A Sub-6GHz 5G Switched-Beam Smart Base Station Antenna Using Dual Parabolic Cylindrical Reflectors with Multiple Feeds

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***Abstract* — A foldable/deployable 5G-sub-6GHz (3.3-7.0 GHz) switched-beam base station antenna has been developed. It consists of dual parabolic cylindrical reflectors with multiple resonant feeds. It can generate an arbitrary number of beams with arbitrary vertical/horizontal beamwidths, arbitrary beam overlapping and arbitrary electric beam-tilt for each beam. It can have a simultaneous vertical and horizontal sectorization. The peaks of the upper beams can be adjusted to be above the nulls of the lower beams and vice versa. Hence, every user will always be close to the peak of a beam. The antenna is gridded, which significantly reduces its weight and the wind-load.**

***Index Terms* — 5G mobile communication, aperture antennas, broadband antennas, directive antennas, reflector antennas.**

I. Introduction

The switched-beam smart antenna creates narrow beams limited to a fixed number of scan directions that the system switches back and forth from, depending upon where the mobile user may be. The multi-beam passive method can be thought of as splitting the standard 120° main-sector, or 90º main-sector, into narrower horizontal and, probably, vertical sub-sectors. This means that the network planers must determine how many sub-sectors they want to split their 120° main-sector, or 90º main-sector, into with one beam for each sub-sector. Different techniques can be used to achieve this splitting and switching [1]-[2].

The currently used switched-beam smart base station antennas use several frequency dependent components and, therefore, they have low frequency bandwidths. In some of the current switched-beam base station antennas, very complicated techniques have been developed using multi-beam forming networks driving planar arrays of radiating elements, such as the Butler matrix [1]. Other classes of switched-beam smart base station antennas based on a classic Luneburg lens have been tried [2]. The Luneburg lenses are composed of layered structures of dielectric concentric shells, each of a different refractive index. The cost of the classic Luneburg lens is high and the process of production is extremely complicated.

In this paper, a foldable/deployable sub-6GHz (3.3-7.0 GHz) of 5G switched-beam base station antenna has been developed. It consists of two parabolic cylindrical reflectors and a set of small size broadband resonant feeds. The basic concept of dual parabolic cylindrical reflector antennas and their broadband resonant feeds was originally invented by the authors of this paper [3]. A GTD software code was written, especially, for dual parabolic cylindrical reflectors and its accuracy was verified experimentally several times with different configurations and applications [4]. Furthermore, this base station antenna technology was certified by testing a basic single beam configuration in Vodafone's network, as a part of an R&D project that was funded by them as shown in Fig. 1.

The proposed antenna can generate an arbitrary number of beams with arbitrary vertical and horizontal beamwidths, arbitrary beam overlapping and arbitrary electric beam-tilt for each beam [3]. Furthermore, the beams can be shaped in the elevation plane in order to eliminate any possible ducting and/or 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. 2(a). Shifting the location of any feed away from the focus of the sub-reflector results in tilting the beam that is generated by this feed. Thus, each beam can be easily tilted vertically and/or horizontally by remotely shifting its feed. Furthermore, an array of these feeds with different horizontal and vertical shifts can be used to generate a simultaneous horizontal and vertical sectorization as shown in Fig. 2(a).

To significantly reduce the weight of the proposed reflectors, several holes can be punched in their surfaces and also in their radome as shown in Fig. 2(b). These holes also make the antenna transparent. Gridded (punched) antennas are not significantly affected by strong winds and they require simple lightweight towers. Moreover, the reflectors of the developed antenna can be remotely folded and deployed [5]. In addition, the parabolic cylindrical reflectors of the new antenna are easy to form from flat sheets with a very high surface accuracy. So, they can be shipped and stored in a form of flat sheets of metal especially if the antenna is required to be large in size according to the application. All that makes this multi-beam antenna advantageous in several applications such as satellites, earth stations and space shuttles.

