94 GHZ BEAM SCANNING DUAL-REFLECTOR ANTENNA WITH A SUB-REFLECTARRAY

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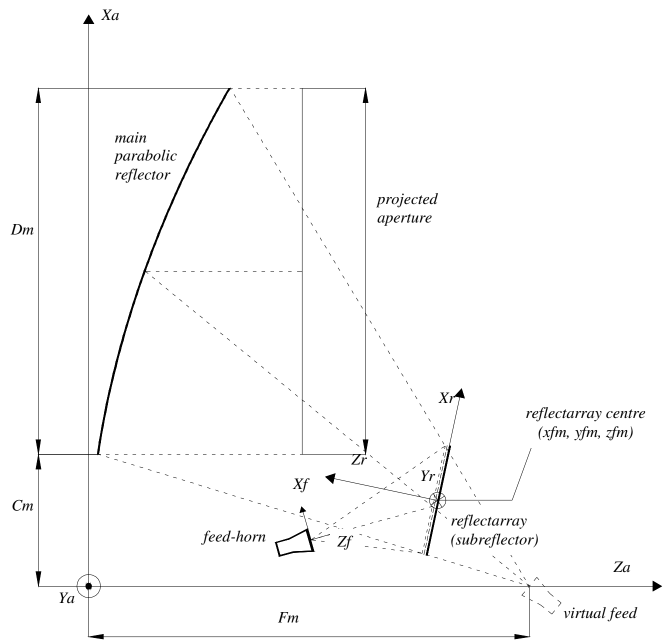
INTRODUCTION

A Cassegrain dual-reflector antenna which employs a flat reflectarray subreflector was analysed in a recent paper [1]. It was shown that the antenna beam can be scanned by introducing an appropriate progressive phase distribution across the reflectarray surface. This configuration is very attractive for steerable beam applications, because it combines the high gain and broad bandwidth properties of the parabolic main reflector with the simplicity of manufacturing a small electronically reconfigurable microstrip reflectarray antenna. The subreflector could be constructed on a thin liquid crystal (LC) substrate, and control of the phase distribution across the aperture would be achieved by applying a bias voltage to the individual elements in the patch array [2, 3]. In addition to the simplicity of this biasing arrangement, phase shifters based on LC materials can be designed to operate with no upper limit on the operating frequency range, thereby removing the main disadvantage of many existing active control technologies. Moreover precision micromachining processes and a quasi–optical measurement technique which are suitable for manufacturing and characterising sub mm wavelength phase agile reflectarrays, have recently been demonstrated at frequencies up to 170 GHz [4]. In this paper we present the design of a dual-reflector antenna which could use an 'active' sub-reflectarray based on liquid crystals to produce the required Earth scene scan profile of a limbsounder radiometric instrument [5]. The validity of the beam scanning concept has been demonstrated by designing, manufacturing and measuring the radiation patterns of a 120mm diameter offset parabolic reflector at 94 GHz. In the first phase of the project we have used three planar solid metal subreflectors of diameter 28-mm to generate a focussed beam in the boresight direction, and at offset scan angles of 2.5° and 5°. Experimental results are shown to be in reasonably good agreement with numerical simulations. In the second phase of the work, the solid metal subreflectors are replaced by a passive microstrip patch subreflectarray which is designed to scan the beam to an angle of 5º. The final stage of the project will employ an electronically controllable LC reflectarray subreflector which will be used to scan the beam over the angular range 0 º to 5º.

