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Improved Design of W-Band Slot Array Antenna Based on Rectangular Micro Coaxial Line

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Abstract—This paper proposes an improved design of a W-band slot array antenna, based on a ridge waveguide and a rectangular micro-coaxial line. To achieve a high gain and wideband antenna with element spacing smaller than half a wavelength, a broadband transition of rectangular coaxial line to ridge waveguide was designed. The improved design has bandwidth around 15.4 GHz (94.8 GHz–110.2 GHz), and the simulated realized gain is about 14.6 dB. Measured results of the fabricated antenna demonstrate that the gain at theta = 0°, and VSWR is better than 13 dB and 2.7, respectively. The antenna's size is about 12 mm × 5.5 mm × 0.46 mm.

1. INTRODUCTION

With the development of communication systems, the communication frequency has been extended to millimeter-wave band to satisfy the increasing demands of data transmission and ever increasing terminals. 5G communication and automotive collision avoidance radar promote the commercial application of millimeter-wave communication systems. However, the high cost and large insertion loss of the communication devices hinder the applications in civil communications, such as the high dielectric loss of microstrip and substrate integrated waveguide (SIW) components and the high cost of metallic waveguide components.

A rectangular micro-coaxial line combines the advantages of planar circuits and waveguide structures, that is, compact size, light weight, easy integration of planar circuits, low loss, high power capacity, and good thermal performance of waveguide structures. Besides, rectangular micro-coaxial line has no dispersion and wide bandwidth.

The rectangular coaxial line is firstly proposed by Omar and Miller in 1952 [1] and firstly fabricated by micro-machined process in 2002 at around 20 GHz by Xiong et al. [2]. Afterwards, it has been widely studied by researchers and finally commercialized by Poly Strata technology. In the last decades, a series of passive millimeter-wave components based on the rectangular coaxial line has been investigated, such as filters, power dividers, antennas, and even communications systems [3–7]. However, it has not been used for civil application until recent years for the maturity of technology and deduction of cost.

In a previous article [5], a W-band waveguide slot array antenna is designed to achieve a high gain and wideband antenna. But the gate appears when being excited at large phase differences due to the large spacing among element antennas, which is determined by the cutoff frequency of the waveguide.

In this paper, an improved design of W-band slot array antenna based on ridge waveguide and rectangular micro-coaxial process is proposed. The improved designed maintains good performances of high gain and broadband; meanwhile, smaller element spacing is realized by using a ridge waveguide. Beside, a rectangular coaxial line to ridge waveguide line transition is designed to facilitate the antenna design. Measured results of the fabricated antenna demonstrate that the gain at theta = 0° and voltage standing wave ratio (VSWR) are better than 13 dB and 2.7, respectively.

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2. RIDGE WAVEGUIDE SLOT ELEMENT ANTENNA

2.1. The Broadband Transition

Similar to the former design, the slot array is fed by a rectangular coaxial line based coplanar waveguide (CPW). Therefore, a broadband rectangular coaxial line to ridge waveguide transition is required. The rectangular coaxial line to ridge waveguide transition is depicted in Fig. 1(a). The metallic ridge determines the cutoff frequency of the ridge waveguide, which decreases as the ridge width increases and then decreases.

A high ridge may be conducive to decreasing the cutoff frequency. In this way, the waveguide width can be reduced as much as possible to acquire a smaller element antenna spacing. An asymptote is used to match the impedance of ridge waveguide and the rectangular coaxial line.

The simulated S-parameters of the rectangular coaxial line to ridge waveguide transition are shown in Fig. 1(b), with a bandwidth of 18.15 GHz ($S_{11} < -20$ dB over 92.45–110.6 GHz), which is much wider than that in the former design.

