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Design of Rotman-Lens Feeding-Circuit for Multi-Layer Beam-Scanning Microstrip Antenna in Millimeter-Wave Band

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1. Introduction

Millimeter-wave technologies have been developed with increasing the need for efficient use of frequency resources. High gain and narrow beam antennas can be achieved in the millimeter-wave band even by using physically small antennas. The same fractional bandwidth with lower frequency corresponds to much broader bandwidth channel in the millimeter-wave band. Beam-scanning technologies are attractive to cover broad angular area with high gain of narrow-beam antennas [1]. Rotman lens is widely used in multibeam antennas for beam forming networks (BFN) which give required aperture distribution in arrays [2], [3]. Discrete beam-scanning can be fulfilled by switching the beams. However, the size of the feeding circuit using Rotman lens is large. Therefore, beam-scanning microstrip antenna in multi-layer configuration is in the development of this work. Rotman lens was developed at 76.5 GHz for the feeding circuit of the antenna. The simulated and measured performances are presented in this paper.

2. Configuration of Proposed Module with Rotman Lens

Rotman lens is often located on the same layer with array antennas connected directly by microstrip lines. The size of the module becomes large because of the bulky Rotman lens. Therefore, in the proposed module, Rotman lens is configured at the back of the microstrip comb-line antenna [4] with common ground plate between them, as shown in Fig. 1. Thus, multi-layer structure is an elegant approach for size reduction of beam-scanning microstrip antenna. This separates the antenna array from the lens by the ground plate with connecting waveguides through microstrip-to-waveguide transitions [5].

The BFN consists of input ports, lens body, output ports and transmission lines. Lens body is composed of the parallel plate waveguide. The input and output ports are connected to microstrip lines through taper structure, printed on a dielectric substrate with a back ground plate. All the microstrip lines from the input and output ports are connected to microstrip-to-waveguide transitions. The dielectric material of the substrate is Fluorocarbon resin film (thickness t = 0.127, relative dielectric constant ε_r = 2.2 and loss tanδ = 0.001).

The input and output contours of Rotman lens are designed as shown in Fig. 2. The BFN is obtained from the condition that all optical paths from input port1 at the center of the input contour are the same to any points on the output contour. The reflection coefficients of the taper structures are designed to be less than −20 dB at the design frequency 76.5 GHz. To prevent diffused reflection in the lens, the width of taper structure is determined for no gap in between, and dummy ports are also arranged at both side contours. The proposed structure consists of five input ports from in1 to in5, seven output ports from out1 to out7 and ten dummy ports from d1 to d8. Focal length F = 18 mm, the largest scan angle α = 30° and radius of input contour R = 10.78 mm.

3. Simulated and Measured Performance

Rotman lens with five input ports and seven output ports is designed and performance is evaluated by simulation. The reflection characteristic is shown in Fig. 3. Simulated frequency dependency for output phase differences of out1, out2, and out3 from out4 is shown in Fig. 4. The maximum reflection coefficient is −13.5 dB in 20 GHz bandwidth centered at the design frequency 76.5 GHz. The bandwidth of reflection less than −15 dB is 14.7 GHz from 71.8 to 86.5 GHz. When power input from port in1, large output phase deviations 40° and 19° are observed only at 66.5 GHz and 71 GHz in 20 GHz bandwidth, respectively. Input power transmits almost in-phase to all output ports over broad frequency bandwidth. Figure 5 is array factors calculated from the simulated output amplitude and phase at the design frequency 76.5GHz. In the calculation of array factor, the BFN generates five beams to −32.1°, −16.4°, 0°, 16.4° and 32.1°. Largest scanning angle input from port out3 is 32.1°. Figure 6 is array factors at 83.5 GHz. 2.4 dB gain reduction is observed in the beam fed from ports in3 and in5, which could be caused by the effect of grating lobes. However, almost similar beam-scanning performance is obtained even in 7 GHz away from the design frequency 76.5 GHz. Therefore, the broadband beam-scanning performance is confirmed.

