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Dual-Band Dual-Polarized Slotted Coaxial Waveguide Antenna

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Abstract—This paper presents a dual-band dual-polarized antenna including one L-band vertically polarized antenna, four C-band horizontally polarized subarrays, and four C-band vertically polarized subarrays. Both the L- and C-band radiation elements are designed based on the concept of slotted coaxial waveguide antenna. The coaxial waveguide structure is in rectangular shape which is suitable for multi-element integration. And bending stripline inside the waveguide cavity plays the role of inner connector for the coaxial waveguide and exciter for radiating slots on the waveguide. Results show that impedance bandwidths of 14.9% for L-band and 5.9% for C-band are obtained with good port isolation. The antenna also exhibits good radiation performance with the low cross-polarization. The results indicate that the proposed antenna is suitable for synthetic aperture radar applications.

1. INTRODUCTION

The rapid development of radar systems puts forward higher and higher performance requirements for antennas, which are developing in the direction of multi-band, multi-polarization (MBMP), and miniaturization. The combination of high and low frequency band antennas has obvious advantages of abundant imaging area information in synthetic aperture radar (SAR) [1]. But MBMP antennas usually face space arrangement problems and weight restriction in airplanes and satellite SAR. Through reasonable layout, multiple antennas with different frequency bands and different polarizations are integrated in the same aperture plane, which can greatly save the space occupied by the antenna without significantly increasing the size and weight of the antenna. Another problem is the strong electromagnetic coupling between MBMP antennas, which affects the normal operation and performance of each antenna. Therefore, it is necessary to optimize the limited space to design the shared-aperture antenna with superior performance and high isolation.

The microstrip patch antenna has the characteristics of lightness, thinness, and easy processing, which is usually used as a shared-aperture antenna [2–4]. A representative MBMP patch antenna design at L/C band for SAR applications is investigated in [5]. The L-band patch is designed to be perforated, and C-band patch elements are embedded in the L-band perforated patch. Generally speaking, the coupling between patch antennas is strong. And the antennas between different frequency bands are prone to interference. In addition, due to the dielectric loss in the patch antenna, the efficiency of the patch antenna is usually low.

Waveguide slot antennas are commonly used in spaceborne radar antennas, which have high efficiency but large size [6]. When integrating the waveguide slot antennas of different frequency bands and different polarizations, it is necessary to compress the size of the waveguide as much as possible. The common method is to use the form of ridge waveguide [7, 8]. In [9], L-band elements are four groups of longitudinal slots on the multiridge waveguide cavity, and for C-band, parallel ridged waveguide slot subarrays are used to realize dual polarizations. In [10], L-band elements are cavity-backed crossed

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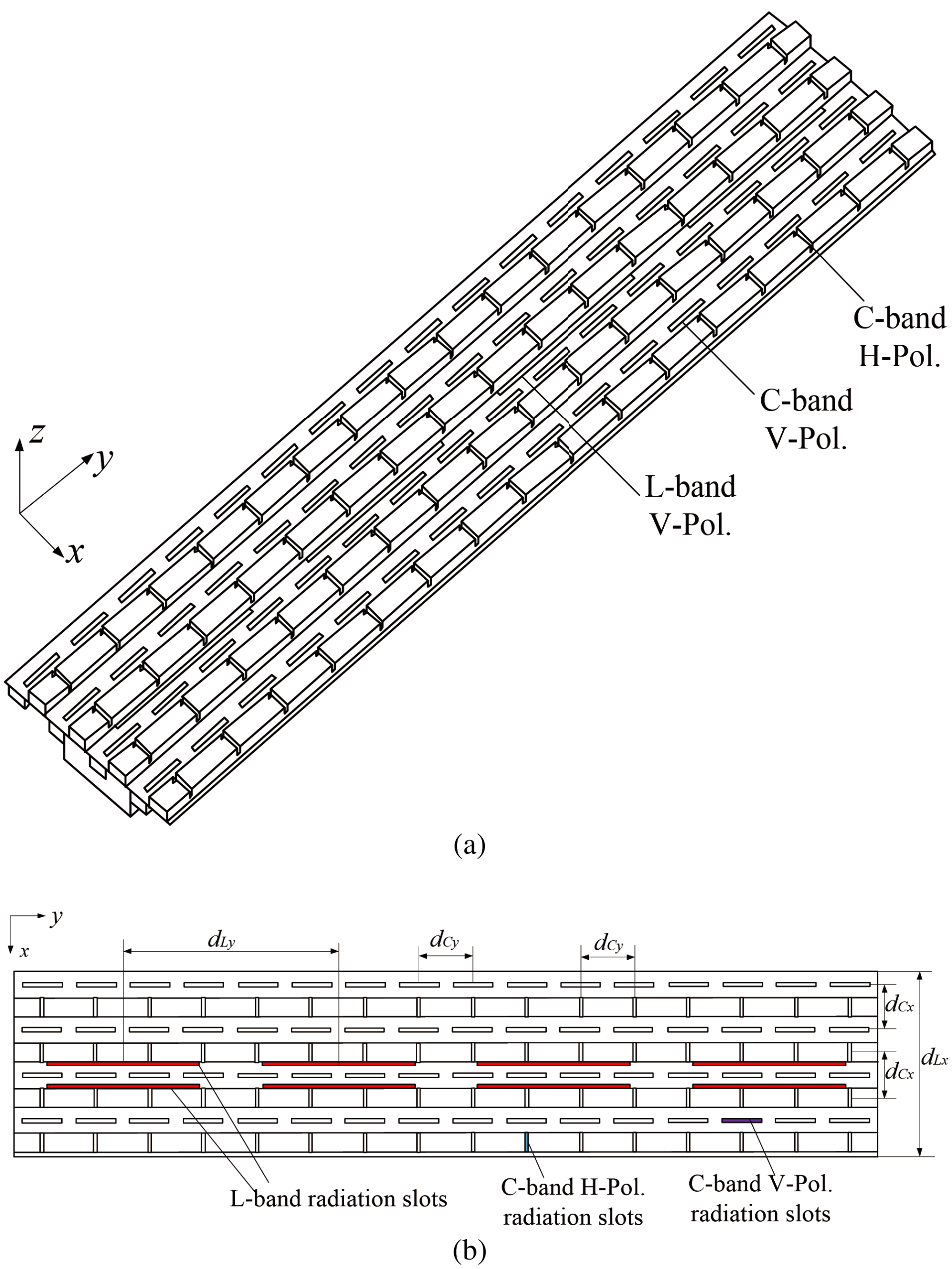
slot elements for dual polarizations, and the X-band elements comprise a group of four slotted ridged waveguide subarrays. It is noteworthy that due to the bent metal cavity inside the ridge waveguide, multiple frequency bands and multiple polarization ridge waveguides require high machining accuracy which is extremely difficult to process and has a high cost.