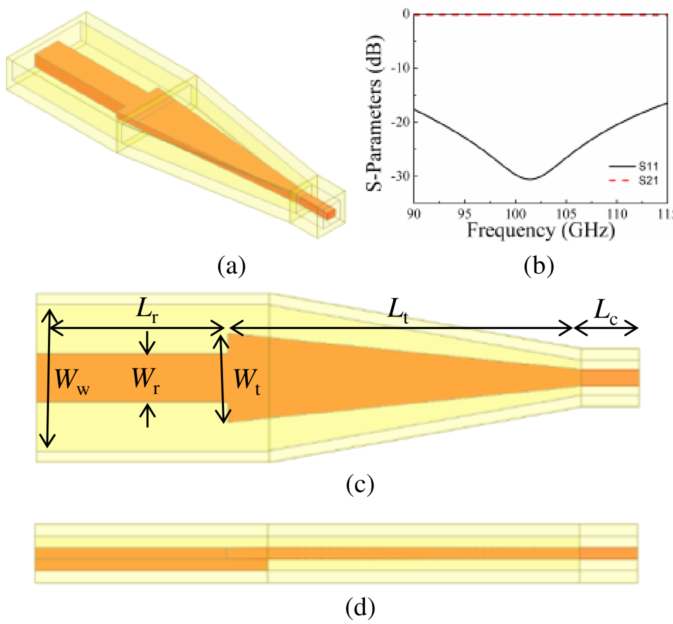
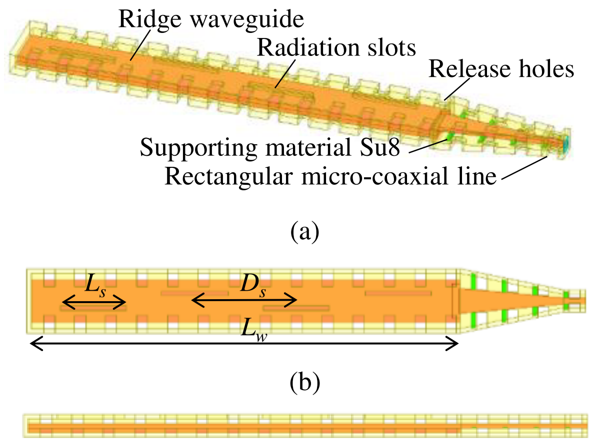


Figure 1. Diagram of the rectangular coaxial line to ridge waveguide transition. (a) The 3D view. (b) The simulated S-parameters of the broadband transition. (c) The top view. (d) The side view. $L_r = 3.03$ mm, $L_c = 0.5$ mm, $L_t = 1.65$ mm, $W_t = 0.76$ mm, $W_r = 0.42$ mm, and $W_w = 1.25$ mm.

2.2. The Ridge Waveguide Slot Element Antenna Design

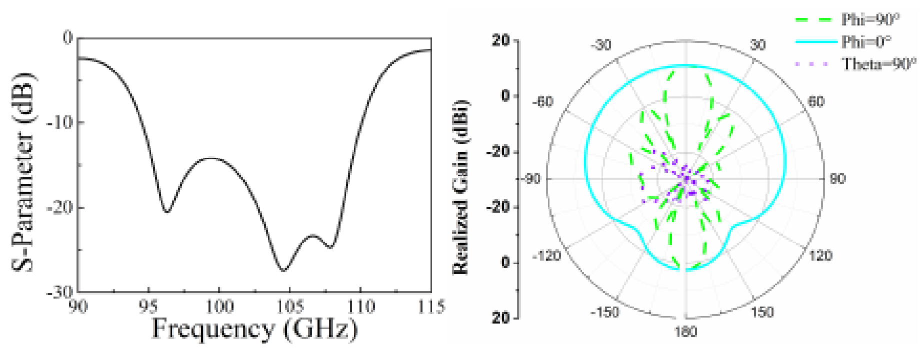
Based on the broadband rectangular coaxial line to ridge waveguide transition illustrated above, a ridge waveguide slot antenna is obtained and presented in Fig. 2, which is a 4×1 slot array antenna. The slot length determines the radiation frequency; the bandwidth of the antenna depends on the offset of the slots to the centerline of the ridge waveguide; and the spacing among the slots determines the radiation pattern. To get a wideband antenna with an upright radiation pattern, the offset is set to be close to the centerline, and the spacing of the slots is set to half wavelength of the center frequency.

