URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

An X-Band Parallel Plate Waveguide Linear Reconfigurable Reflectarray Antenna

Samuel Lavoie*[(1)], Jean-Jacques Laurin[(1)], and Muhammad M. Tahseen[(2)]
(1) Poly-Grames Research Center, Polytechnique Montréal
Montréal, QC, Canada
(2) Research Institute for Microwave and Millimeter-wave Studies (RIMMS),
National University of Sciences and Technology (NUST)
Islamabad, Pakistan

Abstract

A reconfigurable linear reflectarray antenna with an inter-element spacing of 0.3725 lambda operating at 11 GHz is presented. Each reconfigurable element is controlled with two varactors diodes which allows the array to scan in one plane. Firstly, two reconfigurable elements are inserted in a WR-90 waveguide to assess the performance of the unit cell. The minimum return loss of the two elements measured at 11 GHz in the WR-90 waveguide is -5.3 dB and the available phase range is 262°. Then, a linear reflectarray of 40 elements and an H-plane sectoral horn antenna are inserted between two parallel plates to form the reconfigurable reflectarray antenna. A beam scanning from -35° to 20° degree with a 5° step is demonstrated. Within this range, the minimum and the maximum gain measured is 14.45 dBi and 17.17 dBi with an isolation from the cross polarization of -23.01 dB. The average half power beam width is 4.77° and the average side lobe level is -8.04 dB for a beam scanning from -35° to 20°.

1 Introduction

Constellations of low earth orbit (LEO) satellites have been in expansion in the last decades. In order to track the LEO satellites, reflector antennas have to be mechanically rotated. This configuration can only follow one satellite at a time and have a limited speed. On the other hand, reconfigurable reflectarray antennas can scan the beam electronically and possibly have multiple beams although they have a smaller bandwidth than the parabolic reflector antenna.

Reconfigurable reflectarray antennas have been implemented with MEMS, PIN diodes [1] [2] and varactor diodes [3] [4] [5] [6] to realize beam steering. In [4], a unit cell based on a square ring resonator is designed and analyzed. The resonator is formed with successive transmission lines with different widths that can be modelled as capacitors and inductors. The combination of both transmission line widths creates the resonance. The unit cell uses two varactor diodes to scan the beam, the simulated maximum amplitude loss is smaller than 1.5 dB at 10 GHz and the phase range is 290°.

In this paper, a modified version of the unit cell from [4] is used for the reconfigurable reflectarray design. The simulation results and the experimental results of the unit cell are first presented. Then, 40 unit cells are incorporated in a parallel plate waveguide to form a linear reflectarray, based on the work done by [7]. The radiation pattern of the reconfigurable antenna is measured in an anechoic chamber.

2 Unit Cell Design

The unit cell is composed of three metal layers and two dielectric substrate layers. Figure 1 shows the structure of the unit cell. The top metal layer has the resonant square ring with the diodes, the second layer (not shown in Figure 1) is a ground plane and the bottom metal layer includes an RF/DC decoupling network to bias the diodes. Two layers of dielectric from Rogers Corp. are used. The bottom substrate is RO3010 with a relative permittivity of 10.2, dissipation factor of 0.0022 and a thickness of 0.51 mm. On the other hand, the upper substrate is RT6002 with a relative permittivity of 2.94, dissipation factor of 0.0012 and a thickness of 1.52 mm. The unit cell dimension is 10.16 mm x 10.16 mm (0.3725 λ x 0.3725 λ) with a total thickness of 2.03 mm.

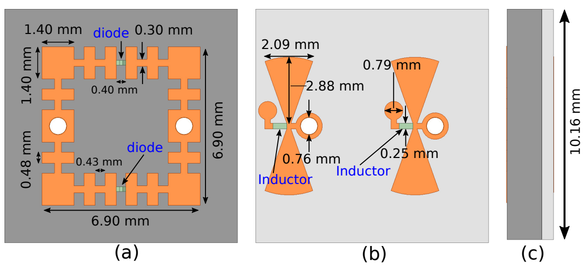

Figure 1. Reconfigurable unit cell structure and dimensions. The two white circles are metallized via holes. (a) Top view. (b) Bottom view. (c) side view.

2.1 Simulations

Two elements were simulated in a WR-90 waveguide with the inter-element distance slightly adjusted to fit in the waveguide width. The TE_{10} mode in the WR-90 at 11

GHz can be interpreted as two plane waves with an incidence angles of ±36.6°. At such high angle, a higher return loss is expected, compared to the case of normal incident plane wave. The varactor diodes (MAVR-011020-1411 from MACOM) are modelled with a resistor ($Rs = 1.6\Omega$) in series with a variable capacitance (Cj = 0.02 pF to 0.2 pF) and an inductor ($Ls = 0.4nH$). A fixed capacitor is added in parallel with the model to add the capacitive effect of the package ($Cp = 0.07pF$). Figure 2 is showing the simulation results for the unit cells in the WR-90 waveguide.

