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REVIEW ARTICLE

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Progress in dual-band dual-polarization shared-aperture SAR antennas

Abstract The progress in dual-band dual-polarization (DBDP) shared-aperture antennas for the synthetic aperture radar (SAR) application in the last decade is reviewed. Several designs of DBDP SAR antenna arrays are introduced with their main performances, then their comparison is summarized. In addition, some techniques enhancing DBDP antenna performances are presented.

Keywords dual-band, dual-polarization, microstrip antenna, shared-aperture, synthetic aperture radar (SAR)

1 Introduction

In June 1978, American satellite SEASAT was launched, which marked the start of the space-borne synthetic aperture radar (SAR) system era. Over 30 years from then, more and more SAR systems have been proposed, developed and manufactured, such as ALMAZ SAR system launched by the former U.S.S.R in 1991, ERS-1 of European Space Agency (ESA) in 1991, JERS-1 from Japan in 1992, RadarSat-1 and RadarSat-2 of Canada in 1995 and 2005, and Terra SAR-X of German in 2007, etc. Another milestone is that the SIR-C/X-SAR of American Space Shuttle Endeavour completed the high resolution three-dimensional (3D) imaging all over the globe in Feb. 2000.

The overall performances of an SAR system such as azimuth/elevation resolution, imaging ambiguity, width of mapping area and so on are directly determined by the performance of its antenna. The dual-polarization operation of the antenna can provide additional information and thus the probability of target detecting and identifying is enhanced; while its multi-band operation will provide more information such as the back-scattering data and the penetration data of objects. L (center at 1.275 GHz), S (3.0 GHz), C (5.3 GHz), and X (9.6 GHz) bands are the common bands of space-borne SARs. For example, the SIR-C/X-SAR system is of L/C/X tri-bands and dual-polarization, whose advantages were proved and the function of 3D mapping was realized by the use of interference imaging [1]. However, as shown in Fig. 1, its antenna consists of L, C, X three sub-arrays with 12 m×4.1 m area, resulting in the bulky structure of about 3000 kg weight. The realization of shared aperture configuration will minimize the volume and weight of the antenna and share the sub-systems behind the array as well. Therefore, the dual-band dual-polarization (DBDP) shared-aperture antenna array has been proposed and studied. In China, following many studies on the dual-polarized planar antenna arrays [2–6], the development of DBDP arrays has also been carried out [7–9].

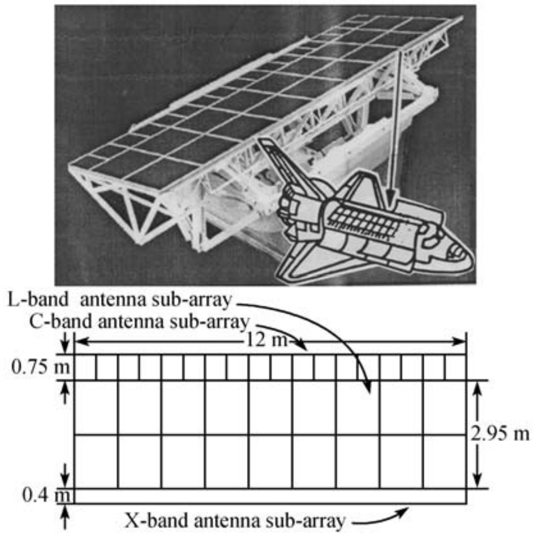

Fig. 1 Antenna of SIR-C/X-SAR

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The typical configuration of DBDP array includes perforated patches [10,11], interlaced slot/dipole with patch [7,8,12,13] and some other forms derived from them [14]. The review and comparison among them will be presented. Some recently developed techniques to enhance DBDP antenna performances will also be introduced.

2 DBDP array design

The dual-band and dual-polarized operation of an antenna has been applied in a lot of systems, such as mobile communications, deep space communications and radio astronomical telescope, etc. The requirements for antennas are varied in different missions. For the former case, an omni-direction pattern is usually required while for the latter two, the reflector antennas are preferred where a horn or a small patch array may be used as the feed [15,16].

