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A New Low Profile Antenna with Improved Performance for Satellite On-the-Move Communications

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Abstract— **A novel design solution for a low-profile full-duplex Satellite-On-The-Move Communications hybrid scanned phased array antenna for low elevation angle coverage (down to 10°) is described. The antenna is operated at Ku-Band. The unique louvered array element geometry in combination with a spatial filter/ "ray bending" lens facilitates the shaping of the element pattern to increase gain at low elevation angles. Preliminary modelling results using simple ray-tracing and 3D E simulation indicate that the desired low angle coverage can be achieved.**

Keywords- Vehicular Communications, Satellite Antennas, Phased Array Antennas

I. INTRODUCTION (HEADING 1)

Satellite-on-the-move (SOTM) communications offers improved services for both commercial and military applications in wide areas of the world. [1]. A basic SOTM operational scenario is shown in Figure 1. The antenna beam must remain "locked" in the direction of the desired satellite during vehicle motion and the polarisation must remain aligned with the satellite.

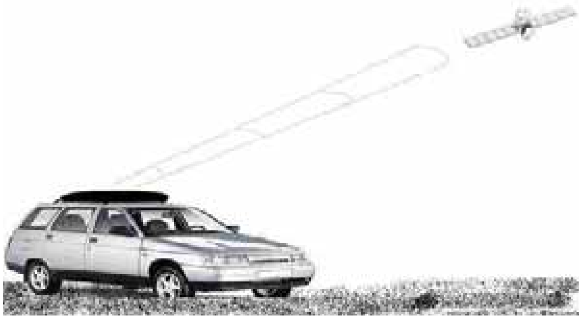

Fig. 1. Basic SOTM Operational Scenario

The performance limiting condition for the SOTM system is depicted in Figure 2. During the most severe tilt conditions of the vehicle, the satellite appears to have a much lower elevation angle to the installed low profile antenna. The antenna beam will have to be steered downwards to point at the satellite in order to maintain the link. For an ideal flat aperture antenna, the gain is proportional to the projected area of the antenna aperture in the direction of the satellite which reduces by sine of the elevation angle. At low elevation angles this leads to a significant reduction in the antenna gain. One method of compensation for this gain reduction is to tilt the elements towards the vertical. This can provide gain improvement but suffers from the drawbacks of degrading the low profile nature of the antenna and introducing blockage between antenna elements. Hence, the design challenge is to minimise the gain reduction for low elevation angles while keeping a low profile antenna structure.

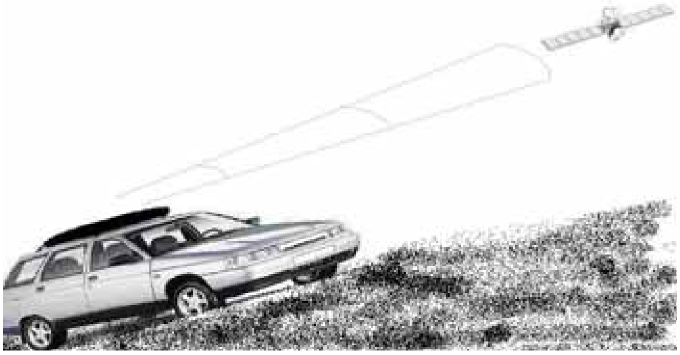

Fig. 2. Performance Limiting Condition

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II. CURRENT SOTM ANTENNA DESIGN

There are a number of existing design approaches for SatCom-On-The-Move antennas [2][3][4][5][6][7] which can be divided into Non-Planar and Planar categories. Non-Planar antennas such as reflector solutions typically require large volume and hence do not meet the low profile requirement. Planar (or nearly planar) phased array antennas are therefore more suitable to potentially meet the low profile requirement. Planar phased array antennas fall into two types: 2D Electronically Scanned and Hybrid Scanned. The hybrid scanned antennas mechanically scan the antenna beam by rotation in azimuth and electronically scan in the elevation plane. Clearly, the hybrid scanned solution facilitates a simpler and lower cost feed network design. Most existing hybrid scanned phased array antenna designs demonstrate poor low elevation angle coverage performance and are mainly designed for receive (down-link) only.

