Gap Waveguide With Interleaved Pins for Higher-Frequency Fabrication

Yaxiang Wu, Jiro Hirokawa, and Takashi Tomura

Abstract – A novel gap waveguide with interleaved pins is proposed in this article. The interleaved pins are extended from both the top and the bottom layers in a gap waveguide to enlarge the distance between the pins on the same plate, thus reducing the fabrication challenge and expense for a higher frequency. The dispersion diagram of the proposed unit cell with interlaced pins is investigated and compared to that of the conventional design. A parametric analysis of the dispersion properties of the conventional and proposed unit cells is also performed. To verify the practicability of the proposed unit cell, two parallel ridge and H-plane groove gap waveguides separated by two rows of interlaced pins and traditional pins are simulated and compared. The ridge and groove gap waveguides based on interlaced pins can provide sufficient reflection, transmission, and isolation compared to ridge and groove gap waveguides with conventional pins.

1. Introduction

A waffle-iron structure was originally invented by S. B. Cohn for the waveguide filter in 1940s [1, 2]. Over decades, similar structures, known as periodic metallic pins, have developed in the gap waveguide [3–5]. The gap waveguide based on periodic metallic pins is attractive for millimeter-wave and terahertz-wave circuits for its low-loss transmission. However, the high-precision fabrication of gap waveguides would be difficult and costly if the periodic metallic pins providing electromagnetic bandgap (EBG) were closely spaced and long, especially at a high frequency.

The half-height pins are developed in the ridge gap waveguide for relaxing the fabrication difficulty [6]. Because the half-height pin is just half the length of the full-height pin, it is easy to fabricate by milling. However, it works poorly in groove gap waveguides. Details will be discussed in Section 2. Another effective way to make the manufacturing process easier is to substitute the pins with glide-symmetric holes, which are also a sort of EBG structure [7]. However, the holey structure generally occupies a larger space than the pin structure for comparable operating frequency bands. Therefore, it would be difficult to adopt the holey glide-symmetric structure in a compact gap waveguide design.

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This article presents a novel gap waveguide where interlaced pins are extended from both the top and the bottom plates to maximize the use of space and enlarge the space between the pins in the same plate for reducing the fabrication difficulty. In Section 2, a groove gap waveguide with half-height pins is discussed. Section 3 presents the geometry and dispersion characteristics of the proposed unit cell with interlaced pins. Section 4 investigates the *S*-parameters of two neighboring ridge and H-plane groove gap waveguides with interlaced pins, respectively. The conclusion is given in Section 5.

2. Groove Gap Waveguides With Half-Height Pins

Figure 1 illustrates the two parallel H-plane groove gap waveguides with half-height pins in the 60 GHz band. The blue pins are from the top transparent layer, while the gray pins come from the bottom gray layer; they have the same height h of 0.75 mm and the same width w of 0.3 mm. The upper and bottom layers are separated by a gap g of 0.05 mm about 0.01λ at 60 GHz between the blue and gray pins. The width of waveguide a is 3.3 mm, and the spacing between the centers of adjacent waveguides is 4.2 mm. The *S*-parameters of two parallel H-plane groove gap waveguides with half-height pins in Figure 1 are shown in Figure 2. The cutoff frequency of the waveguide with half-height pins is higher than 50 GHz since the reflection (S_{11}) is serious, and transmission (S_{21}) is only about −10 dB around 50 GHz. Moreover, the crosstalk (S_{41}, S_{21}) becomes bad as frequency decreases. It can be demonstrated that although the H-plane groove

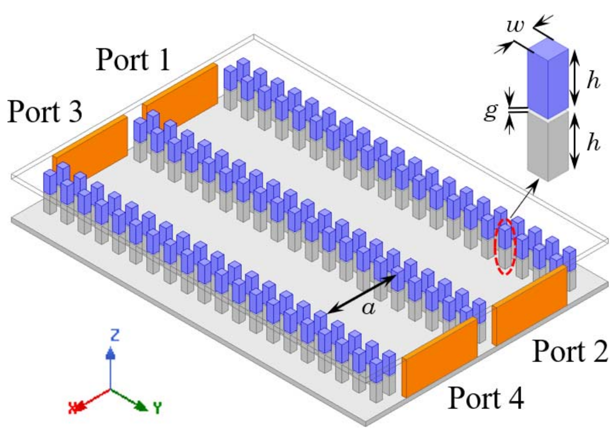

Figure 1. Four-port network based on two parallel H-plane groove gap waveguides with half-height pins.

