A X −/Ka-Band Linearly Polarized Low Profile Shared-Aperture Antenna Array for Satellite Applications

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ABSTRACT An X −/Ka-band shared aperture scanning antenna array for satellite applications is proposed. The Ka-band antenna array consists of 8 × 8 antenna elements in a triangular grid, while the X-band antenna array consists of 4 × 4 antenna elements in a rectangular grid. Notably, the antenna elements of Ka band array and X-band array are planar microstrip dipole antennas to avoid structural overlap and reduce mutual coupling. Besides, the X-band antenna elements and Ka-band antenna elements are interlaced to share the same aperture. Compared with the recently released dual band shared aperture antenna array, the profile of the proposed antenna array is only 0.05 times the air wavelength. The frequency ratio (f_{high}/f_{low}) of the proposed antenna array is 3.1, and the antenna number ratio (N_{Ka}/N_{X}) of the antenna array is 4. These two parameters are close, which can improve the aperture utilization of the array. The measurement results show that the scanning angles of the antenna array at 10GHz and 30GHz are 38° and 30°, respectively.

INDEX TERMS Millimeter wave, shared-aperture antenna array, scanning antenna array, dipole antenna.

I. INTRODUCTION

In recent years, low profile dual band shared aperture antenna arrays have gradually become a research hotspot. One reason is that antenna arrays working in multiple bands can provide more and richer communication services and functions. Another reason is that the shared aperture layout can improve the aperture utilization of multi band antenna arrays. In addition, low profile design of the antenna arrays can be more easily compatible with the structure of the platform. Therefore, the research on low profile dual band shared aperture scanning antenna array is very valuable.

Dual band shared aperture scanning antenna array is mainly realized in the following ways. The first way is that antenna elements of different frequency bands shares one structure [6], [7], [8]. Among them, in [6] and [7], the profiles of the shared aperture antenna arrays are 0.08 wavelength and 0.07 wavelength respectively. However, their low-frequency antennas are single antenna elements, which cannot provide beam scanning function. Although the antenna array in [8] can realize a scanning angle up to 40°, its antenna elements are three-dimensional structure with high profiles. It is clear to see that the shared aperture antenna array realized by sharing one structure is often difficult to meet the requirements of low profile and beam scanning at the same time.

The second way is that the elements of different frequency bands are interlaced with each other [9], [10], [11]. Among them, in [9] and [10], the scanning angle of the antenna array reaches 50° and 30°, respectively, but due to the use of 6-layer dielectric substrates, their profiles reach 0.3 wavelength and 0.5 wavelength, respectively. In [11], the antenna array only uses three-layer dielectric substrates, so that the...
profile is only 0.04 wavelength, but the beam scanning performance is not mentioned.

The third way is that the elements of one frequency band are stacked to the antenna elements of another frequency band. In [12], the antenna array can realize beam scanning, and its profile is only 0.04 wavelength. However, the antenna number ratio of the shared aperture antenna arrays is much larger than the frequency ratio, which diminishes the aperture utilization of the antenna array.

According to the reference [11], [12], it is clear to see that the requirements of low profile and beam scanning of dual band shared aperture antenna array can be realized by reducing the number of layers of dielectric substrates and adopting the way of interlacing elements or stacking elements. Thus, This paper proposes a X-/Ka-band shared-aperture scanning antenna array (now denoted as proposed array) realized by the way of interlacing elements. In addition, the proposed antenna array only contains three layers of dielectric substrates, which diminishes the profile. The X-band antenna array of the proposed antenna array is composed of 4 × 4 elements with an operating frequency of 9.75–10.25 GHz, and the Ka-band antenna array is composed of 8 × 8 elements with an operating frequency of 29.5–30.5 GHz. Because the mutual coupling between arrays will affect the performance of antenna array, it needs to be suppressed [13], [14], [15], [16]. In this paper, the planar microstrip dipoles with small size are used as the array elements of the two working bands, which reduces the mutual coupling and improves the isolation between the two band. Different from [12], the proposed antenna array has an antenna number ratio of 4, which is close to the frequency ratio of 3. Thus, the aperture utilization of the proposed antenna array is up to 75%. In addition, the scanning angles of the proposed antenna array are up to 38° in the X-band and 30° in the Ka-band, respectively.