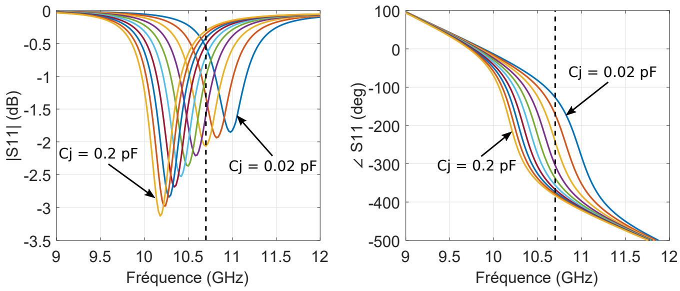

Figure 2. Simulated amplitude and phase of reflection for two reconfigurables elements in a WR-90 waveguide.

At a frequency of 10.7 GHz the return loss varies between 0.3 dB and 2.1 dB with an average of 0.9 dB over the varying capacitance range and a phase range of 256° is obtained.

2.2 Measurements

A circuit with two unit cells was fabricated and tested in a WR-90 waveguide. A one port SOL (Short-Open-Load) calibration was done to measure at a reference plane of the top surface of the unit cell. A metallic plate was used for the short and an adjustable waveguide short of $\lambda/4$ was used for the open. An adapted WR-90 load was also used. Figure 3 is showing the measurement results for the return loss and the phase of S11. A return loss range of 0.6 dB to 5.3 dB is obtained with a phase range of 262° at 11 GHz.

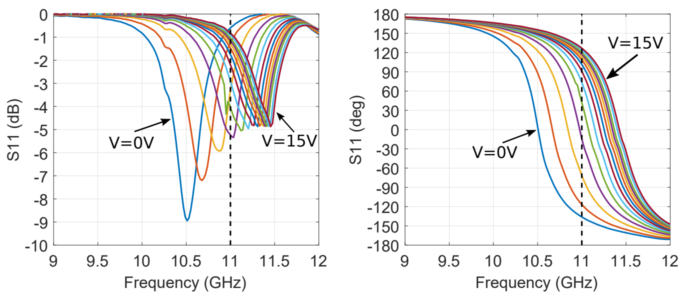

Figure 3. Amplitude loss and phase reflection measured of the two reconfigurables elements in a WR-90 waveguide.

The maximum return loss is higher than what it was expected from the simulation. The model of the diode is probably inaccurate in this configuration and should be modified to better match the measurements. The next section is studying a reflectarray with this reconfigurable element.

3 Reconfigurable antenna design

The reconfigurable antenna based on a parallel plate waveguide is shown in Figure 4. The distance between the two plates is 10.16 mm and the mode of propagation at 11 GHz is transverse electromagnetic (TEM). An H-plane sectoral horn antenna, which can operate from 8.2 GHz to 12.4 GHz, is inserted between the two plates to illuminate the reflectarray. The calculated edge illumination of the reflectarray relative to the maximum is -10.8 dB (first element in Figure 4) and -6.5 dB (last element in Figure 4). The reflectarray is composed of 40 elements with an inter-element spacing of 10.16 mm. Two small pieces of absorbing foam are placed directly at the right end and left end of the reflectarray between the two plates. The inclination angle of the horn measured from the boresigth of the reflectarray is 25°. The 18th element indicated in Figure 4 (b) is receiving the maximum amplitude from the horn. The distance from the phase center of the horn and the reflectarray is 345.46 mm. This makes an Focal to Length ratio (F/L) of 0.85 (where L is the size of linear array). A flare is placed at the end of the two parallel plate waveguide to make a transition to the open space. The angle between flare and the reflectarray is 25°, so that the incident angle perceived at the flare is pointing to the boresight. The reconfigurable elements are controlled from 0 V to 15 V independently with 40 digital to analog converters (DAC). The boards used for the voltage control is from Analog Devices with part numbers EVAL-SDP-CB1Z and EVAL-AD5766SD2Z. The return loss at the input of the coaxial cable was measured with a metallic plate instead of the reconfigurable reflectarray antenna and is shown in Figure 5. The return loss is below -10 dB from 8.5 GHz to 12 GHz. The radiation pattern of the reconfigurable antenna was measured in an anechoic chamber at the Poly-Grames Research Center. The gain and the X-pol level are measured from -90° to 90° with a step angle of 0.5°. Figure 6 is showing the H-plane patterns for several steering directions imposed by the reflectarray.

