Dual-Beam Gain-Reconfigurable Antennas Using A Shared Reflectarray Aperture

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***Abstract* - In this paper, a reflectarray based dual-beam gain-reconfigurable structure is proposed for dynamically controlling the gain of each beam. In this structure, two phased-array feeds are illuminating one shared reflectarray aperture. By modulating the excitation conditions for each phased-array feed and compensation phase distribution on the aperture, dual beams with different gains can be realized simultaneously, which can be useful for fully terminal coverage for the base station antennas of mobile communications. Two sets of beam states have been chosen to validate the novel structure. From the simulation results, a gain of 20.9dB is obtained for equal beam-state resulting in 39.1% aperture efficiency. For the other beam-state, two beams with 22.2dB and 18.4dB gains are achieved. The corresponding aperture efficiency are 40.4% and 31.4%, respectively.**

***Index Terms* – Reflectarray, Phased-array feed, Dual-beam, Gain-control**

I. Introduction

With the growing demands for high data rate, the use of millimeter-wave bands for the next generation wireless communication network such as the fifth generation (5G) mobile systems has generated much attention [1]. Lots of effort has been paid to design efficient highly-directive multi-beam antenna systems to both overcome the high path loss problem in mm-wave band [2] and deploy massive-MIMO technology [3]. Many types of such antennas have been reported [4], for which multi-beam feature with equal gain can be achieved. However, few research works have been reported to realize gain-reconfigurable capability for multi-beam antennas. Gain-reconfigurable multi-beam antennas could be advantageous. On one hand, it can provide high energy and spectrum efficiency. On the other hand, it is helpful for increasing the signal coverage.

In this paper, a novel dual-beam gain-reconfigurable architecture consisting of two phased-array feeds with one shared reflectarray [5] aperture is proposed to dynamically control the gain for each beam. By modulating the excitation condition for each phased-array feed and compensation phase distribution on the aperture, dual beams with different gain and beamwidth can be controlled dynamically. Besides, due to two separated feeds, two channels can be supported. Based on this, a prototype with broadside beams is designed and simulated using HFSS to validate this functionality. In addition, the capability of steering the main lobe direction can be realized by integrating RF switch such as PIN diode or MEMS into unit cell design.

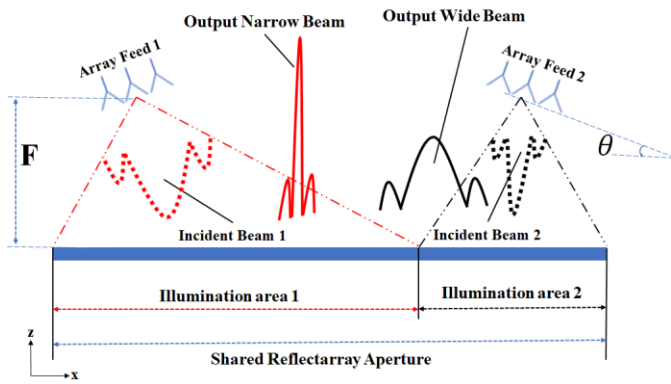


Fig. 1 Geometry of the proposed system

II. Antenna System Design

The architecture of the proposed system is shown in Fig. 1. It consists of two sets of 1x3 planar phased-array feed and one shared reflectarray aperture. The two sets of phased-array feeds are positioned symmetrically in front of the reflectarray aperture with focal distance of F and oblique angle of θ. By controlling the excitation condition for each phased-array feed, incident beams with different beamwidth can be realized. Naturally, when illuminated by these two different incident beams, the shared reflectarray aperture will be divided into two sub-aperture parts, each with different effective illumination area. Then, the sub-apertures are utilized to compensate the spatial phase delay in each area to get two collimated beams. Due to different effective illumination area, different beamwidth and gain for the two collimated beams will be achieved. The two different effective illumination area can be controlled by the excitation condition for each phased-array feed, resulting in dynamic gain control of the two output beams.

