A Compact Microstrip Rotman Lens Design

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***Abstract*—Rotman lenses have long served as analog beam forming networks (BFNs) to support linear scanning arrays. However, most lens designs have large electrical size which limits their uses in compact transceiver systems. In this paper, we aim to design a compact lens structure by folding the lens into two layers, and using coupling slots as transition. The proposed designed structure will reduce the overall dimensions of the conventional Rotman lens by 50%.**

***Index Terms*— Beam forming networks (BFNs), Rotman lens, star-shaped coupling.**

I. INTRODUCTION

ROTMAN lens, which was invented by Rotman and Turner in 1962, is an analog beam former that creates a specific phase taper at its output ports to feed an array antenna. Based on the input parameters (such as the scanning angle (φ), the focal angle (α), number of input and output ports; the lens equations can be solved to determine its receive contour, delay lines (w_i) and the focal arc to generate a desired phase taper [1]. In the past few decades, numerous Rotman lens designs have been developed [2-5]. However, these designs are based on single-layer structures that tend to be electrically large. There have been solutions in the literature to reduce the dimensions of the lens structure using multi-layers with substrate integrated waveguide (SIW) technology [6]. However, the design of these lenses involve complicated steps for integration with waveguides, which makes the fabrication process difficult and expensive. Ref. [7] proposes the idea of folding the conventional lens along its middle and using rectangular via holes as coupling elements. However, there are only few preliminary results provided in LTCC technology at higher frequency than what was demonstrated at 5 GHz. Another simpler approach is to use a circular transition to connect the two halves of the folded lens [8], which is appropriate when the lens needs to conform to a surface. In this paper, we design a folded Rotman lens by folding the lens along a given plane and using rectangular coupling slots with optimized parameters to maximize the received power at the lens output ports. The lens is designed at 28 GHz, and we employ the commercial software package FEKO to study the performance characteristics.

The remainder of the paper is organized as follows. Section II discusses the design and optimization of the rectangular coupling slots, the proposed lens system and simulation results, followed by the conclusions in Section III.

II. COMPACT LENS DESIGN PROCEDURE AND SIMULATION RESULTS

The design parameters for the conventional Rotman lens, which will be folded, are specified in Table 1. After the conventional lens is designed, the folded lens is modeled by cutting it along the mid-line, and coupling slots are created in the common ground plane as a transition. Fig. 1 shows the overall design of the proposed folded lens.

Table 1. Design parameters of Rotman lens

Design parameters	Values
Center frequency (f_0)	28 GHz
Dielectric constant (ε_r)	2.2
Substrate Thickness (h)	0.508 mm
On axis focal length (G)	3.6 cm
Off axis focal length (F)	3.15 cm
Num. of input/output	7 inputs / 10 outputs
Scanning range	-30° to 30°

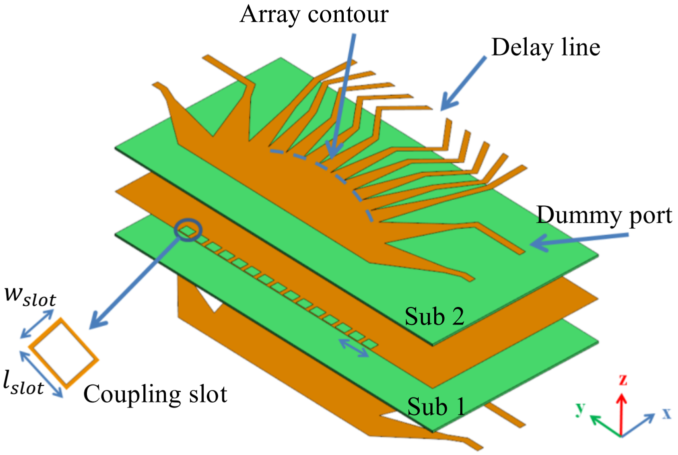

Figure 1. Compact folded lens system

The coupling slots are used to couple the incident TEM wave from input ports in substrate 1 to output ports in substrate 2.

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They are placed along the folded line and proper design values of w_{slot}, l_{slot} will increase the power received at output ports of the lens. The efficiency of the power transfer between the two substrate are then optimized. In order to significantly reduce the computational time, the optimization is implemented on a simplified model composed by two waveguides coupled by one coupling slot [7]. Fig. 2 shows the reflection coefficient of the TEM/TEM transition with optimized rectangular slot using simplified model as discussed above.

