A Parallel Plate Slot-Pair Array Dual Polarization Antenna for Small Satellite SAR

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***Abstract*—A parallel plate slot-pair array antenna panel with dual circular polarization for application in space-based Synthetic Aperture Radar has been designed and fabricated. Multi-objective genetic algorithm is used to find an optimal set of slot-pair linear array power coupling coefficients. HFSS software is used to simulate the structure. The fabricated antenna panel shows aperture efficiency of 50.1% and 49.2% at 9.65 GHz for RHCP and LHCP beams respectively. Frequency dependency of the gain, and beam-shift between RHCP, LHCP beams are studied.**

Keywords—linear antenna arrays, slot antennas, optimization, polarimetric synthetic aperture radar

I. INTRODUCTION

Low cost remote sensing satellites are being widely studied and developed. A Synthetic Aperture Radar (SAR) sensor has several advantages over optical sensors, the major advantages being SAR is weather resistant and images can be captured during both day and night. Further a dual-polarized SAR sensor allows gathering of polarimetric information of the radar cross-section of targets. The main challenge in this mission is the realization of a lightweight, power-efficient SAR antenna which can be supported by a small satellite bus.

In [1], a feasibility study of X-band (9.65 GHz) SAR sensor onboard a small satellite (100 kg) is studied. In [2], a parallel-plate slot-pair array antenna panel with right-hand circular polarization has been fabricated and tested. The antenna panel was designed using HFSS simulator for uniform aperture excitation in amplitude and phase.

This antenna panel was however limited to be single polarized. In this paper we describe the design and realization of a dual-polarized parallel-plate slot-pair array antenna with similar structure as described in [2]. Section II describes the antenna panel. In Section III we explain the design process. Section IV gives the measured (near-field and far-field) characteristics of the fabricated antenna panel. Finally in Section V we conclude.

II. DESCRIPTION OF ANTENNA PANEL

Fig. 1, shows the antenna panel structure. It has a rectangular aluminum parallel-plates, separated by a honeycomb core attached to the aluminum plates by means of adhesive. The top metal layer has slot-pairs through which energy is leaked. Two feeder waveguides (TE_{10} mode) with alternating slots couple power into the parallel plate. Dielectric walls are placed at both sides perpendicular to the feeder waveguides to support quasi-TEM wave along x-axis [3]. If the Left Hand Circular Polarization (LHCP) feeder waveguide is excited, electromagnetic wave in quasi-TEM mode is excited in the parallel plate travelling in the +x direction. This excites the slot-pair to radiate LHCP waves. Similarly if the Right Hand Circular Polarization (RHCP) waveguide feeder (WR90) is excited, quasi-TEM wave travels in –x direction and the panel radiates RHCP waves. [2] gives description of antenna panel developed with similar structure, with however only the RHCP waveguide feeder.

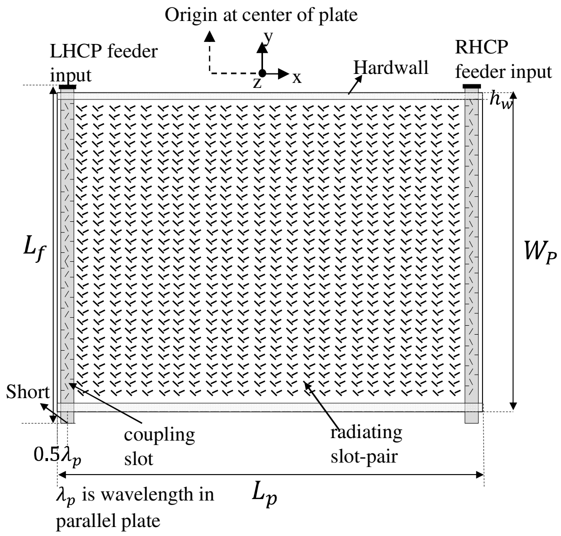

Fig. 1. Structure of Antenna Panel

TABLE I. DIMENSIONS AND WEIGHT OF ANTENNA PANEL

Parameter	Value
Parallel-plate (W_p x L_p)	657.2 mm x 700 mm
Feeder Length (L_f)	678.4 mm
Hardwall width (h_w)	4.89 mm
Al sheet thickness	0.3 mm
Honeycomb core thickness	6 mm
Adhesive layer thickness	0.13 mm x 2 sheets
Total weight	1310 g

III. DESIGN AND SIMULATION

A. *Excitation Synthetsis of radiating slot-pairs*

To allow for simple design we have the slot-pair array along the y-axis (parallel to the waveguide feeder) to be identical, i.e. the slot-pairs have identical slot length and spacing in x-direction. The remaining problem is the design of the slot-pair array along the x-axis, perpendicular to the waveguide feeder.

This problem has the constraint that the slot-pair array should be symmetric about y=0 so that the RHCP and LHCP antenna pattern have main beam in same direction. Another constraint is that the residual power at the end of array should be minimal. In terms of SAR application, the antenna pattern in the XZ plane affects the Range Ambiguity performance [4] and σ_{NEZ0} (Noise-Equivalent Sigma Naught) characteristics [5].