Slotted coaxial waveguide is another good candidate for radiating elements [11]. Wide operating band and compact structure can be realized by using the TEM mode of coaxial waveguide. Detailed design principles of slotted coaxial waveguide are presented in [12]. But the round shape of outer conductor and unstable inner conductor (usually propped by Teflon dielectric, which causes extra transmission loss) is not suitable for dual-band dual-polarized (DBDP) antenna designs.

Based on the above considerations, a dual-band, dual-polarized shared-aperture waveguide subarray is researched and developed by using the concept of slotted coaxial waveguide. The proposed antenna subarray not only can realize the simultaneous operation of multi-band and multi-polarization, but also has the advantages of simple and easy-to-manufacture.



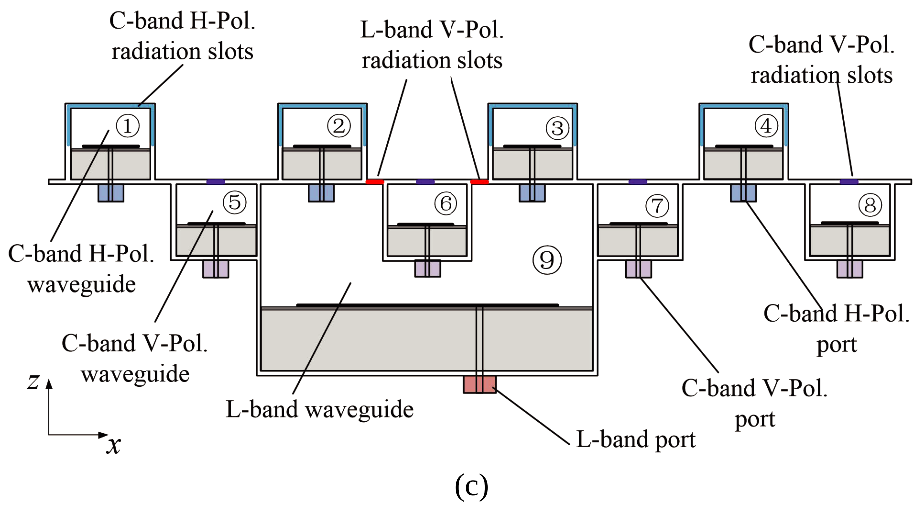


Figure 1. (a) 3-D view, (b) top view and (c) cross section of the proposed antenna.

2. ANTENNA DESIGN

As shown in Figure 1, the proposed DBDP shared-aperture slotted coaxial waveguide slot antenna includes one L-band vertically polarized slotted coaxial waveguide antenna (number 9 in Figure 1(c))

