

Reducing the Need for Multi-Input Multi-Output in Multi-Beam Base Transceiver Station Antennas Using Orthogonally-Polarized Feeds with an Arbitrary Number of Ports

Mohamed Sanad, Noha Hassan

Abstract—A multi-beam BTS (Base Transceiver Station) antenna has been developed using dual parabolic cylindrical reflectors. The $\pm 45^\circ$ polarization feeds are used in spatial diversity MIMO (Multi-Input Multi-Output). They can be replaced by single-port orthogonally polarized feeds. Then, with two sets of beams generated above each other, the $\pm 45^\circ$ polarization ports of any conventional transceiver can be connected to two of these beam sets. Thus, with two-port transceivers, the system will be equivalent to 4x4 MIMO, instead of 2x2. Radio Frequency (RF) power combiners/splitters can also be used to combine the multiple beams into a single beam or any arbitrary number of beams/ports. The gain of the combined-beam will be more than 20-24 dBi instead of 17-18 dBi of conventional wide-beam antennas. Furthermore, the gain of the combined beam will be high over the whole beam angle. Moreover, the users will always be close to the peak gain value of the combined beam regardless of their location within the combined beam angle. The frequency bands of all the combined beams are adjusted such that they all have the same frequency band. Different configurations of RF power splitter/combiners can be used to provide any arbitrary number of beams/ports according to the requirements of any existing base station configuration.

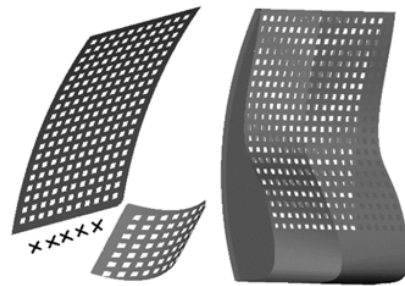
Keywords—5G mobile communications, BTS antennas, MIMO, orthogonally polarized antennas, multi-beam antennas.

I. INTRODUCTION

MULTIBEAM antennas create narrow beams limited to a fixed number of scan directions. They can make extensive coverage for higher data rates. Different antenna techniques can be used to generate multi-beams [1]-[5]. Dual parabolic cylindrical reflector antennas were also used to generate multi-beams. Their basic concept and their broadband resonant feeds were originally invented in [6]. We developed a foldable/deployable 5G multi-beam base station antenna as shown in [7]. It could cover the whole sub-6GHz band (3.3-7.0 GHz) or the mm-wave band (24-34 GHz). It consisted of two parabolic cylindrical reflectors and a set of small size broadband resonant feeds as shown in Fig. 1. The geometry and the dimensions of the sub-6GHz feed were published in [8].

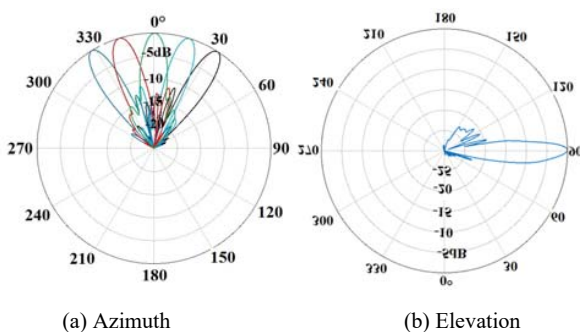
Multi-beam technology could be easily applied to the dual parabolic cylindrical reflector antenna by adding multi-feeds. For example, Fig. 1 (a) shows a penta beam antenna with a line

of five feeds aligned horizontally to generate five horizontal beams having the same elevation angle as shown in Fig. 2. These radiation patterns were calculated with a special software code using the geometrical theory of diffraction [9]. The accuracy of the software was experimentally verified several times [6], [7]. On the other hand, Fig. 3 shows a penta beam antenna with five feeds aligned to generate five beams with different elevation tilt angles.



(a) Multi-feeds for multi-beams (b) Covered with a gridded radome

Fig. 1 Base station antennas using dual parabolic cylindrical reflectors



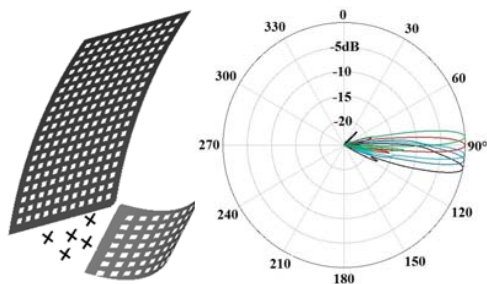
(a) Azimuth (b) Elevation
Fig. 2 Radiation patterns of a penta beam antenna generating five beams having equal elevation angles

Four sub-6 GHz penta-beam antenna units were used as a switched-beam smart base station antenna. Each of these units produces five beams in each 90° azimuth main-sector [6], [7].