II. DERIVATION OF THE X-/Ka-BAND SHARED-APERTURE ANTENNA ARRAY

A. DESIGN OF THE KA-BAND ANTENNA ARRAY

The structure and simulated results of the Ka-band antenna element are summarized in Fig. 1. As shown in Figs. 1(a) and Figs. 1(b), the structure of the Ka-band antenna element is composed of three metal layers and two dielectric substrates [17]. The layout of the Ka-band antenna element is as follows: the dipole strip 1 act as the radiation part is located in the top metal layer, the feed 1 act as feed part is located in the middle metal layer, and the bottom metal layer is the reference ground (GND). In addition, the main parameters of the Ka-band antenna element are summarized in Fig. 1(b).

Notably, the two layers of dielectric are chosen to be 0.508 mm to reduce the feed loss and expand the bandwidth of the antenna element.

The simulated results of the Ka-band antenna element are summarized in Fig. 1(c) and (d). The Ka-band antenna element can achieve S11s less than −10-dB and gains gain larger than 6 dBi in the range from 29-30.5 GHz, as shown in Fig.1(c). In addition, the radiation pattern of the Ka-band antenna element at 30 GHz is shown in Fig. 1(d), where the 3-dB gain beamwidth of the E-plane (XOZ plane) and...
H-plane (YOZ plane) can reach 80°, and the front to back ratio (F/B ratio) is larger than 15 dB.

Fig. 2 shows the influence of the main size parameters of the Ka-band antenna element on the reflection coefficient S11. The selected size parameters are the length \( L_{f1} \) of the feed 1, the width \( W_f \) of the feed 1, and the length \( L_{a1} \) of the antenna element. As shown in Fig.2, all of \( L_{f1}, W_f \) and \( L_{a1} \) have significant impacts on the resonance frequency of the S11. Specifically, when \( L_{f1} = 4\) mm, \( W_f = 0.6-1\) mm and \( L_{a1} = 3.1\) mm, the S11 of the Ka-band antenna element has a minimized value at the center frequency of 30GHz.

Thus, a Ka-band antenna array based on the above Ka-band antenna element is designed. To reserve sufficient space for the subsequent X-band antenna array, it is necessary to appropriately widen the spacing between two adjacent Ka-band antenna elements. However, in the traditional rectangular grid plane array, when the antenna array element spacing exceeds 0.5 wavelength, the grating lobe levels of scanning beams will be greater than 10dB. Therefore, the Ka-band antenna array adopts a triangular grid layout to ensure that the grating lobe level of the scanning beam will not deteriorate when the array element spacing exceeds 0.5 wavelength [18].

The structure and simulated results of the proposed Ka-band antenna array are shown in Fig. 3, where the Ka-band antenna array is composed of 8 × 8 antenna elements. Here, the parameters \( d_{x1} \) and \( d_{y1} \) are the distances between two adjacent antenna elements in the X-direction and Y-direction, respectively. Taking the case of beam scanning in E-plane (XOZ plane) as an example, the scanning beams with different \( d_{x1} \) has been analyzed, where \( d_{x1} \) varies from 5–6.5 mm and the port phase difference (PPD) is set to 150°. As depicted in Fig. 3(b), when \( d_{x1} = 5 \) mm, the beams of the Ka-band antenna array can achieve a maximum scanning angle of 50°. Besides, when \( d_{x1} = 6.5 \) mm, the maximum beams scanning angle of the Ka-band antenna array is 45°, but the grating lobe has deteriorated to −7 dB at this time. Thus, \( d_{x1} \) is set to 6mm to ensure that the scanning angle of the beam can reach 30°.