Rotman lens is fabricated to verify the reliability, as shown in Fig. 7. All microstrip lines are connected to vector network analyzer via microstrip-to-waveguide transitions. Therefore, all performances include the characteristics of the transitions. The measured reflection characteristic is shown in Fig. 8. Figure 9 is array factors calculated from the measured output amplitude and phase to the output ports at the design frequency. Largest reflection is −14.0 dB at the design frequency, and is larger than calculated reflection coefficients. This is due to the effect of the microstrip-to-waveguide transition. In the case of the input from the wide angle of port in3, the large reflection in higher than 80 GHz is caused by reflection from the dummy ports. However, beam-scanning performance with the direction of −32.9°, −15.2° and 2.7° is obtained by measurement of Rotman lens BFN.

4. Conclusion

To realize size reduction of Rotman lens feeding beam-scanning microstrip antenna, we proposed the multi-layer module. In the proposed module, Rotman lens BFN is configured at the back of the microstrip comb-line antenna with common ground plate between them. Rotman lens was developed at 76.5 GHz for the feeding circuit of the antenna. This structure consists of five input ports, seven output ports. The largest scan angle of the array factor calculated from the measured output data was α = 32°. The simulated and measured beam directions agree with the design.

References

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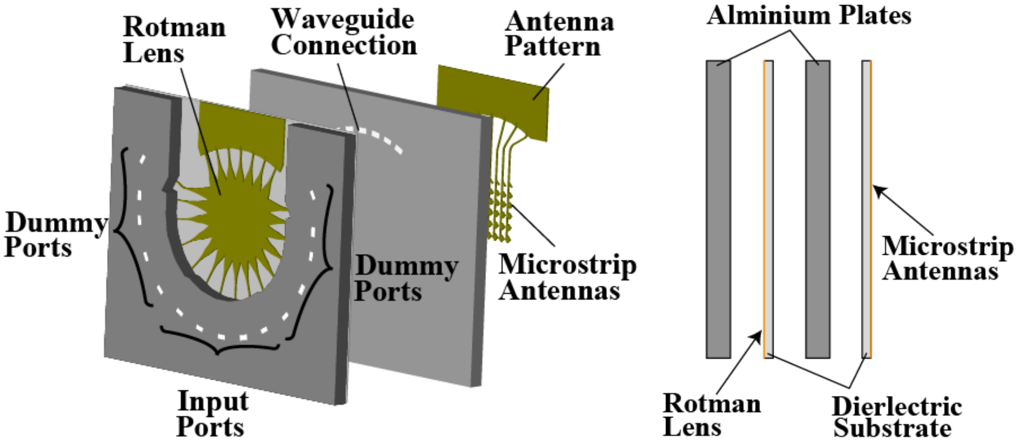

