New Multi-Layer Millimetre-Wave Folded Reflectarray Antennas for Satellite Communications

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Abstract— A **broadside folded reflectarray antenna consisting of 108 dual-polarization antenna elements, operating at Ka band, is presented in this paper. The unit cell antenna employed is dual-polarised aperture-coupled microstrip patch antenna integrated with via-grid cage around the edge of the unit cell in order to reduce mutual coupling between the neighbouring elements. True-time microstrip delay lines connecting two kinds of polarizations are used to achieve the purpose of polarization conversion and phase compensation. The delay lines are connected with the feeding striplines via a vertical RF transitions. The simulated results show that the gain of this folded reflectarray enable to achieve over 20 dBi across the operating frequency band. The proposed structure of the unit cell makes it possible to integrate controllable phase shifter with the antenna together for electronically beam scanning.**

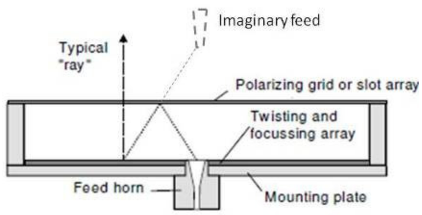
Keywords— Broadside folded reflectarray, aperture-coupled microstrip patch, vertical RF transition, polariser

I. INTRODUCTION

In recent years there has been an increasing demand for high data-rate broadband communication links using Ka-band mobile satellite communication (SatCom) systems (e.g. aircraft, high-speed train or car, as Fig. 1 presents). Folded reflectarray antennas [1-4] are good candidates for such SatCom systems, as they have low profile and low mass, and can be easily fabricated. For these applications, the antenna is usually required to be able to scan its beam electronically within a wide angle range in order to guarantee the service availability to the coverage areas.

Fig. 1. Illustration of mobile broadband SatCom applications.

A folded reflectarray antenna consists of a feed antenna, a main reflectarray for focusing and twisting the incident wave and a polariser grid for polarisation selection. The main reflectarray includes hundreds of microstrip antennas used to produce twisted re-radiation fields and provide phase compensation for focusing. The polarisation filter may be a grid or a resonant slot array and is made of a substrate printed with high-density metal grid, which is transparent to one polarisation but would reflect the other polarisation. The feed is typically a cylindrical-waveguide feed horn, but a planar structure may equally be used.



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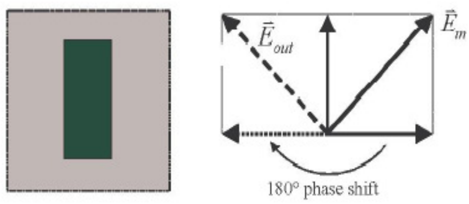

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Fig. 2. (a) Basic principle of the folded reflector antenna and (b) single cell/patch and vector decomposition of incident and reflected electric field for 180° of reflection phase angle difference.

The radiation from the feed is polarised in such a way that it is reflected by the printed polarising grid or slot array at the front of the antenna (see Fig. 2a). Following this, the wave is incident on the reflectarray. The patch element axes are titled by 45° with respect to the incident electric field. The field can be decomposed into two orthogonal components (see Fig. 2b). The dimensions of the patch elements are selected to produce a reflection phase difference of 180° from the two orthogonal components. Thus, the polarisation of the total reflected wave is twisted by 90° compared to the incident one [5]. Such a twisting performance is possible for wide variety of combinations of patch element width and length, differing only in the absolute reflection phase angle. This overall phase shift is adjusted according to the focusing requirement of the reflectarray. The outgoing plane wave then can pass the grid or slot array.

In this study, the unit cell antenna element for the folded reflectarray is required to be a dual linear-polarised antenna with operation at Ka band for frequency range from 29.5 GHz to 30.8 GHz. The antenna spacing between the neighbouring elements (or maximum unit cell size) is set to be 0.51λ in order to avoid grating lobes for higher scanning angle up to 60°. Thus, it is necessary to reduce the mutual coupling between the neighbouring antenna elements so as to avoid scan blindness and subsequently achieve a wide range of angle coverage when the array beam is steered electronically.

II. Unit Cell Module Overview

A vertical RF transition from microstrip line to stripline [6], as Fig. 3 presents, is applied as the feeding structure for this dual-polarised antenna. The vertical RF transition is simulated and optimised using the commercial full-wave Ansoft HFSS. Generally, the diameter of the signal via and the distance between the fence vias and the signal via are adjusted to match the characteristic impedance of the quasi-coaxial-line to 50 Ω. The corresponding simulated results of the vertical RF transition in terms of reflection and transmission coefficients are shown in Fig. 4.