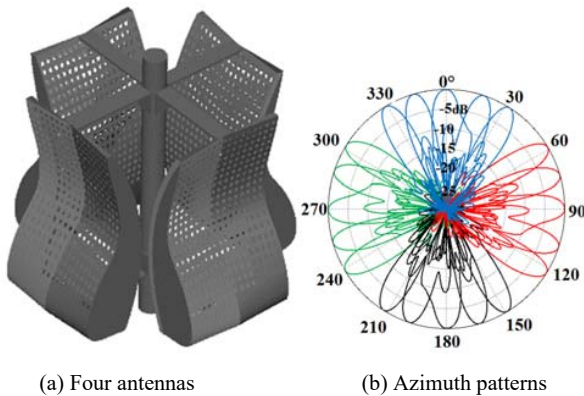
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With these four penta-beam units, 20 beams with 40 ports ($\pm 45^\circ$ polarizations) were generated to cover the whole azimuth plane (360°), as shown in Fig. 4. A sub-6GHz multi-beam antenna unit was manufactured by a 3D printer and then the reflecting portions/faces were covered by a very thin layer of aluminum foil/tape. The length/width of the main reflector were 80/56 cm. The length/width of the sub-reflector were 17/56 cm. The focal lengths of the main/sub reflectors were 40/20 cm. The overall weight of the multi-beam unit with the radome was around 2 kg. Thus, the overall weight of the four units was about 8 kg. The return loss of the antenna was always better than 14 dB over the whole frequency band (3.3-7.0 GHz) [7]. The azimuth radiation patterns of the antenna are shown in Fig. 4 (b). The gain of the manufactured configuration was ranging from 20 to 24 dBi and the front-to-back ratio at 180° was ≥ 30 dB. The first upper side lobe suppression was 15 dB and the isolation between polarizations was ≥ 20 dB. The isolation between beams was ≥ 21 dB. Moreover, each beam could be electrically tilted by an arbitrary elevation tilt angle.



(a) Five feeds with different elevations (b) Elevation patterns
Fig. 3 A penta beam antenna generating five beams with different elevation angles



(a) Four antennas (b) Azimuth patterns
Fig. 4 Four penta beam antennas covering 360° generating 20 beams with 40 ports

The $\pm 45^\circ$ polarization feeds, in base station antennas, are used in spatial diversity MIMO, where the same data are sent to provide a more reliable link, or in spatial multiplexing MIMO, where independent data streams are sent to increase link capacity. A broadband resonant single port orthogonally polarized feed antenna has been used to considerably reduce the

need for spatial diversity MIMO. It is equally sensitive to two perpendicular polarizations ($\pm 45^\circ$) [10]. Thus, the two spatially separated $\pm 45^\circ$ polarization feeds can be replaced by an orthogonally polarized feed with a single port. On the other hand, the need for a spatial multiplexing MIMO may be significantly reduced in this multi-beam antenna because of its high capacity with its large number of beams and wide frequency bandwidth. However, base station transceivers have two ports for $\pm 45^\circ$ polarization diversity. With orthogonally polarized feeds, these two ports can be connected to two different beams above each other. Thus, the system will be equivalent to 4x4 diversity MIMO. RF power combiners/splitters can also be used to combine the multi beams into a single beam or any arbitrary number of beams/ports. The gain of the combined-beam will be more than 20-24 dBi instead of 17-18 dBi of conventional wide-beam antennas. Furthermore, the users will always be close to the peak gain value of the combined beam regardless of the angle of their location inside the beam. Of course, the combined beams must have the same frequency band.

II. REDUCING THE NEED FOR MIMO USING ORTHOGONALLY POLARIZED FEEDS

As mentioned above, the $\pm 45^\circ$ polarizations, in base station antennas, are used in spatial diversity MIMO and/or in spatial multiplexing MIMO. The need for a spatial multiplexing MIMO can be significantly reduced in this antenna because of its high capacity and wide frequency bandwidth. To considerably reduce the need for spatial diversity MIMO, a broadband resonant single port orthogonally polarized feed antenna has been developed to cover the 5G Sub-6GHz spectrum (3.3-7.0 GHz) or the mm-wave spectrum (24-34 GHz) [9]. It is equally sensitive to two perpendicular polarizations ($\pm 45^\circ$). Thus, the two spatially separated $\pm 45^\circ$ polarization feeds can be replaced by an orthogonally polarized feed with a single port. So, the number of ports becomes equal to the number of beams.

The detailed dimensions of the feed can be found in [10]. The arms of the developed orthogonally polarized feed antenna are bent by 90° where the location of the bending point is optimized such that the feed is equally sensitive to two perpendicular polarizations. The radiation patterns of the orthogonally polarized feed in the two vertical planes of the orthogonal arms (x-z and y-z planes) are shown in Fig. 5 at 4.0 GHz as a sample frequency. The radiation patterns in the two vertical planes of the two arms are very similar to each other. This indicates that the orthogonally polarized feed is equally sensitive to two perpendicular polarizations.

