Phase Shifter for Millimeter-Wave Frequency Range Based on Glide Symmetric Structures

Angel Palomares-Caballero[1], Antonio Alex-Amor[1], Juan Valenzuela-Valdes[2], Francisco Luna[1] and Pablo Padilla[2]
[1]Department of Computer Science and Programming Languages, University of Malaga, Malaga, Spain
[2]Dept. of Signal Theory, Telematics and Communications, University of Granada-CITIC, Granada, Spain, pablopadilla@ugr.es

***Abstract*—The use of glide symmetry in radiofrequency devices to introduce dispersive effects has been recently proposed and demonstrated. One of these effects is to control the propagation constant of the structure. Here, we propose a mm-wave phase shifter whose elements have a glide-symmetric configuration to achieve a greater phase shift in the same waveguide space than the non-glide-symmetric case. The glide-symmetric phase shifter is implemented in waveguide technology and is formed by rows of metallic pins that produce the desired phase shift. To assess the better performance of the glide-symmetric phase shifter, it is compared to its non-glide-symmetric version whose metallic pins are located only in one of the broad sides of the waveguide. The operating frequency range of the phase shifter is 67 to 75 GHz. Results show a 180 degree phase shift in regard to the reference waveguide without pins, and 50 degrees more than the non-glide-symmetric version.**

***Index Terms*—phase shifter, glide symmetry, mm-waves, waveguide**

I. Introduction

Pattern beamforming has become a topic of great interest because of its benefits for more complex transmission systems such as multibeam antennas [1]-[4]. Multibeam antennas use beamforming feeding networks to produce several output signals with different phases among them. One of the appealing frequency ranges is the millimeter-wave range (mm-wave). Some future beamforming networks will be in these frequencies. In such way, the phase shifter component is a fundamental part of beamforming networks which contributes with a phase shift among the different paths of the beamforming network. Thus, there is a clear necessity in the design of millimeter-wave phase shifter to implement them into beamforming networks.

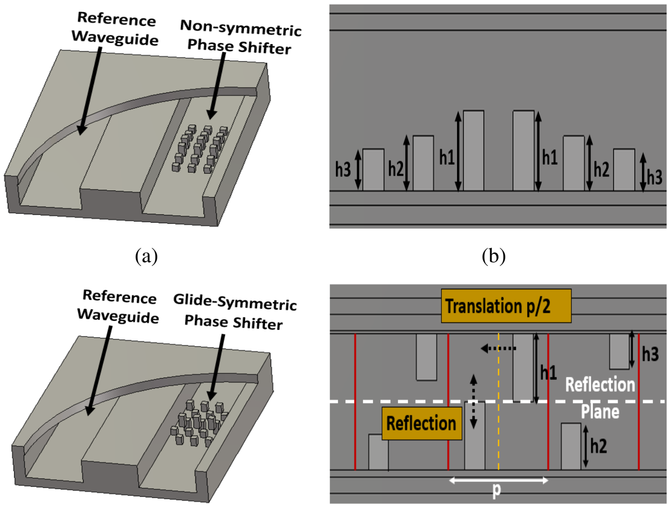
At the present time, there are a variety of phase shifter designs in different waveguide technologies. In the case of substrate integrated waveguide (SIW) technology, there exist some designs for achieving phase shift in the output signal by stretching the broad side of the waveguide [5], [6] or by implementing air holes in the upper metallic layer [7]. The dielectric substrate present in the SIW introduces higher loss levels compared to conventional waveguide technology, which is a drawback at mm-Wave frequencies. Aditionally, none of these designs make use of active elements to produce the phase shift. Another kind of waveguide phase shifter designs are the ones implemented in hollow waveguide, as the one in [8]. This design uses a thin dielectric slab in the middle of the waveguide to achieve the signal phase shift. As mentioned, the use of dielectric material may be unsuitable in mm-wave frequency ranges. In [9], a phase shifter in rectangular waveguide is presented. It is based on locating unequal small corrugations at the upper and lower sides of the waveguide. The main drawback of the latter design is the complex and accurate manufacturing process needed. One attractive phase shifter design in hollow waveguide is the one in [10]. This phase shifter, implemented in groove gap waveguide, utilizes metallic pins at one of the broad sides of the waveguide to obtain the desired phase shift. By adjusting the height of the metallic pin rows, it can be obtained a high frequency phase shifter with a good level of matching and stable phase shift along its operating frequency range. In this work, the design in [10] has been considered as the initial reference for our phase shifter design.

