Research Article

A Multibeam Antenna Array Based on Printed Rotman Lens

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A compact printable multibeam antenna array is studied in this paper. The antenna system is composed of a printed Rotman lens and an antipodal dual elliptically tapered slot antenna array; both of the two components are studied, respectively, at first, and then integrated on a single printed circuit board to make up the integrated unit of the multibeam antenna array. Measured results of all components are presented.

1. Introduction

In modern microwave applications, it is often desired to integrate radar and communication functions such as active/passive target acquisition, combat identification, weapons guidance, secure point-to-point communications, and active protection into a single complete system [1, 2]. Antennas capable of supporting multiple simultaneous beams that can be scanned over a wide range are capable of this objective.

In this paper we will study a complete integrated unit that consists of a Rotman lens and a tapered slot antenna (TSA) array for generating multiple beams, and all these structures are integrated on a printed circuit board (PCB).

As we know, the Rotman lens has the advantages of being low-cost, wide band, and simple to fabricate and has been proven to be a useful beamformer for generating multiple beams. Many kinds of Rotman lens have been studied in the past decades, including parallel-plate Rotman lens [3], printed Rotman lens [4–6], graded dielectric substrate Rotman lens [7], and SIW Rotman lens [8]. The most useful lens equations for designing Rotman lenses were initially derived by Rotman and Turner [3], then modified and refined by Katagi et al. [9] and Hansen [10].

The tapered slot antenna (TSA) is also simple to fabricate, of low-cost, and wide-band component. The tapered slot antenna (TSA), which was introduced by Gibson [11] in 1979, is a wide band antenna component and has been used widely in microwave engineering. In [12], three TSA elements with different shapes of the taper including the linearly tapered slot

antenna (LTSA), the constant width slot antenna (CWSA), and the Vivaldi (exponential taper) antenna have been studied by Yngvesson and others. Gazit has improved the design of the Vivaldi antenna [13] and presented the design method of the antipodal Vivaldi antenna, which has low input resistance and is easy to be matched to the microstrip feed lines. In this paper the antipodal dual elliptically (ADE) TSA [14] is selected to complete the design, because the ADE-TSA has an antenna characteristic similar to that of the antipodal Vivaldi antenna and is easy to be modeled in the existing simulation software such as HFSS.

2. Design of the Printed Rotman Lens

Design parameters of a printed Rotman lens is shown in Figure 1; Σ_1 and Σ_2 are curves where the beam ports and array ports are arranged, respectively, and the Rotman lens region enclosed by curve Σ_1 and curve Σ_2 is usually printed thin copper layer on the dielectric substrate.

The contour Σ_1 is circular arc and the coordinates of the points on contour Σ_2 are defined by the follow formula [3, 9]:

$$\begin{aligned} x &= \frac{-1}{g - a_0} \left((g - 1)w + 0.5b_1^2\eta^2 \right), \\ y &= \frac{b_1}{b_0}\eta(1 - w), \end{aligned} \quad (1)$$

where $w = \sqrt{\epsilon_{\text{eff}}/\epsilon_r}(W - W_0)/F$ and $W, W_0, f, \eta, g, b_1, a_0$ and b_0 have the same meaning as that in [3, 9].

FIGURE 3: Power distribution at array ports.

FIGURE 4: Geometry of the ADE-TSA.

parameters: w : arm width of the radiator, l : arm length of the radiator, equations of ellipse 1 and ellipse 2.

When arranged in an array, the array element is confined in a space with width of d (see Figure 6) to avoid grating lobes and save space. In our design, the value of d is needed to be 11 mm or less to match the Rotman lens designed at Ku-band, so for a conventional design, the width w of both of the radiator arms is 5.5 mm, yet it is difficult to obtain a good design with satisfactory standing wave ratio by this arm size. We extended the width w to 6.5 mm; thus the arm of the element 3 on the top of the PCB is partially cascaded with the arm of element 2 on the bottom of the PCB as shown in Figure 6. However, the two arms which make up the partially cascaded area do not touch each other, because they are located at opposite surfaces of the PCB.

An ADE-TSA array is designed according to the construction shown in Figure 6 and then fabricated, where $w = 6.5$ mm, $l = 10.25$ mm, $d = 11$ mm, and the equations of ellipse 1 and ellipse 2 are

$$\begin{aligned} \text{Ellipse 1: } \frac{x^2}{4.755^2} + \frac{y^2}{5.706^2} &= 1, \\ \text{Ellipse 2: } \frac{x^2}{15.196^2} + \frac{y^2}{7.294^2} &= 1. \end{aligned} \quad (2)$$

The ADE-TSA array with 8 elements is fabricated on a PCB (Rogers RT/duroid 5880, thickness is 0.508 mm) and assembled in a metal cavity as shown in Figure 7. VSWR values of the ADE-TSA elements are measured and given in

FIGURE 5: Construction of the ADE-TSA.

FIGURE 6: ADE-TSA array.

FIGURE 8: Measured VSWR of the ADE-TSA.

FIGURE 7: The ADE-TSA array with 8 elements.

Figure 8, and it shows that most VSWR values of all the ports are less than 2 from 13.5 GHz to 18 GHz, which is satisfactory.

4. Fabrication and Experiment of the Integrated Unit

Because both of the Rotman lens and the ADE-TSA obtained in Sections 2 and 3 have microstrip line ports of the same size, they can be designed on a single PCB and connected seamlessly. An integrated unit made up of a printed Rotman lens and an antenna array of eight ADE-TSA elements is designed and fabricated on a Rogers RT/duroid 5880 PCB (thickness is 0.508 mm); then the integrated unit is assembled in a metal cavity for measuring as shown in Figure 9. During the measurement all the unused beams are terminated with 50Ω loads. The isolation results between several ports are measured from 12 GHz to 18 GHz and shown in Figure 10. Most of the isolation values (dB) fall in an interval from -15 dB to -20 dB, comparable to that in [15, 16]. The voltage standing wave ratios (VSWR) of the beams ports are also measured and shown in Figure 11. It can be seen that the

FIGURE 9: The integrated unit.

FIGURE 10: Isolation of the Rotman lens beam ports.

VSWR values of all the beam ports are below 1.8 in the whole frequency band, which is satisfactory in most engineering applications. The radiation pattern of the integrated unit is also measured at 15 GHz and is shown in Figure 12. The seven beams corresponding to the radiation/receiving beams when incident at beam ports 1~7, respectively, it is clear that the integrated unit can generate satisfactory multiple beams.

5. Conclusion

In this paper, a printed Rotman lens and an ADE-TSA array are studied at first; on the basis of this study, an integrated unit composed of the Rotman lens and the ADE-TSA array is designed on a single PCB and fabricated. Because both of the Rotman lens and the ADE-TSA have microstrip line ports

FIGURE 11: Reflection characteristics of Rotman lens beam ports.

FIGURE 12: Multibeam pattern of the integrated unit at 15 GHz.

of the same size, they are connected seamlessly. Measured results are presented, which show that the integrated unit has good port and multiple beam characteristics. The integrated unit is a good candidate for multibeam antennas, because it is easy to fabricate, of low cost, and compact.

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