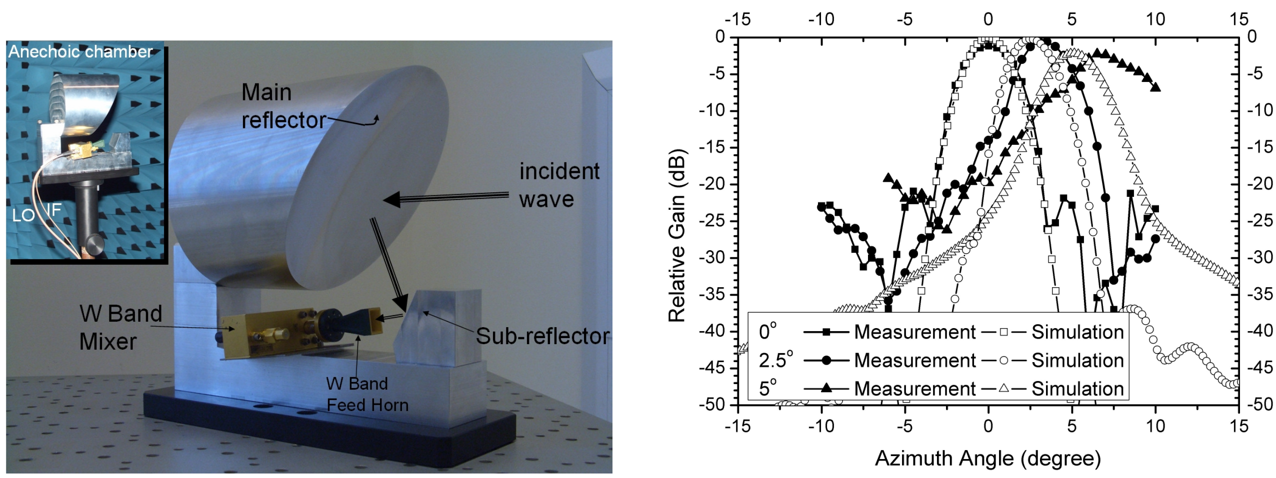
ANTENNA DESIGN AND PREDICTED BEAM SCANNING PERFORMANCE

The antenna configuration which is defined in Fig. 1 has three main components: a linearly polarised pyramidal feed-horn, a planar reflectarray subreflector and an off-set main parabolic reflector. The antenna has been designed to focus the beam in the Z_A direction at 94 GHz when there is a uniform phase distribution across the aperture of the reflectarray. A photograph of the breadboard dual reflector antenna with a flat metal subreflector is depicted in Fig. 2a. The beam can be scanned either mechanically by rotating the subreflector or electronically by introducing a progressive phase shift across the aperture of the reflectarray. The former beam steering strategy was used in the computer model to generate the radiation patterns of the antenna at 0°, and at 2.5° and 5° in the azimuth plane (Y_AZ_A) as depicted in Fig. 2b. The gain at boresight is predicted to be 38.6 dBi, however pattern distortion occurs when the beam is steered off boresight and this reduces the gain to 37.3 dBi at 5º. The accuracy of the computer model is shown in Fig. 2b where computed radiation patterns are compared with measurements. The second option is more interesting since electronic beam steering can in principle be achieved by constructing a single subreflectarray structure on a thin film of tunable liquid crystals. In this case the computed aperture phase distribution depicted in Fig. 3 (which is introduced along the Y_R axis of the subreflector as shown in Fig 4) is required to scan the beam to an angle of 5° from boresight in the Y_AZ_A plane. It is noted that by symmetry the mirror image of the phase distribution about the centre of the reflectarray, gives a -5°shift.



MAIN PARABOLIC REFLECTOR	
Diameter of the aperture (Dm)	120mm
Clearance (Cm)	35mm
Focal distance (Fm)	80mm
SUBREFLECTOR *(data in antenna coordinate system)*	
Centre (xfm, yfm, zfm)	(25.2, 0, 68.4) mm
Periodic cell dimensions	1 × 1 mm
Reflectarray dimensions	28 × 28 cells
Matrix of director cosines *(Relation between Antenna and Subreflectarray Coordinate Systems)*	$\begin{pmatrix} 0.891 & 0 & 0.454 \\ 0 & -1 & 0 \\ 0.454 & 0 & -0.891 \end{pmatrix}$
FEED-HORN *(data in subreflector coordinate system)*	
Phase centre	(-19.8, 0, 41.3)mm
Pointing *(on the reflectarray surface)*	(-2.32, 0, 0)mm

Fig. 1. Schematic of the dual-reflector antenna and main geometrical parameters.



(a) (b)

Fig. 2. (a) Breadboard dual reflector antenna and (b) measured and predicted radiation patterns

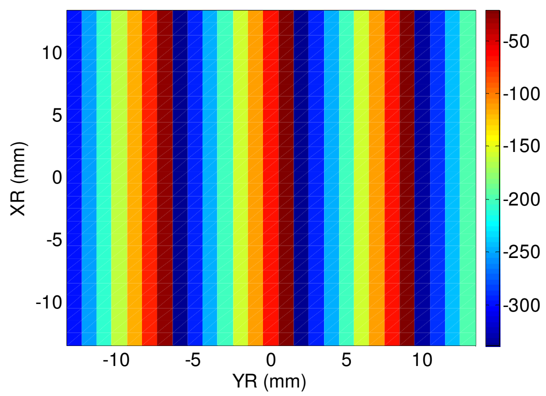


Fig. 3. Required phase distribution across reflectarray aperture for beam steering angle of 5º.