As an example, Fig. 6 shows the antenna with one row of 5G sub-6GHz (3.3-7.0 GHz) orthogonally polarized feeds. The total gain and its $\pm 45^\circ$ components of this penta beam configuration are shown in Fig. 7 at a sample frequency 4 GHz. It covers the whole azimuth with 20 beams and 20 ports instead of 40 ports. The total gain is ranging from 20 to 24 dBi. The $+45^\circ$ and -45° components are close to each other, where each of them is about half of the total gain (i.e., -3 dB).

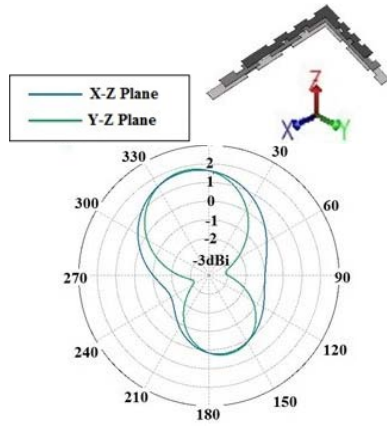


Fig. 5 Radiation Patterns of the orthogonally polarized antenna at 4.0 GHz

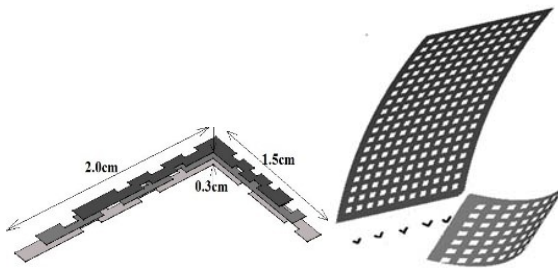


Fig. 6 An orthogonally polarized multi-beam dual parabolic cylindrical reflector antennas using orthogonally polarized feeds

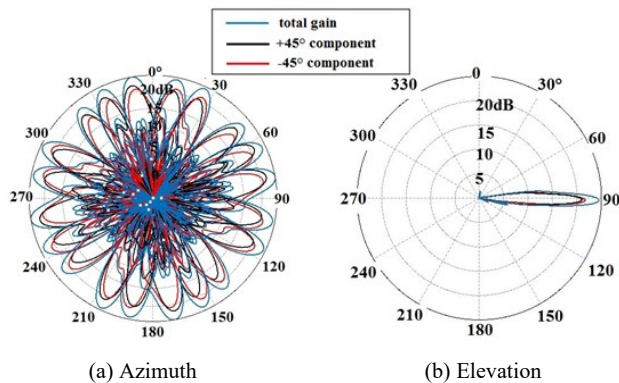


Fig. 7 Total gain and $\pm 45^\circ$ components - One row of feeds generating 20 beams with 20 ports at 4 GHz

III. A SIMPLE 4X4 MIMO CONFIGURATION USING ORTHOGONALLY POLARIZED FEEDS

Simultaneous vertical and horizontal sectorization can be achieved by using several rows of feeds [11]. For example, Fig. 8 shows the radiation patterns of two sets of beams with two rows of feeds. If orthogonally polarized feeds are used, the total number of ports will be equal to the number of beams. Hence, the number of ports will be 40 ports instead of 80. However, each of the current base station transceivers has two different ports for $\pm 45^\circ$ polarization diversity. Instead, these two ports can be used for space diversity MIMO where the $\pm 45^\circ$

polarization ports of the transceivers can be connected to two different beams above each other according to the configuration of Fig. 8. Thus, with only two-port transceivers, the system will be equivalent to 4x4 MIMO, instead of 2x2 MIMO, combining both polarization and space diversities.

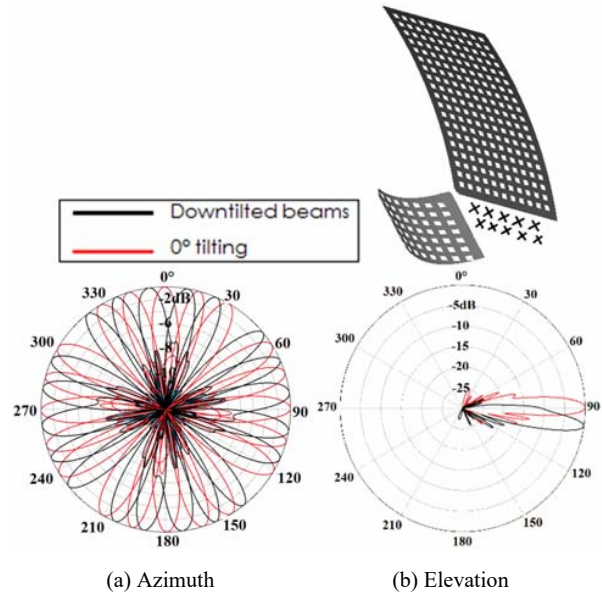


Fig. 8 Four penta beam units covering 360° with 40 beams at a sample frequency 4 GHz