The phase shifter presented in this paper is based on glide-symmetric periodicity. Glide-symmetric periodic structures are based on the existence of two mirrored periodic layers that are shifted half of the unit cell in the periodicity axis [11], [12]. In such way, our design is based on the use of metallic pins placed in a glide-symmetric geometry. These metallic pins in such configuration introduce a higher value of field phase shift, compared to the same non-glide-symmetric metallic pin configuration. In Fig. 1, it is shown two phase shifter designs based on metallic pins and their transversal cut view. The phase shifter design presented in [10] is illustrated in Fig. 1(a), whereas the phase shifter design proposed in this paper corresponds to Fig. 1(c). For both of them, there is a reference conventional waveguide for phase shift comparison.

This document is organized as follows. In section II, it is presented the unitary glide-symmetric cell for both pin-based phase shifters. After that, in section III the simulation results of both structures are provided and discussed. Finally, the conclusions are drawn in section IV.

II. Glide symmetric pin-based unitary cell design

Recent studies of higher symmetries in electromagnetic structures and devices [13] have demonstrated the existence of useful dispersive effects. These effects are related either to field guiding or stopping properties, such as the introduction of a stopband in a frequency range [12], [14], [15] or controlling the behavior of the propagating modes [16]-[18]. All these



(a) (b)

(c) (d)

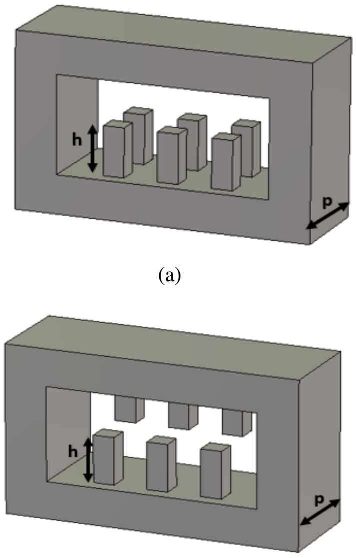
Fig. 1. Waveguide phase shifters: (a) Non-glide-symmetric design and (b) its transversal cut view; (c) proposed glide-symmetric phase shifter design and (d) its transversal cut view. The dimensions are: h1 = 0.635 mm, h2 = 0.435 mm, h3 = 0.335 mm .

effects can be studied through the irreducible Brillouin zone. In the proposed phase shifter design, the metallic pins (Fig. 1(d)) introduce a wider phase shift than the implementation without glide symmetry in the pin-based structure. The dispersion effect added with the glide-symmetric pin configuration is to increase the value of the propagation constant of the first mode. In order to check this dispersion effect, two pin-based waveguide cells are designed and simulated in *CST Microwave Studio*. They correspond to each type of phase shifter, the non-glide-symmetric phase shifter and the glide-symmetric one. The unitary periodic cells of both of them are shown in Fig. 2.

The period of both unit cells is p and the height of all metallic pins which compose both cells is h. Their dispersion diagrams are illustrated and compared in Fig. 3, for the first mode. The comparison is also done with the conventional WR10 waveguide. The first mode of the glide-symmetric periodic cell is parallel and lower than the non-glide-symmetric periodic cell. The consequence of this fundamental mode drop with the glide-symmetric structure is the achievement of a higher phase shift effect for the same period value.

