Ka-band Beam Switchable Fresnel Reflector

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1. Introduction

A new telecommunication service in Ka-band for the communication between satellites and other systems has been prepared [1]. The objective of this study is to develop an antenna for the communication between satellites and an unmanned aerial system (UAS). In this plan, the antenna on the UAS is required to follow the satellites using the electrical beam sweep function and should be compact, light weight due to the UAS's limited payload.

The printed reflector solutions, like reflectarrays [2] or printed Fresnel reflector [3-4] are suitable for this purpose. The reflectarray antenna consists of a reflector and a primary source set at the focal point. The reflector is made up of plural metal patches etched on a substrate. The patches have different phase shift that is defined by their two-dimensional shapes, and they compensate the travelling phase so that the reflector surface is equivalent to a parabolic curve. Then the whole reflectarray focuses incident/transmit waves in the same way as a condensing lens.

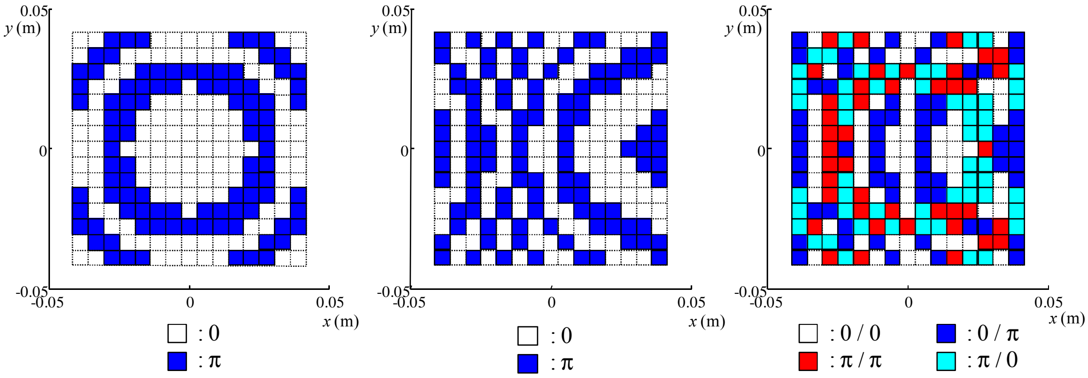
This study aims to achieve a beam switching function of the Fresnel reflector antenna by the introduction of a PIN diode on each patch. The antenna beam can be switched from one direction to the other with the diode bias voltage. In general, array antennas that include numerous diodes consume a lot of power. However it is not realistic to mount it on an UAS since the onboard power source is limited, and we also have to pay attention to the heat radiation from the diode when the voltage is applied.

This paper describes an antenna concept to economize the antenna power consumption, then the study of patch shapes to perform the appropriate phase shift, the patch allocations, and the total characteristics of the designed antenna. This antenna concept does not apply a diode to all the antenna cells and investigates the simplest configuration.

2. Fresnel Reflector Antenna Concept

To design the antenna, first we define the concept and several specifications. The 15 x 15 matrix lined cells compose the antenna, and the cells are allocated according to the 2 zones Fresnel order. This is the simplest configuration of Fresnel reflector antenna that forms a beam. The 2 zones Fresnel reflector antenna requires two sorts of patch phase shifts such as 0, π rad, thus it is less complicated than general reflectarray which adjusts the phase gradually. In this investigation, the antenna target frequency is 27 GHz, and the array cell size is a half wavelength at 27 GHz therefore 5.5 mm x 5.5 mm. The bigger cell size which corresponds to the low frequency enable us to have more flexibility of the patch dimensions although the mismatch generally causes grating lobes to the radiation pattern. Consequently the total antenna dimension becomes 82.5 mm x 82.5 mm. A primary source for this antenna is an open-ended waveguide which aperture dimension is 8.6 mm x 4.3 mm. Specification of the substrate is Duroid(ε_r 2.2), the thickness 0.762 mm.

In this study, the antenna beam direction changes by controlling the bias voltage of a PIN diode put at array patches. This paper only treats 0 and 45 degree direction beams as a first simple trial. Hence, the antenna has 0 degree direction pattern with forward bias and otherwise 45 degree direction pattern. Fig. 1(a) and (b) shows the cell allocation according to Fresnel zone at 0 and 45 degree beam direction. The small square is a unit cell. Each cell shifts the incident phase either 0 or π rad. The reflector antenna should satisfy both of them with one system only turning on the diode bias voltage. Other physical patch dimensions are identical over the two modes. Moreover Fig. 1(c) compares the phase shift between Fig. 1(a) and (b) at each cell, which can be categorised into four different combinations. 0 / 0 rad and π / π rad are the case that the phase shift does not change over the two beam directions, while 0 / π rad and π / 0 rad need to switch the phase shift π rad. Both of two modes 0 / π rad and π / 0 rad can be switched complementary using a PIN diode. The proposed reflector concept, shown in Fig. 1(c), requires two sorts of passive array unit cell and one active cell whose phase shift varies π rad with biased diode.