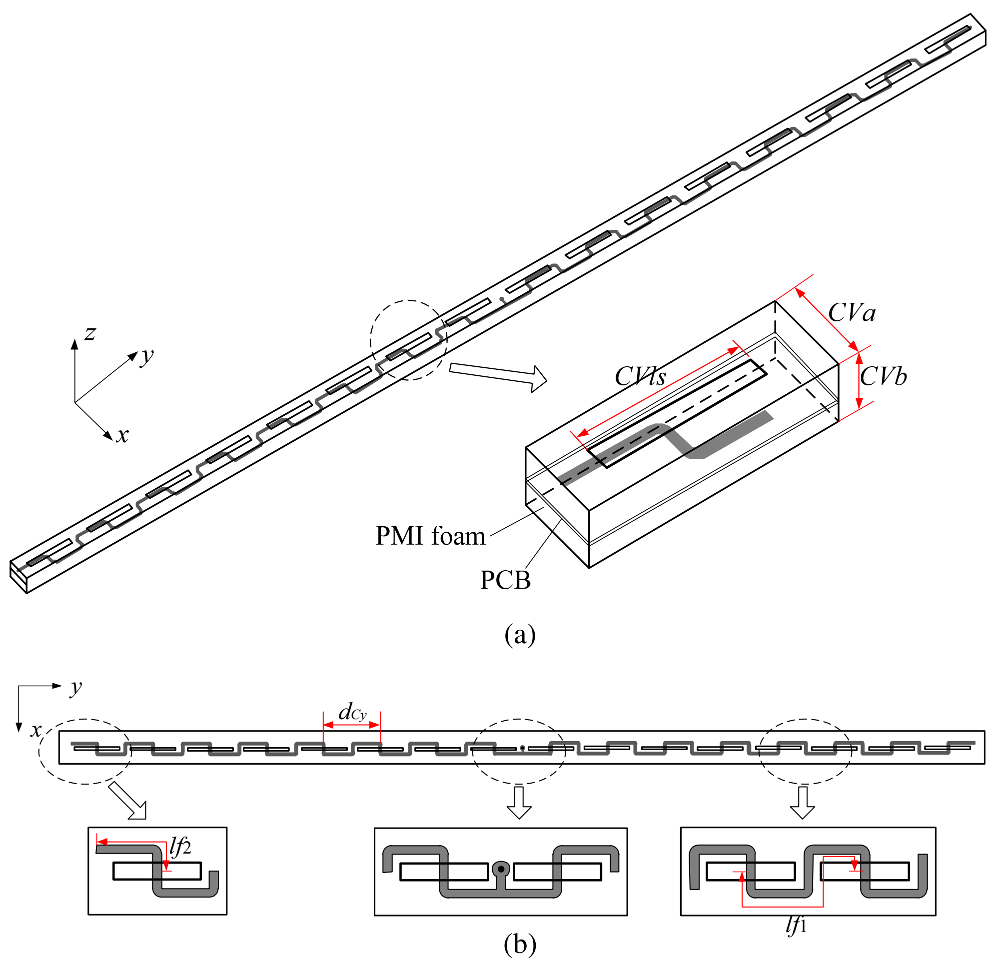
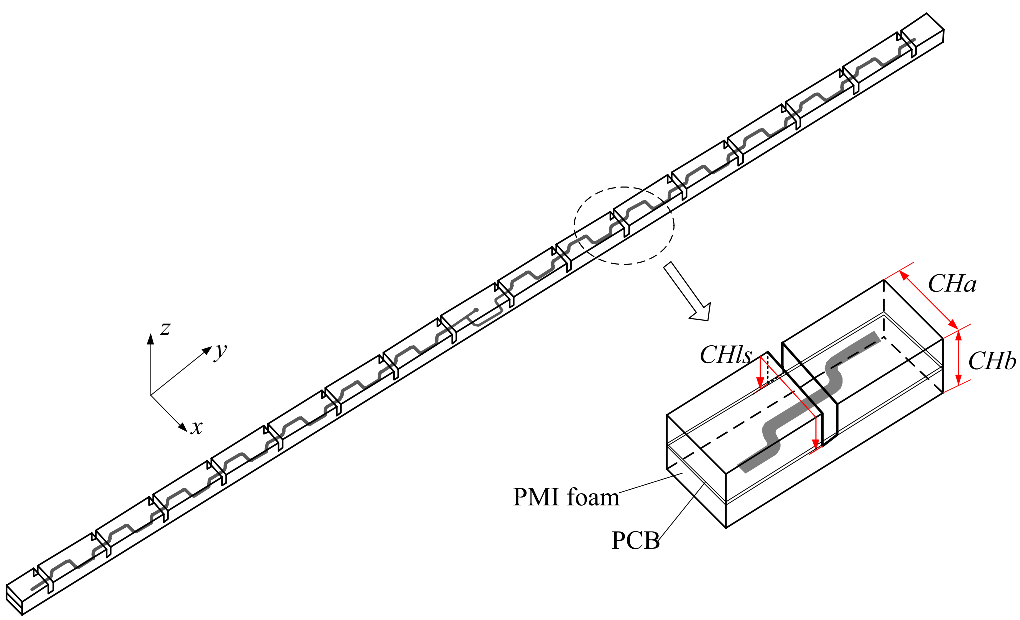