**B. DESIGN OF THE X-BAND ANTENNA ARRAY**

The structure and simulated results of the X-band antenna element are shown in Figs. 4(a)-(d). Here, the antenna element is composed of three metal layers and two dielectric substrates, as shown in Figs. 4(a) and (b). The layout of the X-band antenna element is as follows: dipole strip 2 act as the radiation part is located in the upper metal layer. GND with a loaded H-shaped slot is located in the middle metal layer, and feed 2 is located in the bottom layer. The size parameters of the X-band antenna element are shown in Fig. 4(b). The simulated results of the X-band antenna element are shown in Figs. 4(c) and (d). The X-band antenna element has achieved S11s less than −10-dB and gains larger than 3dBi in the frequency range from 9.9 to 10.1 GHz. In addition, the radiation pattern of the X-band antenna element at 10 GHz has been shown in Fig.4(d), where the 3-dB beam width in the E plane (XOZ plane) is 80°, and the beam width in the H plane (YOZ plane) is 50°. Besides, the F/B ratio of the beam is better than 15dBi.

Similarly, Fig. 5 shows the influence of the main size parameters of the X-band antenna element on the reflection coefficient S11. Specifically, when the array element spacing exceeds 0.5 wavelength, the grating lobe levels of scanning beams will be greater than 10dB. Therefore, the Ka-band antenna array adopts a triangular grid layout to ensure that the grating lobe level of the scanning beam will not deteriorate when the array element spacing exceeds 0.5 wavelength [18].
The selected size parameters are the length $L_{f2}$ of the feed 2, the length $W_{f2}$ of the feed 2, and the length $L_{a2}$ of the antenna element. As shown in Fig. 2, both $L_{f2}$ and $L_{a2}$ significantly affect the resonant frequency of $S_{11}$, and $W_{f2}$ only affects the value at the resonant point of $S_{11}$. Specifically, when $L_{f2} = 4$ mm, $W_{f2} = 0.8$ mm and $L_{a2} = 3.1$ mm, the $S_{11}$ of X-band antenna element has the minimized value at the center frequency of 10 GHz.

Similar to the Ka-band antenna array, the X-band antenna array can be designed based on the X-band antenna element. Fig. 6(a) shows the structure of the X-band antenna array, which is a rectangular planar array composed of $4 \times 4$ elements, and $d_{x2}$ and $d_{y2}$ are the spacing between X-band antenna elements. Fig. 6(b) shows the simulated scanning beams of the X-band antenna array when $d_{x2}$ varies from 10–15 mm, where $PPD = 150^\circ$. Here, when $d_{x2} = 12$ mm ($0.4\lambda_x$), the maximum scanning angle of the beams can reach $55^\circ$. Notably, when $d_{x2} = 15$ mm ($0.55\lambda_x$), the scanning angle is less than $45^\circ$ and the grating lobe level is larger than -10 dB. Thus, $d_{x2}$ is set to 12 mm to ensure that the scanning angle of the beam can reach $38^\circ$ and the grating lobe level less than -10 dB.

**C. PROPOSED X-/Ka- BAND SHARED APERTURE SCANNING ANTENNA ARRAY**

The proposed X-/Ka-band shared aperture scanning antenna array is a composition of the Ka-band and X-band antenna array analyzed above. Its structure is shown in Fig. 7, and it is composed of four metal layers and three dielectric layers.

The layout of the metal layers is as follows: Firstly, the X-band antenna elements and the Ka-band antenna elements are located on the metal sheet 1 and interlaced with each other. Secondly, to ensure the X-band antenna element does not overlap with the Ka-band antenna structure, distance parameters $d_{x2}$, $d_{y2}$, $d_{x1}$ and $d_{y1}$ should satisfy the following relationship that $d_{x2} = 2d_{x1}$ and $d_{y2} = 2d_{y1}$. Thirdly, the feed networks of Ka-band antenna elements are located on the metal sheet 2. Lastly, the metal layer 3 is the GND of the whole shared aperture antenna array. Finally, the feed networks of the X-band antenna array are located at the metal layer 4.

