A Novel Foldable/Deployable Base Station Antenna for All Generations of Wireless Applications including the Whole LTE Spectrum

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***Abstract*— A novel base station antenna with arbitrary beam widths has been developed. It consists of two parabolic cylindrical reflectors and a novel dual polarized broadband resonant feed. The new base station antenna can be easily upgraded to any new generation of wireless technology by replacing the feed instead of replacing the whole antenna which is the case with the current base station antennas. An unlimited number of the novel feed can be used with the same base station antenna. Thus, for the first time, one base station antenna can simultaneously cover an unlimited number of wireless applications. The new base station antenna can cover all, current and future, wireless technology generations such as 2G, 3G, 4G (LTE), --- etc. Furthermore, all mobile operators can share the same network of base station antennas (co-sitting) by adding a separate feed for each operator. The new base station antennas can be automatically deployed/folded onsite and they require simple towers. The reflectors of the new antennas are easy to manufacture with a very high surface accuracy and they are gridded to make them transparent with a low wind-load and light weight.**

Keywords—*Base Station antenna*; *LTE*; *4G*;, *Dual reflectors*; *Broadband resonant feed*; *Foldable/Deployable*; *low wind load.*

I. INTRODUCTION

As the number of wireless applications increases and with the continuous need for more speed and efficiency, the upgrading to the Long Term Evolution (LTE) technology is becoming the only choice for mobile operators to keep up with customer needs. LTE is a 4G wireless communications standard developed to provide up to 10 times the speed of 3G networks for mobile devices such as smart phones, tablets, notebooks and wireless hotspots [1]. Therefore, operators around the world are making plans to enhance their networks by integrating LTE technology and many operators are already building out their networks and transforming them to take advantage of all the benefits of LTE [2]. According to the global LTE deployment map, global 4G/LTE subscriptions will increase from 9 million in 2011 to over 560 million in 2016 [3]. One of the biggest challenges that operators face is ensuring their base stations can cost-effectively support a variety of frequencies. The time, cost and risk associated with antenna site evolution can negatively impact the operators because replacing or adding antennas to accommodate different technologies or frequencies delays time-to-market and also it is expensive. These challenges are of particular concern for operators moving to LTE, where allocated frequencies may be unknown or may change from the trial stage to the deployment stage [2]. Thus, a new ultra wideband base station antenna will be a perfect solution that can help mobile operators to cover existing radio spectrum, while preparing for bandwidth growth and additional radio spectrum availability in the future. It will allow operators to deploy just one antenna rather than several antennas to cover all frequency bands and it is ideal for supporting additional licensed frequencies that are not currently available.

Conventional arrays of crossed dipoles that are commonly used as base station antennas for mobile communications have several problems in moving to LTE [4]. Such arrays have limited frequency bandwidths which are not sufficient for recent expansions in wireless applications. Furthermore, they are heavy in weight and they suffer from high wind loads and, therefore, they need complicated heavy mounting systems. Moreover, they are high in cost and not easy to assemble and disassemble. Therefore, they are shipped and stored in their large-size assembled forms. The currently used base station antennas cannot be upgraded to any new generations of wireless applications if they have different frequency bands where the whole antenna has to be replaced or new antennas have to be added to the existing ones. Furthermore, different cell phone operators must have separate networks of base station antennas since they cannot share the same network of antennas (no co-sitting). As networks grow in size and complexity, more number of heavy weight base station antennas need to be installed. A good cell phone service in urban cities raises concerns that buildings are going to collapse under the overweight of base station antennas. One or more base stations are located on roof tops of the buildings leading to cracks beneath t, which represent a life threat for the residents of the buildings [5]. On the other hand, maintaining and upgrading of cellular towers is considered as one of the most dangerous jobs causing several fall deaths. Thus, veteran climbers predict increase in falls with the build-out of 4G LTE [6]. Base station antennas do not only add load to the towers due to their mass, but also in the form of additional dynamic loading caused by the wind [7].