This paper emphasizes the DBDP antennas for SAR application. For the future remote sensing mission, two-plane phased scanning characteristics are needed, so the possibility of using reflector antenna is excluded. Meanwhile, although the waveguide slotted antenna array has better efficiency and sidelobe characteristics, it is still not preferred in future SAR application, because it is hard to realize two-plane phased scanning/beam-forming DBDP operation and its mass is large [6]. Thus, the microstrip patch array becomes the best choice. Because the operation frequencies of different bands in the DBDP SAR application are widely separated, it is difficult to use dual-frequency radiator element to construct a DBDP antenna array. Thus, it comes as an obvious alternative to construct a DBDP antenna by integrating the radiators for each individual band. And apparently, the multi-layer configuration is required to contain two individual band elements and their feed networks. In addition, the cross-polarization of the array should be less than -30 dB or it will cause imaging ambiguity, and the isolation between dual polarization ports should also be considered carefully. Since the bandwidth impacts the elevation resolution directly, it is more an important target.

2.1 Perforated patch arrays

The DBDP antennas for SAR application are usually operating on two widely separated bands, causing great difference in dimensions of the radiators for dual bands. In order to keep the higher frequency (HF) radiator within a wavelength to suppress the grate lobes, the lower frequency (LF) radiators are perforated and the HF radiators are placed in the perforations. This type of array configuration is usually adopted when the frequency ratio of HF to LF is even. The example is an L/C-band perforated patch array by Shafai et al. (see Fig. 2) [10], where a perforated L-band patch and 16 C-band patches form a unit cell with the frequency ratio of 4:1. The patches co-planarly configured in two bands are stacked to broaden the bandwidth, achieving a bandwidth for return loss (RL) $\leqslant -14$ dB of 300 MHz at C-band (about 5.7%) and 90 MHz at L-band (about 6.4%). The patches of two bands are orthogonally fed to realize dual-polarization operation. The cross-polarization level in the bandwidth is lower than -30 dB. Another L/X DBDP array designed by Pozar and Targonski [11] uses the similar array configuration as shown in Fig. 3. The main advantage of this configuration is its wider bandwidth at LF compared with the other array design, such as that of dipole/patch. However, this will cause a difficulty in designing the antenna due to the dimension of perforation, which should be large enough to avoid hindering the radiation from HF elements. A larger perforation size is also favored in terms of good isolation performance between the two bands and a more symmetric pattern at the cost of bandwidth at LF. Then a tradeoff must be made between the bandwidth and the isolation performance.

2.2 Interlaced slot/dipole with patches

The array configuration of interlaced slot/dipole with patches is also attractive. Because of its smaller size in one dimension, the slot/dipole of LF can be easily placed between two HF elements, thus meeting the interelement-distance requirement. An example is the DBDP array of

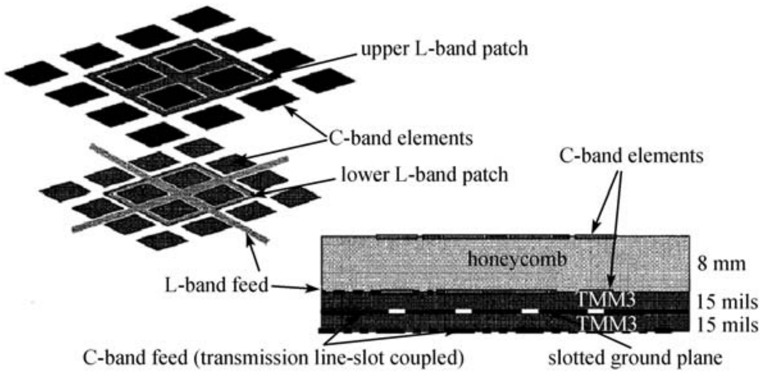


Fig. 2 L/C-band perforated patch array [10]