IV. COMBINING SOME OF THE ADJACENT BEAMS AND PORTS USING COMBINERS/SPLITTERS

RF power combiners/splitters can be used to combine the ports and the beams of the multi-beam base station antenna into any arbitrary number of beams/ports [12]-[15]. So, the gain will be significantly increased over the whole beam angle without any modifications in the used transceivers. The gain of the combined-beams will be more than 20-24 dBi instead of 17-18 dBi of the conventional wide-beam antenna. Furthermore, the users will always be close to a peak gain value regardless of their location within the combined beam angle. Moreover, with the orthogonally polarized feeds, the configuration will be equivalent to 4x4 MIMO, instead of 2x2 MIMO, as explained above. It should be noted that the combined beams should have the same frequency band. For example, Fig. 9 shows a multi-beam antenna with two rows of feeds generating 10 beams. The horizontal feed locations are adjusted such that the peaks of the upper beams are above the nulls of the lower beams and vice versa, as shown in Fig. 8. The antenna will have a total of 20 ports because of the $\pm 45^\circ$ polarizations, where each polarization has ten ports, as shown in Fig. 9 (a). If orthogonally polarized feeds are used, the antenna will have two rows of feeds with a total of ten ports, which is equal to the number of beams, as shown in Fig. 9 (b). Each of these sets, which are five ports each, can be combined into a single port, as shown in Fig. 9 (c). This will result in an antenna with two ports that can be used with any of the existing conventional single beam base stations. The difference, as mentioned above, is that the gain

will be significantly increased over the whole beam-width of the combined beam. Furthermore, the users will always be close to a peak gain value regardless of the angle of their location inside the combined beam. On the other hand, different configurations of RF power splitter/combiners can be used to provide any arbitrary number of ports according to any special requirements. For example, each five ports can be combined into three ports as shown in Fig. 9 (d).



Fig. 9 Two rows of feeds generating 10 beams combined into different configurations of ports

V. CONCLUSION

A multi-beam base station antenna was developed. It could cover the whole sub-6GHz band (3.3-7.0 GHz) or the mm-wave band (24-34 GHz). It consisted of dual parabolic cylindrical reflectors. The developed multi-beam antenna had a high capacity because of its large number of beams and its wide frequency bandwidth. Hence, the need for the spatial multiplexing MIMO could be significantly reduced. To reduce the need for spatial diversity MIMO, a broadband resonant single port orthogonally polarized feed antenna was developed. It was equally sensitive to two perpendicular polarizations ($\pm 45^\circ$). Thus, the two spatially separated $\pm 45^\circ$ polarization feeds were replaced by an orthogonally polarized feed with a single

port. So, the number of ports became equal to the number of beams. The $+45^\circ$ and -45° components of the radiation patterns of the orthogonally polarized feed were close to each other, where each of them was about half of the total gain (i.e. -3 dB). However, the current base station transceivers have two different ports for $\pm 45^\circ$ polarization diversity. Instead, these two ports could be used for space diversity MIMO where two sets of beams were generated above each other. So, the $\pm 45^\circ$ polarization ports of the transceivers could be, alternatively, connected to two different beams above each other. Thus, with only two-port transceivers, the system was equivalent to 4x4 MIMO, instead of 2x2 MIMO, combining both polarization and space diversities. The space diversity was due to the separation between the feeds of the two beams which were above each other. The polarization diversity was due to the single-port orthogonally polarized feeds. On the other hand, RF power combiners/splitters could be used to combine the ports of the multi-beam base station antenna into any arbitrary number of beams/ports. This could result in an antenna with two ports that could be used with any of the existing conventional single beam base stations. The difference was that the gain of the combined-beam was more than 20-24 dBi instead of 17-18 dBi of conventional single wide-beam antennas. Moreover, the gain was increased over the whole beam-width and, hence, the users were always close to a peak gain value regardless of their location within the beam angle. Furthermore, the system was equivalent to 4x4 MIMO, instead of 2x2 MIMO, combining both polarization and space diversities. The space diversity was due to the separation between the feeds of the two beams which were above each other. The polarization diversity was due to the single-port orthogonally polarized feeds. The frequency bands of all the combined beams were adjusted such that, they all operated at the same frequency band. On the other hand, different configurations of RF power splitter/combiners could be used to provide any arbitrary number of ports according to any special requirements. For example, each five ports could be combined into three ports.

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