To solve the above optimization problem, we make a simple discrete linear array model of the slot-pairs spaced uniformly $0.9\lambda_0$ apart, where λ_0 is the free-space wavelength [6]. Each slot-pair is characterized by a power coupling coefficient (optimization variable) which gives the ratio of leaked power to the input power. These coupling coefficients are later used to design the slot-length in HFSS. Pattern of single slot-pair is obtained by simulation in HFSS and used as the elemental pattern in the linear array. From this linear array model we can calculate the far-field pattern. We define three objectives for optimal performance:

1. Maximize peak directivity hence minimize σ_{NEZ0}.
2. Maximize beam efficiency of the 1-D antenna pattern in XZ plane hence minimizing range ambiguity. Main beamwidth is taken as 2 deg.
3. Minimize residual power at end of array

There are a number of classical approaches to synthesize an optimal beam pattern for a linear array problem where the elements can be excited independently. However our problem involves a constrained linear array of a traveling wave antenna, where the element excitations are not independent. A metaheuristic algorithm such as genetic algorithm is deemed most suitable to tackle this problem since it is simple and allows flexibility in selection of objective functions. We use multi-objective optimization algorithm, Non-dominated Sorting Genetic Algorithm (NSGA-II) [7] to solve the above optimization problem. A similar method of optimization of a linear array of slot-pair was implemented in [6]. However in [6] only the array factor term was optimized separately without taking into account the pattern of slot-pair as elemental pattern. Fig. 2 shows the optimal power coupling coefficients obtained from NSGA-II optimization, corresponding smoothened coefficients, and the corresponding amplitude excitations.

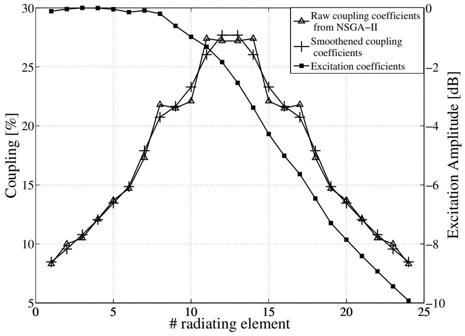

Fig. 2. Original and smoothened coupling coefficients and amplitude excitation of the slot-pair array elements corresponding to the smoothened coupling distribution.

The set of optimal coupling coefficients are used to design the slot length of corresponding slot-pairs in HFSS. More of the design procedure in HFSS is described in [2].

B. *Excitation Synthesis of the Waveguide Feeder*

The RHCP and LHCP waveguide feeder are designed so that they excite the panel uniformly. More of the design process is described in [2].

IV. MEASURED ANTENNA CHARACTERISTICS

Both near and far field measurements are conducted to evaluate the electrical performance of the antenna panel. Fig. 3 shows the peak position at different frequencies of the RHCP and LHCP beams. Though the antenna was designed for center frequency 9.65 GHz, the RHCP and LHCP beams do not coincide at 9.65 GHz (beam shift is 2.1 deg). The RHCP and LHCP beams around 9.77 GHz have better spatial matching. This deviation from design has been attributed to mismatch of dielectric permittivity (adhesive sheets and honeycomb core) modelled in HFSS with the actual panel.

Fig. 4, 5 shows the normalized RHCP, LHCP directivity antenna pattern in the XZ and YZ plane. Fig. 6, 7 show the directivity and gain performance of the panel as a function of frequency. In this plot the antenna panel is pointing at direction corresponding to the peak directivity at 9.65 GHz. RHCP beam has directivity of 35.6 dBic and gain of 34.6 dBic corresponding to aperture efficiency of 50.1%. The LHCP beam has directivity of 35.5 dBic and gain of 34.5 dBic corresponding to aperture efficiency of 49.2%.

V. CONCLUSION

A parallel-plate slot-pair array antenna capable of dual circular polarization radiation has been designed, fabricated and measured. Beam shift of 2.1 deg at 9.65 GHz between the RHCP and LHCP beams are observed in the fabricated panel, while the design simulations in HFSS showed negligible beam shift. Further investigation into this phenomenon will be carried out.

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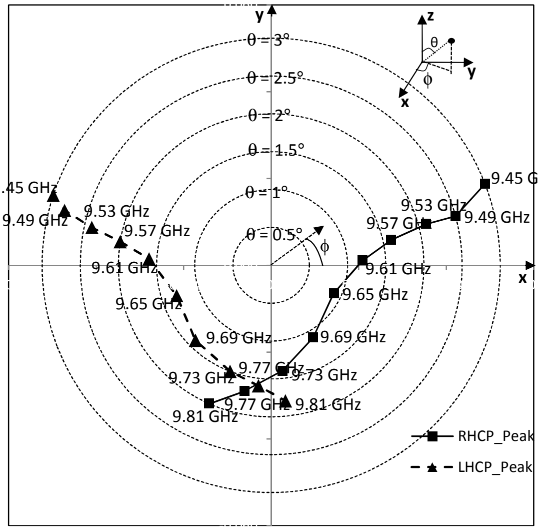

Fig. 3. Projected location of peaks at different frequencies. The RHCP and LHCP beams coincide around 9.77 GHz.

