A VIRTUAL ARRAY CONCEPT FOR REFLECTOR ANTENNA APERTURE

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INTRODUCTION

Reflector antennas are versatile devices with diverse applications in telecommunications, remote sensing and radio astronomy. They have been used in variety of configurations in single or dual reflector geometries and symmetric or offset shapes. They can also be viewed differently in terms of their function. They can be viewed as an imaging device, focusing the radiation energy of one of its foci on the other. In most applications, one of the foci is at infinity and the reflector operates as a transmitting or receiving antenna. Telecommunication is one such application for the reflector antennas. In another form, they can also be viewed as transform operators, affecting the spatial distribution of its focal plane signals. In this capacity, they can be used as a powerful device to perform variety of signal processing functions, such as multiple Fourier transform and convolution operations. Radio astronomy has benefited most from this property of the reflector antennas. In applications involving electromagnetic waves, the vector nature of the field, has added another feature to the reflector antennas, their polarization property. The most common interest area is the polarization isolation, where the two orthogonal directions on the reflector aperture can be viewed independently. Such properties have been used in polarimetric observations in remote sensing, and frequency reuse applications in telecommunications.

The ability of the conical reflectors to perform mathematical transforms provides incentives for exploring additional features for their applications. In this paper we present one such feature, the formation of virtual arrays, on the reflector aperture, using synthesized focal region fields. The concept is presented briefly first, and a simple implementation is described using a dual mode feed. More general implementations will be described during the presentation. This concept of virtual array can be used in diverse areas, such as remote sensing, radar imaging and smart antenna applications, without costly multiple hardware array implementations.

THE CONCEPT

For simplicity we consider a symmetric reflector configuration. If the focal region field is due to a point source symmetric in the azimuthal direction, the reflector performs a conical transform generating a symmetric aperture field in azimuth and tapered radially, in accordance with the reflector curvature. The far field is the Fourier transform of the aperture field, which due to its symmetry, results in a symmetric pencil beam. The main beam has an equivalent phase centre at the physical centre of the reflector aperture. A similar situation also holds for a vectorial field, such as that of a TE_{11} mode, where the aperture field maintains the focal field polarization, in addition to the field symmetry, thus retaining the far field main beam phase centre at the reflector aperture centre.

The situation is somewhat different for asymmetric fields, which can be represented by a Fourier series of the azimuthal modes. Thus, by a judicial selection of the mode coefficients of the focal region field, one can cause desirable aperture field asymmetries, and thus cophasal asymmetric reflector aperture fields. However, since the reflector transforms its cophasal aperture fields to axial far field beams, these asymmetric aperture fields generate axial reflector beams, with physically different equivalent phase centers on the reflector aperture. The reflector aperture

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therefore becomes equivalent to multiple virtual planar arrays, centered individually at each equivalent phase centre. In practice, one can synthesize the asymmetric focal region fields using azimuthal modes, employing waveguides, horns or microstrips. Their analog, or digital, combination can simulate the virtual array that can be used as independent beams in signal processing algorithms. Below, we provide an example using TE_{11} and TE_{21} modes, to generate a two element virtual array. The array has two independent and widely separated phase centers, but identical far field beams, similar to two planar arrays located centrally at the respective phase centers.