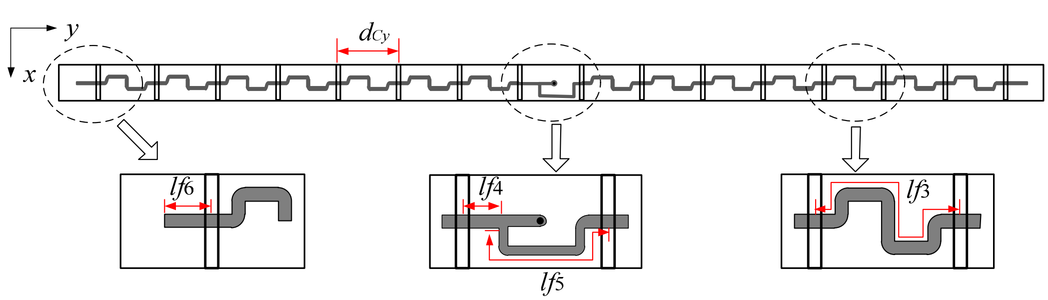
Figure 2. (a) Perspective view and (b) top view of the CV subarray.

and eight C-band slotted coaxial waveguide antenna subarrays, four for horizontal polarization (H-pol., $1 \sim 4$ in Figure 1(c)) and 4 for vertical polarization (V-pol., $5 \sim 6$ in Figure 1(c)). The C-band V-pol. and H-pol. subarrays are design on rectangular coaxial waveguides and alternately arranged. The L-band V-pol. (LV) antenna is located below the C-band subarrays of 2, 6, and 3 and shares the same waveguide wall with subarrays of 5 and 7. The four pair slots of the L-band antenna (red line in Figure 1(b) and Figure 1(c)) are etched on the edges among the C-band subarrays of 2, 6, and 3.

As shown in Figure 2, the C-band V-pol. (CV) subarray consists of a rectangular waveguide, a stripline printed on a thin substrate, and a PMI foam. The PMI foam has relative permittivity of 1.07 and loss tangent of 0.002, which are close to the electric parameters of air. The foam provides the support for feeding line substrate. The feeding line substrate and the foam are bonded to the bottom wall of the waveguide by adhesive. The feeding line and rectangular waveguide form the coaxial waveguide. The height of the foam, the gap between the feeding line and slots, and the width of the feeding line are finely optimized to obtain good impedance matching. There are 16 CV slots in the horizontal direction on the center line of the upper wall of the waveguide. The length of the CV slot *CVls* is about $0.5\lambda_c$, and the spacing between adjacent slots *dcy* is about $0.72\lambda_c$ (λ_c is the wavelength corresponding to the operating frequency of the C-band). The C-band feeding line is a flat bending structure, which is symmetrically distributed in the horizontal direction. In order to excite the slots, the vertical part of the feeding line is underneath the center of the slot. The total length of the feeding line from one slot to another adjacent slot *lf1* is λ_g (λ_g is the waveguide wavelength), so as to ensure



(a)



(b)

Figure 3. (a) Perspective view and (b) top view of the CH subarray.

that the 16 slots can be excited in equal phases. On both edges of the feeding line is an open-circuit line with a length of *lf2* for impedance matching. The center of feeding line is soldered to the inner conductor of a coaxial connector.

As shown in Figure 3, the configuration of the C-band H-pol. (CH) subarray is similar to the CV subarray. The 16 CH slots are in the vertical direction on the upper wall of the waveguide. The H-pol. slots are in "Π" shape, and the total length of the slots $CHls$ is about $0.5\lambda_c$. The horizontal part of the feeding line is underneath the H-pol. slots to excite the slots. The total length of the bending feeding line *lf3* is λ_g, so as to ensure that the slots can be excited in equal phases. The end of the feeding line with length of *lf6* is open-circuit to match the impedance. Different from the symmetric structure of the V-pol. feeding line, the center of the H-pol. feeding line has a length difference (*lf5*-*lf4*) of $0.5\lambda_g$ to keep the left 8 and right 8 slots having equal phases. Similarly, the feeding line is soldered to the inner conductor of a coaxial connector.

The LV antenna is shown in Figure 4. The L-band coaxial waveguide is U-shaped to have a compact structure when integrating with C-band waveguides. Different from the TE mode in typical rectangular waveguide, the coaxial waveguide operates in the TEM mode with much lower cut-off frequency. A small-size coaxial waveguide with fixed internal and external diameter ratio can still maintain the TEM mode. Thus, the overall dimension of the coaxial waveguide is reduced greatly. The center of the waveguide is compressed to be thin to provide place for the C-band feeding connectors. Because C-