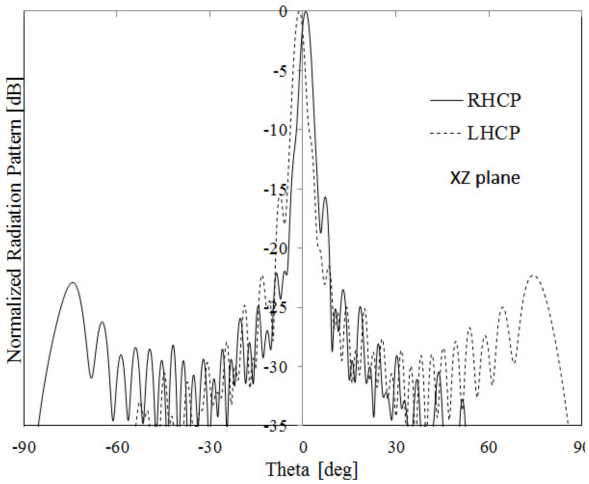

Fig. 4. RHCP and LHCP far-field normalized directivity patterns in the XZ plane (9.65 GHz). Note that the RHCP pattern corresponds to excitation of the RHCP feeder, and LHCP pattern corresponds to excitation of LHCP feeder.

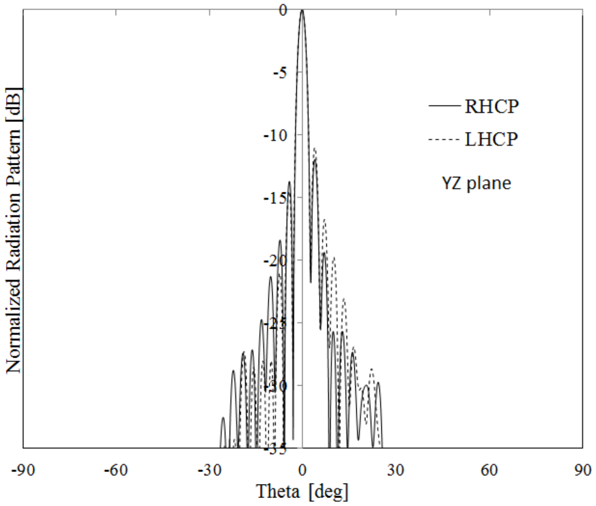

Fig. 5. RHCP and LHCP far-field normalized directivity patterns in the YZ plane (9.65 GHz). Note that the RHCP pattern corresponds to excitation of the RHCP feeder, and LHCP pattern corresponds to excitation of LHCP feeder.

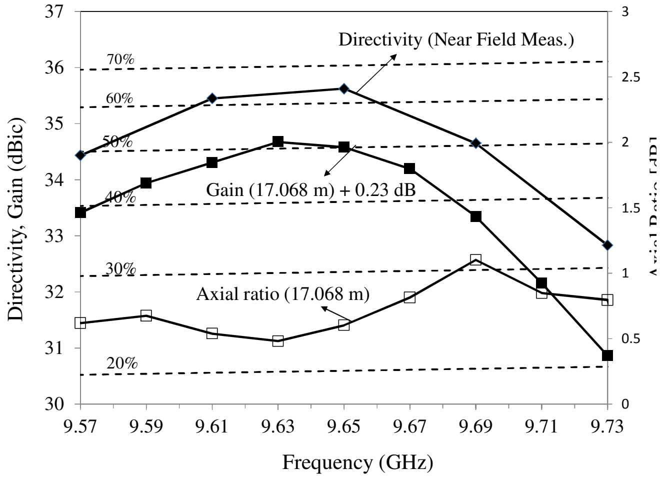

Fig. 6. RHCP directivity, gain and axial ratio. The measurements shown are at direction corresponding to maximum directivity (and gain) at 9.65 GHz. An adjustment factor of 0.23 dB is added to the gain measured at 17.068 m.

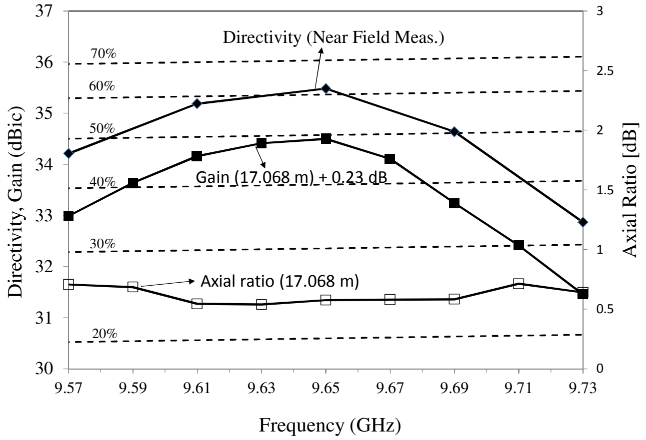

Fig. 7. LHCP directivity, gain and axial ratio. The measurements shown are at direction corresponding to maximum directivity (and gain) at 9.65 GHz. An adjustment factor of 0.23 dB is added to the gain measured at 17.068 m.