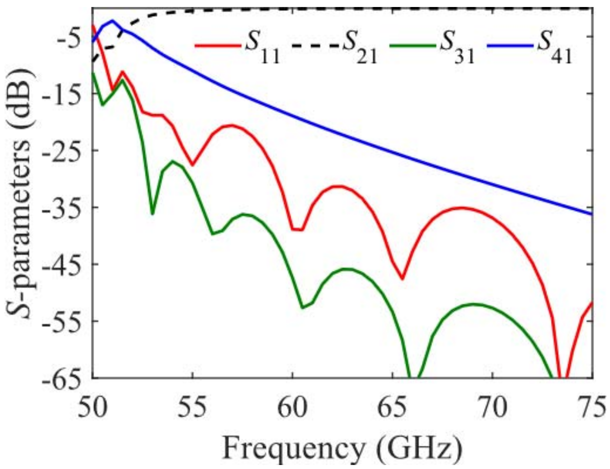

Figure 2. *S*-parameters of the four-port networks based on two parallel H-plane groove gap waveguides with half-height pins.

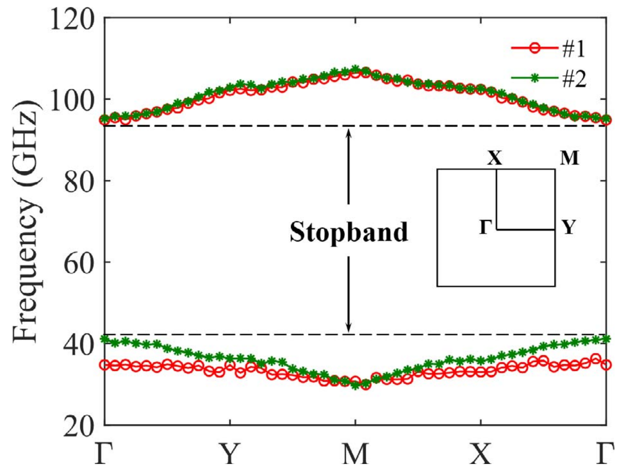

Figure 4. Dispersion diagram of the reference unit cell (#1) and proposed unit cell (#2) with dimensions $w = 0.3$ mm, $h = 1.5$ mm, $g = 0.05$ mm, and $p_x = p_y = 0.8$ mm.

waveguide made of half-height pins can reduce processing difficulty, its cutoff frequency is raised compared to the H-plane groove gap waveguides based on full-height pins with the same parameters in Section 4, indicating that the width of the waveguide must be enlarged in exchange for a lower-pass frequency, which is not advantageous for compact circuit design.

3. Geometry and Dispersion Analysis of the Proposed Unit Cell

The proposed unit cell with interlaced pins and the reference unit cell are shown in top and side perspectives in Figure 3. Each pin in the reference unit cell extends from the bottom gray plate. The smallest distance between the pins is represented by

$$d_1 = \min(p_x - w; p_y - w) \quad (1)$$

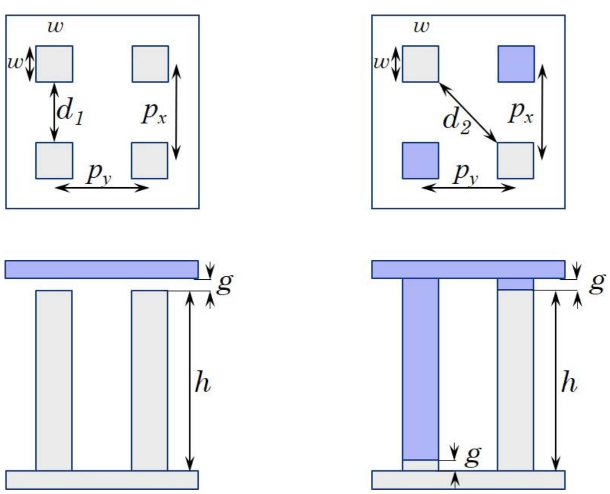

Figure 3. Top view (top) and side view (bottom) of the reference unit cell (#1) and proposed (#2) unit cell with interleaved pins.