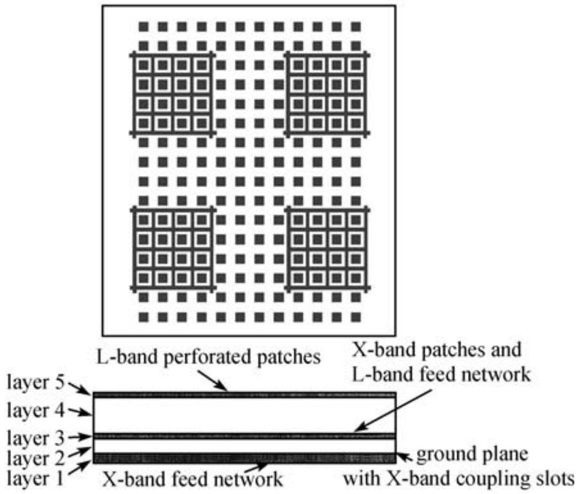


Fig. 3 Top view and side view of L/X-band DBDP antenna [11]

L/C-band interlaced slots with patches designed by Pozar et al. (see Fig. 4) [12], where square patches located on the top layer work at C-band and slots on the ground serve as L-band elements. The slots are orthogonally placed to realize the dual-polarization in L-band. This design achieves a bandwidth of more than 5% in both bands and the isolation is better than 24 dB in C-band and 23 dB in L-band. However, to suppress the backward radiation of the slots, a reflector is placed 1/4 wavelength behind the slot and therefore the dimension of the array is increased.

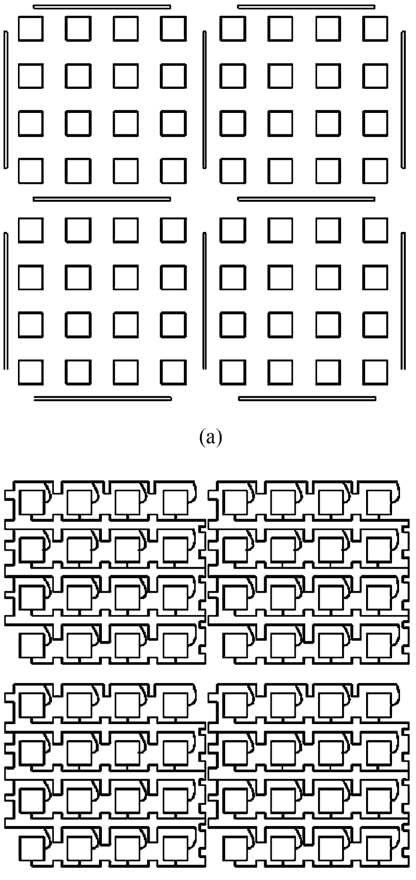


Fig. 4 L/C-band interlaced slots with patches [12]. (a) Top layer parasitic patch; (b) driven patch with feed

In another example, S/X-band interlaced dipoles with patches are proposed by our group [7,8] as shown in Fig. 5, where both stacked patches and stacked dipoles are adopted, which achieve a measured bandwidth of 8.9% and 17% in S-band and X-band, respectively, with its frequency ratio of about 1:3, as shown in Fig. 6. Since the S-band dipoles are cross placed and located on another side of the substrate, with such a configuration, the cross-polarization and the isolation between two ports at S-band are minimized, resulting in the cross-polarization levels of better than −26 dB and −31 dB at S-band and X-band, respectively. In addition, by using dipoles instead of slots, the serious backward radiation is avoided. However, the bandwidth of dipole is usually narrower than that of slot, so a stacked dipole is used and another substrate is needed compared to the interlaced slot/patches array aforementioned. From the radiation patterns of both bands depicted in Fig. 7, it is obvious that both bands have little impact on each other in radiation patterns — from the shape and null points of patterns, so they look like working "separately".

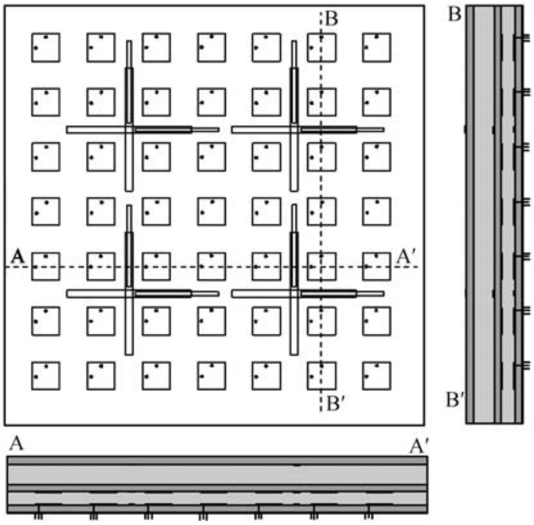


Fig. 5 S/X-band interlaced dipole with patches

2.3 Some other array configurations

Some other array configurations have also been proposed, most of which can be classified as the deriving forms of the two basic types mentioned in Sects. 2.1 and 2.2. One example is the S/X-band cross-patch/patch array proposed by Salvador et al. in Ref. [14] (see Fig. 8). Its S-band

