Comparison between One-body 2-D Beam-switching Butler Matrix and 2-D Beam-switching Rotman Lens

Dong-Hun Kim1, Jiro Hirokawa1, Karim Tekkouk1, Makoto Ando1, and Ronan Sauleau2
1Dept. of Electrical and Electronic Engineering, Tokyo Institute of Technology, Tokyo, Japan
2Institut d'Electronique et de Télécommunications de Rennes (IETR), Université de Rennes, Rennes, France

***Abstract* - The one-body 2-D Beam-switching Butler Matrix and the 2-D Beam-switching Rotman Lens are compared. Those are designed to have sixteen 2-D arranged beams. Comparing the proposed Butler matrix with the Rotman lens, it has the low transmission loss, the high uniformity of distributed beams, and the small size. However when the number of 2-D arranged beams is increased, the size of the Butler matrix is larger than the size of the Rotman lens.**

***Index Terms* — Antenna feed circuit, Beam forming, Butler matrix, Rotman lens.**

1. Introduction

In this paper, 16×16-way one-body 2-D beam-switching Butler matrix and 16-way 2-D beam-switching Rotman lens are discussed about the characteristics and the limitations. Butler matrix and Rotman lens are feed circuits for the beam-switching network. Butler matrix is designed to distribute power equally, but to delay propagation differently from an input port to the output ports using the hybrid couplers, the cross couplers, and the phase shifters [1]. It is same as Cooley-Tukey algorithm [2]. Rotman lens is designed to concentrate power on the beam direction, and to vary optical path length by generating the inner surface of lens and the focal surface [3]. Different design approaches to generate the beams make different the features and the frequency characteristics.

In this paper, 16×16-way one-body 2-D beam-switching Butler matrix and 16-way 2-D beam-switching Rotman lens are discussed about the characteristics and the limitations.

2. Configuration of Beam-switching Networks

The one-body 2-D beam-switching Butler matrix consists of short-slot hybrid and cross 2-plane couplers as shown in Fig. 1 [4]. The size of the one-body 2-D beam-switching Butler matrix depends on the number of short-slot hybrid and cross 2-plane couplers. When the numbers of the input and the output are increased, the numbers of short-slot hybrid and cross 2-plane couplers are exponentially increased. Meanwhile, the 2-D beam-switching Rotman lens consists of a dielectric multi-layers lens with cavity only. Even the numbers of the input is increased, the size is restricted by the length from the on-axis focal point G to the origin O and the radius of the focal surface R as shown in Fig. 1. In this paper, the lengths of G and R are selected 5.37 and 3.97 wavelength, respectively.

The outmost size of the cavity of 16×16-way one-body 2-D beam-switching Butler matrix (2.79 λ_0×1.88 λ_0×12.03 λ_0) are smaller than the outmost size of the cavity of 16-way 2-D beam-switching Rotman lens (6.88 λ_0×6.93 λ_0×5.72 λ_0). When the number of the input ports is increased, the size of the one-body 2-D beam-switching Butler matrix is proportional to $\Theta(3N^{3/2}/2)$ where N is the number of the input port. However the size of 16-way 2-D beam-switching Rotman lens is maintained. Until N=32, the one-body 2-D beam-switching Butler matrix has a volumetric merit.

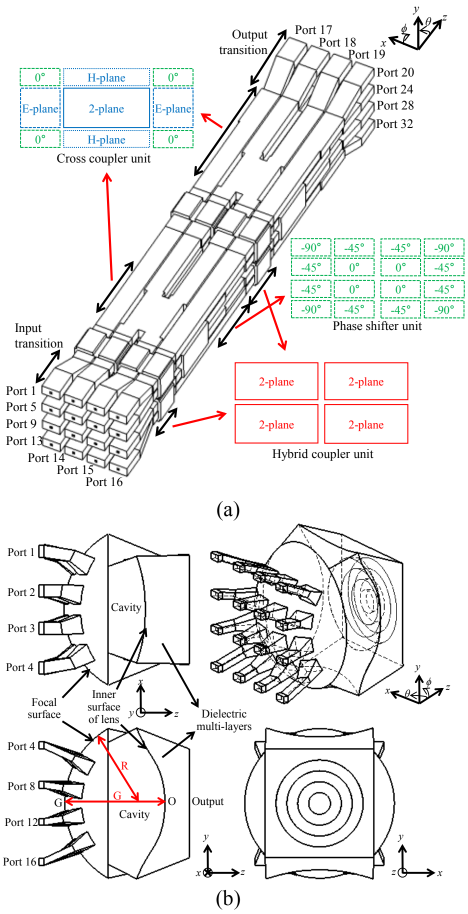

Fig. 1. Configuration (a) 16×16-way one-body 2-D beam-switching Butler matrix (b) Configuration of 16-way 2-D beam-switching Rotman lens.