In order to overcome all the above problems of conventional base station antennas, a novel foldable/deployable base station antenna with arbitrary beam widths has been developed. It consists of two parabolic cylindrical reflectors and a set of novel small size broadband resonant feeds. An unlimited number of such novels feeds operating at different frequency bands can be used with the same base station antenna. For the first time, the new base station antenna can simultaneously cover an unlimited number of wireless applications, regardless of their frequency bands. It can be easily upgraded to any new generation of wireless technology by replacing the feed instead of replacing the whole antenna which is the case with the current base station antennas. The new base station antenna can simultaneously cover all, current and future, wireless technology generations such as 2G, 3G, 4G (LTE), --- etc. All mobile operators can share the same network of base station antennas (co-sitting) [8] by adding a separate feed for each operator. The new base station antennas can be automatically deployed/folded onsite and they require simple lightweight towers. The reflectors of the new antennas are easy to manufacture with a very high surface accuracy. They are gridded and, therefore, they are transparent and they have low wind-loads and low weights. With all these unique properties, each country can have only one low-cost lightweight network of base station antennas for all, current and future, generations of wireless applications and for all operators.

II. FOLDABLE / DEPLOYABLE DUAL PARABOLIC CYLINDRICAL REFLECTORS

Fig.1 shows the geometry of a dual parabolic cylindrical reflector antenna. It consists of two parabolic cylindrical reflectors S1 and S2 with focal lengths F1 and F2 and a feed F positioned on the focal line of S2 [9]. The aperture area of the main reflector S1 is X1Y1 and the aperture area of the sub-reflector S2 is X2Y2. The dual parabolic cylindrical reflector antennas can generate arbitrary azimuth and elevation beam widths with an arbitrary ratio between them.

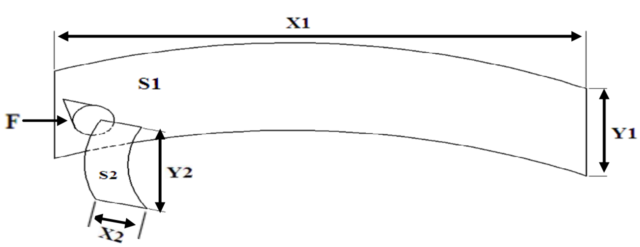

Fig.1 A dual parabolic cylindrical reflector antenna

A prototype of dual parabolic cylindrical reflectors is designed and manufactured as shown in Fig.2. The Dimensions of the antenna are: F1= 87.6 cm, F2 = 70 cm, X1 = 300 cm, Y1 = 30 cm, X2 =30 cm and Y2 = 30 cm. The reflectors are manufactured from 1 mm thick aluminum sheets with a very high surface accuracy. In order to significantly reduce the weight of the reflectors and also reduce the wind resistance, several holes are punched in the reflectors. These holes also make the metallic sheets transparent. The gridded reflectors are stable and not significantly affected by strong winds. The new base station antenna is foldable/ deployable as shown in Fig.3, which makes it very good candidate for other applications such as space shuttle antennas, satellite antennas and earth station antennas.

Fig.2 A prototype of gridded dual parabolic cylindrical reflectors

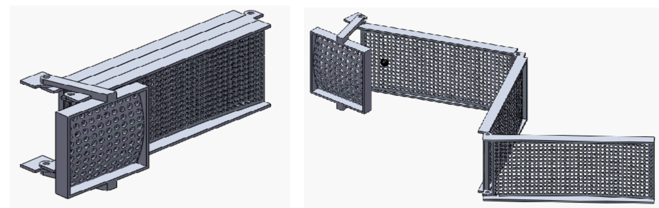

Fig.3 Foldable/deployable dual parabolic cylindrical reflector antenna

II. NOVEL BROADBAND FEEDS

Finding a small size feed with a broad bandwidth that is sufficient for the coverage of the wide 4G LTE spectrum is a very challenging problem in dual parabolic cylindrical reflector base station antennas. Low band feed antennas especially at the LTE 700 MHz band, are usually large in size and, therefore, they can cause severe blockage for the main reflector and/or the sub-reflector [10]. In this research, a new technology has been developed, so that all the possible LTE spectrum bands can be covered by only two small sized feed antennas with bandwidths of 73% and 85% respectively [11]. The first feed antenna is capable of covering the low band of the LTE spectrum starting from 698 MHz up to 1.51 GHz. The second feed antenna is capable of covering the high band portion of the LTE spectrum starting from 1.52 GHz up to 3.8 GHz. When the low band antenna and the high band antenna are combined together in a single configuration as feeds for the dual reflector, the new base station antenna becomes capable of covering 40 LTE bands in addition to the existing 2G and 3G bands.