The aforementioned layout for the antenna element is considered as follows. First, as shown in Fig. 7, both X-band and Ka-band use dipole stripes as antenna elements have a smaller area than the traditional square microstrip patch antenna. This layout can avoid structure overlapping of antenna elements when X-band antenna elements and Ka-band antenna elements are interlaced to each other.
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Secondly, the Ka-band antenna element spacing parameter \(d_{x1}\) is set to 6mm (0.6 wavelength), which can ensure that the scanning angle of the Ka-band antenna array can reach to 30°. Notably, setting the X-band antenna element spacing parameter \(d_{x2}\) to 12 mm (0.5 wavelength) can ensure that the scanning angle of the X-band antenna array can reach to 38°. The Ka-band antenna array adopts a triangular grid array so that when the distance between adjacent antenna elements reaches 0.6 wavelength, the grating lobe levels of the beams are still less than \(-10\) dB. Since the grating lobe level of the X-band antenna array within the scanning range is less than \(-10\) dB, a rectangular grid array is adopted. Finally, the X-band and Ka-band antenna arrays are all located on the uppermost layer of the entire antenna array, so that the pattern distortion of the antenna arrays in these two frequency bands can be avoided.

Then, the antenna number ratio of the proposed antenna array is discussed. Antenna number ratio is defined as the ratio between the number of Ka-band antenna elements and that of X-band antenna elements when the Ka-band array is and the X-band array share similar area. The antenna number ratio of the shared aperture antenna array has an impact on the aperture utilization \(\eta\), where \(\eta = (f_{\text{high}}/f_{\text{low}})/(N_{\text{high}}/N_{\text{low}})\). To illustrate this point, this paper shows the structures of the proposed shared aperture antenna array and the aperture utilizations when the antenna number ratio is different, as shown in Fig. 8.

As shown in Fig. 8 (a), when the number of Ka-band antenna elements is 64 and the number of X-band antenna elements is 16, the antenna number ratio is 4. Thus, the aperture utilization of the proposed X-/Ka-band shared aperture antenna array equals \(3/4 = 75\%\). Similarly, as shown in Fig. 8 (b), when the number of Ka-band antenna elements is 64 and the number of X-band antenna elements is 9, the antenna number ratio is 7. Thus, the aperture utilization of the proposed X-/Ka-band shared aperture antenna array equals \(3/7 = 42\%\). It is clear to see that the closer the frequency ratio is to the frequency ratio, the higher the aperture utilization. That’s why the scheme with the antenna number ratio of 4 is adopted in this paper.

The reasons for this layout of the feed networks of the two frequency bands are as follows. Firstly, to maximize the working bandwidth of the antenna array, the proposed antenna array adopts a parallel feed network topology. However, the feed network of parallel feed tends to have a large area, so the feed networks of the X-band antenna array and feed networks of the Ka-band antenna array cannot be placed on the same metal layer. Second, since the distance between the Ka-band antenna elements is very close, it is necessary to ensure that the width of the feed lines of the Ka-band network are sufficiently narrow to bypass the X-band antenna elements. Besides, if a microstrip line with a narrow line width is adopting the aperture-coupled method through the slot on the ground, the back-lobe level of the antenna array will increase. Therefore, the feed network of the Ka-band antenna array is put above the GND, and that of the X-band antenna array is put below the GND.