Fig. 1 Proposed Rotman-lens antenna module

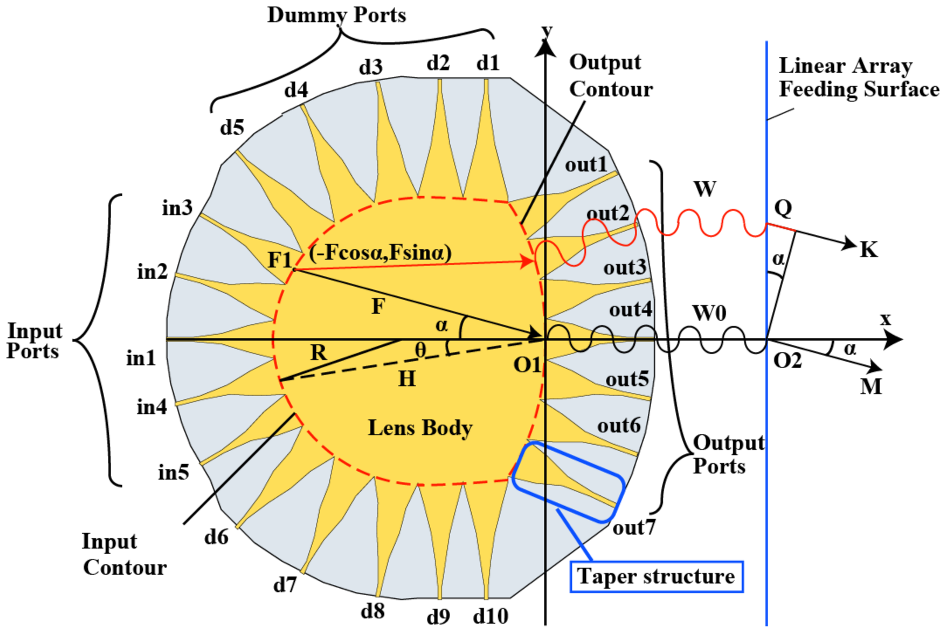

Fig. 2 Schematic view of the proposed Rotman lens

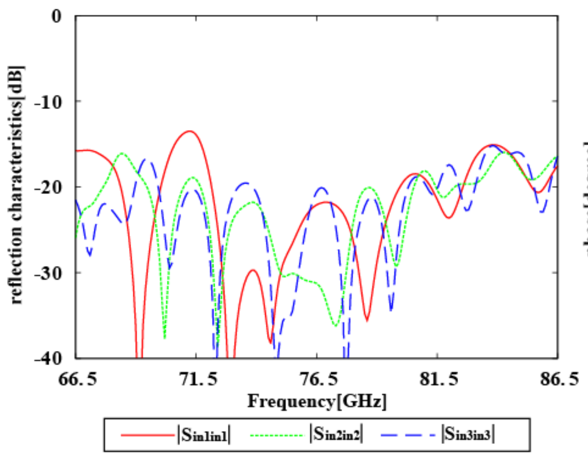

Fig. 3 Simulated reflection characteristics

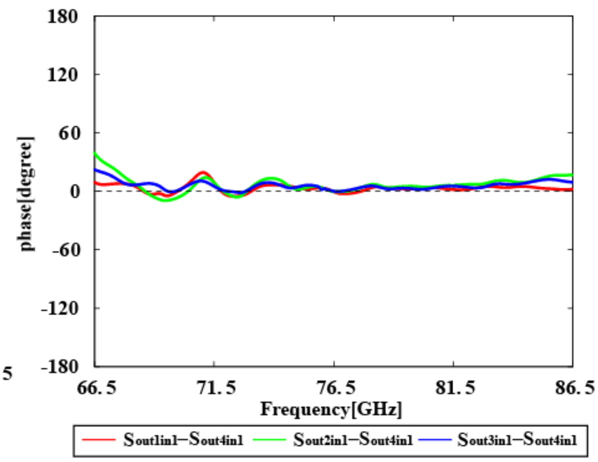

Fig. 4 Simulated frequency dependency for output phase differences of port out1, out2, out3 from out4