As shown in Fig. 4, the geometry of the new feed antenna consists of two narrow printed metallic arms connected together by a short metallic strip. The length of the short arm is L1 and its width is W1 while the length of the long arm is L2 and its width is W2. The thickness of the antenna is T and the antenna is fed at a distance F from the shorted edge. Each arm has a set of slots having different shapes and locations which are optimized in order to maximize the bandwidth of the antenna. Using slots for increasing the antenna bandwidth was originally introduced by the author of this paper [12]-[13]. Also, it has been used in the development of a wide band UHF antenna from 470 MHz to 960 MHz for mobile TV and CDMA/GSM [13]. The dimensions of the low band antenna are: L1 = 7 cm, L2 = 15.6 cm, W1 = 2 mm, W2 =4 mm and T = 2 mm. Thus the overall volume of the antenna is 0.2x0.4x15.6 cm = 2.496 cm^3. It should be noted that this volume is the total volume of the antenna because it does not require an additional ground plane or any matching circuits. The same geometry has been scaled and optimized to cover the high LTE band. The dimensions of the high band antenna are: L1 = 2.5 cm, L2 = 5.55 cm, W1 = 2 mm, W2 = 4 mm and T = 2 mm. Thus the overall volume of the high band antenna is 0.2x0.4 x5.55 = 0.888 cm^3.

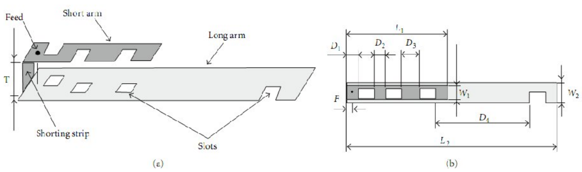

Fig. 4 Geometry of the new feed antenna

IV. DUAL PARABOLIC CYLINDRICAL REFLECTORS WITH THE NEW FEED

The performance of the new feed antennas is numerically calculated by a software packages that uses the moment method (IE3D from Zeland Inc). It was also measured at IMST antenna labs in Germany [14]. Fig.5 shows the return loss of the new LTE low-band and high-band feed antennas with the main reflector behind them. Locating the main reflector behind the feed significantly changes its performance. With the main reflector behind the new LTE low-band and high-band feeds, they naturally resonate from 698 MHz to 1.51 GHz and from 1.52 GHz to 3.8 GHz with a return loss almost lower than -10 dB over the whole band and without using matching circuits or any tuning components.

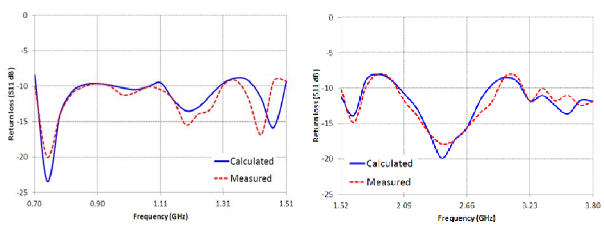

Fig. 5 Return loss (S11) of: (a) The low band feed antenna, (b) The high band feed antenna in front of the main reflector

On the other hand, the existence of the main reflector behind the feed antennas significantly modifies their radiation patterns. The radiation patterns of the feeds alone without the main reflector were omni-directional with a peak gain of about 2 dBi [14]. The calculated radiation patterns of the feed antenna with the main reflector behind them at a sample frequency 1 GHz is shown in Fig. 6(a). The gain of the feed is about 10.5 dBi. The radiation patterns of the dual parabolic cylindrical reflector antenna with the new feed are calculated using GTD (geometrical theory of diffraction) [9]. A GTD software code was written for dual parabolic cylindrical reflectors with arbitrary feed patterns and its accuracy was verified experimentally [16]. Fig. 6(b) shows the calculated radiation patterns of the new base station antenna with the new feeds in two principal planes at 1 GHz. The gain of the antenna is about 15 dBi. A scaled version of the base station antenna is also manufactured and tested in the field for direct broadcast satellite TV reception at Ku frequency band [17].

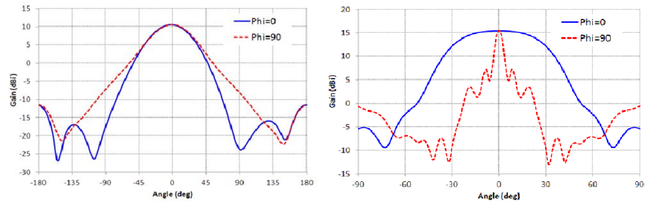

Fig.6 Radiation Patterns of: (a) The feed antenna at 1 GHz, (b) The new base station antenna at 1 GHz.