The 4×1 slot array antenna is simulated with ANSYS EM suite 2019, and the simulated results are depicted in Fig. 3. The simulated antenna has a bandwidth of 15.6 GHz (94.5–110.1 GHz), which is nearly two times wider than that of the former one, while a maximum simulated realized gain of 10.3 dB @ 100 GHz is observed with the sidelobe lower than -2 dB. The added slots are used to increase the gain, meanwhile leading to a narrower bandwidth.



(c)

Figure 2. Diagram of the 4 × 1 slot array antenna. (a) The 3D view. (b) The top view. (c) The side view. $L_w = 8.4\,\mathrm{mm}$, $L_s = 1.58\,\mathrm{mm}$, $D_s = 1.97\,\mathrm{mm}$.



(a) (b)

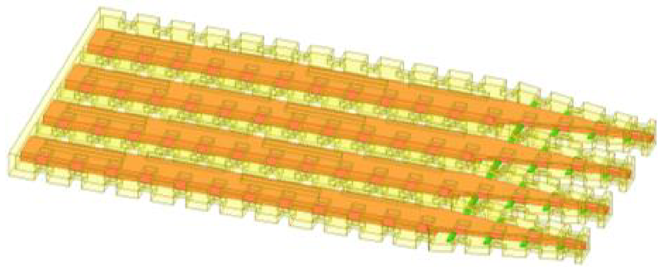
Figure 3. The simulated S-parameters and gain of the 4 × 1 slot array antenna.

As described before, for the rectangular coaxial line, the size of the inner conductor, outer conductor, and side wall is 140 µm × 100 µm, 300 µm × 300 µm, and 100 µm, respectively. The Su8 at the third layer is used for supporting the inner conductor with a dielectric constant of 2.85 and a loss tangent of 0.045.

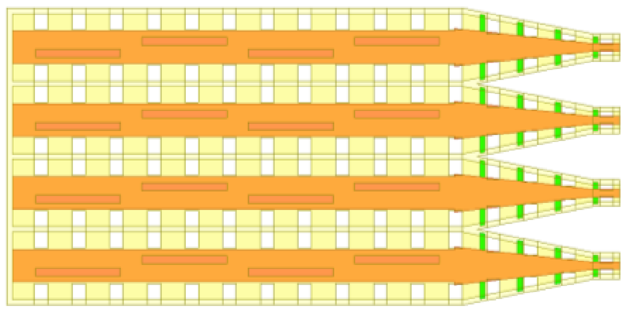
3. RIDGE WAVEGUIDE SLOT ARRAY ANTENNA

The 4 × 4 slot array designed in Section 2 is later utilized as an element to generate a larger array antenna, which is presented in Fig. 4. The width of the ridge waveguide is much smaller than the rectangular waveguide (with a width of 1.8 mm), leading to a smaller element spacing (1.35 mm, smaller than a half wavelength), which decreases the simulated realized gain and the gate of the array.

The four antenna elements are arranged in parallel and re-optimized. The simulated results are shown in Fig. 5. The four elements have nearly the same VSWR of less than 1.7 at 97.5 GHz–102.5 GHz, which is affected little by each other. The isolation of the adjacent elements is larger than 20.1 dB over the whole band. The simulated realized gain is about 14.6 dB observed at 100 GHz.