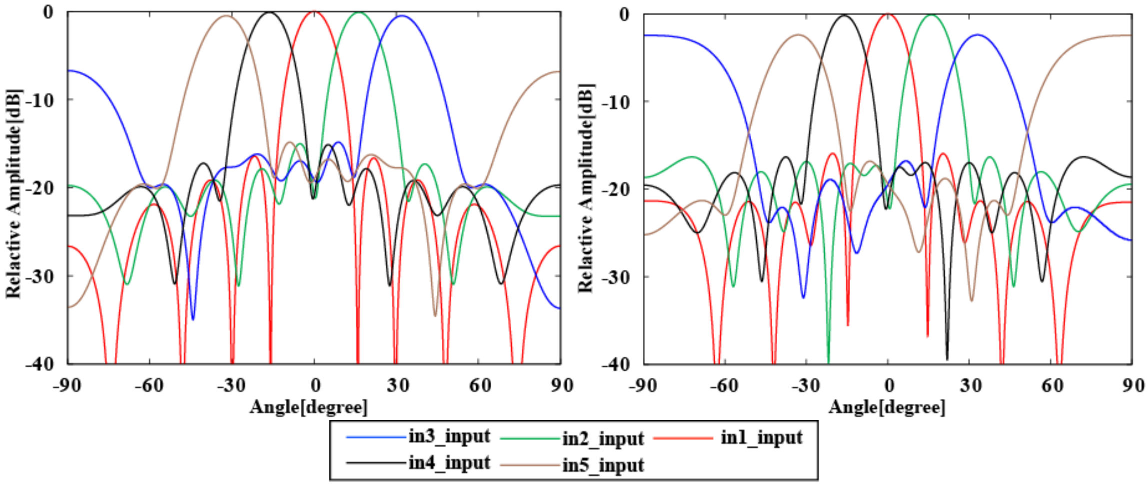

Fig. 5 Array factors at design frequency 76.5 GHz

Fig. 6 Array factors at 83.5GHz

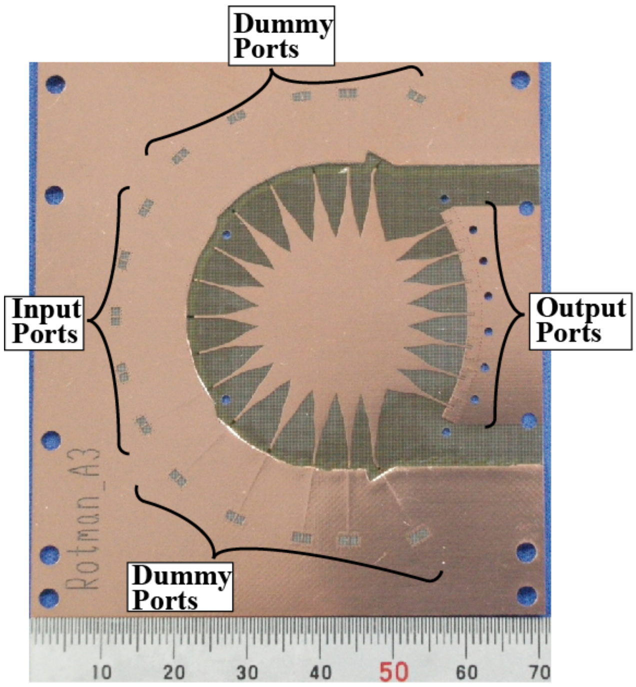

Fig. 7 Fabricated Rotman lens

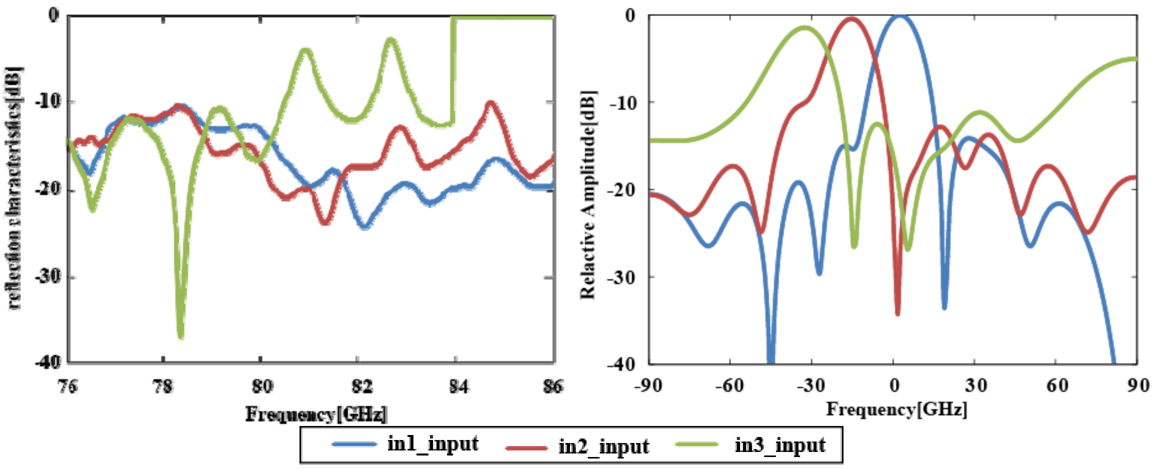

Fig. 8 Measured reflection characteristics

Fig. 9 Measured array factors at 76.5 GHz