V. MIMO (Multi-Input-Multi-Output)

In order to boost signal-to-noise ratio (SNR) and reach the multiplicative effect on throughput, multi-input multi-output (MIMO) technology is essential for achieving the full benefits of LTE[18]. However, gaining the advantages of MIMO requires the installation of multiple array antennas at the base station which increases the burden of LTE rollout on operators including costs of extra number of antennas, increased load on existing base station towers and increasing visual impact that raises social and health concerns. Base station antenna manufacturers are trying to alleviate the burden on cellular operators by combining more than one array under a single cover (radome) [18] to be considered visually as a single antenna which definitely solve the problem of visual impact but it does not solve the weight and cost issues. Installing a single unit of the new wide band base station antenna with multi-feeds is capable of serving the purpose of multiple conventional arrays for MIMO. The interference between the multi-feeds has been investigated as shown in Fig 7. The multi-feed configuration consists of three of the novel wide band feed antennas having the same polarization relative to each other. The first antenna is placed at the focus point of the sub reflector while the second and the third antennas are placed at 30 cm on the left and 30 cm on the right off the focus point, respectively. As shown in Fig. 7 the coupling effects of the three antennas on each other are negligible and the isolation is almost lower than -25 dBi all over the low band and -30 dBi all over the high band.

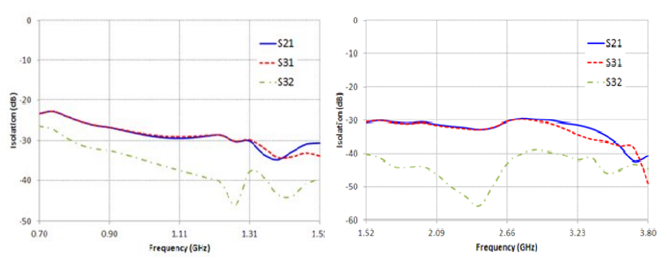

Fig. 7 The isolation between MIMO feed antennas

The gain of the base station antenna has been also investigated when the multi feed antenna configuration is used to feed the dual parabolic reflectors for the MIMO capability. As shown in table.1, the gain of the base station has been found to be almost unchanged for different feed antennas located off thefocus point of the sub reflector by 15 cm and 30 cm shifts, either on the right or on the left off the original focus point.

Table 1The change in the base station antenna gain as the feed antenna is shifted off the focus point

Feed shift (cm)	0	-15	15	-30	30
Base station Gain (dBi)	15.63	15.49	15.49	14.9	14.9

VI. CONCLUSIONS

A novel low-cost, low wind load, light weight foldable/deployable base station antenna with arbitrary beam widths has been developed. It consists of two parabolic cylindrical reflectors and a set of novel small size broadband resonant feeds. An unlimited number of such novel feeds operating at different frequency bands could be used with the same base station antenna. For the first time, the new base station antenna could simultaneously cover an unlimited number of wireless applications, regardless of their frequency bands. It could be easily upgraded to any new generation of wireless technology by replacing the feed instead of replacing the whole antenna which is the case with the current base station antennas. The new base station antenna could simultaneously cover all, current and future, wireless technology generations such as 2G, 3G, 4G (LTE), --- etc. All mobile operators could share the same network of base station antennas (co-sitting) by adding a separate feed for each operator. The new base station antennas could be automatically deployed/folded onsite and they required simple lightweight towers. With all these unique properties, each country can have only one low-cost lightweight network of base station antennas for all, current and future, generations of wireless applications and for all operators.

All the possible LTE spectrum bands could be covered by two small size feed antennas with bandwidths of 73% and 85% respectively. The first feed antenna was capable of covering the low band LTE spectrum starting from 698 MHz up to 1.51 GHz .The second feed antenna was capable of covering the high band portion of the LTE spectrum starting from 1.52 GHz up to 3.8 GHz. When the low band antenna and the high band antenna were combined together in a single configuration as feeds for the dual reflector, the new base station antenna became capable of covering 40 LTE bands in addition to the existing 2G & 3G bands. On the other hand, the new wide band base station antenna with multi-feeds was capable of serving the purpose of multiple conventional arrays for MIMO. The interference between the multi-feeds was investigated. The multi-feed configuration consisted of three of the novel wide band feed antennas having the same polarization relative to each other. The first antenna was placed at the focus point of the sub reflector while the second and the third antennas were placed at 30 cm on the left and 30 cm on the right off the focus point. The coupling effect of the three antennas on each other was negligible and the isolation was almost lower than -25 dBi all over the low band and -30 dBi all over the high band.

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