ADE Omnidirectional Dual Reflector Antennas

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***Abstract*—In this work an axially-displaced-ellipse (ADE) dual-reflector antenna is suggested for the achievement of an omnidirectional covarage. Its geometry is briefly presented and some relevant features are compared aginst previously suggested reflector antennas, designed for the same purpose. The present antenna configuration is capable of yielding the desired aperture illumination with relatively smaller reflector dimensions, providing a compact arrangement suited for use at the base station of point-to-multi-point radio links. Numerical simulations are presented to illustrate the usefulness of the proposed reflector antenna.**

***Index Terms*—Reflector antenna, omnidirectional radiation pattern.**

I. Introduction

The costs involved in the final step of cable systems brought the interest in broadband wireless distribution to consumers (wireless local loop, WLL). The antennas employed in these point-to-multi-point applications follow the cellular telephone concept, where the radio base stations usually employ arrays of antennas at a certain height from the ground for omnidirectional coverage, with element excitations being exercised in order to achieve a suitable elevation pattern synthesis. For the transmission of high-speed data, television, video and voice signals, the ITU has defined standards for Local Multi-point Distribution System (LMDS) or Local Multi-point Communication System MM operating between 25.4 to 31.4 GHz, with 1GHz bandwidth. For TV broadcast, ITU has define standards for the Microwave Video Distribution System (MVDS) that operates from 40.5 to 42.5 GHz.

The use of increasing frequencies, up to mm-waves, makes attractive the employment of compact reflector antennas capable of providing wider absolute bandwidths, necessary to transmit wideband signals. For omnidirectional coverage in the azimuthal plane and vertical polarization, a circularly symmetric dual reflector antenna was presented in [1]. The circularly symmetric configuration consists of a parabolic subreflector and a conical main reflector fed by a coaxial horn, which was designed to transmit only the TEM mode. Depending on the required polarization, different designs with the coaxial feed replaced by electromagnetic horns radiating TM01 or TE01 modes were also investigated [1]. In [2], geometrical optics was employed to shape both reflectors in order to control the phase and power at the antenna aperture, thus increasing the gain. Alternatively to the dual reflector antenna, a configuration employing a single circularly-symmetrical shaped reflector surface fed by a coaxial conical horn was presented in [3]. The reflector surface was shaped to attain a cosecant squared-like power pattern in the vertical plane to account for free space attenuation, while concentrating the radiated energy bellow the horizon line for reduced interference. When compared with the omnidirectionl dual reflector antenna, the major disadvantage of the single reflector system is the large reflector diameter required to achieve the necessary aperture width for adequate control of the vertical radiation pattern.

In this work, an alternative dual-reflector antenna is presented, where the subreflector is an ellipsoid, with one of the focii displaced from the symmetry axis, and the main reflector is shaped to achieve the cosecant squared-like radiation pattern in the vertical plane. For the antenna design, geometrical optics and physical optics were used. The design also aimed the achievement of a compact configuration, in which the electromagnetic coupling between the feed and reflectors becomes a relevant issue. So, in order to validate the design an analysis based on the the method of moments was conducted to obtain the electrical characteristics of the whole structure.

II. ADE Omnidirectional Dual Reflector Antenna

Several authors have proposed a dual-reflector system that provides omnidirectional coverage [1,2], herein called the Omnidirectional Dual-Reflector (ODR) antenna. The conventional ODR antenna is depicted in Fig. 1. The subreflector is a paraboloid while the main-reflector is a cone with internal semi-angle of 45 degrees, such that the reflected rays arrive at the cylindrical aperture with a right angle with respect to the symmetry axis of the reflector system (Fig. 1). For the same antenna aperture (Wa), the conventional ODR can yield more compact configuration when compared with the single-shaped reflector antenna, as shown in [1]. However,

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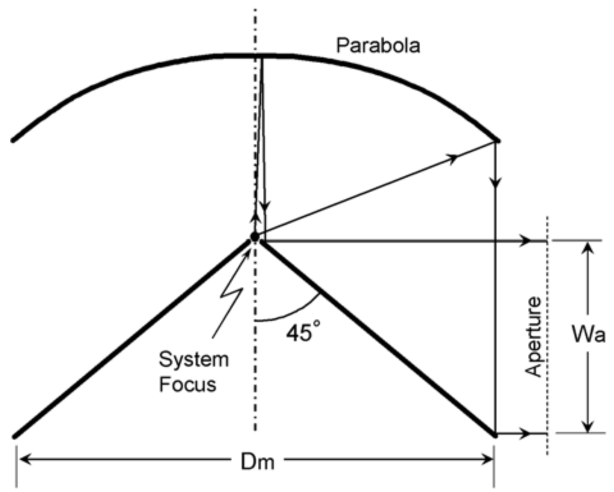

Fig. 1– Omniderctiona dual reflector antenna.