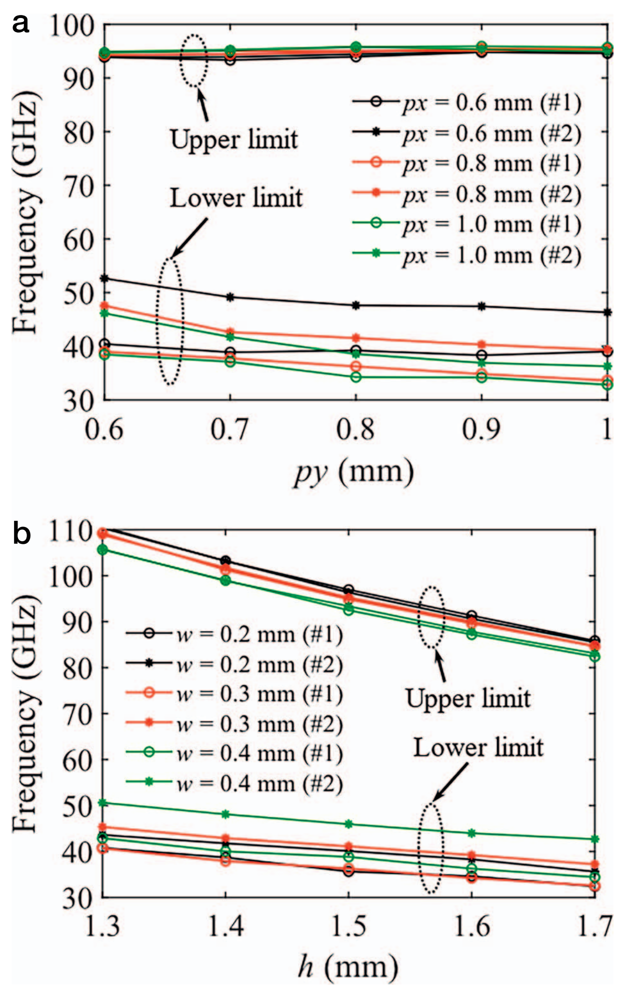

Figure 5. Frequencies of the stopband for the reference unit cell (#1) and proposed unit cell (#2) with (a) varied p_x and p_y and (b) varied w and h.

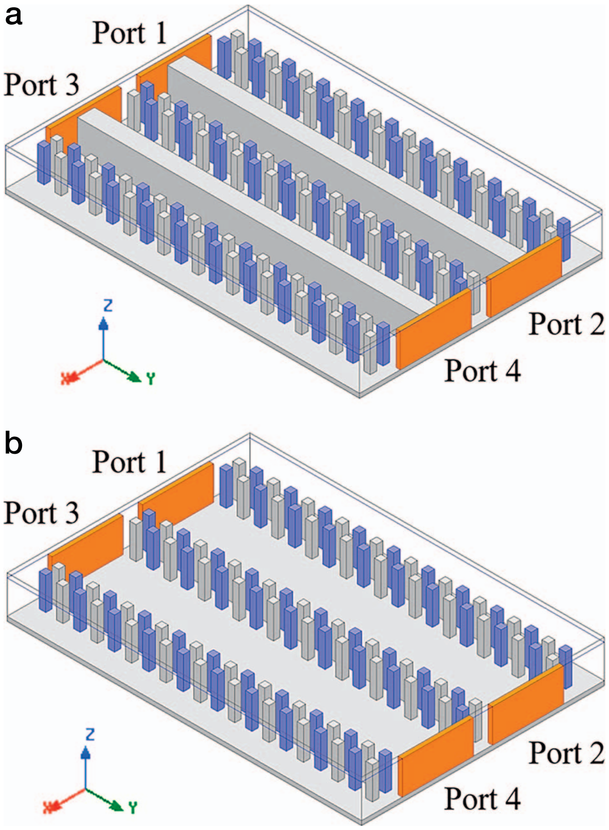

Figure 6. Four-port network composed of two parallel (a) ridge gap waveguides with interleaved pins and (b) H-plane groove gap waveguides with interleaved pins.

We propose a new unit cell in which the gray pins are attached to the bottom gray plate and the blue pins originate from the top blue plate. The distance between pins at the same plate is

$$d_2 = \sqrt{(p_x - w)^2 + (p_y - w)^2} \tag{2}$$

Evidently, d_2 is greater than d_1, and as the difference between p_y and p_x grows, the difference between d_2 and d_1 will be at its maximum. From the fabrication point, a larger spacing allows for a larger-diameter drill, so the interleaved pins reduce fabrication cost.