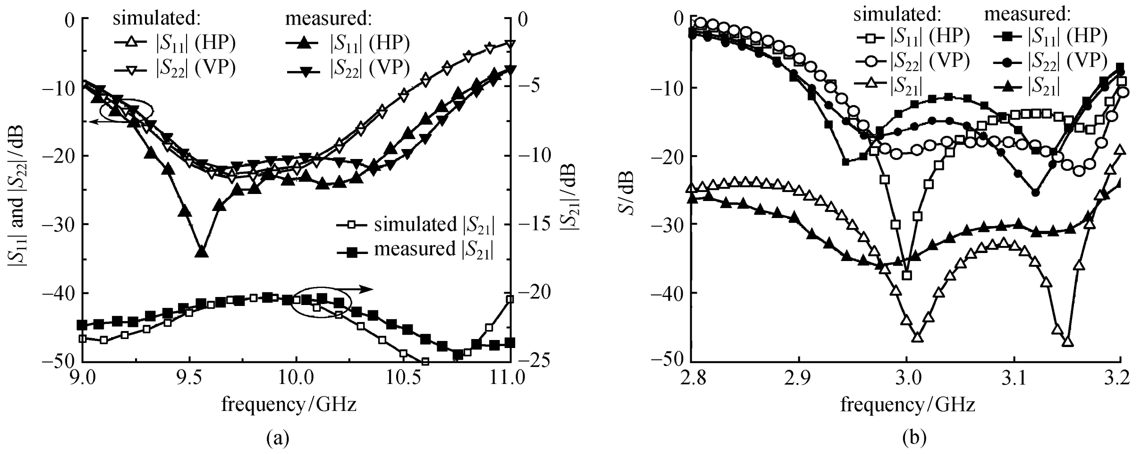


Fig. 6 Measured *S* parameter of S/X-band array. (a) X-band element; (b) S-band element

