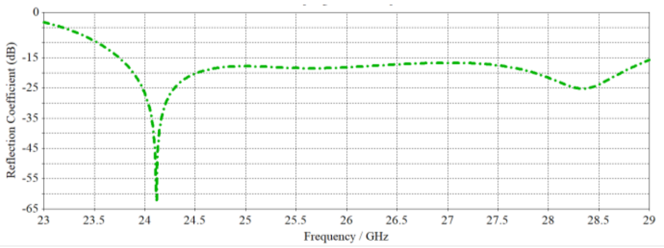


Figure 2. Reflection coefficient of the antenna.

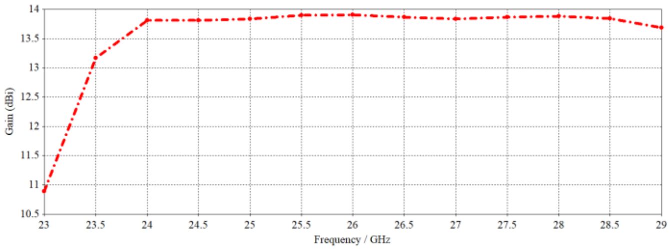


Figure 3. Broadside gain of the antenna.

Antenna 3D pattern is shown in Fig.4 where symmetric sidelobes in either direction (azimuth or elevation) are present. The antenna co-pol patterns at 3 different frequencies are displayed in Figs. 5 through 7. Within the target band, HPBW changes +/- 2 degrees relative to mean value. Target sidelobe level at higher frequencies exceeds design specifications at the expense of nearly constant HPBW throughout the band. The SLL can be further reduced in an array setting.

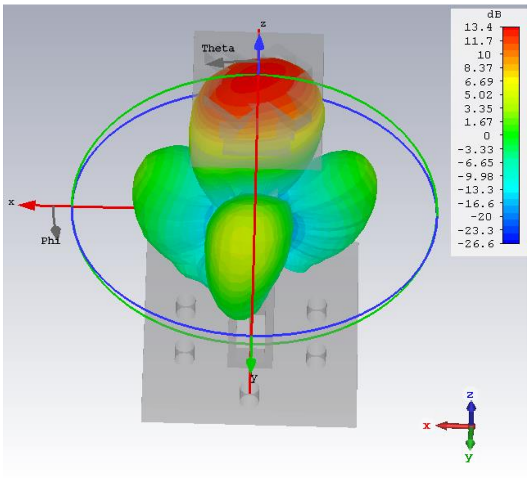


Figure 4. 3D co-pol radiation pattern of the antenna.

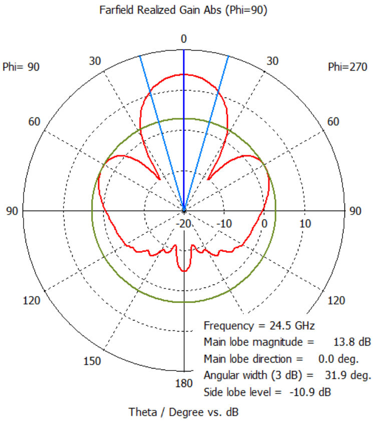


Figure 5. Azimuth (H-plane) radiation pattern of the antenna at 24.5 GHz.

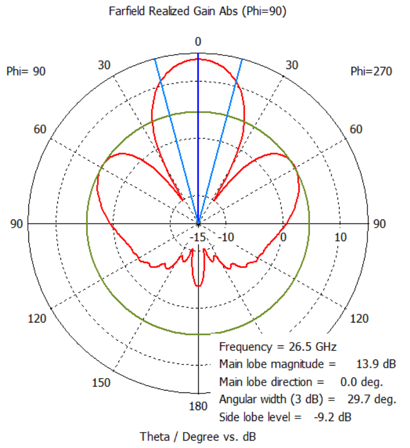


Figure 6. Azimuth (H-plane) radiation pattern of the antenna at 26.5 GHz.

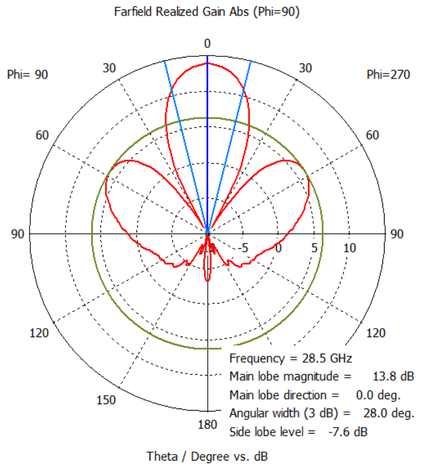
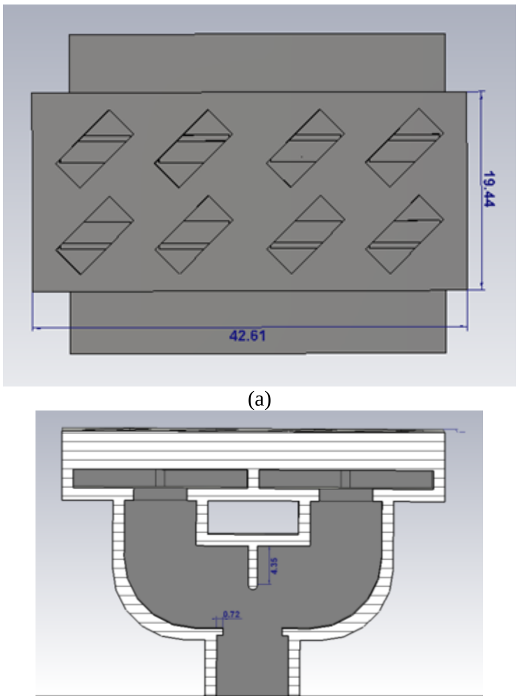


Figure 7. Azimuth (H-plane) radiation pattern of the antenna at 28.5 GHz.

