Applications of Tri-mode Waveguide Feeds in Adaptive Virtual Array Antennas

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***Abstract*—This paper presents the formation of an adaptive virtual array antenna in a parabolic reflector illuminated by a tri-mode circular waveguide feed. The modes of interest are the TE_{11}, TE_{21}, and TM_{01} type modes. By appropriately exciting these modes in the primary feed, the effective source of radiation is displaced within the reflector aperture while the resulting secondary patterns remain axial.**

I. INTRODUCTION

Phased array antennas have been used in a variety of applications such as satellites and modern wireless and communication systems for beam scanning, beam shaping, adaptive nulling, and displacing the phase centre locations. Each of these specific features requires a unique excitation distribution by a proper excitation of radiating elements as a vectorial basis. In particular, a cluster of elements may be spatially weighted in order to shift the effective source of radiation, also called the phase centre location, of the phased array antenna. Inspired by the degrees of freedom offered by such adaptive arrays and their discrete analogous to the aperture antennas, herein an adaptive virtual antenna is presented through the use of a single parabolic reflector antenna illuminated by an over-moded circular waveguide feed. Beam scanning properties of such multi-mode feeds are profoundly beneficial to effectively shift the phase centre location of the reflector antenna by illuminating different parts of the reflector aperture, other than its centre. Thus, the resulting antenna provides multi-phase centre locations over a single aperture.

Multi-phase centre reflector antennas were studied in [1]-[4], using dual-mode waveguide feeds for ground moving target indicator radars. The displacement of the phase centre was simply obtained by changing the excitation amplitude ratios and phase shifts of the two modes. No polarization control was investigated in any of the above work and the phase centre motion was achieved only in a single plane. The detailed elucidation of adaptive virtual array antennas with dual-mode feeds is published by the authors in [5], where other than the mode excitations, their polarization and mode alignments were also investigated resulting in adaptively displacing the phase centre location in any desired plane.

In this paper, the concept of virtual array antenna is reviewed when a tri-mode circular waveguide is employed as a primary feed in a symmetrical-cut parabolic reflector antenna. The modes include the TE_{11}, TE_{21}, and TM_{01} type modes. The operation frequency is 10 GHz. The simulations are carried out using the physical optics, geometrical optics, and geometrical theory of diffraction software TICRA's GRASP v.7 [6] for reflector antennas. First, an analytical model of the primary feed, which is used in our investigation, is given in section II. Then, the results of the compound reflector and the feed are presented in section III.

II. PRIMARY FEED MODEL

To simplify our study on the virtual array antenna with a tri-mode circular waveguide feed with the TE_{11}, TE_{21}, and TM_{01} type modes, first the primary feed is analytically modelled by appropriate radiation functions to closely approximate the aforementioned modes over a practical aperture size of the feed. The dual-mode feed model was well discussed by the authors in [7]. Herein, the model is extended to the tri-mode operation. Without loss of generality, it is assumed that the transverse electric modes have symmetric E- and H-plane patterns. As for the transverse magnetic field, its ϕ-component is zero. Therefore, the mathematical expressions of the combined tri-mode feed are expressed as follows:

$$E_\theta = C_1 \cos^n\theta \sin\phi - j\, C_2 (\sin 2\theta \cos\theta) \cos 2\phi + j\, C_0 \sin 2\theta \cos\theta \qquad (1.a)$$

$$E_\phi = C_1 \cos^n\theta \cos\phi + j\, C_2 (\sin 2\theta \cos\theta) \sin 2\phi \qquad (1.b)$$