A single layer variable-sized patch is utilized as the unit cell for the reflectarray aperture. All elements are simulated by using periodic boundaries together with Floquet excitation mode. Fig. 2 shows the simulated reflection response results and geometrical model.

A pin-fed rectangular patch antenna is employed as an element of the planar phased-array feed. The patch antenna element is designed to resonant at 28GHz. A series 1x3 patch array is deployed as the phased-array source feed.

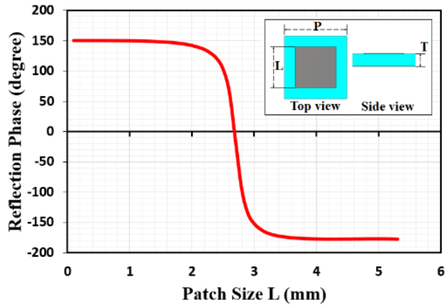


Fig. 2 Reflection phase response versus patch size L, inset is the geometrical model of the unit cell.

In order to validate the functionality of the system, two sets of beam state are selected. It should be noticed that one can obtain two beams for each beam state. For simplicity, the beam directions for both beam states are broadside. Illumination area ratio of 1 is selected for beam state 1 to obtain two same beams. For beam state 2, illumination area ratio of 2 is chosen, which should result in a 3dB gain difference between the two beams. For aperture efficiency calculation, the aperture area is based on the sub-aperture size, since only these sub-apertures are illuminated efficiently. The detailed system design parameters are listed in Table I.

III. Simulation Results

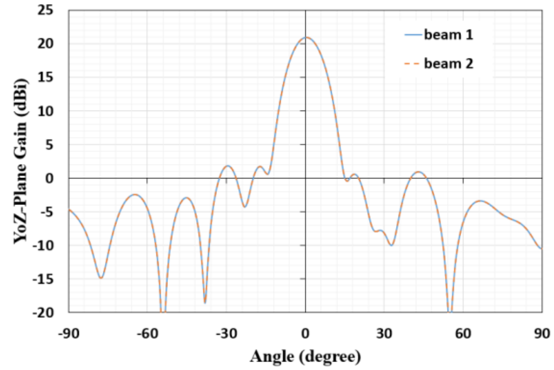
Fig. 3(a) shows the radiation patterns in E-plane for the two output beams in beam state 1, while Fig. 3(b) shows the radiation patterns in H-plane for beam state 1. The radiation patterns for both phased-array feed in beam state 1 are symmetrical due to equal illumination area. The gain of 20.9dB is obtained for both beams resulting in 39.1% aperture efficiency.

For beam state 2, the radiation patterns in E-plane are illustrated in Fig. 4(a). Fig. 4(b) presents the radiation patterns in H-plane. For beam 1, the gain of 22.2dB is achieved, while the gain of 18.4dB is obtained for the other beam. The corresponding aperture efficiency are 40.4% and 31.4%, respectively. According to theoretical analysis, if designed properly, the two beams should have a 3dB gain difference, since the effective illumination area ratio is 2. However, a 3.8dB gain difference is observed from the simulation results. This sight difference between theoretical analysis and full-wave simulation is mainly caused by the inefficient illumination of the phased-array feed, which should be further optimized.

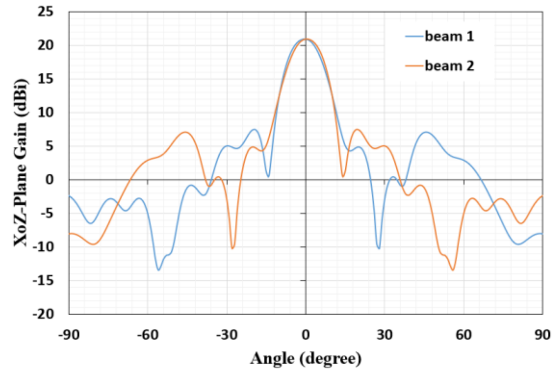
Table I Detailed design parameters

Center Frequency		28GHz	
Focal distance, F		$2.5\lambda_0$	
Oblique angle, θ		20°	
Unit-cell periodicity, P		$0.5\lambda_0$	
Unit-cell patch length, L		0.1~5.3 mm	
Unit-cell substrate thickness, T		0.4 mm	
Aperture size		$10 \times 20(5\lambda_0 \times 10\lambda_0)$	
Beam state	Illumination area ratio	Excitation for array feed 1	Excitation for array feed 2
1	1:1	(X, 0°, X)	(X, 0°, X)
2	2:1	(X, 0°, X)	(188°, 94°, 0°)

