Untilted Slot Array Antenna at the Narrow Wall of the Waveguide Using Double-Ridge

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ABSTRACT: In this article a novel array antenna composed of untilted slots in the narrow wall of the double-ridge waveguide, with significantly improved cross-polarization, is presented. In the first step, suitable radiating elements for designing a linear slot array antenna were created. An untilted slot which is created the narrow wall of the double-ridge waveguide is suggested to be used as the radiating resonance slot. The concave and convex ridges are located under the untilted slots only. It is shown that the concave and convex double ridge waveguides can produce an orthogonal current distribution in the place of the slots. They are also placed successively to produce the required phase inversion between adjacent slots. The linear array consists of nine uniform resonant untilted slots in the double ridge waveguide and is designed at the frequency of 5 GHz using the normalized conductance of each radiating slot. Analyzing the simulation results shows that cross-polarization of the designed array was significantly improved, it was also found that the cross-polarization and the SLL were respectively about −65 and −16 dB. © 2010 Wiley Periodicals, Inc. Int J RF and Microwave CAE 20:699–710, 2010.

Keywords: untilted slot; double ridge waveguide; cross-polarization; linear array

I. INTRODUCTION

The slotted waveguide array is widely used in radars and communication because of its simplicity, low fabrication cost, proper electric performance, precise control of aperture distribution, and low loss. In this antenna, the radiating element is simply a narrow slot milled in the broad wall or the narrow wall of a rectangular waveguide. For some applications, edged slot waveguides are desired. The slot is easily machined and handles high power. However, this slot does not radiate for the dominant TE10 mode, for it does not intercept the current flow on the narrow wall. Therefore, the slot is tilted. The tilted edged slot produces an undesirable cross-polarized component. This cross polarization coupled with the variation of the slot admittance with frequency, causes pattern deterioration and loss in array efficiency [1–6].

A strong cross-polarized component, which increases as the slot array scanned at an angle away from broadside, produces interference and jamming problems.

To minimize the undesired cross-polarization, some array approaches have been used [7], resulting in complex structures.

Alternatively, untilted slots may be excited in a manner to produce desired asymmetry in field and current distributions near the slot. To achieve this distribution, replacing slot inclination with field inclination was suggested [8], in which a probe was inserted into the guide adjacent to the slot. The probes can also be used to compensate the 180° phase difference produced by $\lambda_g/2$ spacing of the slots. Another way is that the conventional excitation elements be tilted wires [1, 9], but this method may have problems in fabrication of a large array, because the titled hold for the wires must be drilled in the waveguide walls and the wires must be soldered to the walls. This makes it impossible to experimentally tune the wire location and length, and it is difficult and expensive to drill the tilted holes accurately. Furthermore, an untilted slot excited by a dielectric plate with conducting strips on both sides was developed [10]. In this way we can control the coupling more easily and more accurately than wire excitation; however, there is a problem that the dielectric plate must be fixed stably to the waveguide walls, especially for antennas working under difficult conditions [11]. The slot in excited by compound iris which produced an

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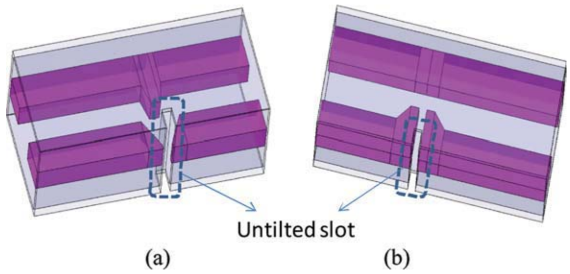


Figure 1 Proposed structure for excitation of the untilted slot (a) convex double-ridge slot waveguide, (b) concave double-ridge slot waveguide. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

inclination of the electric field as it passes the slot, although, the power handling capability of the slot is limited by the iris structure. Using a pair of shaped irises that flank the slot instead of the aforementioned wires or stripes in [12] the measured result for 16-element slot shows cross-polarization level less than −40 dB.

In this article, a novel untilted slot in the narrow wall of the double-ridge waveguide is proposed and a linear untilted slot array antenna with ultra low cross-polarization composed of untilted slots is designed. The proposed structure is realized by inserting a convexity and reducing the concavity in one of the ridges of the double-ridge waveguide. The current distribution in the double ridge waveguide will be shown in Section II. The uniformly untilted slot array was designed to have a normalized input admittance of $y = 1$ at the frequency of 5 GHz. The proposed array antenna with untilted slots in the narrow wall of the double-ridge waveguide is simulated by two established packages, named Ansoft HFSS and CST microwave studio. The former is based on the finite element method, and the latter on the finite integral technique.

