A Sub-6 GHz Multi-Beam Base Station Antenna for 5G with an Arbitrary Beam-Tilting for Each Beam

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***Abstract* — A sub-6 GHz (3.3 – 7.0 GHz) multi-beam base station antenna has been developed for 5G. It consists of two parabolic cylindrical reflectors and several feeds. It can generate an arbitrary number of beams with arbitrary vertical and horizontal beamwidths. Each beam can be electrically tilted with an arbitrary vertical/horizontal tilt angles. It can have horizontal and vertical sectorization at the same time. This doubles the number of beams. Hence, every user will always be close to the peak of one of the beams. So, it can be used as a good configuration for switched beam smart base station antennas.**

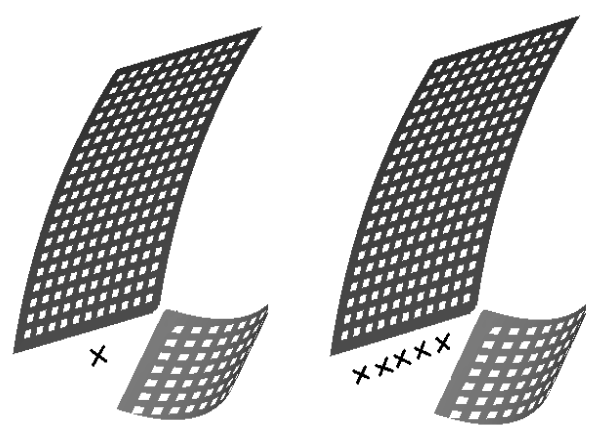
***Index Terms* — Antennas, aperture antennas, broadband antennas, directive antennas, reflector antennas.**

I. INTRODUCTION

In the current multi-beam base station antenna technology, very complicated antennas have been developed using multi-beam forming networks driving planar arrays of radiating elements, such as the Butler matrix [1]. Other classes of multi-beam antennas based on a classic Luneburg cylindrical lens have been tried [2]. The cost of the classic Luneburg lens is high and the process of production is extremely complicated. The currently used multi-beam technologies use several frequency dependent components and, therefore, they have low frequency bandwidths.

In this paper, a sub-6 GHz (3.3 – 7.0 GHz) of 5G multi-beam base station antenna has been developed using dual parabolic cylindrical reflectors. It consists of two parabolic cylindrical reflectors and small size broadband resonant feeds as shown in Fig. 1. The basic concept of dual parabolic cylindrical reflector base station antennas and their broadband resonant feeds was originally developed by the authors of this paper [3]. A GTD software code was written, especially, for dual parabolic cylindrical reflectors [4] and its accuracy was verified experimentally several times with different configurations. Furthermore, this base station antenna technology was verified by testing a basic single beam configuration in Vodafone's network. To significantly reduce the weight of the proposed dual parabolic cylindrical reflectors, several holes are punched in their surfaces as shown in Fig. 1. Punched antennas are not significantly affected by strong winds and they require simple lightweight towers. The proposed antenna can generate an arbitrary number of beams with arbitrary vertical and horizontal beamwidths and arbitrary beam overlapping [3]. Furthermore, the beams can be shaped in the elevation plane in order to eliminate the ducting and/or the interference with the surrounding base station antennas [5].

Multi-beam technology can be easily applied to the dual parabolic cylindrical reflector antenna by adding multi-feeds as shown in Fig. 1(b). Shifting the location of any feed away from the focus of the sub-reflector results in tilting the beam that is generated due to this feed. Thus, each beam can be easily tilted vertically and/or horizontally by remotely shifting its feed. For example, the five feeds that are presented in Fig. 1(b) generate five horizontal beams as shown in Fig. 2(a). The horizontal angle of each beam can be arbitrarily controlled by shifting its feed, horizontally. Similarly, the vertical tilt angle of each beam can be arbitrarily controlled by shifting its feed, vertically. Actually, the five beams can be tilted such that their vertical tilt angles are all different from each other, if required, as shown in Fig. 2(b). This property makes the proposed multi-beam technology very valuable in several other applications such as satellite antennas.



(a) A single (dual-polarized) feed (b) Multiple feeds

Fig. 1. Dual parabolic cylindrical reflectors.