*This research was fully financed by and assigned for Amant Antennas (www.amantantennas.com)

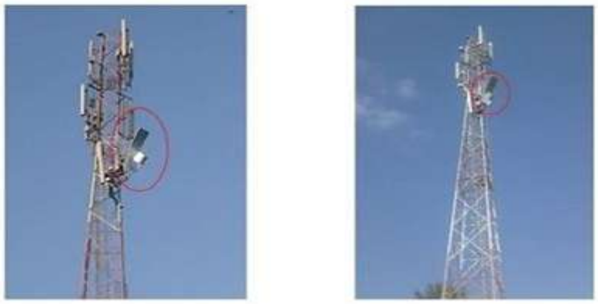
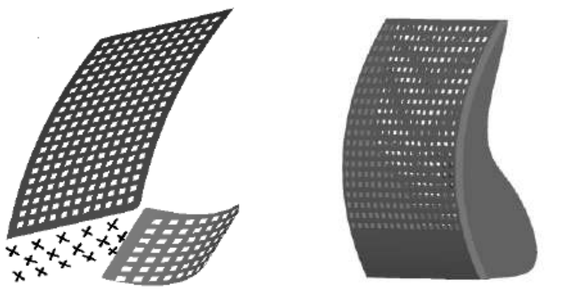


Fig. 1. Testing the single beam antenna in Vodafone's network.



(a) An array of feeds (b) Covered with a radome

Fig. 2. A multi-beam dual parabolic cylindrical reflector antenna.

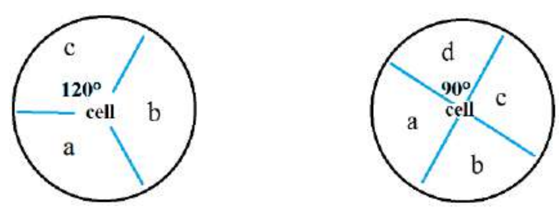
II. COVERING 360° WITH THE DEVELOPED SWITCHED BEAM SMART ANTENNA

As explained above, the switched-beam smart base station antenna technology increases the number of beams covering the same main-sector and, thus, reducing the beam-widths. Hence, every user will always be near to the peak of a beam. In our developed technology, this can be achieved in different forms depending on the required overall number of beams, their vertical/horizontal tilting angles and their required beamwidths. The whole azimuth plane (360°) can be divided into three 120° main-sectors or four 90° main-sectors as shown in Fig. 3. Each main-sector is then covered by one of the proposed 5G sub-6GHz (3.3-7.0 GHz) multi-beam antenna units as shown in Fig. 4. Each of these units can generate three (triple), four (quad), five (penta) or even more beams (sub-sectors) in each main-sector. The number of beams that are generated by each unit can be controlled by modifying the number of feeds and their locations. For example, three triple-beam units are used, where each of them covers 120°. Thus, 9 beams with 18 ports (±45° polarizations) are generated to cover the whole azimuth plane (360°) as shown in Fig. 5(a) at a sample frequency 4 GHz. To increase the overall number of beams, three quad-beam antenna units are used, where each of them generates four beams in each azimuth main-sector (120°). So, 12 beams with 24 ports are generated to cover the whole azimuth plane as shown in Fig. 5(b).

To significantly increase the overall number of beams that cover the whole azimuth plane (360°), two things are done together. The number of the azimuth main-sectors is increased from three to four main-sectors such that each of them covers 90° instead of 120° as was shown in Fig. 3(b). Furthermore, each main-sector is covered by a larger number of sub-sectors (multi-beams). For example, four penta-beam antenna units are used, where each of them produces five beams in each 90° azimuth main-sector as shown in Fig. 6. With four of these penta-beam units, 20 beams with 40 ports (±45° polarizations) are generated to cover the whole azimuth plane (360°) with an arbitrary electric vertical/horizontal beam tilt for each beam.

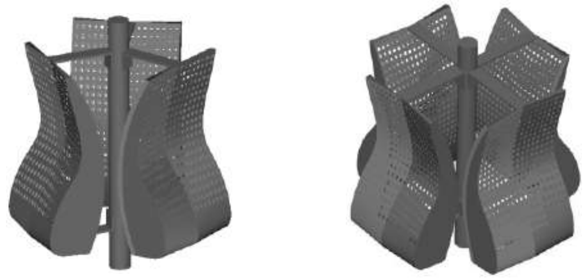
A sub-6GHz multi-beam antenna unit is manufactured by a 3D printer and then the reflecting portions/faces are covered by a very thin layer of aluminum foil/tape. The length/width of the main reflector are 80/56 cm. The length/width of the sub-reflector are 17/56 cm. The focal lengths of the main/sub reflectors are 40/20 cm. It should be noted that the vertical and the horizontal beamwidths of the generated beams can be controlled, separately, by adjusting the dimensions of the antenna. Several holes are punched in the antenna and the radome to reduce their weight and the wind-load. The overall weight of each multi-beam unit with the radome is around 2 kg. Thus, the overall weight of the switched-beam antenna that covers the whole azimuth with three/four units is about 6/8 kg.