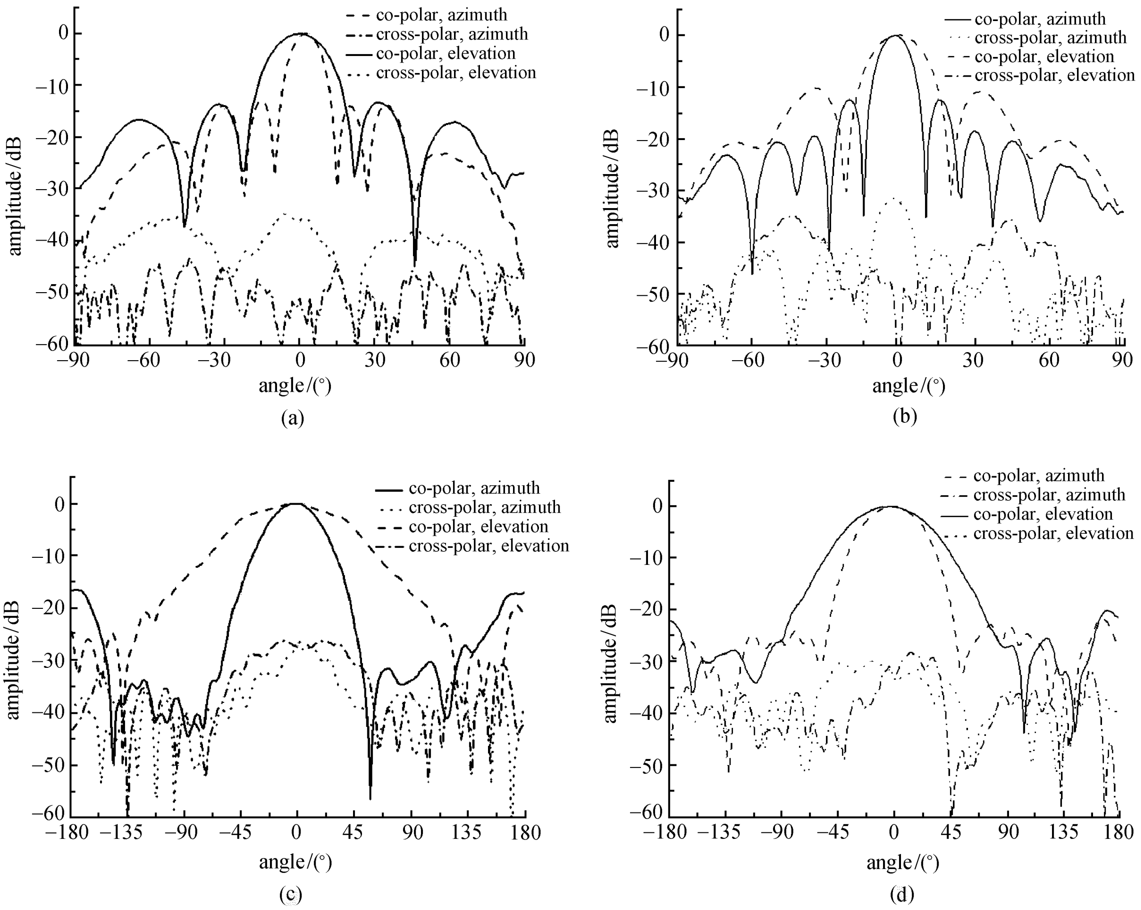


Fig. 7 Measured radiation patterns of S/X-band arrays. (a) H-polarization of X-band; (b) V-polarization of X-band; (c) H-polarization of S-band; (d) V-polarization of S-band

cross-patch and X-band patches are co-planarly interlaced. It may be seen as the corner-removed perforated patch (L-band perforated patch in Fig. 2) or the co-plane cross-placed dipole (S-band dipole in Fig. 5). The bandwidth of the cross-patch is proportional to the width of its “leg”, which is constrained by the interelement distance. An obvious drawback is that if the gap between two bands is narrow (the leg of cross-patch is too wide), serious

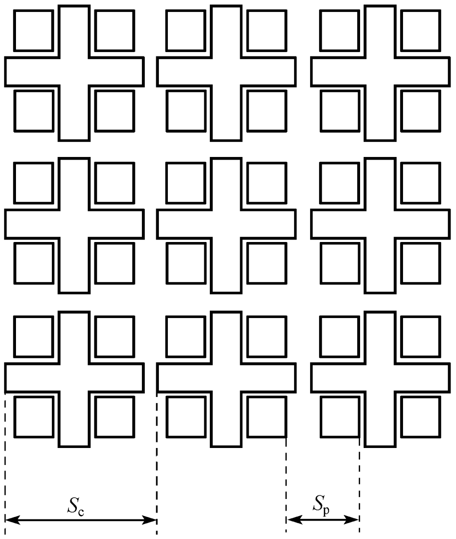


Fig. 8 S/X-band interlaced cross-patch with patch [14]

inter-band couple will be caused and the radiation pattern will be distorted.

Another example in Ref. [15] adopts interlaced L-band perforated cross-patch with C-band patch whose top view and cross section of interlaced perforated cross patch with patches are shown in Fig. 9. The LF perforated cross-patch on the top layer is interlaced and rounded by 9 HF patches located on another substrate behind it to form a unit cell. Also, the unit cells are cascade-fed to make up a traveling wave linear sub-array [16], and then a linear sub-array is used to construct a sub-array. Benefiting from its "H"-shape slot aperture coupled in both bands, the simulated cross-polarization at dual bands are claimed to be less than -40 dB, and the backward radiation is also small enough. However, the isolation performance may probably be a problem.

A comparison of several DBDP designs is listed in Table 1, showing that generally evaluated by the listed three performances, the "interlaced dipole and patch" may be one of the best choices and its flexibility in array configuration makes it more preferable.