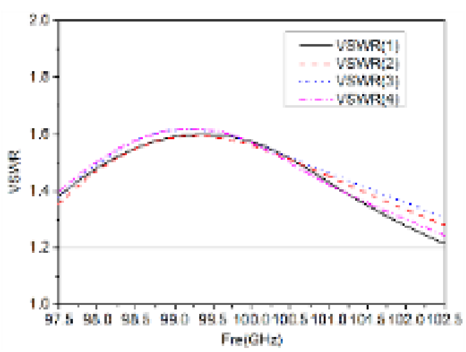


(a)

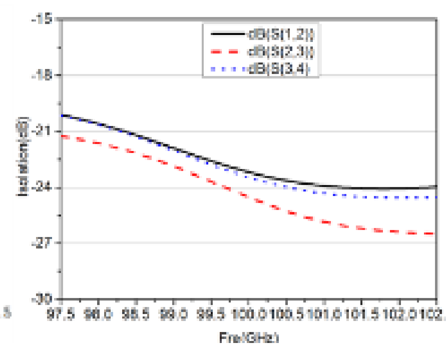


(b)

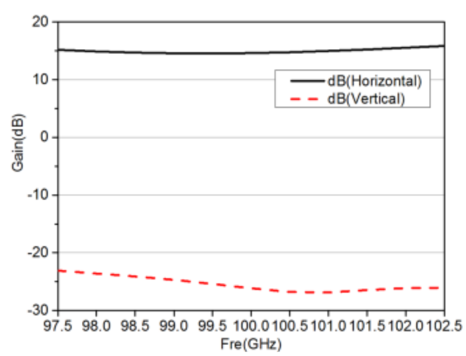
Figure 4. Illustration diagrams of the ridge waveguide slot array antenna. (a) The 3D view. (b) The top view.



(a)



(b)



(c)

Figure 5. The simulated VSWR, isolation and realized gain of the ridge waveguide slot array antenna.

4. RESULTS AND FABRICATION

The proposed antenna is fabricated on silicon with Poly Strata technology. The processing flow of micro-coaxial line is shown in Fig. 6. Step 1: a metal seed layer is deposited on the Si wafer, and a uniform photoresist is coated on the substrate by spin coating. The super thick photoresist is used as the sacrificial layer, and the photoresist thickness is consistent with the thickness of the subsequent electrochemical deposition layer, and then the standard lithography process is used to make grooves. Step 2: prepare the metal layer in the groove by electrochemical deposition of Cu. Step 3 and step 4: repeat steps 1 and 2. Step 5: by using photolithography technology and using SU-8 photoresist to photolithograph, a strip structure supports the suspended inner conductor. Step 6 to step 11: repeat steps 1 and 2. Step 12: degumming. Step 13: the whole micro-coaxial structure is released from the substrate by sacrificial layer technology.

