Ka-band Compact Phase Shifter Based on Multi-Step and Flip Symmetric Structures

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***Abstract*—This paper introduces a compact waveguide differential phase shifter using flip-symmetric design for precise phase adjustments. Operating from 0 to 90 degrees in the Ka-band, the waveguide length is L=1λ, enhancing performance and size efficiency.**

Keywords—Ka-band, differential phase shifter, waveguide, beamforming network,

I. INTRODUCTION

Beamforming technology is crucial for the functionality of multi-beam antennas, enabling the creation of electromagnetic beams directed in various paths. This technique allows multi-beam antennas to generate multiple output signals with distinct phases, facilitating simultaneous signal transmission or reception in multiple directions. To execute this intricate technique, beamforming networks are utilized, and within these networks, phase shifters play a critical role. These phase shifters adjust the precise phase difference between two points to ensure optimal beam control and maximize radio communication performance. They are valuable in satellite communication, wireless networks, and other technologies that require precise signal control, making them indispensable tools in modern communication.

Throughout different periods, a spectrum of strategies have been devised to create a divergence in phase shift within a circuit. A novel E-plane stub-loaded rectangular waveguide phase shifter with wide bandwidth and low insertion loss has been developed. This design takes into account higher order mode interaction, resulting in compact structures suitable for integrated components.[2] And using glide symmetry in waveguide setups gives us a new way to control phase changes.[3] But there are also limits and downsides to this method. Adding glide symmetry to the setup makes things more complex during designing and making it. We have to put metal pins in just the right spots inside the waveguide, and that can make manufacturing harder. These problems are important to think about when we decide how useful and good this technology is. In addition, a phase shifter using multi-step ridge sections and width steps in the transition line has been introduced to reduce the size of waveguide systems.[4] However, it faces the drawback of increased design complexity due to the intricate nature of multi-step ridge sections.

This study presents an innovative approach that capitalizes on the utilization of multi-step structures to effectively reduce the size of components that are not essential. Furthermore, it integrates the concept of flip symmetry, a fundamental principle in geometry, to further enhance the reduction in the length dimensions of phase shifters that are built upon multi-step configurations.

II. PRAMETRIC ANALYSIS AND SIMULATED RESULTS

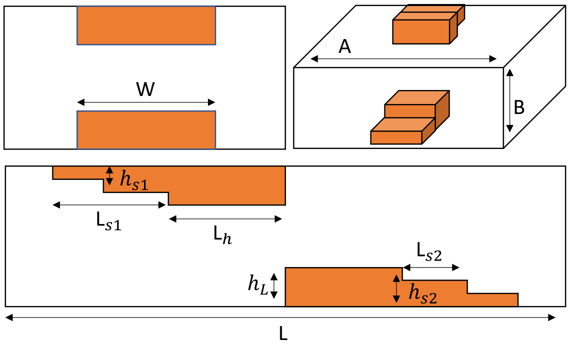
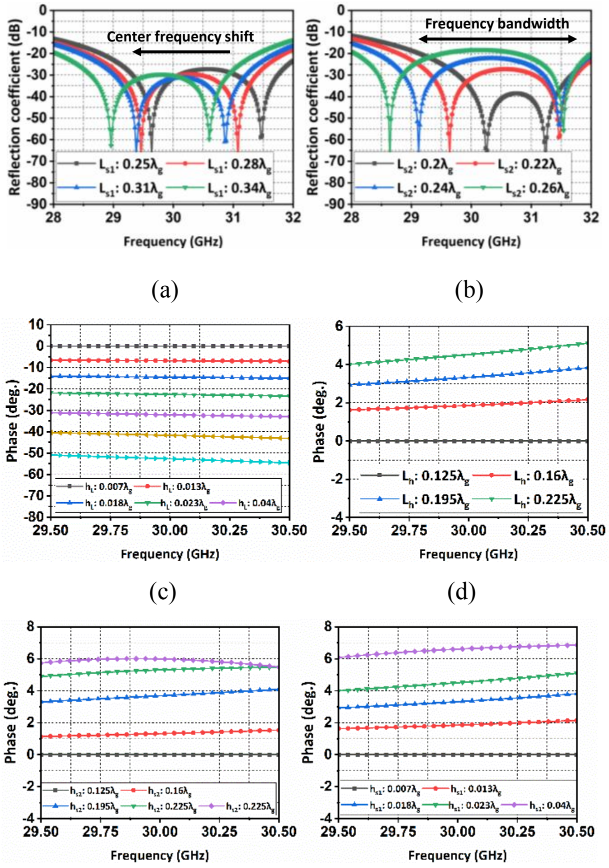


Fig. 1. Proposed waveguide configuration of the multi-setep PS

Figure 1 provides a visual representation of the proposed waveguide differential phase shifter's structure. Inside the waveguide, a multi-step step shape is skillfully inserted using flip-symmetry. This innovative design allows for precise adjustments in impedance matching and phase differences, tailored to the height and length of the multi-step step. Additionally, the implementation of the flip-symmetric technique not only ensures efficient functionality but also contributes to reducing the overall size of the waveguide PS.

To elaborate further, the simulation process adhered to the WR-35 waveguide standard, ensuring consistency and reliability. Through optimization, the waveguide dimensions were fine-tuned to specific values: A = 8.64mm, B = 4.32mm, and W=B, while L was set at 1λg. This strategic sizing enhances the waveguide's performance and compatibility within the desired frequency range.

Overall, the comprehensive approach of combining flip-symmetric insertion and meticulous parameter adjustments yields a versatile and compact waveguide differential phase shifter, exemplifying the synergy between innovative design and rigorous simulation.