wherein C_1, C_0, and C_2 are the content factors of the TE_{11}, TM_{01}, and TE_{21} modes, respectively. To represent the vectorial form, they are complex numbers. The tapering factor of the dominant TE_{11} mode is determined by n, which depends on the aperture size of the feed. The first term of (1) corresponds to the TE_{11} mode type of a circular waveguide and it produces a broadside pattern, as expected. The second term of (1) approximates the TE_{21} type mode, which generates a bore-sight null pattern. The TM_{01} mode has only E_θ component, which is modelled by the third term of (1.a). It also generates a split beam with a null at the boresight direction. To conduct our study, a symmetrical-cut parabolic reflector is selected with an F/D=0.5 and a diameter of 30λ, where λ is the free-space wavelength at the frequency of 10 GHz. If a single TE_{11} feed is to illuminate such a geometry, the factor n in the first term of (1) should be equal to 2.25 to provide about -10dB edge illumination. Therefore, n=2.25 is assumed throughout our study. With regard to the phase shifts between the modes, there are four possible cases with each of the higher order modes having ±90° phase shifts, with respect to the TE_{11} mode. For brevity, two cases with phase shifts of same polarity are reported here. Their associated primary patterns are shown in Fig. 1, when $|C_2/C_1|$=0.6 and $|C_0/C_1|$=0.2. As a result, the primary radiation patterns are scanned at both diagonal and asymmetry planes of ϕ=45° and 90°, respectively. This will, in turn, illuminate the reflector aperture asymmetrically, as will be fully discussed in the following section.

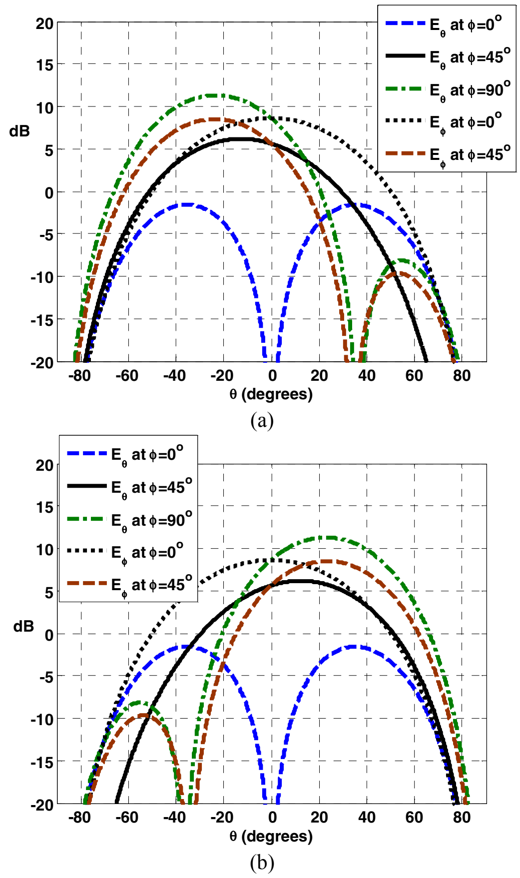


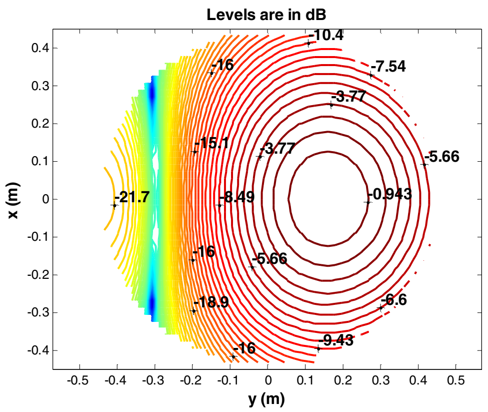
Fig. 1 Primary radiation patterns of the tri-mode waveguide feed defined by (1) when n=2.25 at f=10GHz: (a) C_2/C_1=0.6/+90° and C_0/C_1=0.2/+90° (b) C_2/C_1=0.6/-90° and C_0/C_1=0.2/-90°.