II. ANTENNA DESIGN

Untilted slot should be used to reduce the cross-polarization in an array of waveguide slots. But, this slot does not intercept the current flow on the narrow wall and therefore does not radiate. Thus, the current distribution must be changed in the place of the slot so that the untilted slot radiates. In previous works, attempts were made to replace slot inclination with field inclination, so that cross-polarization could be improved. But, more reduction in the cross-polarization and also an improvement in the array antenna performance can be obtained by using orthogonal current distribution in the place of the slots.

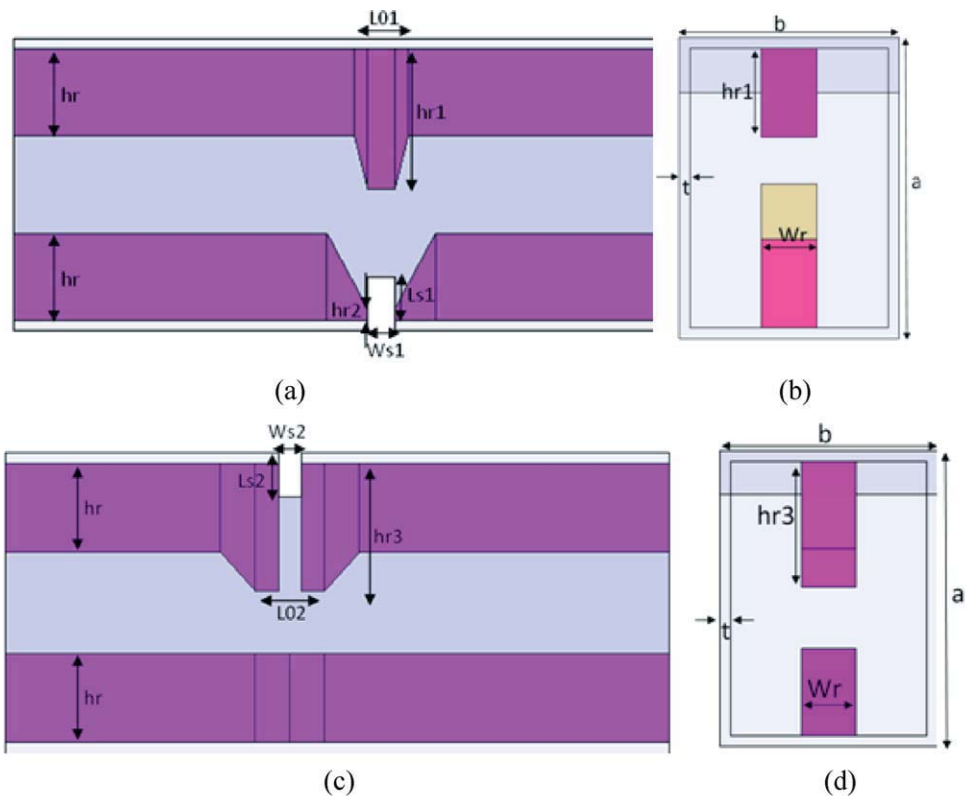


Figure 2 Dimension of proposed antenna (a) top view of convex double-ridge slot waveguide, (b) side view of convex double-ridge slot waveguide, (c) top view of concave double-ridge slot waveguide, (d) side view of concave double-ridge slot waveguide. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

TABLE I Dimensions of the Slotted Convex Double-Ridge Waveguide

a	*b*	*t*	Wr	hr	Ws1	hr1	hr2	Ls1	L01
50.4	30	2	10	16	1.55	26	2	12	15

units: mm.

TABLE II Dimension of the Slotted Concave Double-Ridge Waveguide

a	*b*	*t*	Wr	hr	Ws2	hr3	Ls2	L02
50.4	30	2	10	16	1.55	26	12	15

units: mm.