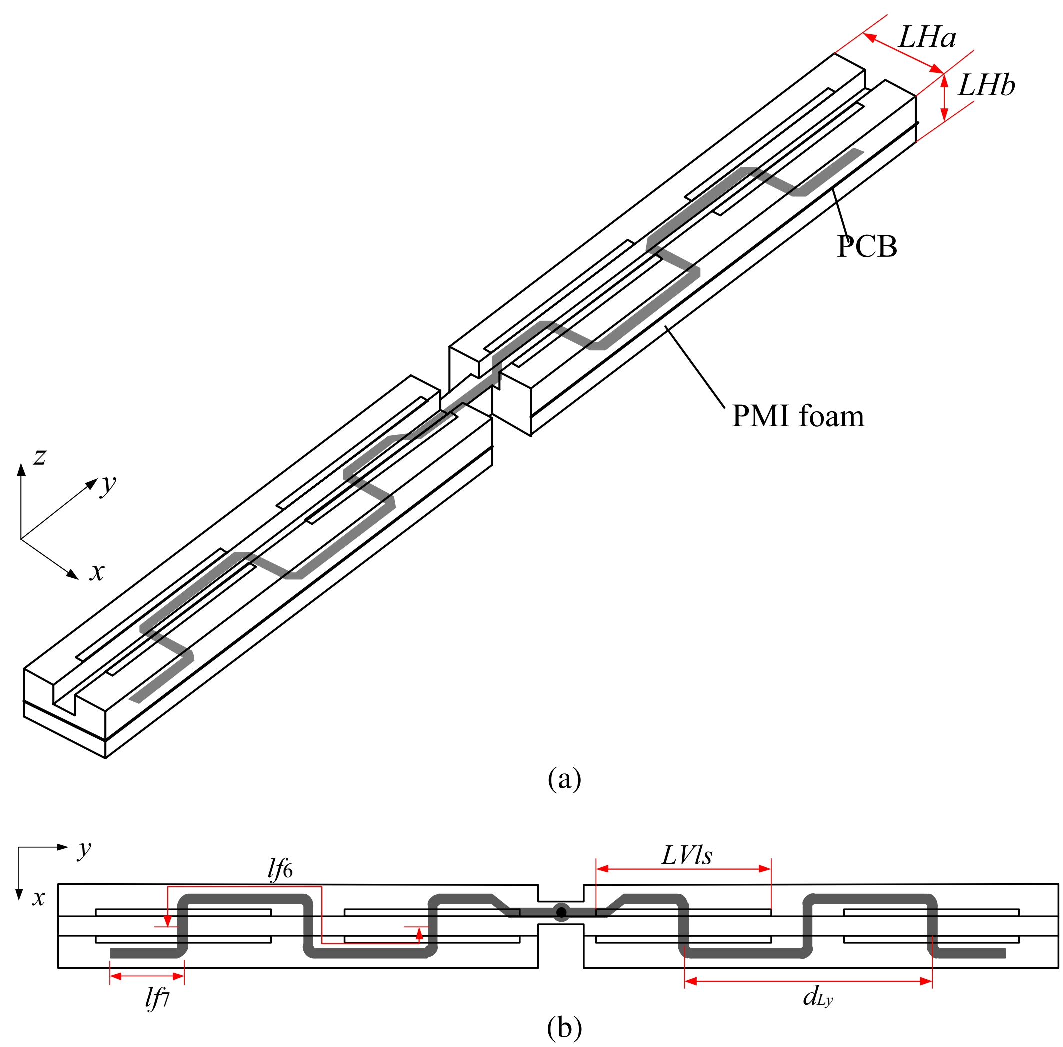
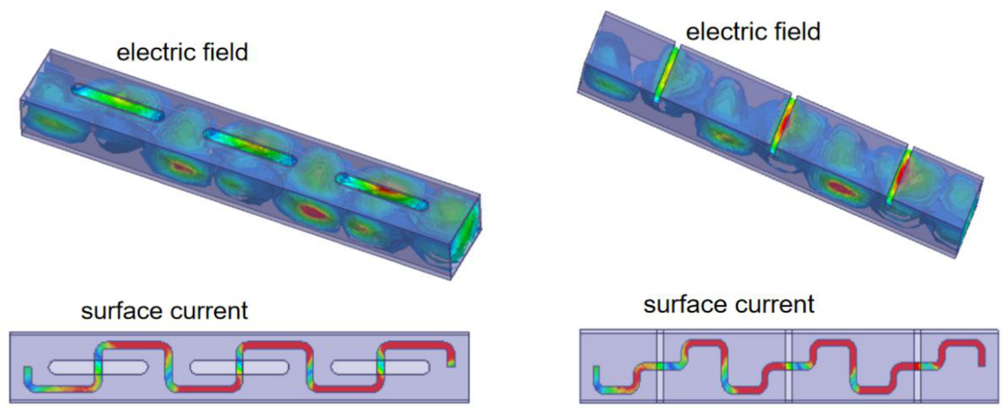


Figure 4. (a) Perspective view and (b) top view of the LV subarray.

band subarrays 2 and 3 have an occlusion effect on L-band slots, four pairs of slots with length $LVls$ of $0.5\lambda_L$ are employed to achieve symmetric radiation patterns. The radiation of the two columns of slots is equivalent to single column of slots along the center line. Moreover, the spacing between adjacent slots dLy is $4 \times dcy$. Then the total length of the L-band antenna is equal to the length of the C-band subarrays. Similarly, the total length of the bending feeding line between adjacent slots is waveguide wavelength in L-band.

Figure 5 shows the electric fields inside the C-band waveguide and the current distributions on the feeding lines. It can be seen that the electric field is distributed periodically in the waveguide. The radiating slots are excited when the peak of the electric fields is propagated along the waveguide. The current distributions further illuminate that the length of the feeding line between adjacent slots is one waveguide wavelength. Consequently, all the radiating slots are excited in equal phases. The working mechanism of the L-band coaxial waveguide is the same as the C-band waveguide.