EXAMPLE

Consider a symmetric parabolic reflector, as shown in Fig. 1, with an aperture diameter of $D=50\lambda$ and $f/D= 0.375$ at 10 GHz. We now assume the focal region field is due to a combination of the TE_{11} and TE_{21} modes and compare their aperture fields in Figs. 2, and far fields in Figs. 3 and 4. When the excitation is due to the TE_{11} mode alone, the aperture field is symmetric and is shown in Fig. 2(a). For the combined case, infinite possibilities can exist, but for simplicity, we assume equal amplitudes for the modes. For their relative phase we select four different cases: 1) the in-phase case of $TE_{11} + TE_{21}$, 2) out of phase case of $TE_{11} – TE_{21}$, and the two quadrature phase cases of 3) $TE_{11} + jTE_{21}$ and 4) $TE_{11} – jTE_{21}$. For the first two cases, the aperture field amplitudes are symmetric and identical. They are shown in Fig. 2 (b). Their aperture phases are, however, asymmetric and cause scanning of the far fields, as shown in Figs. 3(a) and 3(b). The reflector aperture is therefore, equivalent to two coincidental array elements with equal amplitudes and anti-symmetric phase distributions. The most interesting cases are the last two, with quadrature relative phases in (3) and (4). Their resulting aperture amplitude distributions are shown in Figs. 2(c) and 2(d), having significant field values over only one half of the aperture, to the left or right. These distributions are similar to the TE_{11} mode, but shifted to the left, or right of the aperture centre. Their far field patterns are also similar to that of the TE_{11} mode, as shown in Figs. 4(a) and 4(b), with slightly lower gains, due to the reduced aperture sizes. These two excitations are, thus equivalent to a two element array, having elements occupying the left or the right hand side of the reflector aperture. Their relative phase centers are therefore shifted to the left or right, near the centers of their field distributions. Because they generate far field patterns, almost identical to the TE_{11} mode, but have distinctly different phase centers, they can be used together as elements of a virtual array. This possibility provides an opportunity for implementation of algorithmic signal processing in diverse applications, such as remote sensing or radar image processing.

In the last two cases, the mode amplitude ratio influences the aperture distributions and phase centre displacements. This was also investigated, and the resulting gains and phase centre displacements are shown in Fig. 5. With equal amplitude ratio in (3), a maximum phase centre displacement of 21.50 cm was achieved. However, with 40% amplitude in TE_{11} and 60% amplitude in TE_{21} mode, a maximum phase centre displacement of 30 cm, from the reflector centre, was achieved. Thus, the maximum phase centre separations of the last two distributions (3) and (4) are equal to 60 cm, a significant distance, without causing any grating lobe formations.

CONCLUSION

In this paper, the concept of virtual array formations, on the reflector aperture, using synthesized focal region fields were presented. A simple implementation of the proposed concept was described using a dual mode (TE_{11}+TE_{21}) feed. More general implementations will be described during the presentation. This concept of virtual array can be used in diverse areas, such as remote sensing, radar imaging and smart antenna applications, without costly multiple hardware array implementations.

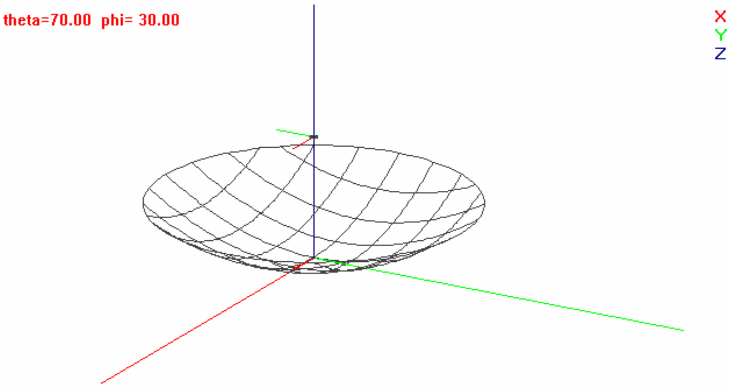

Figure 1: Symmetric parabolic reflector antenna geometry, D=50λ and f/D= 0.375.

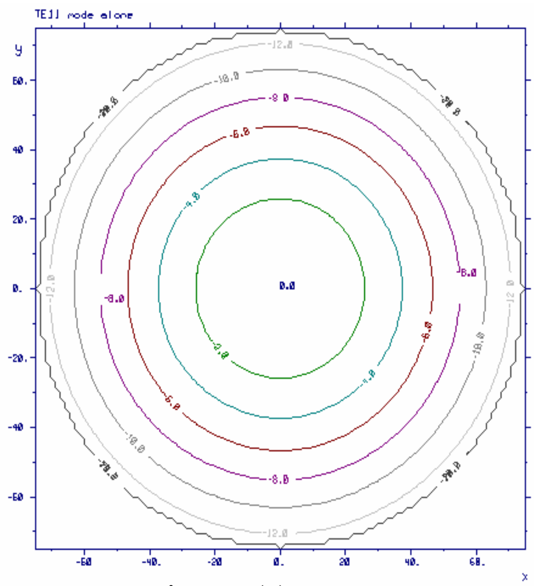

Figure 2(a)