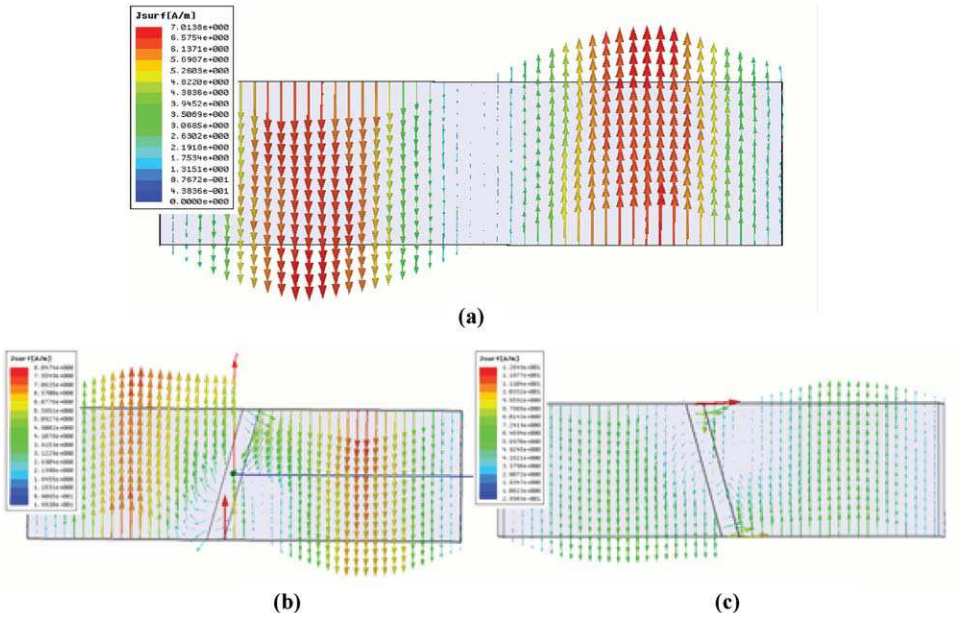


Figure 3 Current distribution in narrow wall (a) waveguide, (b) waveguide with tilted slot by positive angle, (c) waveguide with tilted slot by negative angle. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

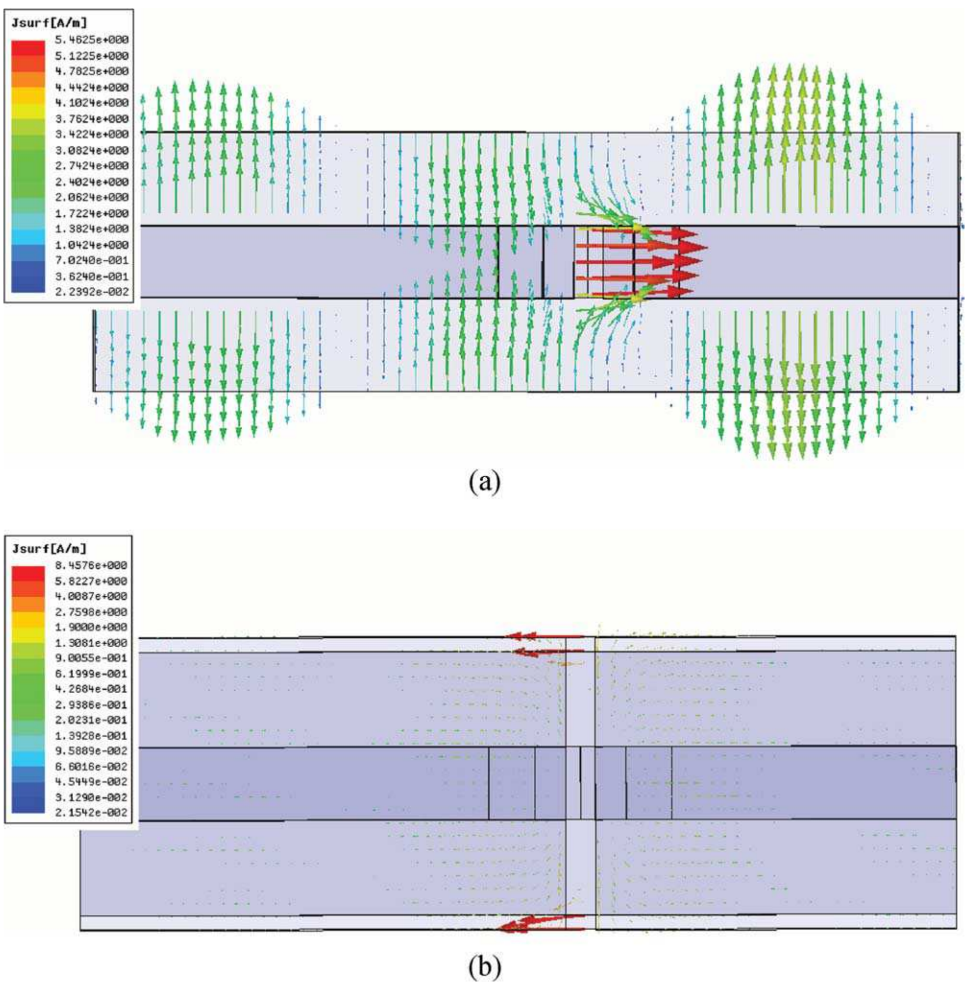


Figure 4 Current distribution in narrow wall (a) convex double-ridge waveguide, (b) convex double-ridge waveguide with untilted slot. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