(a) (b)

Figure 5. Electric fields in waveguide and current distributions on the feeding lines for (a) CV subarray and (b) CH subarray.

3. SIMULATED AND MEASURED RESULTS

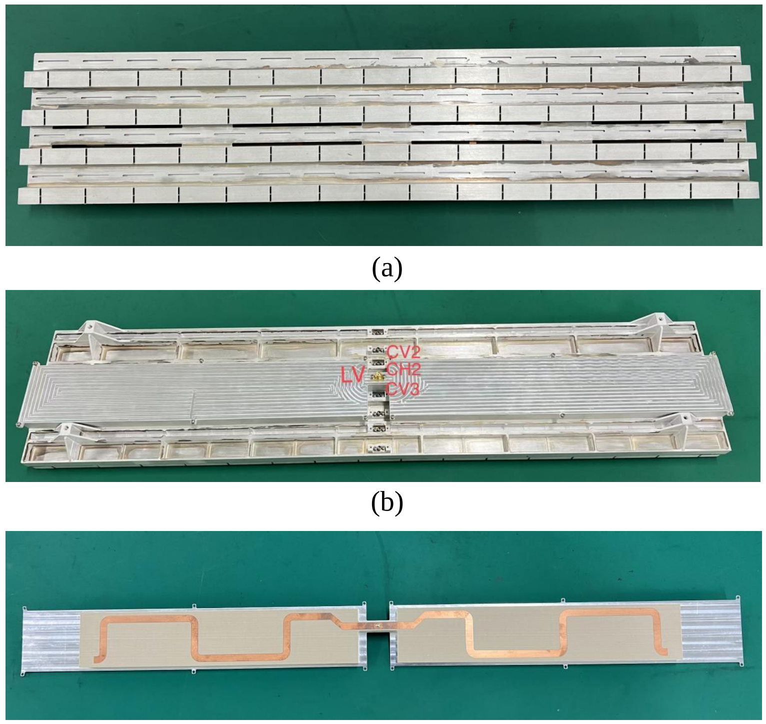
The proposed antenna has been fabricated, and its S-parameters as well as radiation pattern have been characterized experimentally. The antenna prototype in Figure 6 shows that the port of LV subarray is inserted between the port 2 of CH subarray and port 3 of CV subarray. The comparisons of simulated and measured VSWRs and isolations are depicted in Figure 7 and Figure 8. Measured impedance matching bandwidth for VSWR < 2 is of 14.9% (1.18–1.37 GHz) at L-band and 5.9% (5.26–5.58 GHz)

Table 1. Performance comparison of the proposed antenna with others.

	Polarization	Bandwidth	Cross-pol	Efficiency	Gain	Weight
[5]	H&V-pol. @L-band H&V-pol. @C-band	7.8% @L-band 1.9% @C-band	< -30 dB	$\sim 75\%$	LV&LH: ~ 7 dBi* CH&CV: ~ 22 dBi*	light
[9]	V-pol. @L-band H&V-pol. @C-band	11.36% @L-band 4% @C-band	< -35 dB	$\sim 85\%$	LV: 9.95 dBi CH: 25.4 dBi CV: 25.6 dBi	heavy
proposed	V-pol. @L-band H&V-pol. @C-band	14.9% @L-band 5.9% @C-band	< -35 dB	$\sim 82\%$	LV: 11.2 dBi CH: 25.0 dBi CV: 25.2 dBi	medium

* The gain of the array in Reference [5] is not specified. The estimated results are given.

at C-band, respectively, which is similar to the simulated ones. The measured isolation between the L-band element and either of the two C-band elements is observed to be below −50 dB at L-band and −28 dB at C-band. Additionally, the isolation between H-pol. and V-pol. at C-band is below −35 dB. Radiation pattern of the proposed antenna has been measured in an anechoic chamber. Figure 9 compares the simulated and measured YOZ-plane radiation patterns at 1.275 GHz and 5.4 GHz. The measured cross-polarization for both L-band and C-band subarrays is better than 35 dB relative to the main beam level. The measured gain is of 11.2 dBi for LV subarray, 25.0 dBi for 4 CH subarrays, and