3 Techniques of enhancing DBDP antenna performances

3.1 Pair-wise anti-phase feeding technique

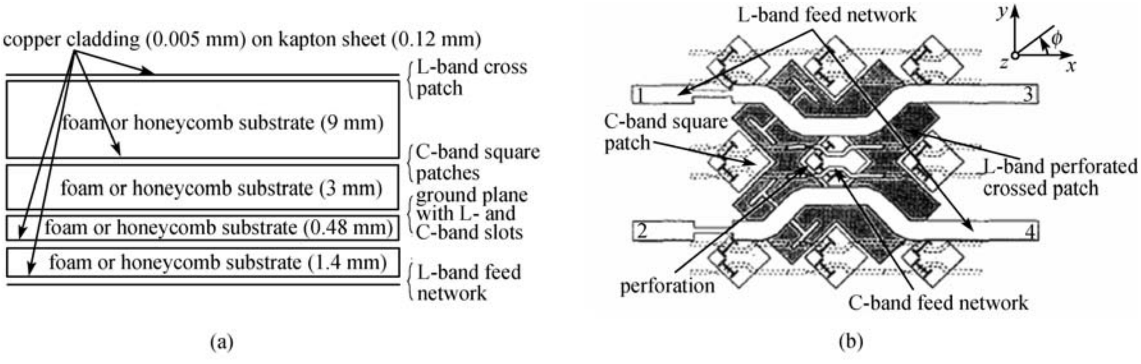
The cross-polarization level of a DBDP antenna is influenced by the figure of its element, the feeding form and the array configuration. In general, more symmetric element shape and thinner substrate (for the patch element) will lead to a lower cross-polarization level. Besides these, the "pair-wise anti-phase feeding technique" is proposed (see Fig. 10) [17,18]. The neighboring patches are mirror configured and anti-phase fed in H-port or in V-port, and thus all elements in subarray are of same effective excitation and the cross-polarization level are obviously improved at the boresight. As to the cost, in the area out of main beam, the cross-polarization level is raised.

3.2 Slot-loaded patch for improving port isolation

It is proposed to etch a slot in the corner of a driven patch by our group [19] (see Fig. 11). The effect of using the slot-loaded method can be seen from Fig. 12, where the isolation level between two ports is improved for at least 5 dB. However, the field under the patch is disturbed by the slot, then the cross-polarized field is brought out and the cross-polarization level deteriorates. In Ref. [20], a similar method is adopted. The only difference is that "T"-shaped slot and some edge-slot are etched on the driven patch, which also achieves a good isolation.

3.3 Bandwidth enhancement technique

SAR system using impulse compression technology to realize the high-resolution at elevation direction and thus wider bandwidth is required for the antenna to radiate narrower impulse (in time domain). An antenna system cannot broaden bandwidth by means of array synthesis, and the antenna bandwidth generally lies on its element bandwidth. Therefore, a lot of bandwidth enhancement methods for antenna elements have been proposed, such as



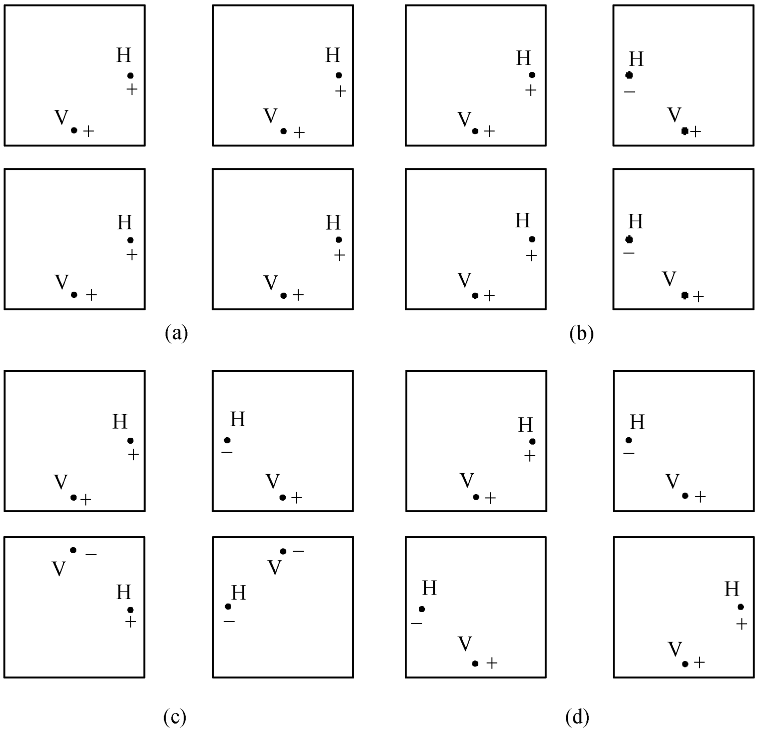
(a) (b)