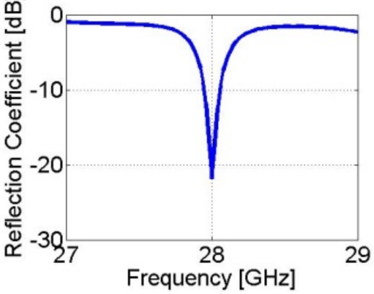

Figure 2. Reflection coefficient at beam port #4 of the folded lens with slots dimensions $w_{slot} = 2.1\ mm$, $l_{slot} = 2.7\ mm$

The magnitude and phase performances of beam ports 1, 2, 3, and 4 are shown in Fig. 3 and Fig. 4, respectively. Due to the symmetrical structure of the lens, the performance of beam ports 5, 6, and 7 are expected to be identical to the performance of beam ports 3, 2, and 1, respectively. The performance of the planar conventional lens at the center frequency (i.e. 28 GHz) with identical design parameters is also plotted for comparison. Fig. 5 shows the radiation pattern of the linear array on the planar structure fed by the output ports of the folded lens with 15 dB gain and -4 dB SLL.

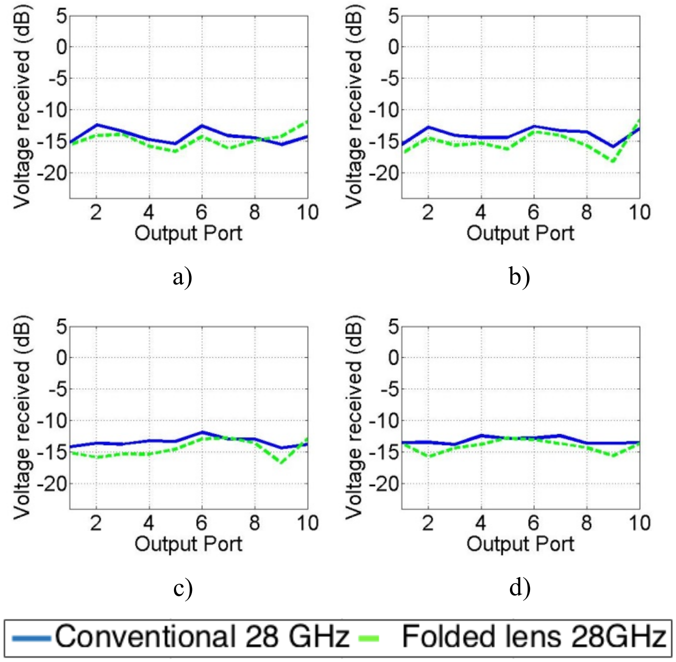

Figure 3. Magnitude performance of the folded lens for active a) Port 1, b) Port 2, c) Port 3, d) Port 4

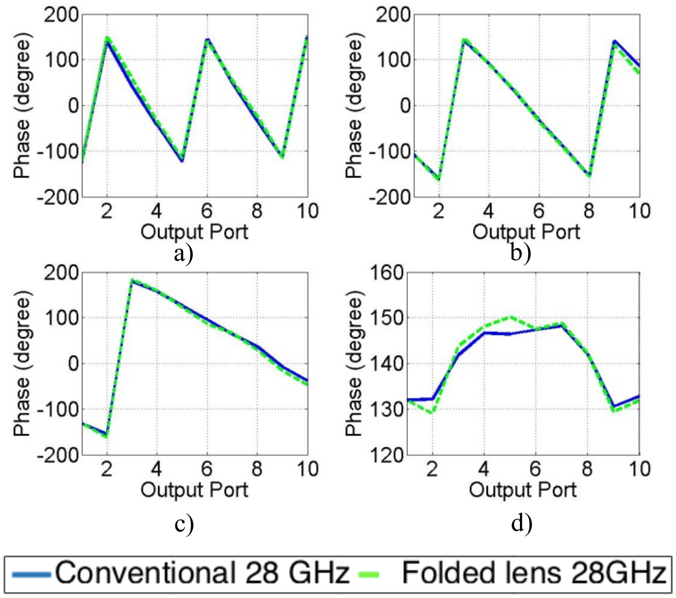

Figure 4. Phase performance of the folded lens for active a) Port 1, b) Port 2, c) Port 3, d) Port 4

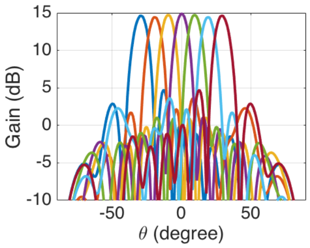

Figure 5. Radiation pattern of the linear array

III. CONCLUSION

In this work, we design and investigate the performance of a dual-layered Rotman lens structure using rectangular coupling slots as transition to allow efficient power transfer from beam ports to output ports residing on two different layers of the lens. The folding design reduces the overall dimensions of the lens by 50% without significantly affecting the performance.

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