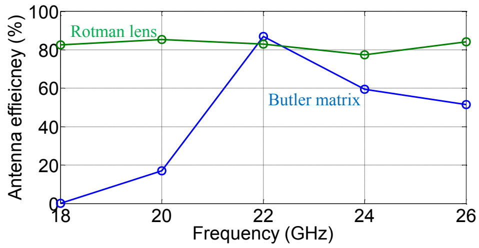

Fig. 2. Antenna efficiencies.

3. Frequency Characteristics

Due to differences of the fundamental structure, the one-body 2-D beam-switching Butler matrix which generates quadric propagation modes has narrow fractional bandwidth (2~3%) than 2-D beam-switching Rotman lens which generates true time-delay response (20%~). Designed two beam-switching networks are equipped antenna elements to work as an array antenna.

(1) Radiation Efficiency

The loss of the one-body 2-D beam-switching Butler matrix consists of the return loss and the conduction loss mainly. The return loss can be suppressed by impedance matching, however the conduction loss is proportional to the inverse of square root of the conductivity and propagation length in given frequency. The propagation length of the one-body 2-D beam-switching Butler matrix is proportional to $\Theta(3N^{1/2}/2)$. On the other hand, the propagation length of the 2-D beam-switching Rotman lens is a constant. Additionally, the 2-D beam-switching Rotman lens is considered the spillover loss. It can be suppressed by reducing the distance between the inner surface of lens and the focal surface.

Above mentioned things are reflected to the radiation efficiency as shown in Fig. 2.

(2) Gain Pattern

The 3.9 dB-down beam coverages of gain patterns and the positions of peak gains of 16×16-way one-body 2-D beam-switching Butler matrix and 16-way 2-D beam-switching Rotman lens are acquired by EM simulation as shown in Fig. 3. The number of beams and those directions of the one-body 2-D beam-switching Butler matrix are 2^n where n is an integer. Its beam coverages are separated equi-distantly and occupied equi-territorially, because antenna apertures are separated equi-distance (0.73×0.73 wavelength). On the other hand, the beam directions of the 2-D beam-switching Rotman lens is freely selected the number of beams and those directions. Its beam coverages are separated un-equi-distantly and occupied un-equi-territorially because the dielectric materials are distributed discretely in the lens. Beam-coverages are determined by the phase delay of phase shifters in the Butler matrix and the f-stop which is the ratio of the focal length to the effective aperture in the Rotman lens, respectively.

The peak gains of 16×16-way one-body 2-D beam-switching Butler matrix and 16-way 2-D beam-switching Rotman lens are within 15.3±2.2 dBi and 16.3±0.9 dBi, respectively.

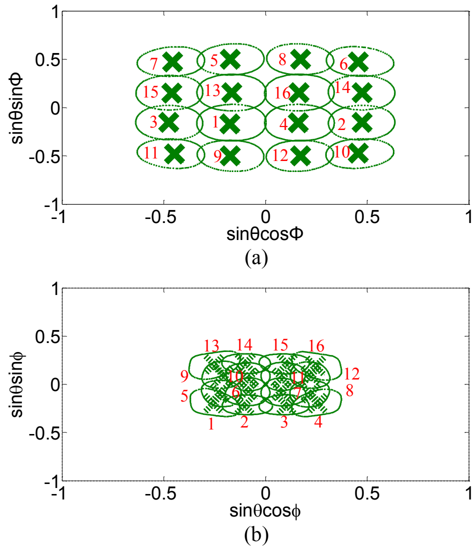

Fig. 3. 3.9 dB gain patterns (a) 16×16-way one-body 2-D beam-switching Butler matrix (b) 16-way 2-D beam-switching Rotman lens. The number and the symbol X indicate the input port number and the position of peak gain

4. Conclusion

The one-body 2-D Beam-switching Butler Matrix and the 2-D Beam-switching Rotman Lens are discussed. The one-body 2-D Beam-switching Butler Matrix has a high uniformity. The 2-D Beam-switching Rotman Lens has a constant size, a large fractional bandwidth, and arbitrary the number of beams and those directions.

Considering the size and the performances of the one-body 2-D Beam-switching Butler Matrix and the 2-D Beam-switching Rotman Lens, the one-body 2-D Beam-switching Butler Matrix has a merit when N is less than or equal to 64.

Acknowledgment

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References

[1] J. Butler and R. Lowe, “Beam-forming matrix simplifies design of electronically scanned antennas,” *Electron. Des.*, vol.9, no. 8, pp. 170-173, Apr. 1961.

[2] J. W. Cooley and J. W. Tukey, “An algorithm for the machine calculation of complex fourier series,” *Math. of Comput.*, 19, pp. 297-301, 1965

[3] W. Rotman and R. F. Turner, “Wide angle microwave lens for line source application,” *IEEE Trans. Antennas Propag.*, vol. AP-11, pp. 623-630, Nov. 1963.

[4] D.-H. Kim, J. Hirokawa, and M. Ando, “Design of Waveguide Short-slot 2-plane Couplers for One-body 2-D Beam-switching Butler Matrix Application,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 64, no. 3, pp. 776-784, Mar. 2016.