(a) 0 degree (b) 45 degree (c) 0/45 degree integrated

Figure 1: Fresnel reflector patch allocation

Here, Tab. 1 notes quantity and the ratio cell type in Fig. 1(c). The four modes are roughly distributed in equal over the all 225 (= 15x15) cells. Consequently only the 52(=28+24) % of cells needs an active patch with a diode for each. Already the power consumption of the antenna become 52 % to the general case which uses a diode par one cell(100 %). Moreover, PIN diode requires the bias voltage in only one of the two modes, therefore almost half of the active cells are not applied the voltage. As a result, quantity of the biased diode is almost a quarter (28 or 24 %) of the global cell. Thus this antenna saves 74 % of power consumption on average to general active reflectarrays. It means the heat radiation from the diodes would also be 74 % reduced.

Table 1: Cell quantity and the ratio in Fig. 1(c)

	Passive cell		Active cell	
0 / 45 (deg)	0 / 0	π / π	0 / π	π / 0
Cell quantity (The ratio)	67 (30 %)	42 (18 %)	62 (28 %)	54 (24 %)

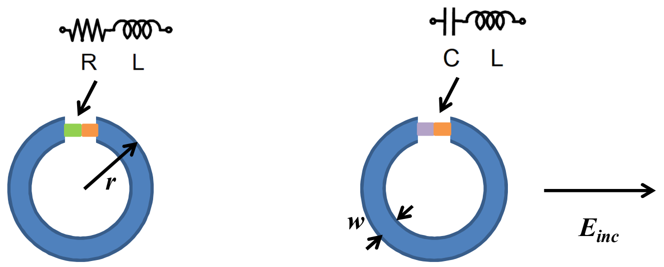
3. Unit cell Design

The unit cell is composed of a metal patch on a substrate, and the back is covered with a metal ground plane. The patch shape is defined with a finite element method (FEM) simulation. The phase shift of each cell is simulated independently, and it also considers mutual couplings of the vicinity patches. According to the antenna concept, we design two sorts of passive array unit cell and one active cell whose phase shift varies π with biased diode.

To realize the antenna, we chose circular shape patches. Generally the circular shaped patches have enough wide phase shift variety. As passive cell, a disk shaped patch is used. The diameter is only parameter of the phase shift and the patch is always placed at the centre of the cell.

Active cell consists of a C-shape patches. The ring diameter and the width play the phase shift. The gap width to put diode is fixed as 0.3 mm due to the diode chip dimensions [5].

Fig. 2 shows equivalent circuit of two diode statuses on the simulation. When the diode is biased in forward, the equivalent circuit is expressed as R-L serial circuit, here the resistance is 5 Ω and the inductance is 30 pH, while there is no bias voltage, it is expressed as C-L serial circuit, where the capacitance is 27 fF [5-6]. The inductance includes loss of mounting the chip. This equivalent circuit expression means the active patch works as quasi ring with biased diode and as quasi chipped ring (C) with not biased diode. Change of current distribution on the patch varies the phase shift. The currents concentrate two points on the ring shape patch while three points on the C -shaped patch [7].



(a) Diode biased (b) Diode not-biased

Figure 2: Active C - shaped patch

4. Whole Fresnel Reflector Antenna Design

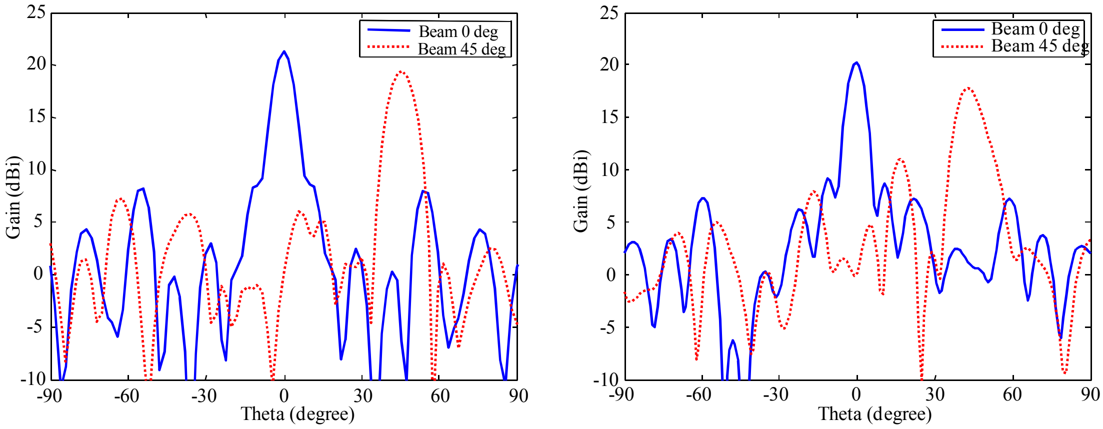
The whole reflector is made up with three sorts of total 225 patches. They are placed at the appropriate position under the concept that mentioned above. Tab. 2 shows the chosen patch dimensions. All the active cells are the same dimension but the diode switch mode is different such as 0 / π rad or π / 0 rad. Error between the ideal phase shift and the allocated phase shift (simulation results) is less than 20 degrees.