To verify that the proposed array can operate as desired, the isolation performance between the X-band antenna array and the Ka-band antenna array is analyzed. As shown in Fig. 9, isolations between the X-band input port and Ka-band input port are larger than 23dB in the X-band and larger than 35dB in the Ka-band, respectively. Fig. 10 shows the dielectric layer magnetic-field (H-field) distributions of the proposed array. As depicted in Fig. 10(a), when the X-band antenna array is excited at 10 GHz, its H-field amplitude reaches 100A/m, while the H-field of the Ka-band antenna array is only less than 20 A/m. This shows that only a small amount of energy is coupled to the Ka band

![FIGURE 9. Simulated isolations between X-band input port and Ka-band input port.](image)

![FIGURE 10. H-field distribution. (a) 10 GHz. (b) 30 GHz.](image)
antenna array when the X-band antenna array works alone. Because the coupling energy is very small, Ka band antenna array cannot work, so the electromagnetic field isolation performance of X-band array and Ka band array is good. Similarly, the X-band antenna array is slightly coupled when the Ka-band antenna array is excited at 30 GHz, as depicted in Fig. 10(b). Therefore, Fig. 10 has validated that the electromagnetic field isolations between X-band antenna array and Ka-band antenna array of the proposed array are also very good.

The radiation patterns of the proposed array with different PPD (0°, 90°, and 157°) in 10 GHz and 30 GHz are also studied and plotted in Fig. 11. As depicted in Fig. 11(a), the X-band beams of proposed array are similar to those of the single X-band antenna array. As depicted in Fig. 11(b), the beams of proposed array in the Ka-band are also well matched with those of the single Ka-band antenna array at 30 GHz. Here, the beam scanning ranges of (0°, −55°) and (0°, −45°) are achieved at the X-/Ka-band, respectively.

Then, the influence of the air gap between the dielectric layers on the antenna array is analyzed. Different from the single-layer antenna array, the air gaps of multi-layer antenna array structure will have influences on the antenna performance, which needs to be discussed. The simulated model is shown in the Fig. 12, which is similar to the structure of...
antenna array in Fig.7, except that there are two air gaps between each layer of dielectric substrates. It should be noted that the thickness of the air gap between the lowest substrate and the middle substrate is named as $g_1$, and the thickness of the air layer between the middle substrate and the uppermost substrate is named as $g_2$. Then, Fig.13 shows the patterns of antenna array when parameters $g_1$ and $g_2$ take different values.

As depicted in Fig.13, the increase of the thickness $g_1$ and $g_2$ will reduce the gain of the proposed antenna array whether at 10GHz or 30GHz. In addition, the increase of $g_1$ and $g_2$ will also improve the profile of the antenna array. Therefore, in the proposed antenna array, each layer of dielectric substrates was stacked without air gap ($g_1 = g_2 = 0$mm) to avoid the decline of beam gain and reduce the profile.

**D. DESIGN OF THE FEED NETWORK**

In order to verify the proposed X-/Ka-band shared aperture antenna array, beams with two scanning angles are selected in X-band and Ka-band, respectively [19], [20]. Among them, the selected X-band scanning angles are $0^\circ$ and $38^\circ$, respectively. And the selected Ka-band scanning angles are $0^\circ$ and $30^\circ$, respectively. It should be noted that the scanning planes of the above beams are XOZ planes. Then, two groups of X-band feed networks and two groups of Ka-band feed networks need to be designed according to the above scanning angle. The schematic diagrams of X-band and Ka-band feed networks are shown in Fig.14, which are composed of power dividers and phase shifters. The phase differences between adjacent ports of the phase shifters of the feed network are determined in this way. For the X-band feed network, the scanning angle of the selected beam is $0^\circ$ and $38^\circ$, so the phase differences of the output ports of the two groups of feed networks can be calculated as $0^\circ$ and $120^\circ$, respectively. Similarly, the phase differences between the adjacent ports of the two groups of Ka-band feed networks are $0^\circ$ and $120^\circ$, respectively. The structures of the designed feed networks realized by microstrip lines are shown in Fig. 15.