Fig. 9 L/C-band perforated cross-patch/patches array [15]

Table 1 Comparison of various DBDP designs

array configuration	bandwidth	cross-polarization	port isolation	cross-band isolation
perforated patch [10]	L: 6.4%	L: about −32 dB (peak)	—	—
(in Fig. 2)	C: 5.7%	C: ⩽ −30 dB	—	—
perforated patch [11]	L: ⩾ 6%	L: about −22 dB (peak)	L: ⩽ −20 dB	⩽ −40 dB in both bands at both polarization
(in Fig. 3)	X: ⩾ 10%	X: ⩽ −20 dB	X: ⩽ −18 dB	
interlaced slot and patch [12]	L: ⩾ 5%	L: ⩽ −23 dB	—	L: ⩽ −15 dB
(in Fig. 4)	C: ⩾ 5%	C: ⩽ −24 dB	—	C: ⩽ −40 dB
interlaced dipole and patch [7]	S: ⩾ 8.9%	S: ⩽ −26 dB	S: ⩽ −20 dB	—
(in Fig. 5)	X: ⩾ 17%	X: ⩽ −31 dB	X: ⩽ −20 dB	—
interlaced slot and slot [13]	C: 5% *	C: ⩽ −21 dB	—	—
	X: 2%–3%	X: ⩽ −18 dB	—	—

* voltage standing wave ratio (VSWR) < 1.5



(a) (b)

(c) (d)

Fig. 10 Subarray configuration [17]. (a) Distant HH−; (b) close HH−; (c) HH− & VV−; (d) distant & close HH−

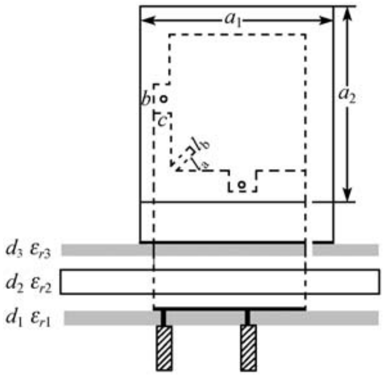


Fig. 11 Slot-loaded patch

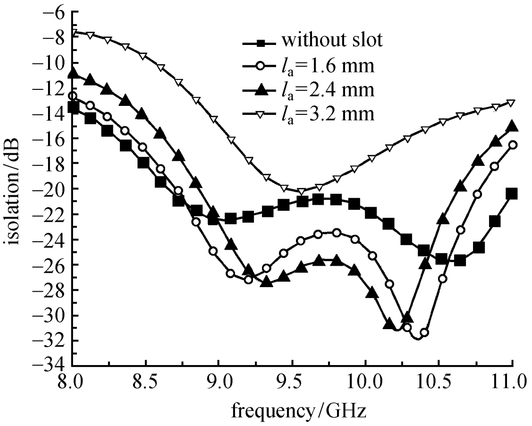


Fig. 12 Isolation S_{12} for various slot lengths

co-planar/stacked parasitic patches. In DBDP antenna array design, the distance between elements is limited by the scanning requirement and the use of stacked parasitic patches is probably the most effective broadbanding method for its room saving structure. This can achieve at least a bandwidth of 15% [19], about three times of that of a conventional patch.

4 Conclusion

The recent progress in DBDP shared-aperture antennas for SAR application has been reviewed. The merits and the shortcomings of various designs are analyzed and compared. Some techniques enhancing antenna performance are introduced.

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