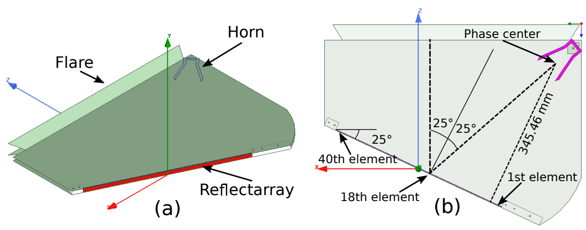

Figure 4. Geometry of the reconfigurable reflectarray antenna. (a) Isometric view. (b) Top view.

The results are showing that the beam can be scanned from -35° to 0° without a significant gain degradation. A maximum gain of 17.2 dBi is observed when the inclination angle is -15°. The average side lobe level from a scan angle of -35° to 0° is -8.15 dB while the average half power beam width 4.31° and the average of gain 16.72 dBi is obtained. The minimum X-pol/co-pol ratio is -23.01 dB and it is observed at 0°.

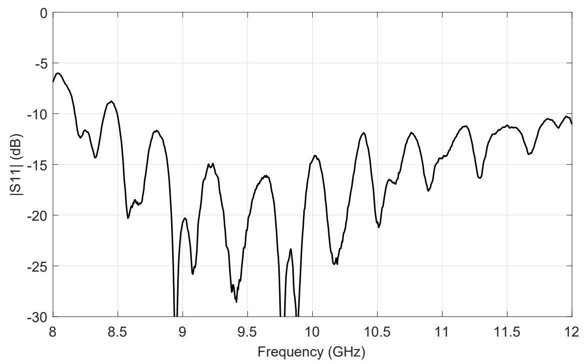

Figure 5. Return loss measured at the input of the coaxial cable of the reconfigurable reflectarray.

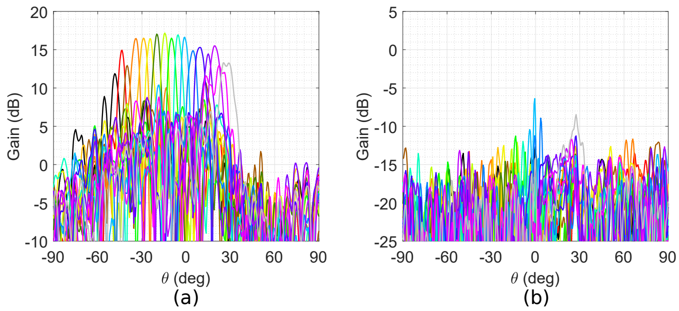

Figure 6. Results of the measurements done in the anechoic chamber. (a) Measured gain as a function of angle of incidence. (b) Measured cross-polarization as a function of angle of incidence.

4 Conclusion

A reconfigurable X-band reflectarray antenna was presented and a scan angle from -35° to 0° was demonstrated. The theoretical model of the diode should be modified to better match the measurements and improve the performances of the reconfigurable element. The limited phase range of the reconfigurable element introduces phase errors in the reflectarray and affects its performances. Also, the reconfigurable element presents high loss. These limitations reduce the gain and increase the side lobe level. It is noted that the performance of the antenna could be improved if loss of the element is reduced and phase range increased.

References

[1] H. Zhang, X. Chen, Z. Wang, Y. Ge and J. Pu, "A 1-Bit Electronically Reconfigurable Reflectarray Antenna in X Band," in IEEE Access, vol. 7, pp. 66567-66575, 2019.

[2] X. Pan, F. Yang, S. Xu and M. Li, "A 10 240-Element Reconfigurable Reflectarray With Fast Steerable Monopulse Patterns," in IEEE Transactions on Antennas and Propagation, vol. 69, no. 1, pp. 173-181, Jan. 2021.

[3] M. E. Trampler and X. Gong, "Dual Polarization, Dual Resonant Reflectarray Element for Beamsteering Applications at X Band," 2018 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, Boston, MA, pp. 1727-1728, 2018.

[4] M. M. Tahseen and J. Laurin, "Low-Profile Electronically Tunable Low-Loss Single Layer Reflectarray Element," 2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting, Atlanta, GA, USA, pp. 1959-1960, 2019.

[5] M. E. Trampler, R. E. Lovato and X. Gong, "Dual-Resonance Continuously Beam-Scanning X-Band Reflectarray Antenna," in IEEE Transactions on Antennas and Propagation, vol. 68, no. 8, pp. 6080-6087, Aug. 2020.

[6] E. Carrasco, J. A. Encinar and J. Perruisseau-Carrier, "Evaluation of a reflectarray with independent scanning of two linearly-polarized beams," 2012 6th European Conference on Antennas and Propagation (EUCAP), Prague, pp. 2967-2970, 2012.

[7] R. Deban and J. Laurin, "An X-band planar reflectarray antenna," 2014 IEEE Antennas and Propagation Society International Symposium (APSURSI), Memphis, TN, pp. 797-798, 2014.