III. Simulation Results

In this section, a comparison of the two phase shifters formed by the described periodic unit cells is carried out. The designed phase shifters correspond to Fig. 1(a) and 1(c), respectively, and are composed by three periods of the unit cell each one. Both designs have exactly the same metallic pins, in height and in width, with the only difference on the metallic pin location configuration: one with non-glide-symmetric metallic pin configuration (Fig. 1(a)) and the other with glide-symmetric metallic pin configuration (Fig. 1(c)). Both phase shifters have three different pin height values



(a)

(b)

Fig. 2. Unitary periodic cells: (a) Non-symmetric phase shifter cell design, and (b) proposed glide-symmetric phase shifter cell design. The dimensions are: p = 1.2 mm, h = 0.635 mm .

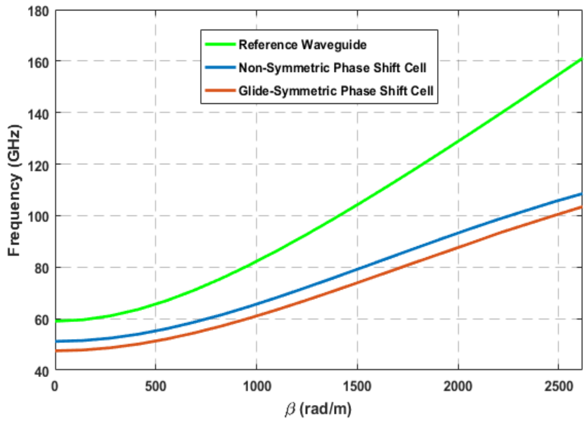


Fig. 3. First mode of the non-glide-symmetric phase shifter cell, the glide-symmetric phase shifter cell and the reference waveguide.

$(h_1, h_2$ and $h_3)$. The reason of the unequal height for each pair of pin rows is to produce proper impedance matching, both at the beginning and at the end of the phase shifter. Also, the pin heights have influence in the phase shift produced.

Taking into account the effects of the pins in the impedance and the phase shift, a 180^o glide-symmetric phase shifter is designed. The equivalent non-symmetric phase shifter is formed by the same pin size than the glide-symmetric phase shifter but without glide configuration, as it can be seen in Fig. 1(b) and 1(d).

Once the phase shifters have been designed, some simulations in comparison with the reference waveguide have been carried out. These simulations evaluate the reflection and transmission coefficients in module and in phase. Figure 4

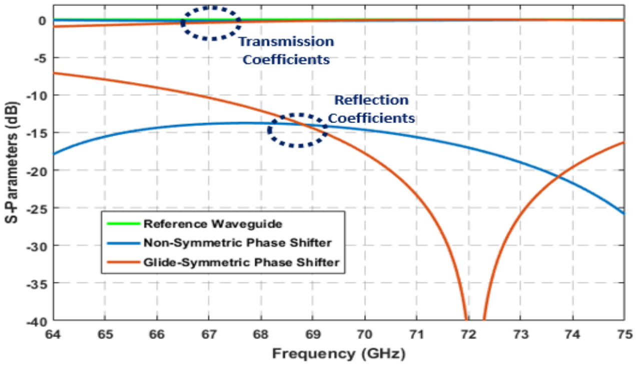


Fig. 4. S-parameter results (amplitude) of the described phase shifters and the reference waveguide.

illustrates the amplitude value of the S_{11} and S_{21}, for both phase shifter designs and for the reference waveguide. Both phase shifters have a reflection coefficient lower than -10 dB and almost 0 dB transmission coefficient in the 67-75 GHz range.

In Figure 5, the phase response and complete phase shift, in regard to the reference waveguide along the frequency range, are plotted. From Fig. 5(a), it can be extracted that both phase shifter designs have a parallel phase behavior compared to the reference waveguide. However, there is a phase response difference of 50^o between both phase shifters. The one providing a more phase shift value is the glide-symmetric case as it is clearly observed in Fig. 5(b).