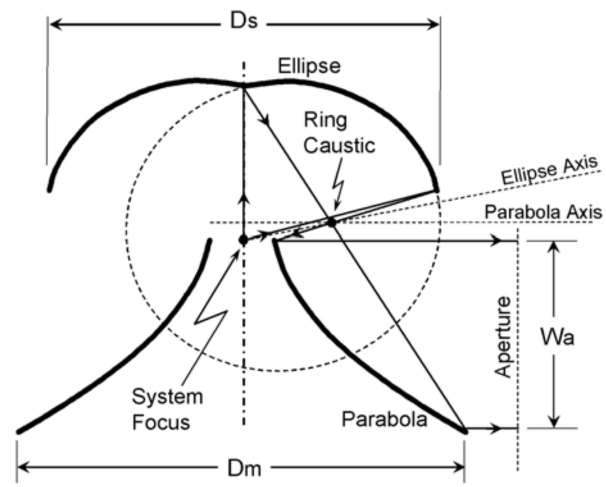

Fig. 2 – Basic ADE geometry and parameters.

higher return losses at the feed waveguide are expected, since the energy radiated around the symmetry axis is reflected by the subreflector back to the feed aperture. This effect becomes a relevant concern when compact designs are desired.

The antenna configuration proposed in this work is depicted in Fig. 2 with some relevant parameters and rays. Its geometry is derived from the classical Axially-Displaced Ellipse (ADE), first investigated by Yerukhimovich [4,5] and further generalized as a family of the classical axially-symmetric dual-reflector antennas [6]. The subreflector is generated by an ellipse, which has one of its foci (the system focus) located at the symmetry axis. The second focus of the ellipse coincides with focus of the parabola, which generates the main-reflector (see Fig. 2). After the rotation around the symmetry axis, this focus will describe a real ring caustic between the sub- and main-reflectors. So, the dual-reflector system provides the collimation of the spherical wavefront emanating from the system focus into a cylindrical wavefront at the main-reflector aperture (see Fig. 2). With some minor modifications, the design equations provided in [6] can be suited for the present geometry by requesting a right angle between the symmetry axis and the parabola axis (see Fig. 2).

As the ODR configuration, the ADE offers a dual-reflector system with minimum blockage mechanisms. However, in principle a better aperture illumination can be attained, as the feed radiation is reversed toward the aperture, i.e., the feed principal ray (along the axis of symmetry) is directed toward the main-reflector outer rim, while the feed ray toward the subreflector edge is directed toward the internal rim of the main reflector (see Fig. 2). The reverse of the feed radiation compensates for the increase in the spatial attenuation as the feed ray direction deviates from the principal ray, thus yielding a more uniform aperture illumination. Another important feature of the ADE configuration is due to the proximity between the main-reflector and its ring caustic. By displacing the associated parabola focus away from the symmetry axis of the reflector system, the ADE configuration permits, in principle, the attainment of a larger aperture width (Wa) when compared against an ODR antennas with the same main-reflector diameter (Dm).

III. ANTENNA DESIGN AND ANALYSIS

The antenna initial design followed the geometrical optics principles described in the previous section. For shaping the subrefletor surface the procedure described in [7] was adopted. That employs a physical optics (PO) analysis embedded in an optimization scheme to adjust the surface shape to attend far-field radiation pattern specifications. To attain a compact configuration, the subreflector was placed close to the feed. To properly account for the near-field effects of the feed radiation upon the subreflector, the PO-optimization scheme employed a feed model based on a spherical wave expansion obtained from the coaxial horn measured data [3]. Figure 3 illustrates the measured radiation pattern of the TEM coaxial horn employed in the present design. To properly account for second order effects resulting from feed and reflector surface electromagnetic interaction, the method of moments (MoM) was employed to numerically solve the rigorous formulation of the electromagnetic scattering problem. The MoM numerical procedure adopted was that described in [8], where an equivalent distribution of electric and magnetic currents excites only the fundamental TEM mode toward the cable-antenna junction. This scheme also eneables the evaluation of the return loss at the cable [8].