III. PROPOSED SOTM ANTENNA DESIGN

The proposed design adopts a hybrid scanned phased array antenna to provide good low elevation angle coverage down to 10° elevation above the horizon. The antenna aperture is completely utilised for full duplex (down-link & up-link) high data rate communications.

As beam steering in the azimuth direction is by mechanical rotation and steering in the elevation direction is electronic, the element radiation pattern does not need to be symmetric and therefore can be designed to be tilted to enhance low elevation angle gain performance. The proposed design solution consists of a novel louvered reflector together with a dielectric filter/lens structure as shown in Figure 3. The novel louvered reflector tilts the element to low elevation angels with minimum blocking of the radiation from adjacent elements. By incorporating an overlying dielectric layer, or layers this pattern can be bent the further downwards enhancing the element gain performance at low elevation angles. Each radiating element of the array antenna will be dual-frequency and dual-polarised for full duplex services.

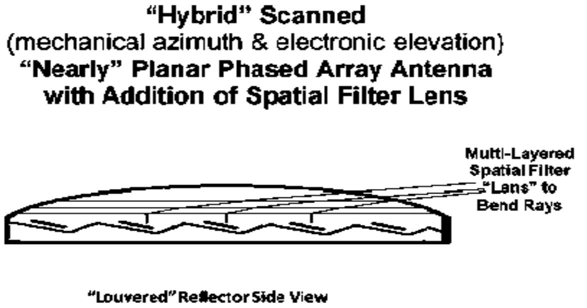

Fig. 3. Cross sectional view of the proposed structure

IV. ANALYSIS – RAY TRACING

Preliminary design and modelling has been carried out based on simple ray-tracing with an assumption of ideal radiating elements. Under these conditions the effects of interaction with the Filter/Lens and the mutual coupling between elements are not taken into account. Additionally it has been assumed that the antenna structure is infinite in the transverse directions. It is well known that the radiation from a single element can be considered as a spectrum of plane waves. [8] The spectrum of plane waves produced by a single non-tilted element passing through the filter/lens will be symmetrically bent to low elevation angles as shown in Figure 4 (a). For the case of a tilted single radiating element, as shown in Figure 4 (b). An asymmetric pattern is produced "steering" the beam towards lower elevation angles on one side as desired. As discussed previously, the array antenna is mechanically rotated in azimuth and therefore does not require a symmetrical element radiation pattern. This means that higher element gain can be realised over the required elevation scan range than would be possible with a symmetric design.

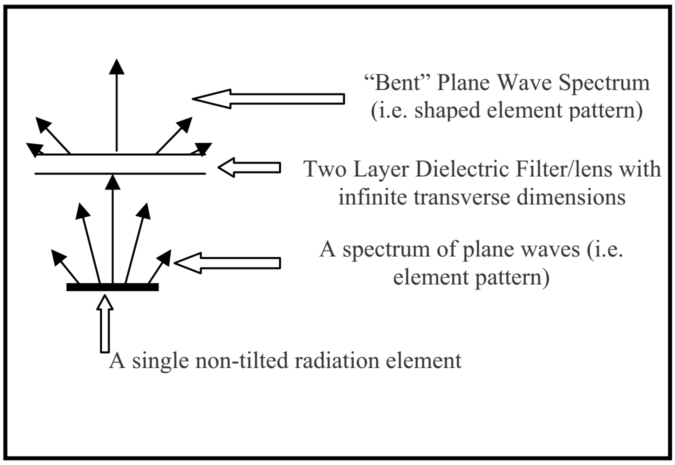

Fig. 4 (a) A single non-tilted element with filter/lens

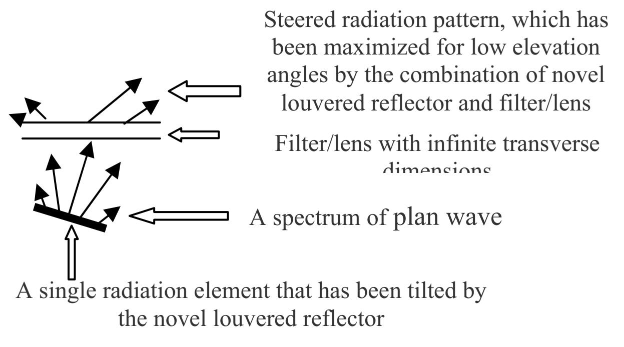

Fig. 4. (b) A single tilted element with filter/lens

Mathematical modelling using Mathcad software has been carried out for the multilayer structure shown in Figure 5 where εa is the relative permittivity of the layer containing the radiating element, ε1 and L1 are the relative permittivity of the first layer, ε2 and L2 are the relative permittivity of the second layer and ε3 = 1 is free space.