III. Reflector Results

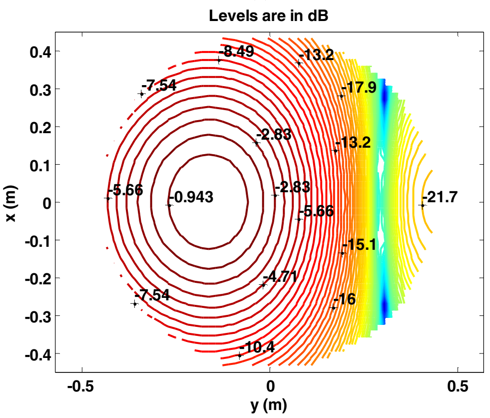
In this section, the performance of a symmetric reflector antenna with the tri-mode circular waveguide feed, discussed in the preceding section, is presented. The parabolic reflector antenna under investigation has a diameter of D=30λ with an F/D=0.5 at the frequency of 10GHz.

In an adaptive multi-phase centre aperture antenna, the phase centre location of the composite reflector and the feed should be displaced from the physical centre of the reflector aperture while producing identical secondary radiation patterns at the far-field zone. To this end, the primary feed should asymmetrically illuminate the reflector aperture with its phase centre located at the focal point of the reflector. With the tri-mode circular waveguide as a primary feed, the phase shift of ±90° between the modes results in scanned primary main beams, in which the phase centre of the feed itself is located at its physical centre. This point must be coincident with the reflector focal point to generate axially symmetric patterns at the far-field region.

In order to locate the phase centre location of the reflector, the normalized amplitude aperture distributions of the symmetric reflector, illuminated by the primary tri-mode feed shown in Fig. 1, are illustrated in Fig. 2. As can be seen, the peak intensities of the electric field shift away from the physical centre of the aperture along the y-axis. The phase distributions across the aperture are uniform and are not shown here for brevity. The secondary radiation patterns are depicted in Fig. 3, with the main beam at the boresight angle, as expected. It should be mentioned that the secondary patterns remain unchanged for the negative mode phase shift signs as well, which are omitted here. Therefore, such adaptive apertures will have multi-phase centre locations by controlling the mode content factors of the primary feed. More results will be presented in the conference.



(a)



(b)

Fig. 2. Normalized amplitude aperture distributions of the symmetric reflector with F/D=0.50, D=30λ fed by the tri-mode feed defined by (1) when n=2.25 at f=10GHz: (a) C_2/C_1=0.6/+90° and C_0/C_1=0.2/+90° (b) C_2/C_1=0.6/-90° and C_0/C_1=0.2/-90°.

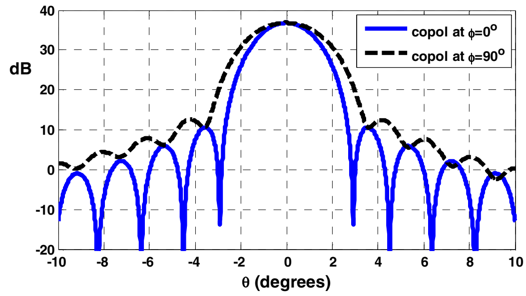


Fig. 3. Secondary radiation patterns of the symmetric reflector with F/D=0.50 and D=30λ fed by the tri-mode feed defined by (1) when n=2.25, C_2/C_1=0.6/+90°, and C_0/C_1=0.2/+90° at f=10GHz.

IV. CONCLUSION

An adaptive multi-phase centre antenna was studied in a single-aperture parabolic reflector antenna. The primary feed was a tri-mode circular waveguide antenna operating at the TE_{11}, TE_{21}, and TM_{01} type modes. It was shown that by controlling the amplitude ratios of the modes and applying quadrature phase shifts between the modes, the phase centre location of the reflector can be shifted away from its physical centre. One example was presented, which successfully validated the concept of virtual array antenna with multi-phase centre location within a single aperture. The developed antenna may be used in electronically displaced phase centre antenna technique well suited for radars with moving platforms to suppress the clutters from the targets.

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