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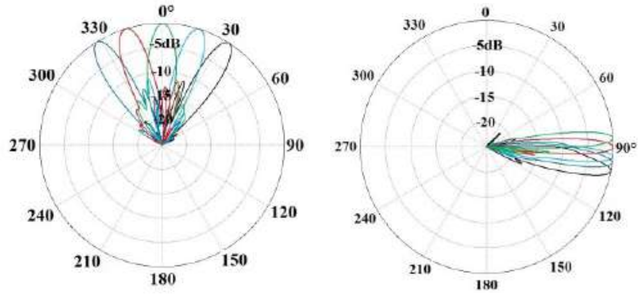


(a) Azimuth (b) Elevation

Fig. 2. Radiation patterns of a Penta beam antenna with five different beam vertical angles.

II. A Penta Beam Sub-6 GHz Base Station Antenna With Multiple Rows of Feeds

Simultaneous horizontal and vertical sectorization can double the number of the horizontally sectorized beams several times, which doubles the overall system capacity as shown in Fig. 3. The peaks of the upper group of beams are, usually, adjusted to be above the nulls of the lower group of beams and vice versa. Hence, every user will always be close to the peak of one of these beams. An array of dual polarized feeds with different horizontal and vertical shifts can be used together to generate a simultaneous horizontal and vertical sectorization as shown in Fig. 4. For example, Fig. 4(a) shows a sample configuration of the proposed sub-6 GHz multi-beam antenna that is selected to be a reference design for 5G. It is a dual-penta beam configuration with a simultaneous vertical and horizontal sectorization. It generates two sets of penta beams in two different vertically sectorized zones, which provides a total of 10 beams with 20 ports for ±45° polarizations. A total of 20 feeds are used, for ±45° polarizations, where each feed covers the frequency band 3.3 – 7.0 GHz of 5G. It should be noted that the two vertically sectorized sets can be used together or only one of them (5 beams with 10 ports) is generated and utilized, according to the application and its requirements. Furthermore, a third row of feeds can be added in order to generate three different vertically sectorized sets of penta beams with a total of 30 ports as shown in Fig. 4(b). This forms a penta horizontal sectorization simultaneously with a triple vertical sectorization.

A prototype of the above proposed configuration was manufactured using a 3D printer and then the inner reflector surfaces were covered by a very thin metallic tape. The length of the main reflector is 80 cm while its width is 56 cm. The length of the sub-reflector is 18 cm and its width is 56 cm. The focal lengths of the main and sub-reflectors are 45 cm and 25 cm, respectively. The vertical and the horizontal beamwidths of the generated beams can be controlled, separately, by adjusting the dimensions of the antenna. Fig. 5 shows the manufactured penta-beam sub-6 GHz antenna prototype covered with a radome. The overall weight of the manufactured prototype is less than 2 Kg. Moreover, the reflectors of the developed antenna can be remotely folded and deployed, as shown in Fig. 6 [5]. All that makes it advantageous in several applications such as satellites, earth stations and space shuttles.

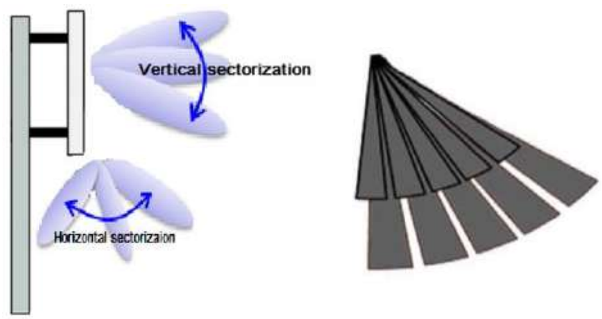
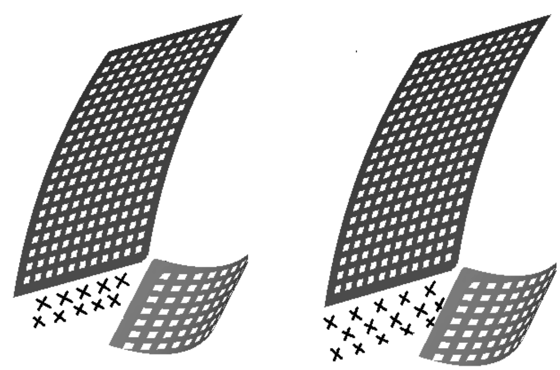
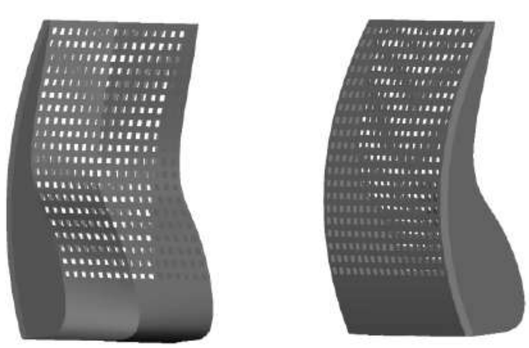


Fig. 3. A simultaneous vertical and horizontal sectorization.



