Design of Shaped Offset Dual-Reflector Antenna for 5G Mobile Base Station

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***Abstract* — In 5G mobile communication system, new technical subjects such as millimeter wave, small cell size and multibeams at a base station will be introduced in relating to radio wave technologies. For a millimeter wave base station antenna, an aperture antenna such as a reflector will be possible. In this paper, reflector shaping method of offset dual-reflector is shown. Based on the shaping method, a reflector shaping program is developed on a MATLAB software. Some base station antennas are designed and installation conditions on a base station are examined.**

Index Terms — offset dual-reflector antennas, reflector shaping method, 5G Antennas, MATLAB program.

I. Introduction

Massive Multi Input Multi Output (MIMO) is expected to be one of the pillars of 5G that promises to address the massive capacity requirement by 5G. In Massive MIMO, one beam is assigned for one user. Therefore, base station antenna should produce multibeams. Multibeams offer high energy efficiency due to concentration of radiated energy on user and it will remain very important in the future and it is a key requirement for 5G.

When considering millimeter wave use, the base station antenn size becomes small such as some tenth of centimeter. Any antenna types such as array and aperture antennas become possible. In this study, an offset dual-reflector antenna is selected because of simplicity of antenna configuration and installation easyness to a base station as shown in Fig. 1. Multibeams can be produced by arranging many feed horns.

Up to now, few numerical and analytical studies on offset dual reflectors have been investigated by [3]-[5]. The reflector shaping method of an offset Gregorian dual-reflector antenna based on energy conservation law was carried out by Lee *et al* [3]. The shaping scheme can be used to generate main reflector and sub reflector. In 2002, Granet [4] reported a simple procedure to design classical displaced-axis dual-reflector Gregorian and Cassegrain antennas. Unfortunately, no shaping method of the proposed dual-reflector is taken into account in their paper. Whereas Villiers [5] developed an analytical formula to predict the diffraction efficiency of offset dual-reflector antenna.

In this paper, a design method based on ray tracing concept for offset Cassegrain dual-reflector antenna with single on-axis feed is developed using MATLAB software. Basic theory of offset Cassegrain dual-reflector antenna design based on conventional parabola concept is explained in Section 2. The third section is concerned with the method of obtaining results for this study. Meanwhile, the fourth section presents the findings of the research. The final section summarises the main findings of this study.

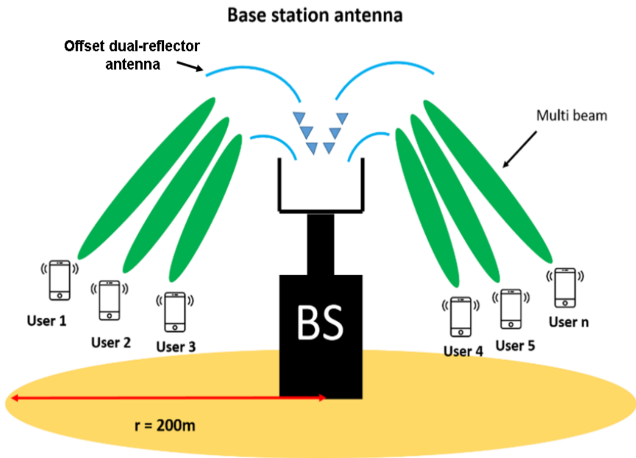

Fig. 1. The structure of offset dual-reflector antenna at the 5G base station.

II. Reflector Shaping Method of An Offset Cassegrain Antenna

Fig. 2 illustrates the offset Cassegrain antenna with on-axis feed geometry. It consists of a feed antenna, an offset main reflector and sub reflector. According to Fig. 2, it is clearly seen that the sub reflector and the feed horn do not block the rays arriving to the antenna aperture.The radiation pattern of the feed horn is denoted as $E_p^2(\theta)$. The aperture distribution is denoted as $E_d^2(x)$. The feed horn is placed at the focus of a Cassegrain configuration.