An antenna array is formed by combining 1x2 antenna elements to further increase gain and reduce HPBW. The structure of the array and its feed network are shown in Fig. 8. A simple H-plane combiner/divider is designed with waveguide lens to achieve impedance match over the target bandwidth.

Impedance bandwidth of the 1x2 array antenna with waveguide combiner is shown in Fig. 9. Return loss bandwidth is slightly reduced from 5.25 GHz to 5 GHz compared to that of single antenna element, but it is still within the target bandwidth of 24-28.5 GHz.

Broadside gain of the array antenna is displayed in Fig. 10. The gain is above 16.75 dBi across the entire band and above 17 dBi between 24 GHz and 26.5 GHz. Azimuth and elevation radiation patterns of the array are shown in Figs. 11 and 12, both at 24.5 GHz. SLL has been reduced in both planes and HPBW's closely match the expected values.



(a)

(b)

Figure 8. 1x2 Array of antenna element, a) top view, b) waveguide combiner (H-field) network.

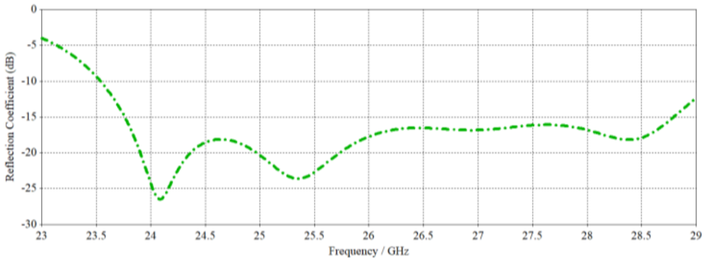


Figure 9. Reflection coefficient of 1x2 antenna array.

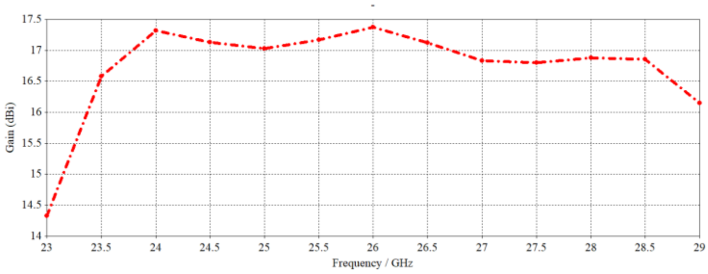


Figure 10. Broadside gain of 1x2 antenna array.

To reduce HPBW in elevation, further antenna elements can be combined in vertical (phi=0 degrees) direction. The outdoor or indoor usage of the base station antenna determines its coverage area and the presented antenna element can be easily scaled to desired application. In conventional base station antennas, 5 to 7 degrees elevation HPBW is usually adequate for electrical downtilt at macrobase stations. However, 5G applications comparably at lower antenna coverage range may require elevation HPBW around 10 degrees. Azimuth HPBW coverage can be quite complex depending on MIMO capability and base station location.

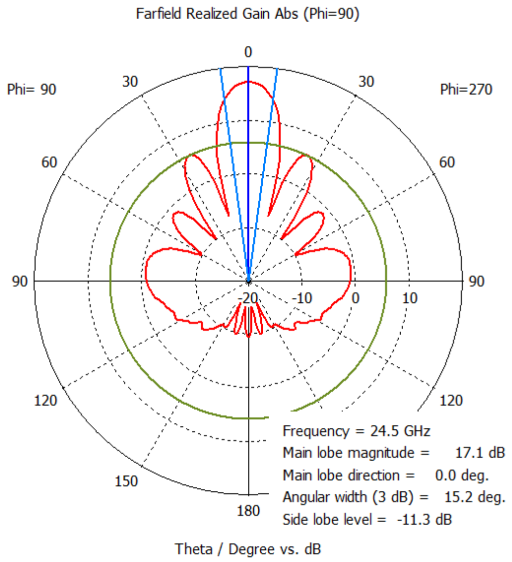


Figure 11. Azimuth (H-plane) radiation pattern of 1x2 antenna array at 24.5 GHz.

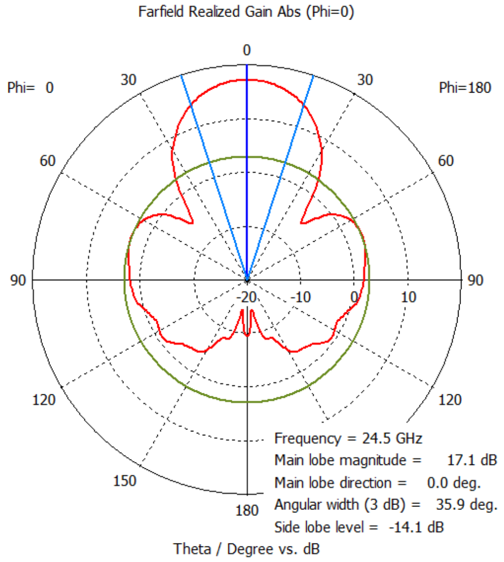


Figure 12. Elevation (E-plane) radiation pattern of 1x2 antenna array at 24.5 GHz.

## V. CONCLUSIONS

A novel base station antenna element is introduced and it simulation results are presented. The antenna element has quite stable gain broadside gain with 0.25 dB variation across 5 GHz bandwith from 24 GHz to 29 GHz. HPBW variation within the bandwidth is also constrained to less than 2 degrees around mean value. Wideband performance of the antenna element makes it an ideal candidate for antenna array and MIMO applications where the antenna HPBW can be scaled to desired value without compromising its single element features.

## ACKNOWLEDGMENT

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