DESIGN OF REFLECTARRAY SUBREFLECTOR FOR BEAM SCANNING

To demonstrate the validity of the proposed concept, a passive microstrip patch reflectarray has been designed to generate a beam in the scan direction of 5° at 94 GHz. The reflectarray will be manufactured on a metal backed quartz wafer (ε_r=3.78, tanδ= 0.002) using similar fabrication processes as the LC based phase agile subreflector. The simulated and experimental radiation patterns of the dual reflector antenna will be compared to demonstrate the accuracy of computer model and manufacturing processes. Moreover the results should be very similar to the scanned beam at 5° which was obtained using a metal subreflector as shown in Fig. 2b. The phase of the reflected signal is adjusted by varying the dimensions of the patches about their resonant length. In the first stage of the design process the reflection phase and Ohmic loss are computed as a function of the element dimensions by using the Spectral Domain Method of Moments assuming a periodic array of square patches [6]. The measured thickness of the wafer (115-µm ± 5 µm) was used in the simulations and the period was chosen to be 1-mm (0.3λ) because this provides a broader bandwidth, as shown in [7]. The computed reflection phase and signal loss plots are depicted in Fig. 4(a) at normal incidence. At 94 GHz the maximum phase range is shown to be 320° which is sufficient for a practical antenna design. The geometry of the passive reflectarray was obtained by using an iterative routine which adjusts the dimensions of the individual patches in the reflectarray structure until the required phase is achieved for both polarisations. The resulting array pattern is shown in Fig. 4(b).

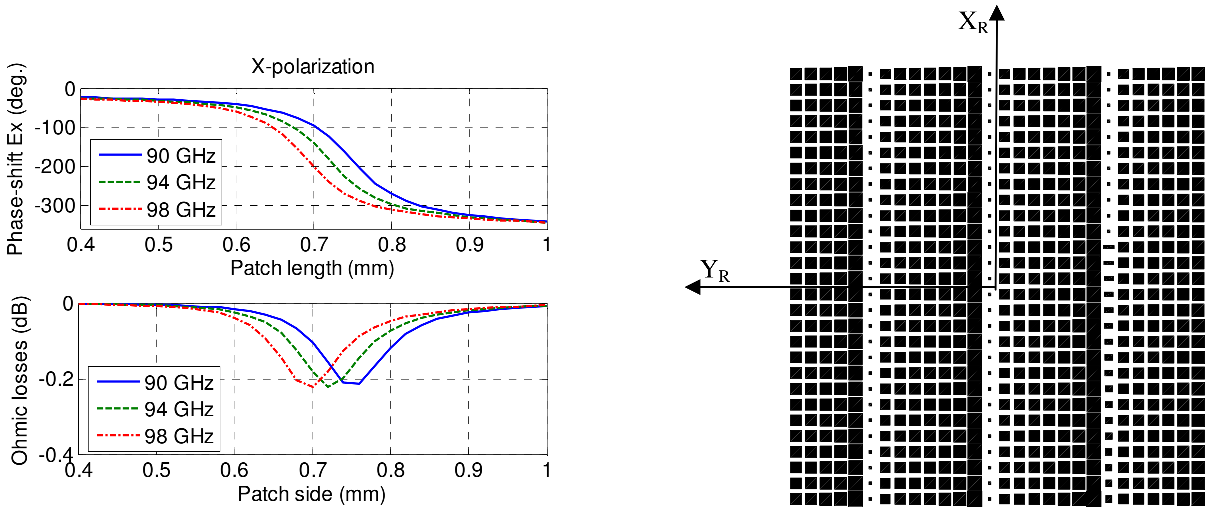
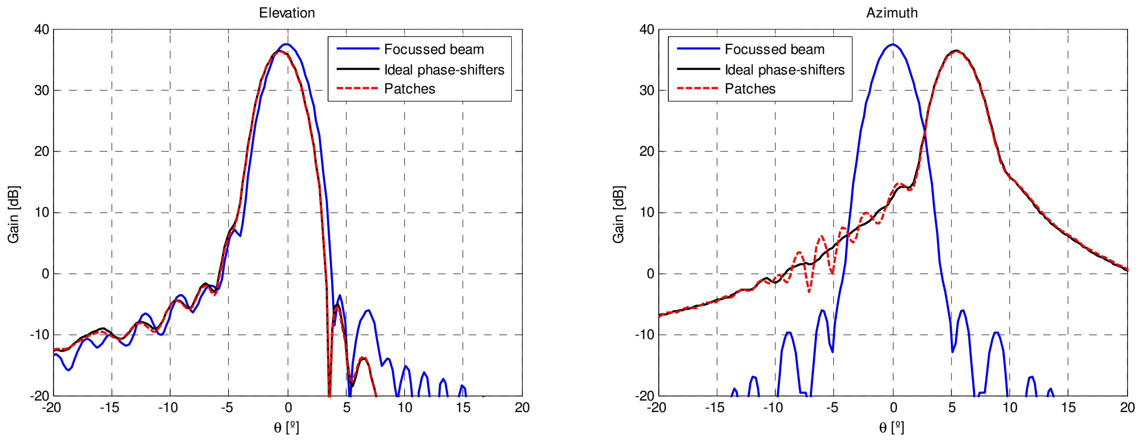