Three equations are used in designing a conventional Cassegrain antenna [6]:

1) Reflection on sub reflector

The reflection condition on sub reflector surface and it is given by the following equation:

$$\frac{dr}{d\theta} = r \tan \frac{\theta + \phi}{2} \tag{1}$$

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2) Reflection on main reflector

Meanwhile, the reflection on main reflector surface can be determined using:

$$\frac{dz}{d\theta} = \frac{dx}{d\theta}\tan\frac{\phi}{2} \tag{2}$$

3) Energy conservation law

Ray tubes from the feed to the antenna aperture is shown in Fig. 3. The electric power containing in a ray tube should be conserved. The relation of energy conservation can be written as:

$$\frac{dx}{d\theta} = \frac{E_p^2(\theta)\int_0^{x_m} E_d^2(x)dx}{E_d^2(x)\int_0^{\theta_m} E_p^2(\theta)\,d\theta} \tag{3}$$

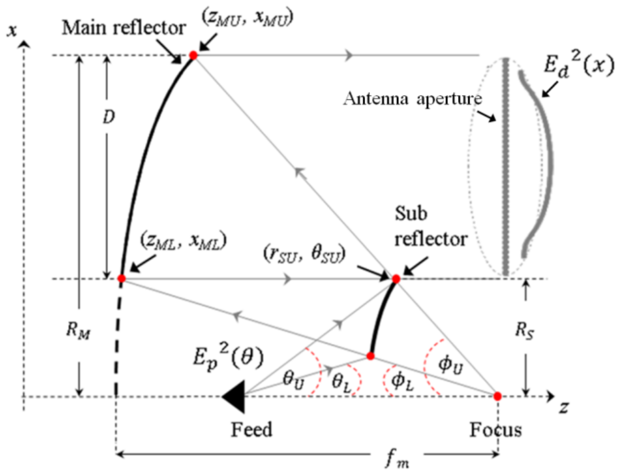

Fig. 2. The Offset Cassegrain antenna structure.

The largest and lowest values of the main reflector surface are symbolized in (x_{MU}, z_{MU}) and (x_{ML}, z_{ML}) coordinate systems, respectively. On the other hand, the coordinates (r_{SU},θ_{SU}) and (r_{SL},θ_{SL}) denote the maximum and minimum of the sub reflector profiles.

The projected-aperture diameter of the offset reflector, D, can be found using [7]:

$$D = \frac{4\, f_m \sin\phi_C}{\cos\phi_B + \cos\phi_C} \tag{4}$$

where

$$\phi_B = \frac{\phi_U + \phi_L}{2} \tag{5}$$

$$\phi_C = \frac{\phi_U - \phi_L}{2} \tag{6}$$

The feed antenna in the offset structure is tilted θ_c away from the z-axis. The $E_p(\theta)$ value is given as the following formula:

$$E_p^2(\theta) = \cos(\theta - \theta_c)^q \tag{7}$$

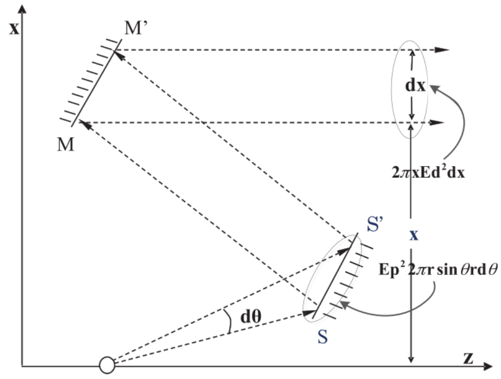

Fig. 3. Energy relation [6]

The central angle of the feed antenna that is symbolized by θ_c can be calculated using [7]:

$$\theta_c = \frac{\theta_U + \theta_L}{2} \tag{8}$$

where θ_U and θ_L are treated as the maximum and minimum offset angles of the feed antenna.

It is noteworthy that the reflected rays from the main reflector become parallel to z-axis since the dual-reflector antenna is designed using *GO* concept. Afterwards, they create the aperture distribution of $E_d(x)$ that is defined by:

$$E_d^2(x) = \left[1 - \left(\frac{x - x_c}{x_{MU} - R_s}\right)^2\right]^{4p} \tag{9}$$

where R_s is the radius of the sub reflector and x_{MU} is the maximum value of x-point on the main reflector surface. On the other side, the value of x_c point can be determined using:

$$x_c = x_{MU} - R_s \tag{10}$$

III. MATLAB Program

A MATLAB program is developed in order to solve the simultaneous differential equations (i.e., Eqs. (1), (2), (3), (4), and (6)). Fig 4 below depicts the MATLAB designing block diagram in which the stages of methodology in obtaining desired results. It begins at the reflector edges in which the main and sub reflector coordinates are symbolized by (x_{MU}, z_{MU}) and (r_{SU}, θ_{SU}), respectively.