In order to complete the phase shift evaluation of the proposed glide-symmetric phase shifter, an E-field representation is shown in Fig. 6. The comparison with the E-field propagation in the reference waveguide makes visible the 180^o addition achieved by the glide-symmetric phase shifter.

IV. Conclusion

A novel metallic pin configuration for waveguides, based on glide symmetry, has been presented, and implemented in a waveguide phase shifter. With this configuration applied to the metallic pins of a waveguide phase shifter, it is achieved a larger phase shift in the same waveguide space and with the same metallic pins than in the non-glide-symmetric case. We propose a 180^o glide-symmetric phase shifter in millimeter-wave band, which presents a 50^o increase of phase shift compared to the non-glide configuration. The higher compactness provided by this glide-symmetric configuration can be useful for the future millimeter-wave beamforming networks.

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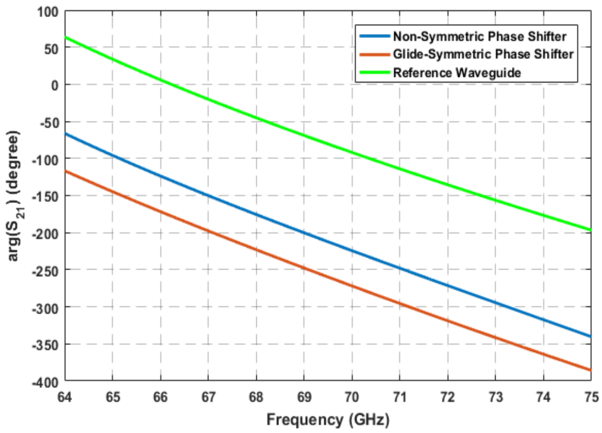
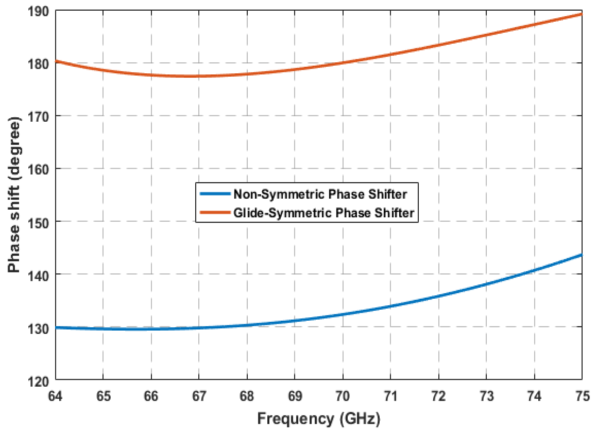


(a)



(b)

Fig. 5. Comparison between complete phase shifter designs: (a) in regard to the reference waveguide, and (b) phase differences of two presented phase shifters.

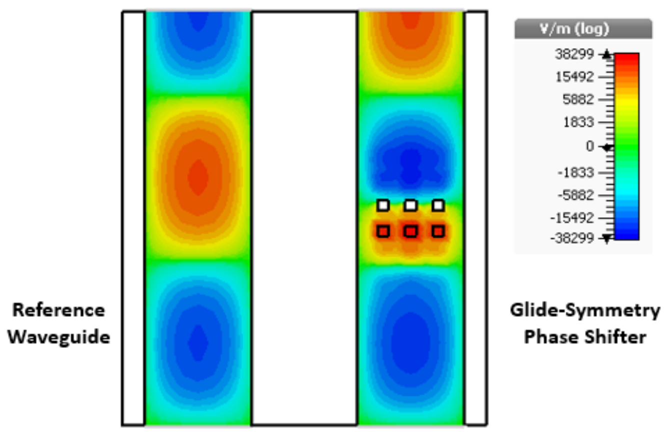


Fig. 6. E-field distribution comparison between the proposed glide-symmetric phase shifter and the reference waveguide.

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