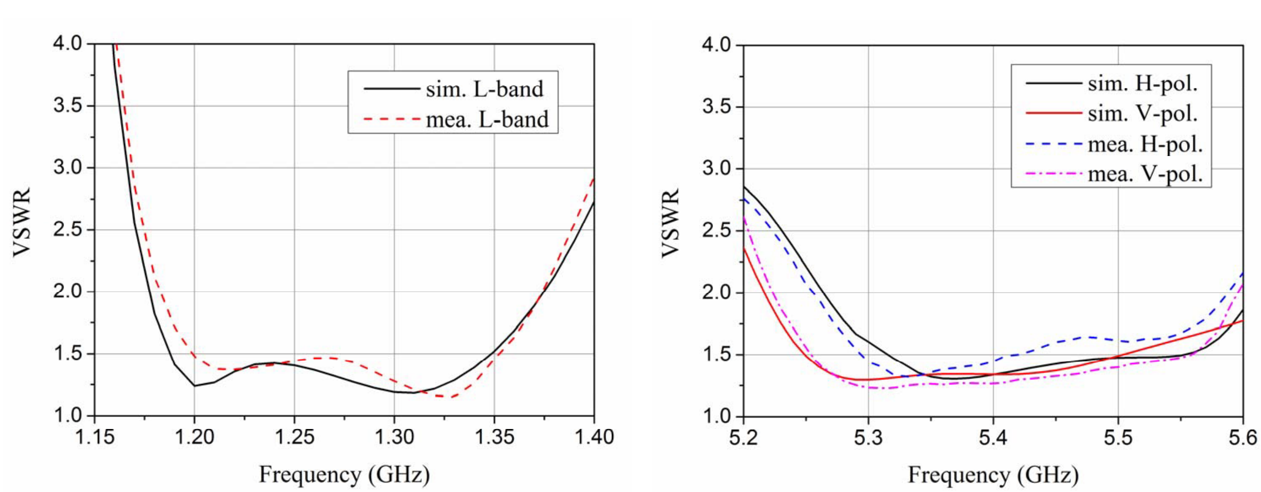


(a)

(b)

(c)

Figure 6. Fabricated prototype of the proposed DBDP antenna. (a) Top view, (b) back view and (c) the L-band inner feeding line.



(a)

(b)

Figure 7. Simulated and measured VSWR of (a) L-band subarray and (b) C-band subarray.

25.2 dBi for 4 CV subarrays (the inserting loss of the C-band 1 : 4 power divider is excluded). The measured radiation efficiency is 85.2% at L-band and 82.6% at C-band, respectively. Since the strip line on the substrate is a finite conductor, partial efficiency loss is caused by the feeding lines.