(a) Two rows of feeds (b) Three rows of feeds

Fig. 4. Multiple rows of feeds for a simultaneous horizontal and vertical sectorization.



(a) Front view (b) Back view

Fig. 5. The penta-beam sub-6 GHz antenna with radome.

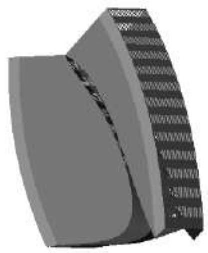


Fig. 6. A folded sub-6 GHz base station antenna.

III. Results

The return loss and the radiation patterns of the penta beam sub-6 GHz base station antenna are calculated using the special sftware code that was mentioned above. Furthermore, the calculated results are verified experimintally using a basic setup on the roof of a high building, with a Vector Network Analyzer and two calibrated reference horn antennas. Fig. 7 shows the reflection coefficient of the antenna. The electrical specifications of the proposed penta beam antenna are summarized in Table. 1, while the mechanical specifications are listed in Table. 2. Samples of the horizontal and vertical patterns of the penta beam sub-6 GHz antenna with a simultaneous horizontal and vertical sectorization are shown in Fig. 8 in the horizontal and vertical planes at a sample frequency 4 GHz. The azimuth peaks of the first (upper) five beams are adjusted to be above the nulls of the second (lower) five beams and vice versa. Thus, there are ten peaks in one horizontal main-sector in two different vertically sectorized zones. Actually, the proposed sub-6 GHz multi-beam base station antenna is a good candidate for switched beam smart antennas since every user will always be close to the peak of one of the beams [6]-[7].

On the other hand, the proposed sub-6 GHz penta beam base station antenna can be used to generate different configurations of vertical sectorization at the same time with the horizontal sectorization. For example, as shown in Fig. 9(a), three vertically sectorized sets of the horizontally sectorized penta beams are generated with upward, zero and downward vertical beam tilting. In Fig. 9(b), two sets of the penta beams are tilted down by different tilt angles, while the third one is not tilted at all. Any of these configurations of vertical sectorization can be produced according to the application. In either cases, all the planned vertically sectorized sets may be produced and utilized together, resulting in 15 beams with 30 ports (±45° polarizations). Alternatively, only some of these planned vertically sectorized sets of either configurations may be generated and utilized, according to the requirements of the application. For example, only two vertically sectorized sets may be produced to provide 10 beams with 20 ports. Of course, only one set can be generated, if required, to provide 5 beams with 10 ports.

It should be noted that tilting the beams upwards and/or downwards in vertical sectorization depends on the requirements of the application. For example, tilting the beams down can be used to serve vertically split inner and outer cells as shown in Fig. 10(a). On the other hand, tilting the beams up is very useful when targeting users that may be located on top floors of a high-rise building, through serving them with a dedicated beam or vertical sector as shown in Fig. 10(b).

TABLE I
ELECTRICAL SPECS OF THE NEW PENTA-BEAM ANTENNA

Frequency Band	3.3-7.0 GHz
Horizontal Beam center, degrees	0, ±16°, ±33°
Vertical Beam center, degrees	0, 8°
Gain, dBi	20:24
Horizontal Beamwidth, degrees	10:14
Vertical Beamwidth, degrees	4:7
Front-to-Back Ratio at 180°, dB	≥ 30
Return Loss, dB	14
1st Upper Side lobe Suppression, dB	15
Isolation (between polarizations), dB	≥ 20
Isolation (between beams), dB	≥ 21
Polarization	±45°
Impedance, Ohm	50
Electrical Down tilt, degrees	0-10

TABLE 2
MECHANICAL SPECS OF THE NEW PENTA-BEAM ANTENNA

RF Connector Quantity, total	10,20 or 30
Length	80 cm
Width	56 cm
Net Weight, without mounting kit	< 2 Kg