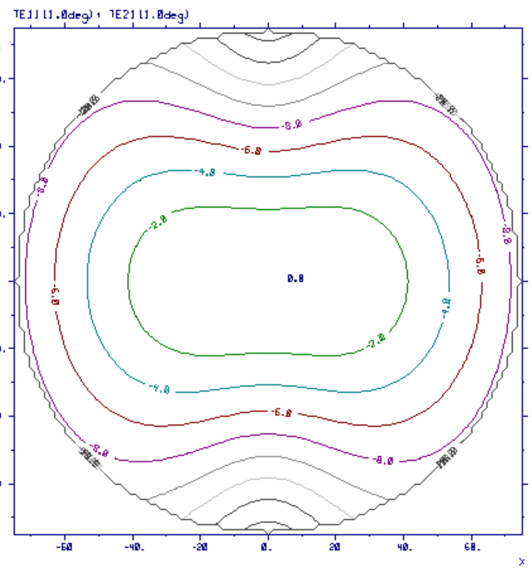

Figure 2(b)

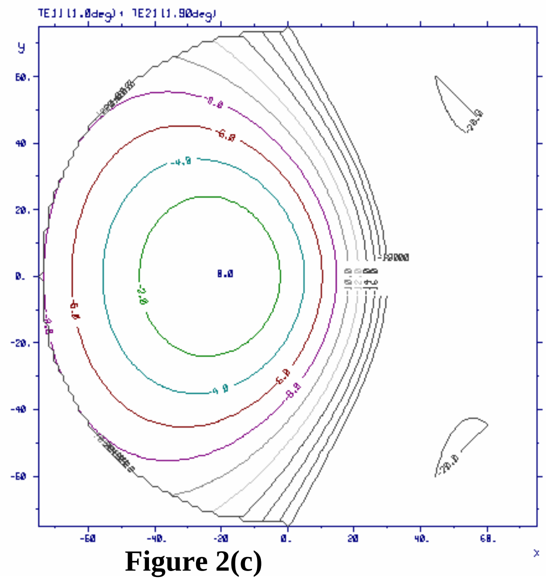

Figure 2(c)

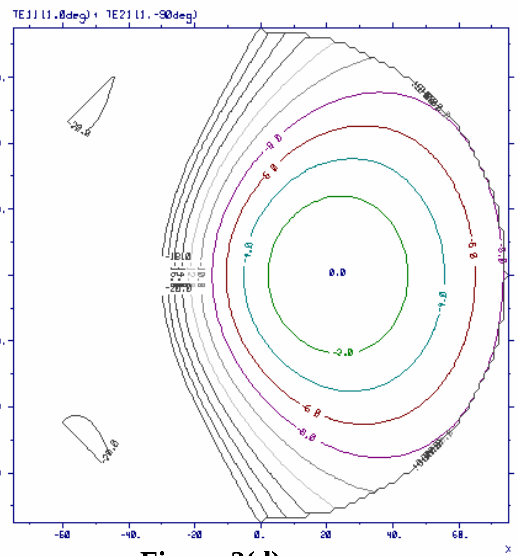

Figure 2(d)

Figure 2: Reflector aperture field distributions due to: (a) TE_{11} mode alone, (b) $TE_{11} + TE_{21}$, and $TE_{11} - TE_{21}$, (c) $TE_{11} + jTE_{21}$, and (d) $TE_{11} - jTE_{21}$.

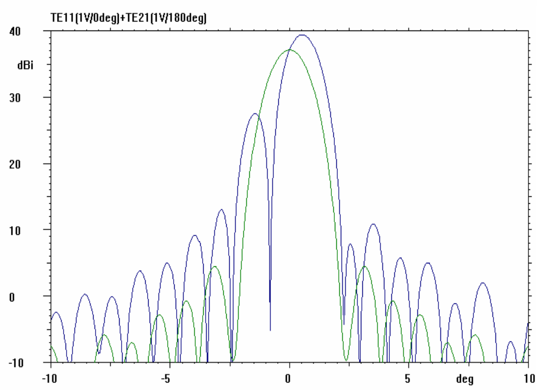

Figure 3(a)