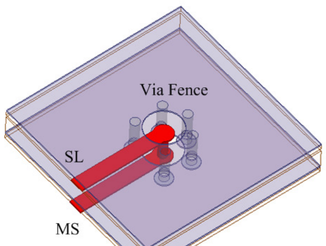


Fig. 3. 3D view of the MS to SL vertical transition.

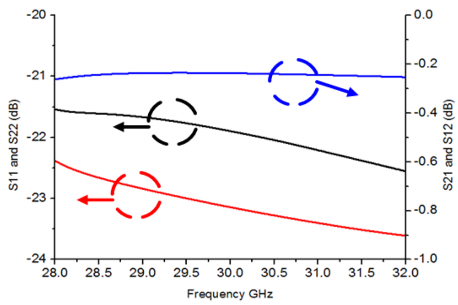
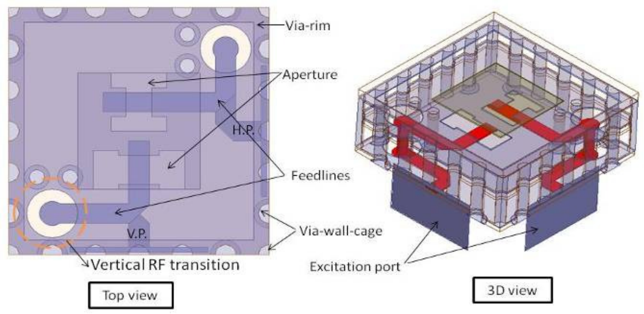


Fig. 4. Simulated S_{11} (in black), S_{22} (in red) and S_{21} and S_{12} (superposition in blue) for MS to SL vertical transition.

The return loss is larger than 20dB from 28GHz to 32GHz for both ports, which implies that good matching performance is obtained using five vias as a fence. However, the vertical transition should be used in combination with the via-cage to save space .

The dual-polarized aperture-coupled antenna element in a unit cell configuration is illustrated in Fig. 5; it consists of a via-grid cage and its feeding structure (i.e. vertical RF transition) [7].

The antenna element unit cell is placed in an infinite array environment emulated by periodic boundary conditions, in which the mutual coupling around the neighbouring elements is taken into account during simulation. Performance of the dual-polarized antenna element can be characterized by a few important parameters, including antenna reflection coefficient for the horizontal polarization (H.P.) and vertical polarization (V.P.), input-port isolation level and cross-polarization level.



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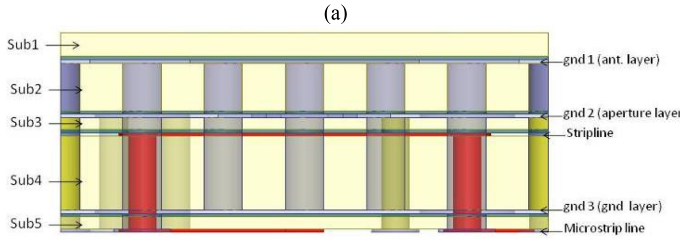

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Fig. 5. The proposed dual-polarised unit cell radiating element. (a) Top view and 3D view; (b) side view.

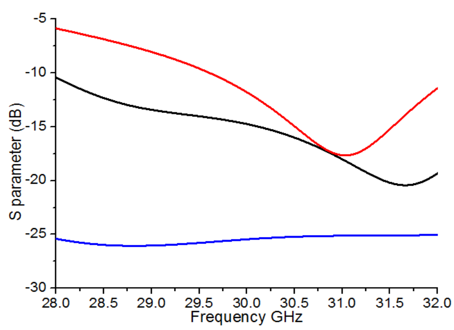


Fig. 6. Simulated results of the S_{11} (V. P. in black), S_{22} (H. P. in red), S_{21} and S_{12} (superposition in blue) for the proposed element.

Fig. 6 presents the S-parameters simulated with periodical boundary for broadside direction. As can be seen, the antenna resonances are slightly drifted to the higher frequency, which is designed deliberately to offset the antenna resonance. This is because the antenna resonances tend to shift up as the scanning angle increases in beam scanning operation. Moreover, the matching and isolation performance is satisfied over the operating frequency band.