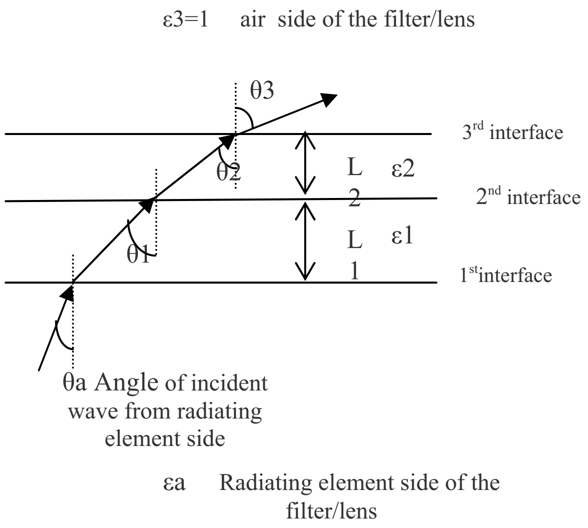

Fig. 6. Dielectric filter/lens details

Parametric studies have indicated optimum values of εa=9, , ε1= 5, L1 = 3.175mm , ε2= 3 and L2 = 3.175mm.

Far field radiation patterns have been obtained for an ideal single radiating element inclined at an angle of 15° to the horizontal in free space as shown in Figure 7. As anticipated these results show a symmetrical pattern with maximum gain at an elevation angle of 75°. At an elevation angle of 20° the gain is approximately 5 dB down from the maximum.

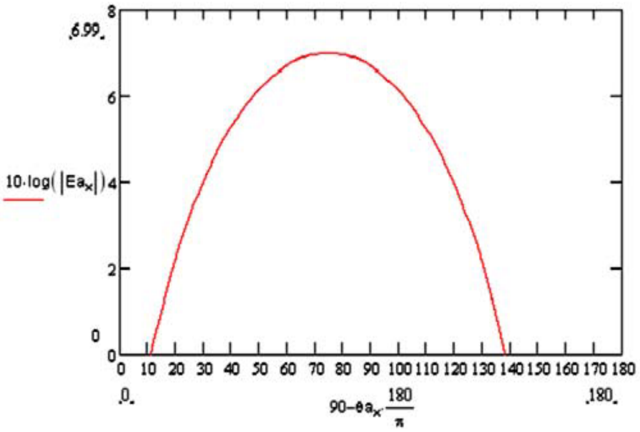

Fig. 7. Power pattern of the plane wave spectrum produced by a tilted single radiating element.

Results for a similar geometry immersed in the multilayer dielectric structure shown in Figure 6 have also been obtained and are shown in Figure 8 (a) and (b) for the cases of perpendicular and parallel polarisations respectively. The asymmetric nature of the pattern is evident in each case. Additionally the improved low elevation angle gain can also be observed, for the case of perpendicular polarisation at an elevation angle of 20° the gain is down by approximately 2.5 dB, an improvement of 2.5 dB, and for the case of parallel polarisation at an angle of 20° the gain is down by approximately 0.5 dB, and improvement of 4.5 dB.

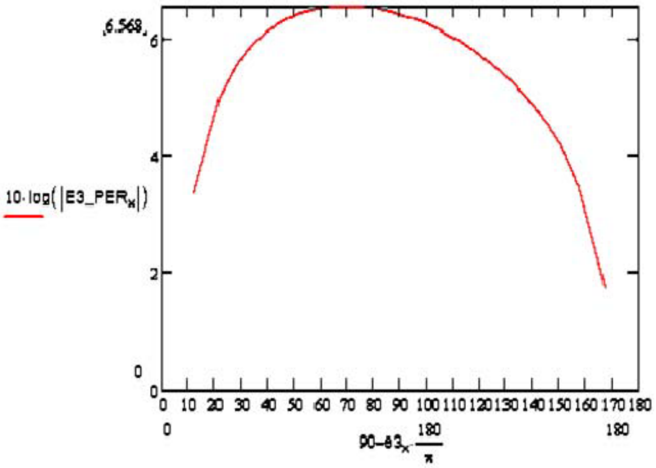

Fig. 8 (a). Resultant transmission wave pattern (dB) for perpendicular polarisation