Then, the feed networks are connected with the proposed antenna arrays to form two X-/Ka-band shared aperture scanning antenna arrays, called Type-A and Type-B. For Type-A, the phase differences between adjacent ports of X-band feed network and Ka-band feed network are $0^\circ$, so the scanning angles of X-band beam and Ka-band beam are $0^\circ$.

For Type B, the phase difference between the adjacent ports of X-band feed network and Ka-band feed network is $120^\circ$, so the scanning angles of X-band beam and Ka-band beam are $38^\circ$ and $30^\circ$, respectively. It should be noted that in Type B, the scanning angle of X-band beam is different from that of Ka-band beam, which is caused by the difference between the number of antenna elements of X-band antenna array and Ka-band antenna array. In addition, the simulated models of Type-A and Type-B are shown in Fig.16.
III. FABRICATION AND MEASUREMENT

The picture of the fabricated Type-A and Type-B are shown in Figs. 17. Besides, a microwave anechoic chamber (NSI-2000) is used to measure the Type-A and Type-B.

The reflection coefficient curves of X-band and Ku-band for Type-A and Type-B are shown in Figs. 18(a) and Figs. 18(b), respectively. Here, the simulated S11s and S22s of Type-A and Type-B are well-validated with the measured ones, respectively, except that measured S22s have unexpected harmonic modes, which may be due to slight fabrication error such as air gaps during assembly and the reflection of the coax connector. Nevertheless, in the range of 9.9-10.2 GHz, all S11s of Type-A and Type-B are less than −10dB. In addition, in the range of 29.5-to 30.6 GHz, all S22s of Type-A and Type-B are less than −10dB. By further observing the isolation level plotted in Figs. 18(c) and Figs. 18(d), Type-A exhibits an isolation greater than 20 dB in 9.5-10.5 GHz, whereas its corresponding isolation in Type-B was only >13 dB, which is due to the loading of additional
phase shifters in close proximity with the H-shaped slot of X-band antenna elements. Notably, very desirable isolation levels of $>30$ dB were measured across the Ka-band of the two prototypes. The measured and simulated radiation patterns of the two prototypes at 10 GHz and 30 GHz are plotted in Fig. 19(a) - Figs. 19(d), respectively, and the measured results are well-validated with the simulated ones. At 10 GHz, the scanning angles of Type-A and Type-B are approximately $0^\circ$ and $38^\circ$, respectively. The measured maximum gain (MMG) of Type-A reaches 12.6 dBi, and that of Type B reaches 12.8 dBi. At 30 GHz, the scanning angles of Type-A and Type-B are approximately $0^\circ$ and $-30^\circ$, respectively. Here, the MMG of Type-A reaches approximately 20.1 dBi, and the MMG of Type B reaches approximately 17.5 dBi. The maximum gain difference between X-band and Ka-band are 7.5 dB and 5.7 dB for Type-A and Type-B, respectively.

As depicted in Fig.20, the maximum efficiencies of the proposed antenna array are 45% and 65% in X-band and Ka-band, respectively. In addition, the gains of the proposed antenna array in the operating frequency band is shown in Fig.21. It can be seen that in the X-band, the gains of the proposed antenna array type-A and type-B are in the range of 11.5dBi-12.6dBi and in the range of 11dBi-12.8dBi, respectively. In addition, in the Ka-band, the gains of the proposed antenna array type-A and type-B are in the range of 16.5dBi-20.1dBi and in the range of 16.4dBi-17.5dBi, respectively. Notably, the discrepancy between the measured and simulated results is mainly caused by the alignment errors and fabrication errors.