For the design study, the antenna configuration depicted in Fig. 2 was fed by a coaxial horn with aperture center located at the focus of the subreflector. The feed was designed to propagate only the fundamental TEM mode, radiating an omnidirectional azimuthal pattern with a null along the symmmetry axis. To minimize feed back-scattering and, consequentely, the feed interference with the antenna radiation pattern below the horizon, a quarter-wave chocke was placed at the feed aperture plane (as indicated in Fig. 5). The coaxial horn radiation pattern calculated from the MoM analysis is shown in Fig. 3 and compared with the measured data. The coaxial horn gain is about 9 dBi.

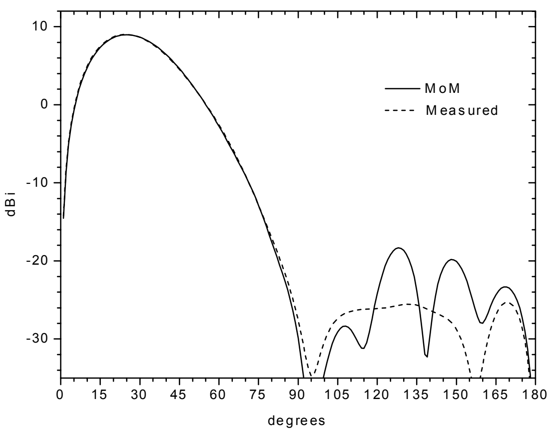

Fig. 3 – Feed radiation pattern at central frequency: calculated (solid lines) and measured (dotted).

To ensure the control of the antenna geometry, as reflector, aperture and clearance dimensions, the conventional ADE configuration was used as initial solution for the optimization algorithm. The chosen ADE parameters are as follows: subreflector diameter (D_S) of 10λ, main reflector diameter (D_m) of 16λ, subreflector semi-edge angle is 60^0, the ellipse focal distance is 2.73λ, subreflector axial angle is 63^0, and parabola focal distance is 2.11λ. These parameters were adjusted to provide a aperture width (W_a) of 7λ and free of subreflector blockage. To reduce the spill over below the horizon, the main reflector was made slightly larger than necessary to reflect the energy coming from the center of the subreflector. A compromise between subreflector spillover and feed return loss determined the design of the subreflector diameter and edge semi-angle. The chosen geometry is shown by the dotted line in Fig. 5 and vertical radiation pattern obtained via MoM is shown in Fig. 4. The observed 9.4 dBi directivity is essentially due to the main reflector projected effective aperture of about 6λ, which approximately corresponds to the 10^0 half-power beam width found in the vertical radiation pattern.

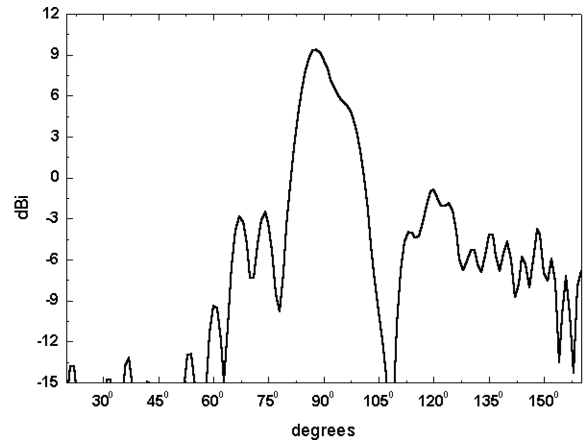

Fig. 4 - Conventional ADE radiation pattern at the central frequency.