The radiated rays from the feed antenna reach sub reflector surface at the angle of θ in which is denoted by (r, θ) and the radiated ray spacing is given by $\Delta\theta$. Eq. (1) used to determine the change of dr. Thereafter, these radiated rays are reflected toward the main reflector surface at an angle of ϕ and they become parallel with z-axis at the coordinate point (z, x). The surface shaping experession $dz/d\theta$ can be determined using Eq. (2). Meanwhile, the value of x-point is generated using Eq. (3). By repeating the steps of computation through numerical solutions of the simultaneous differential equation, the shaping profiles for the offset main and sub reflector surfaces can be obtained.

the top of the sub reflector surface. It means the x_{ML}-point and R_s have the same value.

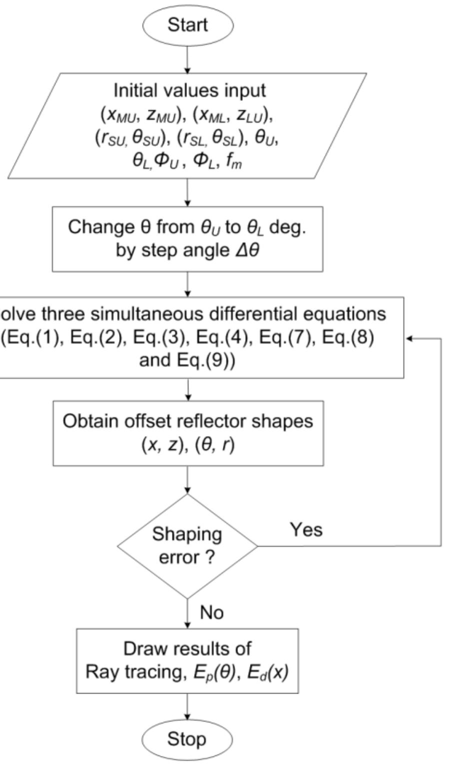

Fig. 4. MATLAB designing block diagram

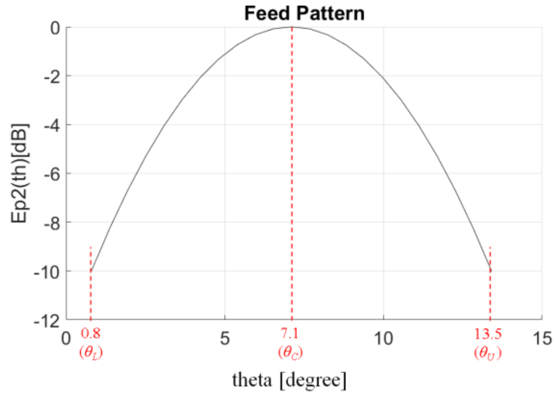

Fig. 5. Feed radiation pattern

IV. Designed Results

In order to design the offset Cassegrain dual-reflector, initial parameters of the antenna structure are determined. The frequency at 5G mobile base station must be at least 28GHz, thus the value of the frequency is set at 28GHz. The values in Table 4.1 are obtain through mathematical calculation and understanding of conceptual dual-reflector.

TABLE I
Initial Parameters

Parameters	Value	Unity
Frequency	28	GHz
Diameter of main reflector (D_m)	300	mm
Diameter of sub reflector (D_s)	37	mm
The projected-aperture diameter of the offset reflector (D)	131.5	mm
Main reflector focal length (f_m)	100	mm
Maximum angle of sub reflector (θ_U)	13.5	degree
Maximum angle of main reflector (ϕ_M)	70	degree

Fig. 5 provides the radiation pattern for the tilted feed antenna. The minimum of feed radiation pattern must at least at -10dB. The lower the radiation pattern, the better. However, the size of the horn antenna will also need to be reduced. Therefore, we set the feed pattern to -10dB. The angle of θc is the centre of angle where the feed radiated maximum radiation pattern.

The reflected rays occuring on different shaped surfaces (p= 0 and p= 1) are shown in Fig. 6. It is considered that the lowest point of the projected-aperture diameter (D) lie on

On the other hand, the aperture distribution of $E_d(x)$ for different p-values (uniform and taper) is plotted in Fig. 7. It can be observed that the value of p= 0 generates uniform aperture distribution $E_d(x)$ and p= 1 is able to provide a smooth taper from the centre to the edge where aperture field is null.