Table 2: Patch dimensions

Cell in Fig. 1(c)	Beam 0 degree (rad)	Beam 45 degree (rad)	Radius (mm)	Ring width (mm)
□ (white)	0	0	1.9	-
■ (red)	π	π	1.5	-
■ (blue)	0 <not-biased>	π <biased>	1.7	1.2
■ (cyan)	π <biased>	0 <not-biased>	1.7	1.2

* < > is the diode status.

Fig. 3 shows the simulated radiation pattern of the whole reflector at 27 GHz using Finite Difference Time Domain (FDTD) method. Fig. 3(a) is the all passive 15 x 15 size Fresnel reflector using disk shaped patches (Fig. 1(a) and (b)) as a comparison, and Fig. 3(b) is the proposed antenna with a combination of passive and active array cells as shown in Tab. 2 (Fig. 1(c)). In Fig. 3(b), the mode change of diodes is expressed by the equivalent circuit of the diode status shown in Fig. 2 using a lumped element of R, L, and C. The beam direction is well controlled to 0 degree and 45 degrees as intended. The gain is 20.2 dBi and 17.7 dBi, the half-power beamwidth is 7 degrees and 10 degrees respectively. Compared to the all passive 15 x 15 size Fresnel reflector in Fig. 3(a), the gain of the proposed antenna is 1 dB smaller at 0 degree beam, and 1.7 dB smaller at 45 degree beam. The global gain degradation is due to the loss at the diode. On the other hand, the half power beamwidth are the same.



(a) With all passive array cells

(b) Active antenna

Figure 3: 15 x 15 Fresnel reflector radiation pattern

5. Conclusion

This paper proposed an active Fresnel reflector antenna. The antenna consists of two different dimensions of passive array cell and one active array cell. Phase shift of the active cell varies π rad by applying bias voltage into a diode. Advantage of the reflector antenna is small power consumption due to the limited number of active cells and their complement function mode. The concept achieves to save about 74 % to general active reflectarray that includes a diode for every cell. Effectiveness of the antenna concept is confirmed with a full wave simulation including equivalent circuits of the diode. The PIN diode switched the antenna beam direction 0 degree or 45 degree as intended. The gain degradation due to the active cells was only 1 - 1.7 dB in spite of power consumption saving.

The next step of this study is to design the practical feeding circuit for diodes and to prepare the antenna prototype, then to measure the characteristics.

References

[1] J. M. Baracco, P. Ratajczak, P. Barachat, and G. Toso, “Dual Frequency Ka-Band Fresnel Reflectors,” Proceedings of AP-S/URSI 2011, pp. 2187-2190, July 2011.
[2] J. Huang, and J. Encinar, “Reflectarray antennas,” John Wiley & Son Ltd, 2007 ISBN: 978-0470084915.
[3] B. D. Nguyen, C. Migliaccio, Ch. Pichot, N. Yonemoto, K. Yamamoto, “W-band Fresnel Zone Plate Reflector for Helicopter Collision Avoidance Radar”, IEEE Trans. Antennas Propagat. Vol. 55, no. 5, pp.1452-1456, May 2007.
[4] B. D. Nguyen, J. Lanteri, J.-Y. Dauvignac, Ch. Pichot, C. Migliaccio, "94 GHz Folded Fresnel Reflector Using C-Patch Elements”, IEEE Trans. Antennas Propagat. Vol. 55, no. 5, pp. 3373-3381, November 2008.
[5] MA-COM, data sheet of GaAs Flip Chip PIN, MA4GP907
[6] H. Kamoda, T. Iwasaki, J. Tsumochi, and T. Kuki, ” 60GHz Electrically Reconfigurable Reflectarray Using p-i-n Diode,” Proceedings of IEEE IMS2009, pp.1177-1180, 2009.
[7] A. Kohmura, J. Lanteri, F. Ferrero, C. Migliaccio, P. Ratajczak, S. Futatsumori, and N. Yonemoto, "Ka-band Dual Frequency Switchable Reflectarray," Proceedings of EuCAP2012, 2012.