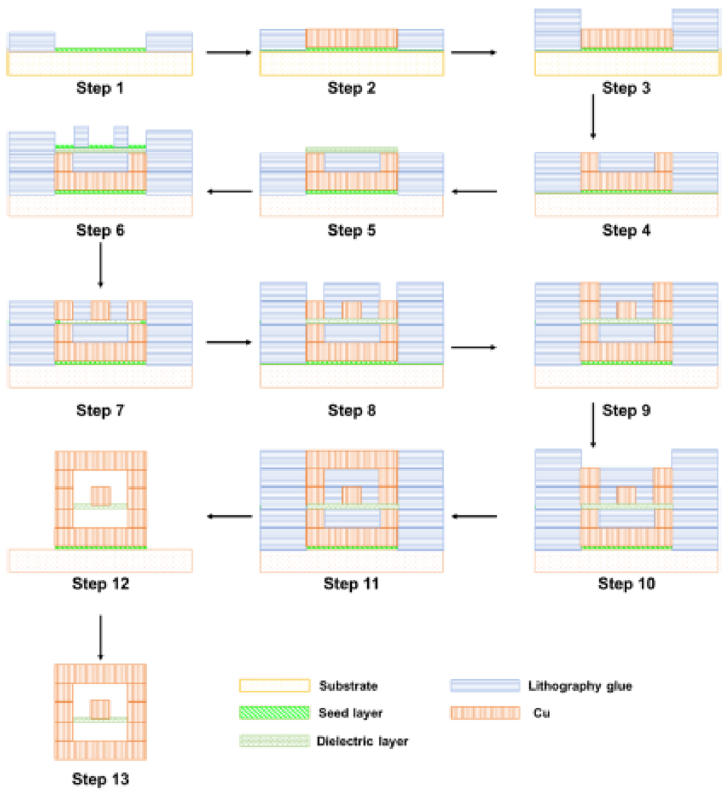


Figure 6. The process of the Poly Strata technology.

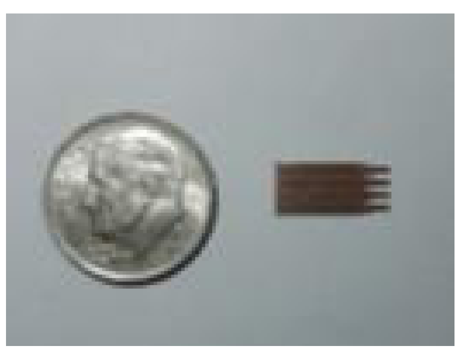


Figure 7. A photograph of the fabricated array antenna.

A photograph of the fabricated array is shown in Fig. 7. The measured size of the antenna array is 12.04 mm × 5.50 mm × 0.46 mm, as shown in Fig. 8.

Figure 8. The size of the fabricated array antenna.

The measured S-parameters of the rectangular coaxial line to ridge waveguide transition are shown in Fig. 9, with a bandwidth of 5 GHz (VSWR < 2.7 over 97.5–102.5 GHz), which is the VSWR of the four ports.

The measured gain of the rectangular coaxial line to ridge waveguide transition is shown in Fig. 10. The result shows that the horizontal polarization gain of the antenna gain is greater than 13 dB.

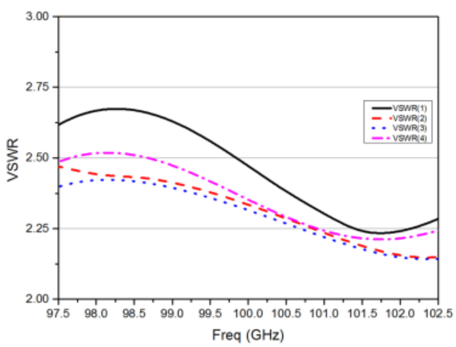


Figure 9. Measured VSWR. of the proposed antenna.

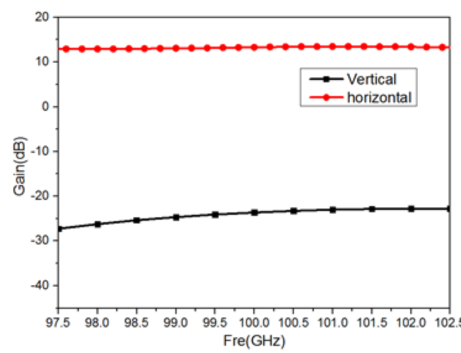


Figure 10. Measured gain of the proposed antenna.

5. CONCLUSION

To decrease the gate of the former designed W-band waveguide slot array antenna at large excitation phase differences, an improved design is presented in this paper. The 4×4 slot array antenna is used as element to form a ridge waveguide slot array antenna so as to achieve a high gain and a broadband antenna. The ridge waveguide is used and optimized to achieve a broadband transition and small element spacing. The designed W-band ridge waveguide slot array antenna is with a bandwidth of 15% and a simulated realized gain of 14.6 dB. The size of the W-band slot array antenna is 12.04 mm × 5.50 mm × 0.46 mm. Measured results of the fabricated antenna demonstrate that the gain at theta = 0° and VSWR are better than 13 dB and 2.7, respectively.

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