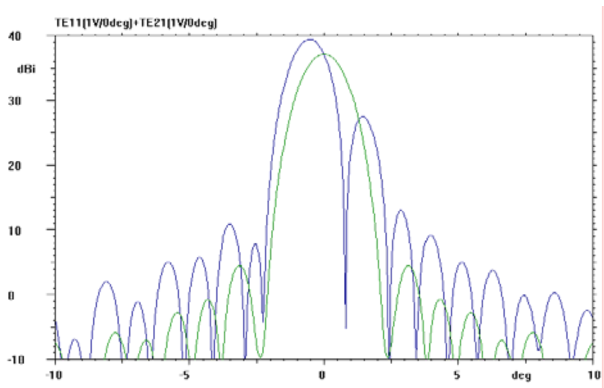

Figure 3(b)

Figure 3: The $\phi=0^o$ plane, and $\phi=90^o$ plane radiation patterns due (a) TE_{11} + TE_{21} and (b) TE_{11} – TE_{21} (which are squinted in $\phi=0^o$ plane).

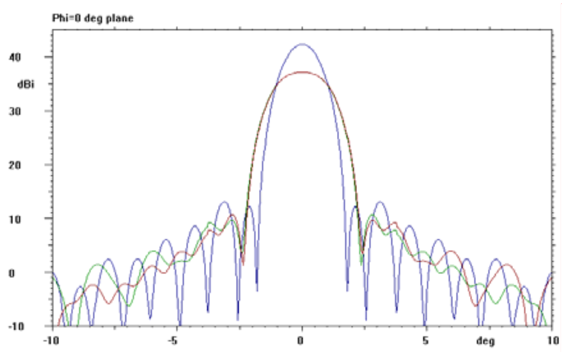

Figure 4(a)

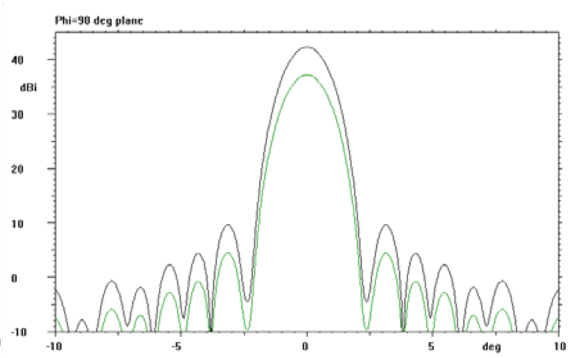

Figure 4(b)

Figure 4: Comparison of radiation patterns due to TE_{11} and TE_{11} + jTE_{21} and TE_{11} – jTE_{21} (which are identical), (a) $\phi=0^o$ plane, and (b) $\phi=90^o$ plane.

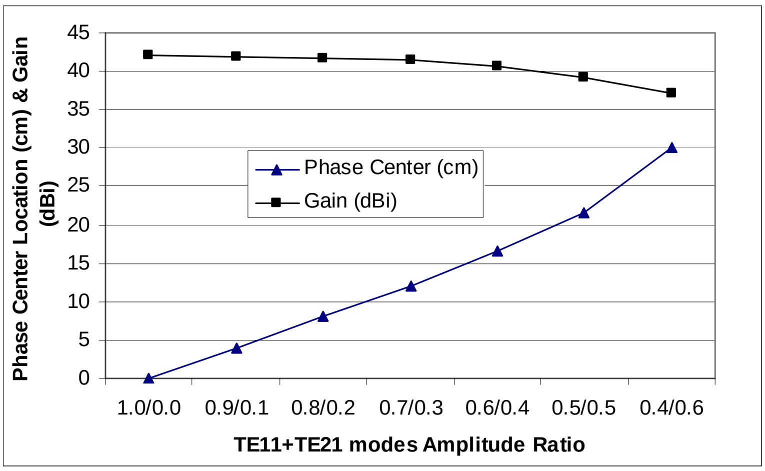

Figure 5: Effect of TE_{11} and TE_{21} mode amplitude ratios in (3) TE_{11} + jTE_{21} on the Phase centre displacement and Gain.