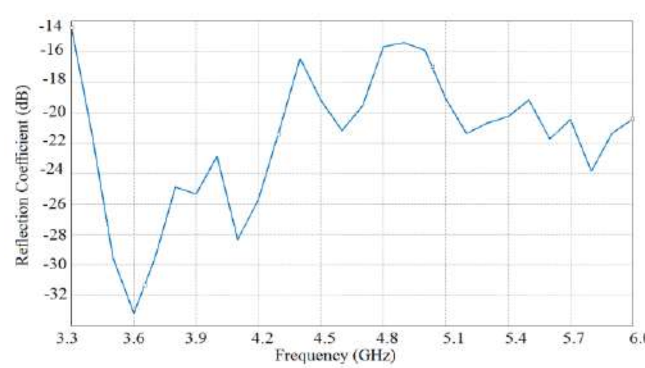
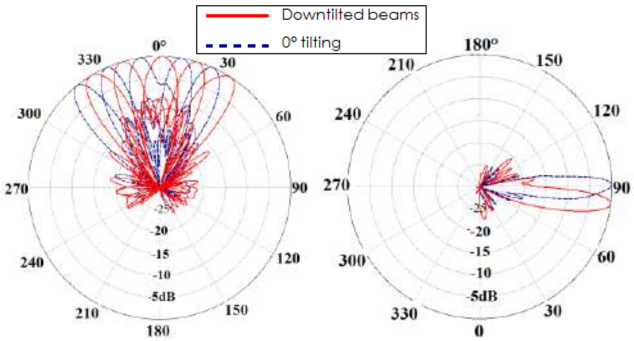
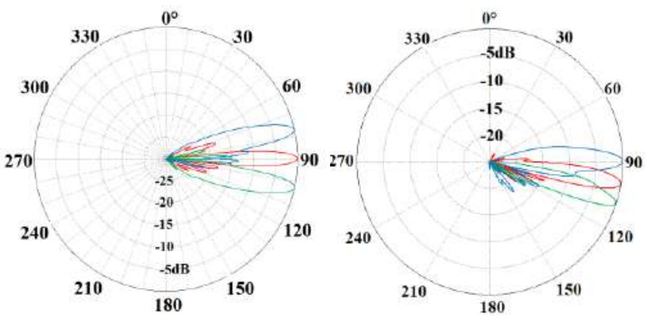


Fig. 7. The reflection coefficient of the new antenna.



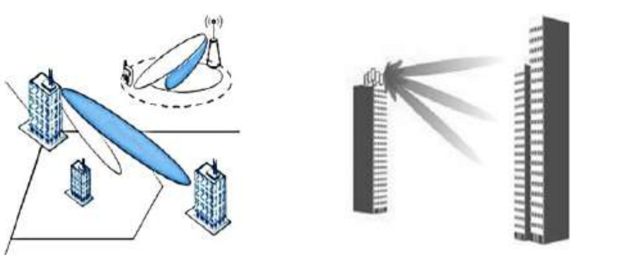
(a) Azimuth (b) Elevation

Fig. 8. Radiation patterns of the new dual-penta-beam antenna.



(a) Upward, downward and 0° tilting (b) Downward and 0° tilting

Fig. 9. Different configurations of vertical sectorization.



(a) Serving inner and outer cells (b) Serving high-rise buildings

Fig. 10. Vertical sectorization in different cases.

IV. CONCLUSION

A low-cost light-weight low wind-load foldable /deployable sub-6 GHz (3.3 – 7.0 GHz) penta-beam base station antenna was developed for 5G. It could have simultaneous horizontal and vertical sectorization, which doubled the overall system capacity. It could generate different configurations of vertical sectorization with a penta horizontal sectorization. For example, two and three vertically sectorized sets of the horizontally sectorized penta beams were generated. The vertical and the horizontal beamwidths of the beams and their overlapping could be controlled, independently. The beams could also be shaped in the vertical plane to eliminate the ducting and the interference with the other base stations.

The proposed penta beam base station antenna could include up to 15 beams with 30 ports (±45° polarizations) or even more, which could facilitate any further needed capacity expansions. Each beam could be remotely tilted vertically and/or horizontally by any arbitrary angle. The proposed multi-beam antenna technology could be used in smart base station antennas since every user would always be close to the peak of one of the beams. A prototype of the antenna was manufactured using a 3-D printer. Several holes were punched in the antenna and the radome to reduce the wind-load and the weight. The overall weight of the antenna with the radome was less than 2 Kg.

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