**IV. COMPARISON**

The comparison between the proposed X-/Ka-band shared aperture scanning antenna array and other dual band arrays is shown in Table 1. In [6] and [7], the low-frequency antenna of the shared aperture antenna arrays are single elements, and the beam scanning characteristics are not mentioned. The shared aperture antenna array in [8], [9], and [10] have the disadvantage of high profile. In [11], the beam scanning performance of shared aperture antenna array is not analyzed. The antenna number ratio of the shared aperture antenna array in [12] is greater than the frequency ratio, which reduces the aperture utilization of the array. Different from the above antenna array, the proposed X-/Ka-band shared aperture scanning antenna array can meet the requirements of low profile and beam scanning in the operation band at the same time. Besides, the antenna number ratio is close to the frequency ratio, which improves the aperture utilization.
TABLE 1. Performances comparison between the proposed work and other references.

| Ref. | Freq (GHz) | $f_{\text{high}}/f_{\text{low}}$ ratio | $N_{\text{high}}/N_{\text{low}}$ ratio | Antenna-geometry | array | Minimum Profile | Max$\theta$ | Maximum Gain(dB) | Efficiency (%) |
|------|------------|-----------------|-----------------|-----------------|-------|----------------|------------|----------------|----------------|
| [1]  | 5.3/9.6    | 1.81            | NM              | Patch/Slot      | Yes/Yes | NM             | 0°/0°      | NM/NM          | NM/NM          |
| [6]  | 3.6/25.8   | 8               | 64              | Patch/Slot      | No/Yes  | 0.08λ         | 0°/0°      | 10.88/22.4     | 65.3/43        |
| [7]  | 3.5/60     | 17              | 144             | Slot/Slot       | No/Yes  | 0.07λ         | 0°         | 7.3/24         | NM/NM          |
| [8]  | 20/30      | 1.5             | 1               | Dipole/Open waveguide | Yes/Yes | NM             | 40°/40°    | 13.2/17.2      | 76.03/74.4     |
| [9]  | 20/30      | 1.5             | 2               | Patch/Patch     | Yes/Yes | 0.3λ          | 50°/50°    | NM             | NM             |
| [10] | 1.25/3.6/10| 1.28            | 1.6/10.5        | Dipole/Patch/Patch | Yes/Yes | NM             | 30°/30°/30° | 13.2/18.6/21.79 | NM             |
| [11] | 9.6/14.8/34.5| 1.5/3.7         | 4/1             | Patch/Dipole/Patch | Yes/Yes | 0.04λ         | 0°/0°/0°   | 13.8/18.1/19.2 | 85/82/80       |
| [12] | 3.1/9.1    | 2.9             | 11              | Metasurface/patch | Yes/Yes | 0.04λ         | 50°/50°    | NM             | NM             |
| This work | 10/30 | 3.1             | 4               | planar          | Yes/Yes | 0.05λ         | 40°/30°    | 12.8/20.1      | 45/65          |

NM: not mentioned.

V. CONCLUSION
An X−/Ka-band shared-aperture scanning antenna array has been proposed for the SAR in satellite applications. The Ka-band antenna array is a triangular grid planar array made up of 8 × 8 antenna elements and the X-band antenna array is a square grid planar array made up of 4 × 4 antenna elements. The antenna elements of the X-band array and the Ka-band array are microstrip dipole antenna. By interlacing the Ka-band antenna elements and the X-band antenna elements with each other, the proposed shared-aperture antenna array can be obtained. Due to the use of compact antenna elements and the way of interlacing the antenna elements of the two frequency bands, the isolation between the X-band antenna elements and Ka-band antenna elements are higher than 30dB at the operation band of 10GHz and 30GHz. Notably, the proposed antenna array achieves an antenna number ratio ($N_{\text{Ka}}/N_{\text{X}}$) of 4, which is close to the $f_{\text{high}}/f_{\text{low}}$ equals 3.1. Thus, the aperture availability is up to 75%. In addition, the overall structure profile of the proposed antenna array is only 0.05λ, where λ is the air wavelength at 10GHz. The measured results show that a scanning angle of up to 38°, an efficiency of 45%, and a maximum gain of 12.8 dBi can be achieved in X-band. Besides, a scanning angle of up to 30°, an efficiency of 65%, and a maximum gain of 20.1 dBi can be achieved in Ka-band.

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