Fig. 4. Passive reflectarray on quartz substrate. (a) Reflection phase and signal loss at 94GHz as a function of patch size, (b) Patch array layout to scan the beam 5° in the Y_AZ_A plane.

The reflectarray design has been used as a subreflector and the entire dual-reflector antenna has been analyzed using the technique described in [8]. The computed horizontally (Y_A) polarised radiation patterns in the principle planes are depicted in Fig. 5 for a focussed beam in the boresight direction and at 5° in the azimuth cut. It is noted that the latter result is virtually identical to the radiation pattern which is generated using the full 360 ° phase range in the distribution which is shown Fig. 3. The computer model predicts gain values of 36.35 dBi and 36.22 dBi respectively for the 'ideal' and the 'practical' reflectarray designs, which includes the small-phase errors and the dissipative losses in the Quartz substrate. In Fig. 5(a) a small beam squint (0.5°) is shown in the elevation cut because the progressive phase is not introduced along the Y_A-axis, but only along the Y_R-axis and the subreflector is not vertical. This small distortion can be reduced by introducing an appropriate phase distribution on the reflectarray.

DISCUSSION AND CONCLUSIONS

Numerical simulations have been used to study the radiation pattern performance of an offset Cassegrain antenna when the metal subreflector is replaced by an active reflectarray. It was shown that the peak gain is reduced by 0.1dB and 1.3dB when the beam is scanned to angles of 2.5° and 5° respectively. The computer model is in good agreement with experimental results which were performed at 94 GHz using suitably designed metal subreflectors. A printed quartz reflectarray has been designed to replicate the results at a scan angle of 5°, and the measured results will be available shortly. Electrical characterisation of a commercially available liquid crystal mixture has been made using a novel quasi optical measurement over the frequency range 100 GHz-170 GHz [4]. Although the preliminary results are very encouraging, further work is required to achieve a dynamic phase range in excess of 300°. As part of a continuing work programmed, various strategies are being investigated to improve the performance of the reconfigurable reflectarray



(a) (b)

Fig. 5. Computed radiation patterns of the dual-reflector antenna for a metal subreflector (blue line), an 'idea' subreflectarray (black line) and the 'real' subreflectarray (red line).

including the use of specially synthesized liquid crystal material and the optimization of the unit cell geometry. One very useful application of the proposed phase agile dual-reflector concept is in radiometric remote-sensing instruments which operate in the millimetre and sub-millimetre wave bands [5]. These systems currently use mechanically scanned reflectors, however the design concept that is described in this paper is a more attractive option because an electronic beam steering antenna would reduce the payload mass and power consumption, and moreover this would also increase the reliability of the instrument. An example of an application for this technology is the reflector antenna on the MARSCHALS airborne limbsounder [9] which scans the atmosphere through approximately 5°. The instrument starts the scan at an altitude of -2 km (-5°) and finishes at an altitude of 20 km (0°) in 1 km steps. These scan positions could be achieved by steering the dual reflector antenna beam over an angular range ± 2.5° because as shown in Fig. 2b this would minimize the pattern distortion.

ACKNOWLEDGEMENT

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