III. THE DESIGN OF THE FOLDED REFLECTARRAY

This section mainly focuses on the design and characterisation of a folded reflectarray, realised using the dual-polarised unit cell element studied in the previous section, in addition to the design of its associated grid polariser.

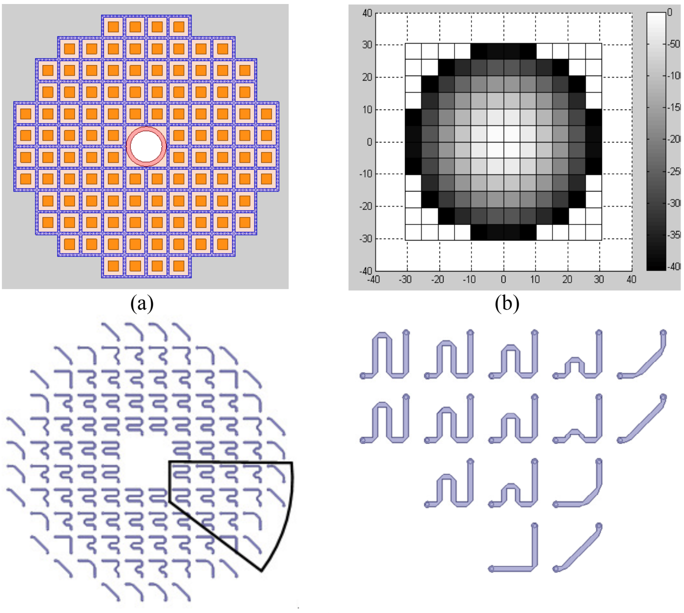


Fig. 7. Configuration of the proposed folded reflectarray; (a) top view; (b) the corresponding phase delay on each of the unit cell element of the fold reflectarray. (c) the layout of microstrip delay lines.

Fig. 7a shows the top view of the geometry of the folded reflectarray. The designed reflectarray is made up of 108 reflective elements, which are employed by the dual-polarised antenna element in a unit cell condition. The four central elements were removed and replaced by a feed horn. The reflectarray functions as field twisting and focusing array, and the polariser grid is for polarisation selection, as shown in Figs. 2 and 8. The strip grating lines on the polariser are designed in parallel to the polarisation of the wave radiated from the feed antenna. Performance of the strip grating lines can be observed in Fig. 9, where the insertion loss is found to be below 0.4 dB, whereas the return loss is better than 25 dB for the orthogonal polarization from 29.5 GHz to 30.8 GHz.

The field twisting can be realised by connecting the two antenna feeds by true-time microstrip delay lines. The imaginary feed is centered at 32mm distance from the planar reflectarray. Hence, the depth of the folded design from the polariser grids becomes 16mm. To get a broadside radiation beam pattern, the phases of the re-radiated field should be coherent at the plane of the polariser. Fig. 7b presents the corresponding phase delay of the path length of the wave radiated from the feed horn on each of the unit cell element located on the reflectarray. Compensation of this phase delay is achieved by adjusting the length of the horizontal and vertical true-time microstrip lines of each dual-polarised antenna element.

In total, 15 different lengths of the true-time microstrip delay lines are necessary in this folded reflectarray configuration (see Fig 7c), which are corresponding to the elements on the different location of the folded reflectarray. In addition, the phase compensations of the remaining elements can be selected from these 15 layouts without re-calculating them with respect to the symmetrical structure in the broadside array.

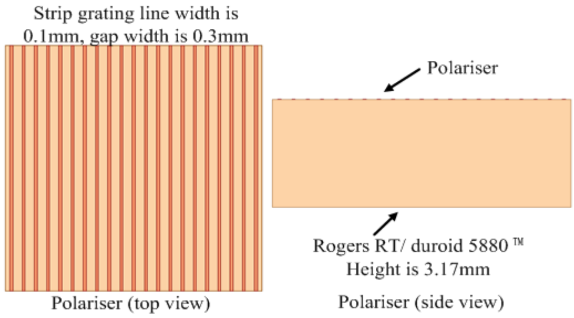


Fig. 8. Top view and side view of the polariser design for the proposed folded reflectarray.