(a) (b)

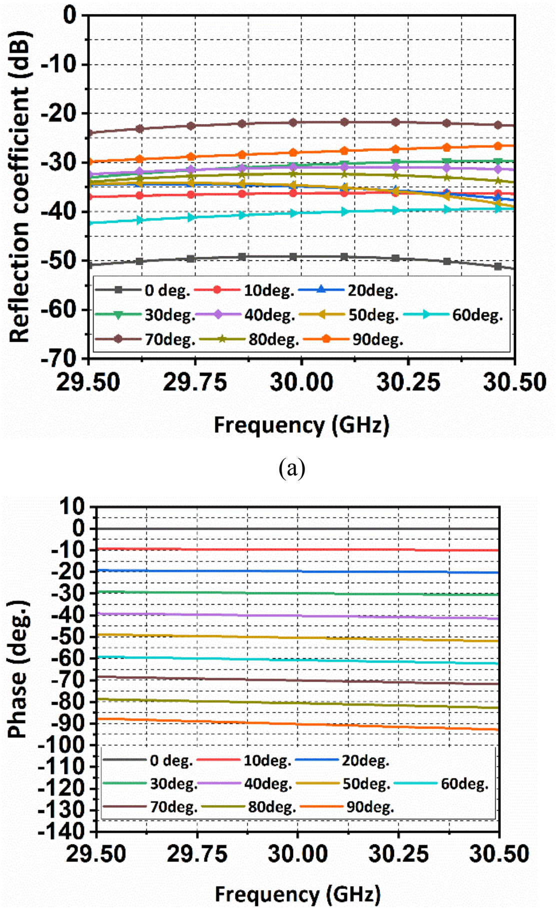
(c) (d)

(e) (f)

Fig. 2. Parametric variation of reflection coefficient and phase
reflection coefficient: (a) LS1, (b) LS2
phase: (c) HL, (d) LH (e) HS1 (f) HS2

Figure 2 illustrates the reflection coefficient patterns and alterations in phase for individual parameters. Figure 2(a) displays the reflection coefficient trends corresponding to the length adjustments of LS1. As LS1's length increases, the center frequency shifts towards the left. In Figure 2(b), the reflection coefficient trends relate to the variations in LS2's length. It's evident that an extended LS2 length leads to a wider bandwidth. As a result, these specific parameters have an impact on establishing the central frequency and ensuring impedance alignment within the waveguide

The graphs (c), (d), (e), and (f) in Figure 2 all represent normalized values based on the smallest parameter value in the plot. The graph (c) show the phase difference according to the hl size. Notably, HL has the most influence on the phase difference. However, a distinct slope becomes apparent at relatively large phase differences. This slope results from changes in the beta value as the inner waveguide length changes. Instead, by making changes to LH, HS1, and HS2 values, we can minimize the gap in the slope. The graphs (D), (e), and (F) show how the phase slope changes for each parameter value.



(a)

(b)

Fig. 3. Simulated results of proposed wavugudie multi-step PS
(a) reflection coefficieint, (b) phase

Figure 3 represents the simulation results for the phase and reflection coefficient of proposed waveguide multi-step PS. A range of distinct PS configurations, varying phase delays from 0 to 90 degrees in increments of 10 degrees, were devised within the frequency band of 29.5 to 30.5 GHz. Another important point is that all PS variations consistently show a reflection coefficient of less than 20 dB while the phase errors vary from ±0.2° for the 20-degree phase to ±2.7° for the 90-degree phase.

TABLE I. DIMENSIONS OF PROPOSDED WAVEGUIDE PS OF DEGREES (UNITS IN λ_g @30GHZ, ROUNDED TO THREE DECIMAL PLACES)

Δ_Φ	*0°*	*10°*	*20°*	*30°*	*40°*	*50°*	*60°*	*70°*	*80°*	*90°*
h_L	0.06	0.07	0.08	0.08	0.09	0.09	0.1	0.1	0.11	0.12
h_{s1}	0.19	0.19	0.19	0.19	0.19	0.15	0.01	0.02	0.03	0.01
h_{s2}	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.03	0.03	0.02
L_h	0.26	0.24	0.25	0.23	0.23	0.22	0.22	0.23	0.24	0.18
L_{s1}	0.24	0.24	0.25	0.25	0.25	0.25	0.25	0.27	0.27	0.23
L_{s2}	0.21	0.24	0.24	0.22	0.22	0.25	0.25	0.25	0.25	0.25

Table 1 presents the specifications for the proposed waveguide PS. It provides values for each parameter of the multi-step design, ranging from 0 degrees to 90 degrees.

III. CONCLUSION

This paper introduces a small-sized waveguide differential phase shifter through a flip-symmetric design using fewer multi-step structures The proposed approach allows precise phase adjustments based on step height and length, while optimizing the waveguide dimensions for efficient performance. The flip-symmetric technique enhances functionality and reduces size, ensuring compatibility within the desired frequency range. The synergy of innovative design and simulation results in a versatile and compact waveguide phase shifter. The proposed waveguide phase shifter operates from 0 to 90 degrees in the Ka-band (29.5 – 30.5 GHz). It works throughout this range, and the total waveguide length is adjusted to L=1λ

ACKNOWLEDGMENT

This work was supported by a grant from the Institute of Information & Communications Technology Planning & Evaluation (IITP), funded by the Korean government (MSIT, KCG, ME) (No. 2021-0- 01715, Development of Communication Payload for GEO Public Complex Communications Satellite)

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