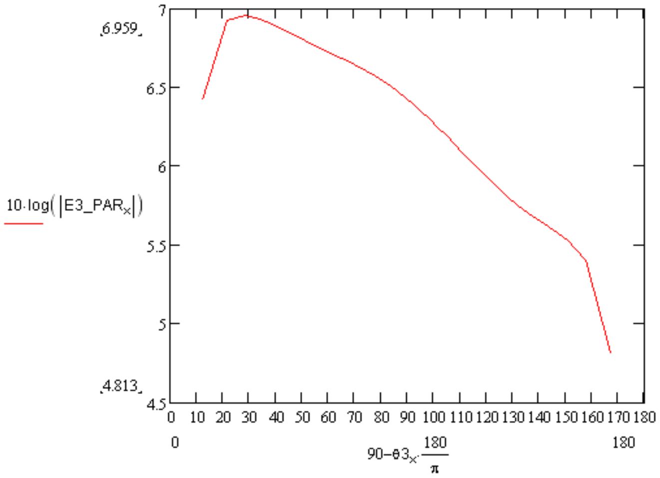

Fig. 8 (b). Resultant transmission wave pattern (dB) for parallel polarisation

V. ANALYSIS – EM SIMULATION

A full 3D EM simulation for the multilayered antenna structure shown in Figure 6 has been undertaken using CST Microwave Studio software using a square waveguide section as the basic radiating element. The geometry in this case has been altered to allow excitation of the waveguide by tilting the dielectric multilayered structure by an angle of 15º. An outline of the far field radiation pattern relative to the antenna geometry is shown in Figure 9 at a frequency of 12.3 GHz where it is apparent that the main lobe of the antenna has been tilted by considerably more than the initial 15º.

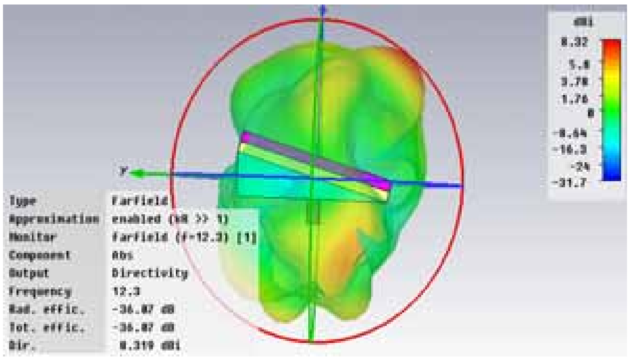

Figure 9 3-D Far field radiation pattern at 12.3GHz for a dielectric loaded waveguide radiating element with tilted filter/lens

Examination of the 2D cuts shown in Figure 10 (a) and (b), taken at 12.3 GHz. and 14.3 GHz. respectively, show the directions of maximum tilt to be 38º at 12.3 GHz. and 43º at 14.3 GHz.

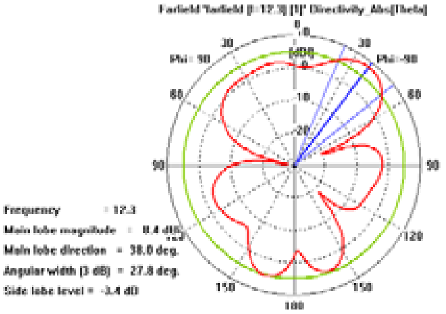

Fig. 10 (a). Demonstration of beam tilting at 12.3 GHz.

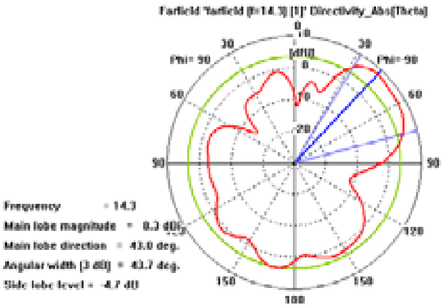

Fig. 10 (b). Demonstration of beam tilting at 14.3 GHz

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