For the main reflector optimization, the far field specifications required a cosecant-squared radiation pattern-like, from 90^0 to 140^0, below horizon, as described by the dotted line in Fig. 5. Above the horizon ($\theta < 90^0$), the specifications require a sidelobe envelope below –7dBi for $30^0 < \theta < 80^0$. To ensure a better use of the antenna-projected aperture, the synthesis required that the junction between the main reflector and the feed to be at the aperture plane. The optimization had to minimize an objective function built from the residues obtained from a comparison between calculated and specified radiation pattern at series of chosen far-field directions. To accommodate the natural pattern oscillations due to the finite aperture, in the region below the horizon the

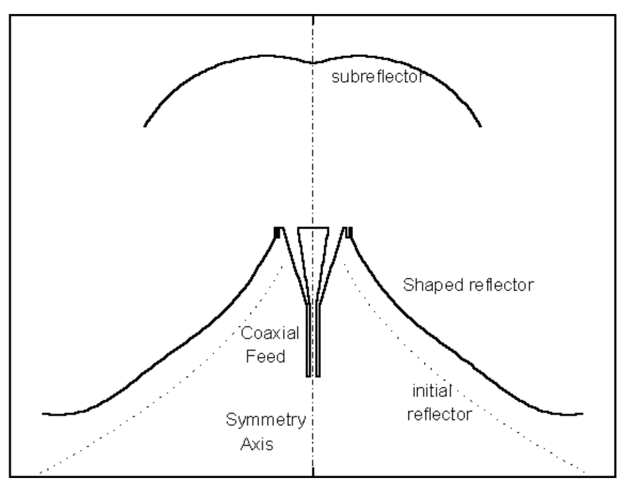

Fig. 5 - ODR with shaped main reflector (full line) and conventional ADE main reflector (dotted line).

objective function considered only the differences large than 1.5 dB from the cosecant squared.

The optimized main reflector, subreflector and feed are shown in Fig. 5. The shaping has move upwards the main reflector placing the junction with the feed at the aperture plane. The antenna radiation pattern is shown in Fig. 6 and compared to the cosecant squared pattern (dotted line). Above the horizon the radiation pattern behaves as expected.

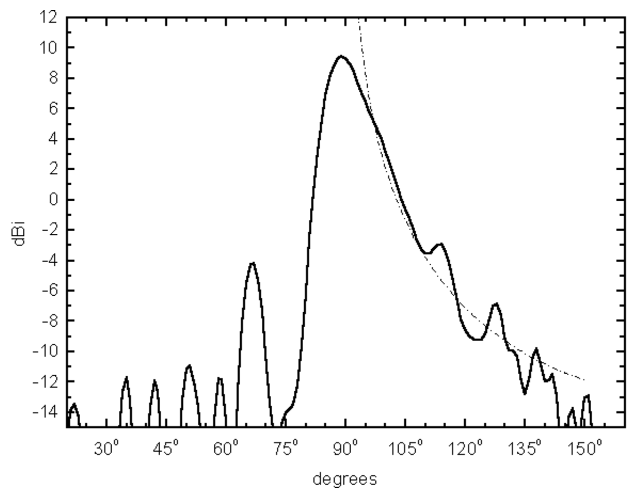

Fig. 6 - Vertical radiation pattern of the ODR antenna with shaped main reflector (full line) and cosecant squared pattern (dotted line).

Figure 7 shows the return loss values obtained at different frequencies ranging from ±5% from the central frequency. These values reveal an interaction between feed and reflector surfaces resulting in a frequency dependent behavior. The ODR (paraboloid and 45^0cone) explored in [2,7] have similar subreflector and feed dimensions. When the results in [2,7] are compared with the values in Fig. 7, the oscillations observed in the modified ADE are significant lower.

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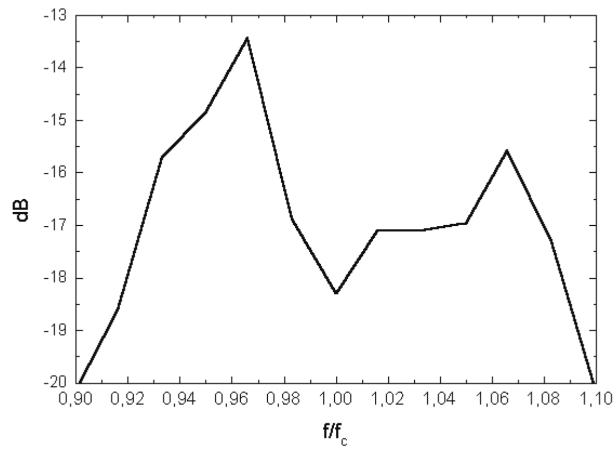

Fig. 7 – Modified ODR return loss.

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