The radiation patterns of the above configurations (triple, quad and penta) and also their return losses are calculated using the special software code that was mentioned above. Furthermore, the calculated results are verified experimintally using a basic set up on the roof of a high building, with a Vector Network Analyzer and two calibrated reference horn antennas. In all configurations the return loss is always better that 14 dB over the whole frequency band (3.3-7.0 GHz). The gain is ranging from 20 to 24 dBi and the front-to-back ratio at 180° is ≥ 30 dB. The 1st upper side lobe suppression is 15 dB and the isolation between polarizations is ≥ 20 dB. The isolation between beams is ≥ 21 dB. Each beam can be electrically tilted by an arbitrary tilt angle.



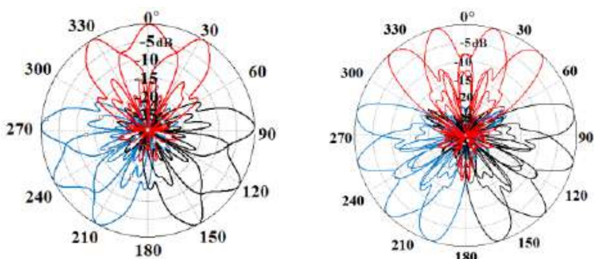
(a) Three main-sectors (b) Four main-sectors

Fig. 3. Different azimuth cell sectorization schemes.



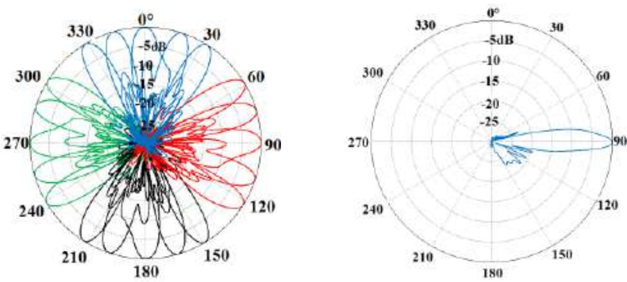
(a) Three units (b) Four units

Fig. 4. Covering 360° by dual parabolic cylindrical reflectors.



(a) Tri beam antennas (b) Quad beam antennas

Fig. 5. Patterns of three antennas covering 360° at 4 GHz.



(a)Azimuth (b) Elevation

Fig. 6. Four penta beam units covering 360° at 4 GHz.

III. A Simultaneous Vertical and Horizontal Sectorization

To double the number of the horizontally sectored beams, the developed sub-6GHz 5G switched-beam smart base station antenna can generate multiple beams with a simultaneous vertical and horizontal sectorization as shown in Fig. 7. Simultaneous vertical and horizontal sectorization can be achieved by using two, three or even more rows of feeds at the same time, as was shown in Fig. 2(a). This adds more freedom to generate multi-beams in different forms. For example, Fig. 8 shows the radiation patterns of two sets of penta beams in two different vertical groups using two rows of feeds. The horizontal feed locations in the two rows are adjust such that the peaks of the upper group of beams are above the nulls of the lower groups of beams and vice versa. Hence, every user will always be close to the peak of one of these beams. The whole azimuth (360°) is covered by 40 beams and 80 ports (±45° polarizations) with an arbitrary electric vertical/horizontal beam tilt for each beam. Moreover, three feed rows can also be used together with the penta-beam configuration to cover the whole azimuth plane (360°) by 60 beams with 120 ports as shown in Fig. 9.

It should be noted that the horizontally sectorized beams may be generated with downward, zero and/or upward vertical beam tilting with arbitrary tilt angles as shown in Fig. 10. All that can be fulfilled and also modified at any time without replacing the antenna. Only the locations of the feeds have to be changed. Actually, tilting the beams upwards and/or downwards in vertical sectorization depends on the requirements of the application. For example, 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. 11(a). On the other hand, tilting the beams down can be used to serve vertically split inner and outer cells as shown in Fig. 11(b).