Figure 4 depicts the dispersion diagram of the reference (#1) and proposed unit cells (#2) with the same dimensions. It should be noted that the period of the two unit cells is twice p_x or p_y in the x- or y-direction. For both configurations, the upper frequency of the bandgap is around 95 GHz. In contrast, compared to the reference unit cell, the lower frequency of the bandgap is raised by 5 GHz for the proposed unit cell. The proposed unit cell has a decreased stopband, but it still covers the full V-band with a bandwidth of approximately 54.1 GHz from 41.1 GHz to 95.2 GHz. Analysis and discussions on the stopband characteristics of the reference and proposed unit cells with different dimensions are presented in Figure 5. The case of varied

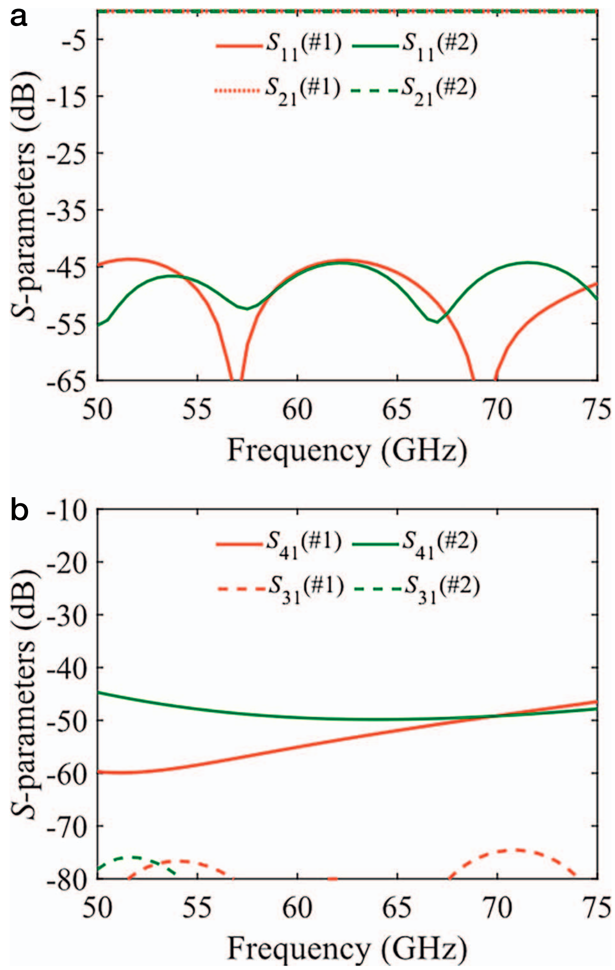

Figure 7. S-parameters of the four-port networks composed of two parallel ridge gap waveguides with the reference pins (#1) and proposed interleaved pins (#2). (a) Reflection and transmission. (b) Crosstalk.

p_x and p_y with $w = 0.05$ mm and $h = 1.5$ mm is shown in Figure 5a. The upper limit of the stop band of the reference and proposed unit cells remains essentially unchanged whether p_x and p_y rise or decrease, while its lower limit decreases as p_x and p_y increase, indicating that the bandwidth of the stopband expands. The findings for varying w and h at $p_x = 0.8$ mm and $p_y = 0.8$ mm are shown in Figure 5b. The lower limit of the stopband rises as w increases, while the upper limit of the stopband falls, resulting in a reduction in the bandwidth. The center frequency of the stopband is shifted to a lower frequency when the pin height h is increased. Higher pins are preferable from a performance perspective since the stopband exactly covers the desired band of 50 GHz to 75 GHz without offset.

4. Interleaved Pins in the Two Parallel H-plane Ridge and Groove Gap Waveguides

The proposed unit cell with interleaved pins is applied in two parallel ridge and H-plane groove gap