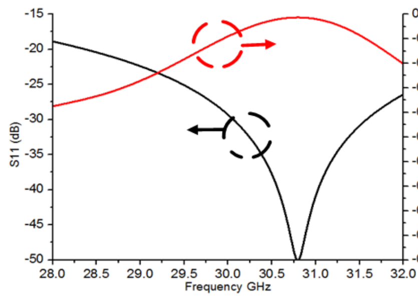
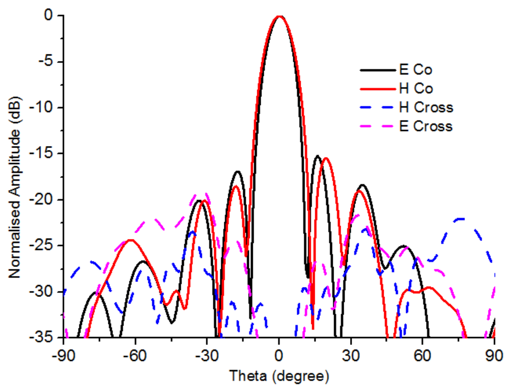


Fig. 9. insertion loss (in red) and return loss (in black) for two orthogonal polarizations



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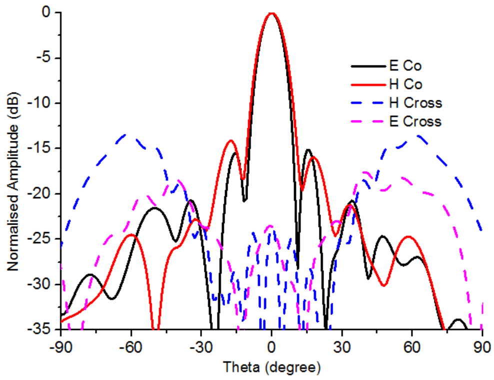

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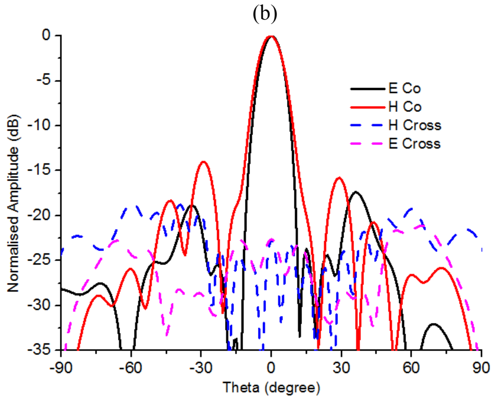

(c)

Fig. 10. Simulated results for E-plane and H-plane, including co-polarization and cross-polarization normalized radiation patterns; (a) 30.1GHz (b) 29.5GHz (c) 30.8GHz.

Both the E-plane and H-plane, co-polarization and cross-polarization normalized radiation patterns are presented in Fig. 10, in which 3 dB beamwidth of the array are observed as 10° and 11°, respectively. In addition, the normalized radiation patterns at the operating band edge (e.g. 29.5 GHz and 30.8 GHz) are also shown in Figs. 10b and 10c. Their beamwidth are found to be 9.5° in E-plane at both frequencies, whereas the beamwidths are 10.4° and 10.5° in H-plane, respectively. Moreover, the antenna gain across the operating frequency range from 29.5 GHz to 30.8 GHz is all above 20 dB, as Fig.11 presents.

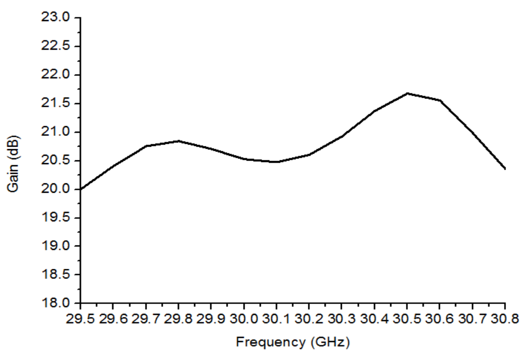

Fig. 11. Simulated antenna gain in the operating frequency band.

IV. Conclusions

A passive folded reflectarray with 108 dual-polarization aperture-coupled microstrip patch elements operating at Ka band is presented. Polarisation conversion in every element was obtained by connecting the end of the horizontal and vertical feeding microstrip lines. Phase compensation was achieved by adjusting the length of the true-time delay lines. The simulated results show that the designed antenna can achieve a gain over 20 dBi at Ka band.

The proposed structure can be integrated with controllable phase shifter at the backside of the antenna for electronically beam scanning. The future work will be concentrated on the scanning performance of the folded reflectarray presented in this paper.

Acknowledgement

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