The radiation pattern distribution can be obtained by integrating the rays from the feed antenna with the $E_d(x)$. Fig. 8 compares an overview of the radition pattern for p= 0 and p= 1. Black solid line corresponds to the radiation pattern with the value of p is zero whereas p= 1 is represented by dotted line. It can be observed, the first Side Lobe Level (*SLL*) of uniform aperture distribution with p= 0 is -13.3 dB. On the other hand, the *SLL* of -23 dB is observed with the given value of p= 1. Therefore, it can be concluded that the taper with p= 1 is capable to yield lower side lobe compared to p= 0.

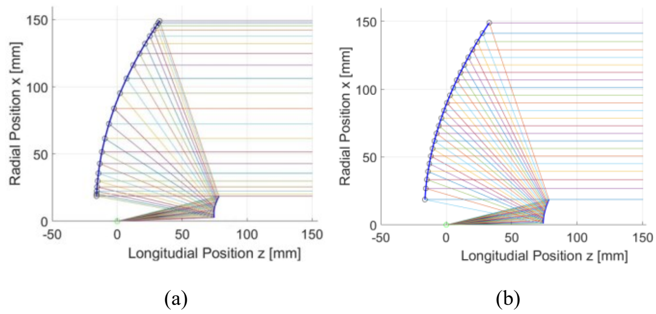

Fig. 6. Ray tracing results for (a) p = 0 and (b) p = 1

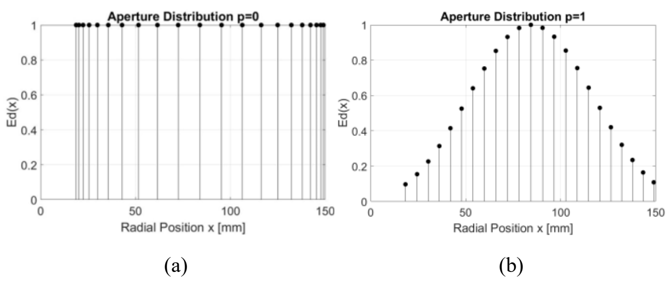

Fig. 7. Aperture distribution of $E_d^2(x)$ for (a) p= 0 (uniform) and (b) p= 1 (tapered)

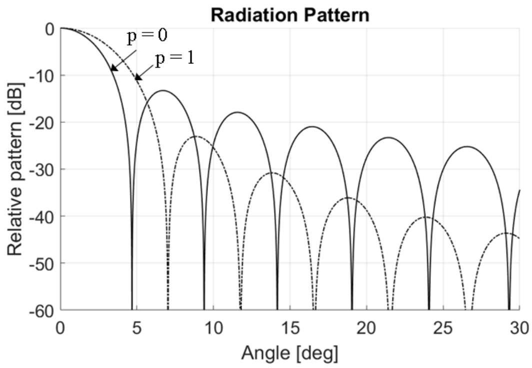

Fig. 8. Radiation patterns in *2-D* for $p=0$ and $p=1$

In order to ensure installation conditions of designed antennas, the proposed antennas are placed on the top of mobile base station tower as shown in Fig. 9. The antenna structures seem suitable for antenna tower installation.

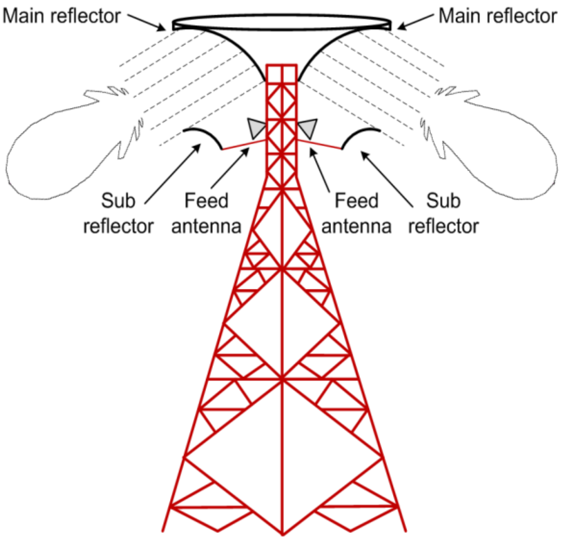

Fig. 9. Installation structure of designed offset dual-reflector antenna

V. Conclusion

In order to achieve multibeams dual-reflector antenna, fundamental dual-reflector shaping method is applied for an offset dual-reflector antenna. The MATLAB software is developed to conduct reflector shaping. Ability to design the offset dual-reflector surface is shown by the results of the ray tracing, the aperture distribution $E_d(x)$ and the radiation patterns. Moreover, configuration of antenna installation on an antenna tower is examined.

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