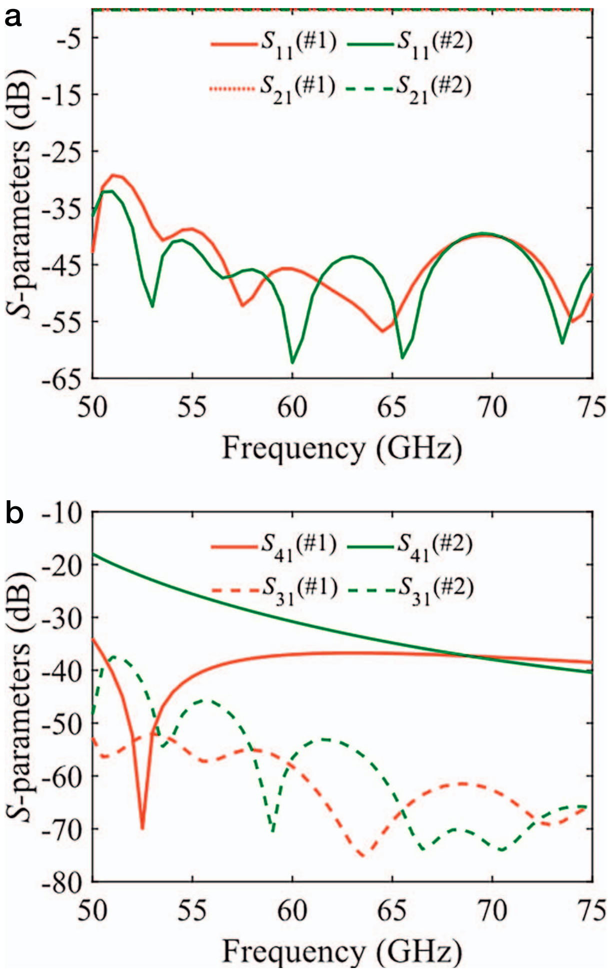

Figure 8. *S*-parameters of the four-port networks composed of two parallel H-plane groove gap waveguides with the reference pins (#1) and proposed interleaved pins (#2). (a) Reflection and transmission. (b) Crosstalk.

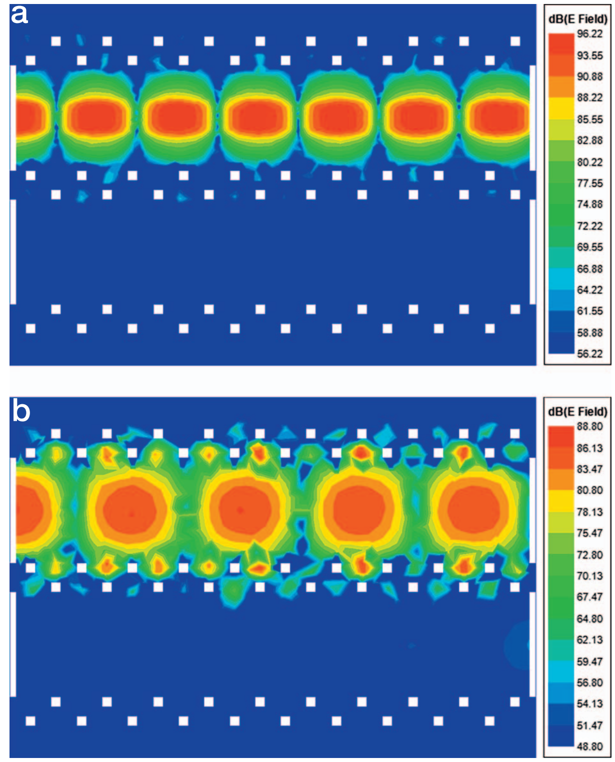

Figure 9. Electric field distribution on the inner surface of two parallel (a) ridge and (b) groove gap waveguides with interleaved pins within the 40 dB range at 61.5 GHz.

waveguides as shown in Figure 6 for demonstration. The parameters of the two models are identical. Each square pin has a width w and a height h of 0.3 mm and 1.5 mm, respectively. The gap g between the upper or lower layer is 0.05 mm. The periodic spacing p_x and p_y of the pins are 0.6 mm and 0.8 mm, respectively. The waveguide width a is 3.3 mm, and the center-to-center spacing between neighboring waveguides is 8.4 mm. The width and height of the ridge are 0.8 mm and 1.4 mm, respectively.

The *S*-parameters of the two parallel ridge and H-plane groove gap waveguides with the reference pins (#1) and proposed interleaved pins (#2) are shown in Figures 7 and 8. The reflection and transmission properties of the ridge waveguides with two types of pins are excellent, as shown in Figure 7a, and their reflection (S_{11}) is less than –40 dB in the V band. Moreover, their crosstalk levels are extremely low with S_{31} less than –70 dB and S_{41} less than –40 dB over the desired frequency range. In contrast, the reflection levels of the H-plane groove gap waveguides with two types of pins are higher, especially near the low-frequency band, but they are also lower than –29 dB, as illustrated in Figure 8a. In terms of crosstalk, S_{41} with the proposed unit cell is higher and increases as frequency decreases, but it remains below –17.9 dB all over the V band. When Port 1 is excited, the electric field distribution on the inner surface of two parallel ridge and groove gap waveguides in the 40 dB range is depicted in Figure 9. The waves are well restricted in both the ridge and H-plane groove gap waveguides.

5. Conclusion

This article has presented a new type of gap waveguide with interleaved pins extending from the top and bottom plates for easier and higher-frequency fabrication. The proposed unit cell with interleaved pins operates similarly to the reference unit cell under various parameters, except that the lower limit of the stopband was approximately 5 GHz higher compared to the reference cell. The simulation results of the four-port network with two parallel ridges as well as an H-plane groove gap waveguide indicate that both the ridge and the groove gap waveguide with interleaved pins is capable of achieving satisfactory reflection, transmission, and isolation.

6. References

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