** the excitation has the format of phase excitation in degree, X means no excitation*

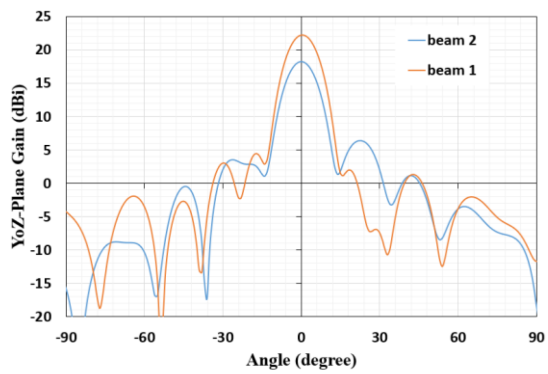


(a)

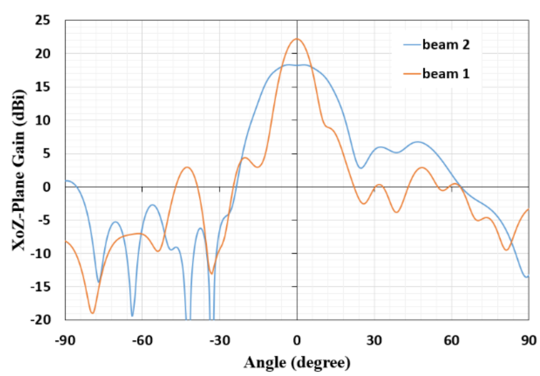


(b)

Fig. 3 Radiation patterns for beam state 1 in (a) YoZ-plane. (b) XoZ-plane.



(a)



(b)

Fig. 4 Radiation patterns for beam state 2 in (a) YoZ-plane. (b) XoZ-plane

IV. CONCLUSION

In this paper, a novel dual-beam gain-reconfigurable antenna system that contains a shared reflectarray aperture has been proposed, designed and simulated. The gain-reconfigurable capability has been validated in the full-wave simulations. From the results, a gain of 20.9dB is obtained for equal beam-state resulting in 39.1% aperture efficiency. For the other beam-state, two beams with 22.2dB and 18.4dB gains are achieved. The corresponding aperture efficiency are 40.4% and 31.4%, respectively.

REFERENCES

[1] (2015). *Studies on Frequency-Related Matters for International Mobile Telecommunications Identification Including Possible Additional Allocations to the Mobile Services on a Primary Basis in Portion(s) of the Frequency Range Between 24.25 and 86 GHz for the Future Development of International Mobile Telecommunications for 2020 and Beyond, I.W.R.C. Resolution 238.* [Online]. Available: http://www.itu.int/dms_pub/itu-r/oth/0c/0a/R0C0A00000C0014PDFE.pdf

[2] D. M. Pozar, *Microwave Engineering*, 3rd ed. Hoboken, NJ, USA: Wiley, 2005.

[3] E. G. Larsson, O. Edfors, F. Tufvesson, and T. L. Marzetta, “Massive MIMO for next generation wireless systems,” *IEEE Commun. Mag.*, vol. 52, no. 2, pp. 186-195, Feb. 2014.

[4] W. Hong *et al.*, “Multibeam antenna technologies for 5G wireless communications,” *IEEE Trans. Antennas Propag.*, vol. 65, no. 12, pp. 6231-6249, Dec. 2017.

[5] J. Huang, J. A. Encinar, *Reflectarray antennas*, Hoboken, NJ, USA: Wiley, 2008.