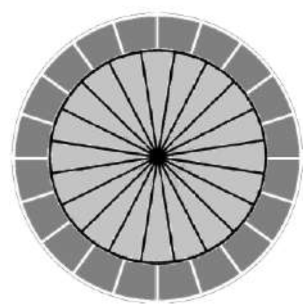
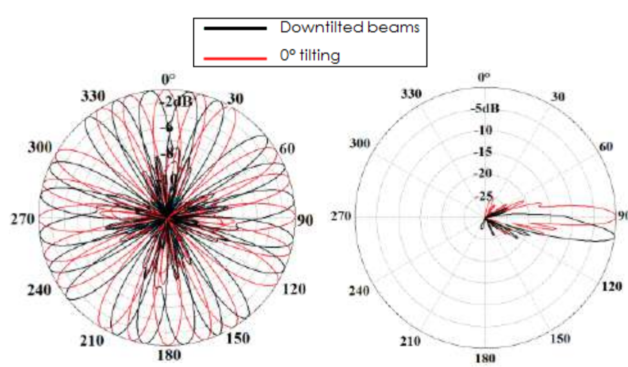
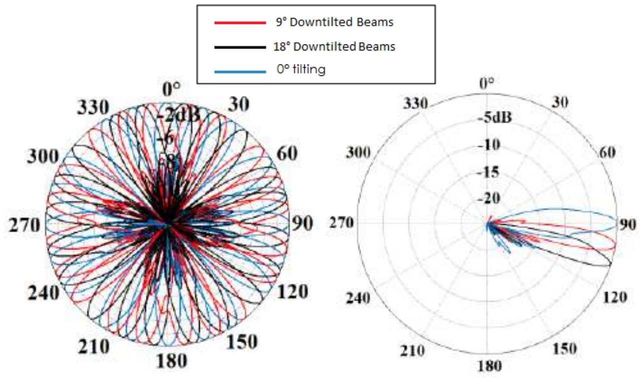


Fig. 7. Simultaneous vertical and horizontal sectorization.



(a) Azimuth (b) Elevation

Fig. 8. Four penta beam units covering 360° with 40 beams.



(a) Azimuth (b) Elevation

Fig. 9. Four penta beam units covering 360° with 60 beams

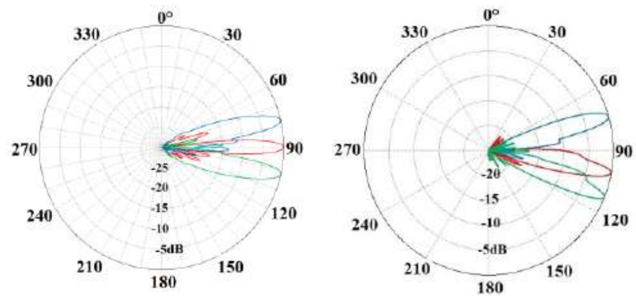
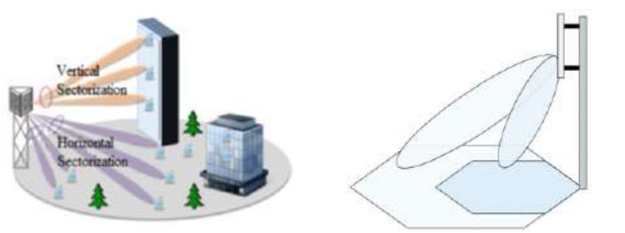


Fig. 10. Vertical sectorization with upward and downward tilting



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

Fig. 11. Vertical sectorization in different cases.

IV. CONCLUSION

A foldable/deployable 5G-sub-6GHz (3.3-7.0 GHz) switched-beam smart base station antenna was developed. It consisted of dual parabolic cylindrical reflectors with multiple resonant feeds. The developed antenna could cover the whole azimuth plane (360°) with an arbitrary number of beams ranging from 9 to 60 beams and 18 to 120 ports (±45° polarizations) with an arbitrary electric vertical/horizontal beam tilt for each beam. It could have horizontal and vertical sectorization at the same time. The peaks of the upper beams could be adjusted to be above the nulls of the lower beams and vice versa. Hence, every user was always close to the peak of one of these beams. The vertical and horizontal beamwidths and the beam-overlapping could be arbitrarily controlled. The beams could also be shaped in the vertical plane to eliminate any possible ducting and/or interference with the other base stations. Furthermore, each beam could be remotely tilted with an arbitrary vertical and horizontal tilt angles. So, if required, the vertical and horizontal tilt angles of all beams could be different from each other regardless of their number. All that could be fulfilled and also modified at any time without replacing the antenna. Only the locations of the feeds had to be changed.

The antenna and its radome were gridded (punched), which significantly reduced the wind-load and the weight. The overall weight of each multi-beam unit (triple, quad or penta) with the radome was around 2 kg. Thus, the overall weight of the switched-beam smart base station antenna that consisted of three/four of these units to cover the whole azimuth (360°) was about 6/8 kg. All that made this multi-beam antenna advantageous in several applications such as satellites, earth stations and space shuttles.

ACKNOWLEDGEMENT

The authors would like to thank Ibrahim Abdelgaied for his great effort in preparing this paper.

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