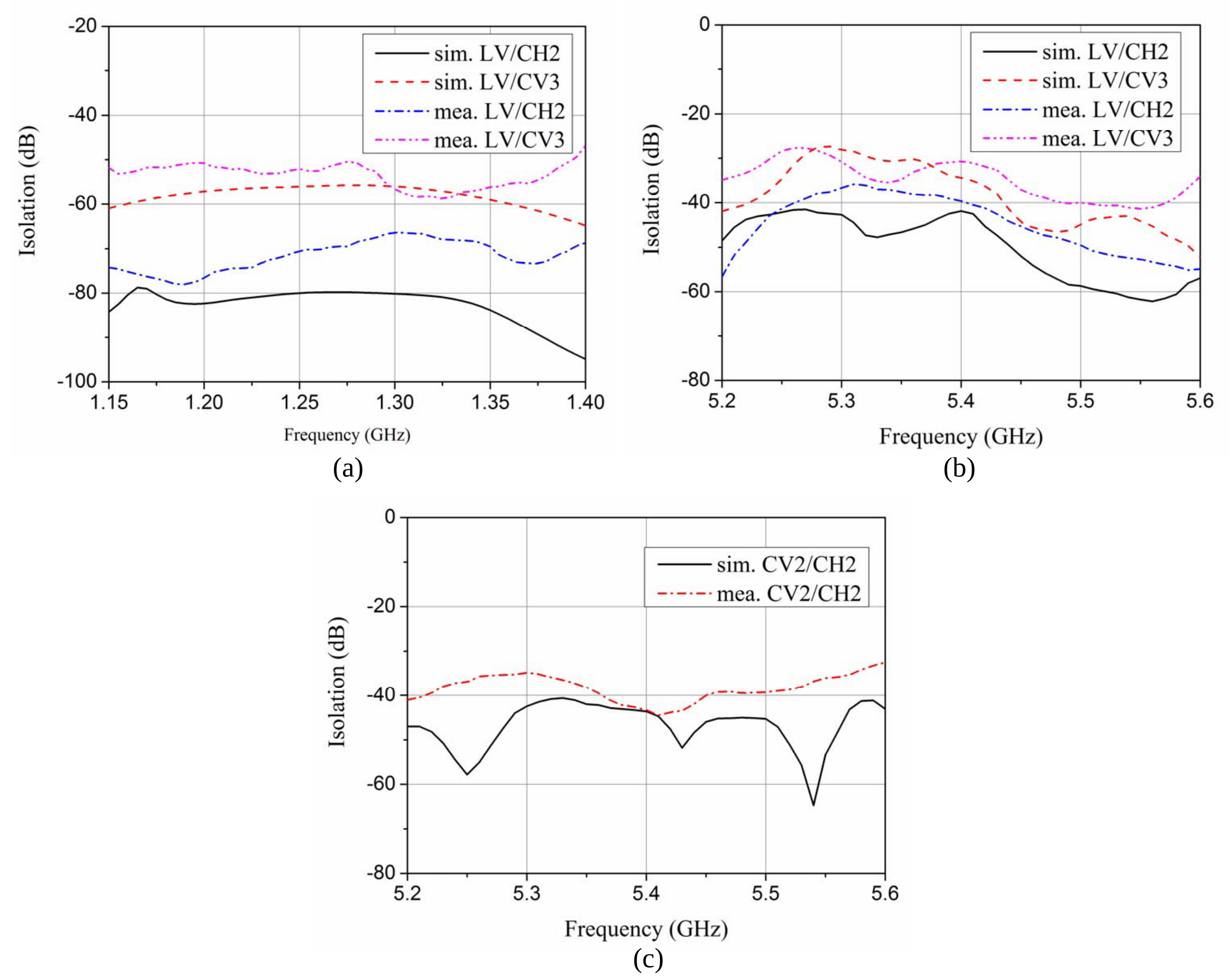
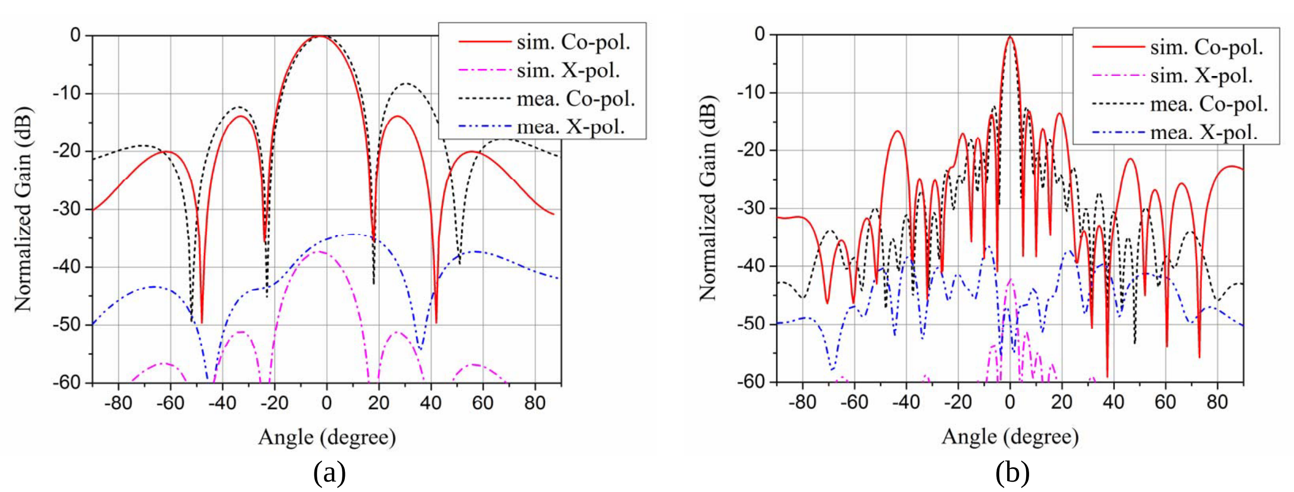
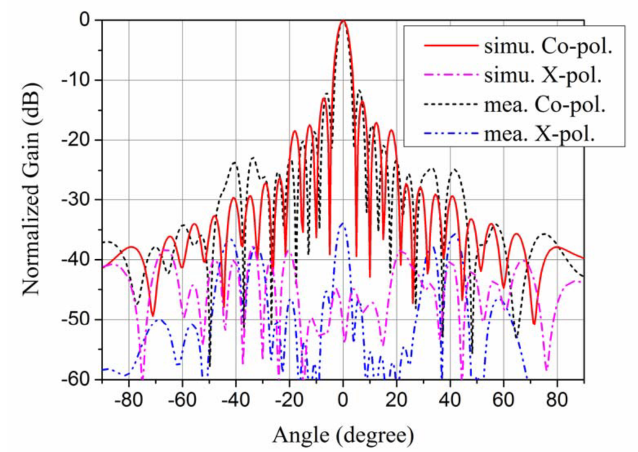


Figure 8. Simulated and measured isolation between (a) dual-band ports in L-band, (b) dual-band ports in C-band, and (c) H/V ports in C-band.





(c)

Figure 9. Simulated and measured radiation patterns of (a) LV subarray, (b) CH subarray and (c) CV subarray.

The performance comparison of the proposed antenna with [5] and [9] is listed in Table 1. It can be seen that the proposed antenna has wide bandwidth, low cross-polarization level, and comparable radiation efficiency. Compared with [9], the proposed antenna has higher L-band gain because of more concentrated radiation slots and comparable C-band gain. Moreover, substantial weight reduction makes the present antenna suitable for satellite platform.

4. CONCLUSION

A dual-band dual-polarized slotted coaxial waveguide antenna operating at L- and C-bands is presented in this paper. By inserting bending stripline into the metal waveguide, a coaxial waveguide structure is realized, and radiating slots are excited. Simulated and measured results demonstrate that the proposed antenna has good impedance matching and radiation characteristics at both L- and C-bands, including high isolation and stable radiation patterns with low cross-polarization. Furthermore, the antenna has good mechanical characteristics, including compact structure, low profile, and easy fabrication. These advantages make the DBDP antenna a good candidate for SAR applications.

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