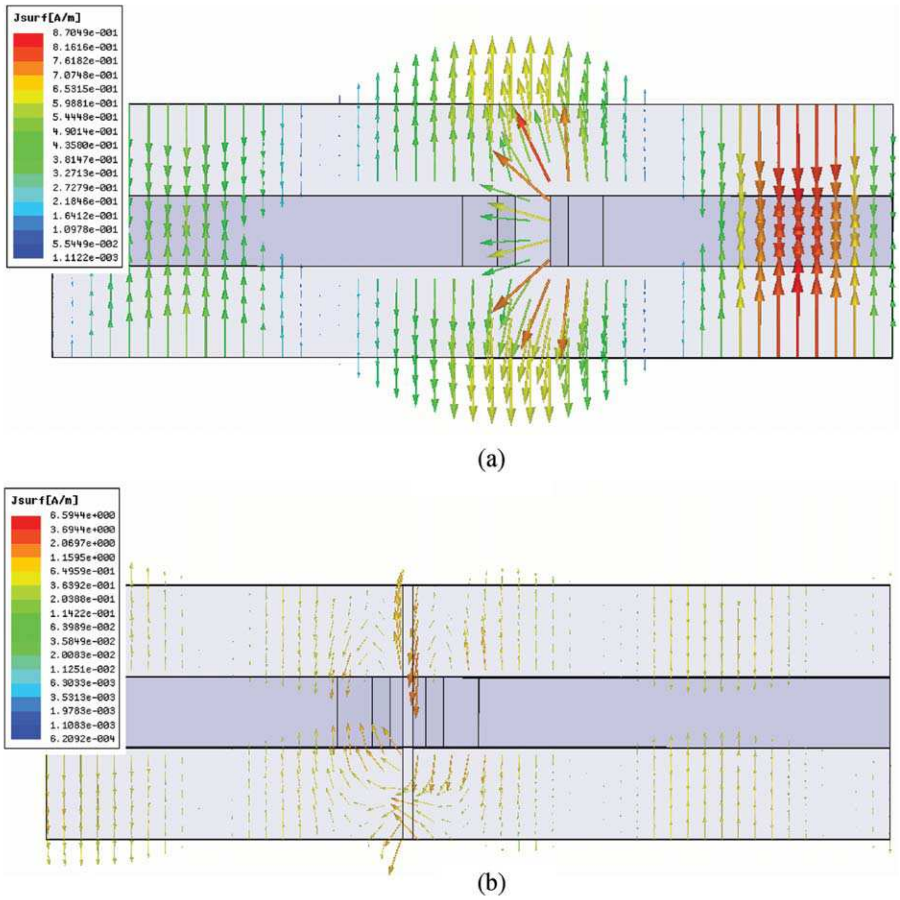


Figure 5 Current distribution in narrow wall (a) concave double-ridge waveguide, (b) concave double-ridge waveguide with untilted slot. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

One should try to make the field distribution inclined or orthogonal to the slot in the place of the slot for the radiation from the slot. To do this, one of the best methods is to use ridge inside the waveguide, for the ridges inside the waveguide conduct the fields through the desired direction so that the most of fields are conducted between the ridges inside a double-ridge waveguide. To do this, one should use ridges with which the currents nearly orthogonal at slot could be created. Figure 1 shows a proposed structure as a proper candidate to be replaced with the dominant tilted waveguide slot antenna. As shown in Figure 1, the field between two ridges starts moving depending on the convexity or concavity of the ridges in the place of the slots the field moving toward the slot radiating with the untilted slot. However, as described in the analysis of the current distribution further in this text, current distributions are nearly orthogonal to the slot in this case which results in no cross polarization.

Figure 1 shows that in this structure an untilted slot is cut in the narrow wall of a double-ridge waveguide. The ridges exist in the narrow wall of the waveguide. Figure 1a shows the convex double-ridge waveguide in which the convexity of the lower ridge is exactly under the untilted slot. Figure 1b shows the concave double-ridge waveguide in which the concavity of the upper ridge is exactly under the untilted slot. Figures 2a and 2b, respectively show top and side views of the untilted slot in convex double ridge waveguide including dimensions.

Some parameters of Figures 2a and 2b are comprised of: the depth of the resonance slot (Ls1), the width of the resonance slot (Ws1), the height of the ridges (hr), the height of the convexity in the lower ridge (hr1), and the width of the ridges (Wr). The top and side views and dimensions of the untilted slot in the concave double-ridge waveguide are shown in Figures 2c and 2d. Some parameters in Figures 2c and 2d are comprised of: the depth of the resonance slot (Ls2), the width of the resonance slot (Ws2), the height of ridges (hr), the height of concavity in the lower ridge (hr3), and the width of the ridges (Wr).

The dimensions of the slotted convex and concave double-ridge waveguides are shown in Tables I and II.

The dominant electromagnetic mode and the current distribution are inclined in the place of the slots on the narrow wall of the convex and concave double-ridge

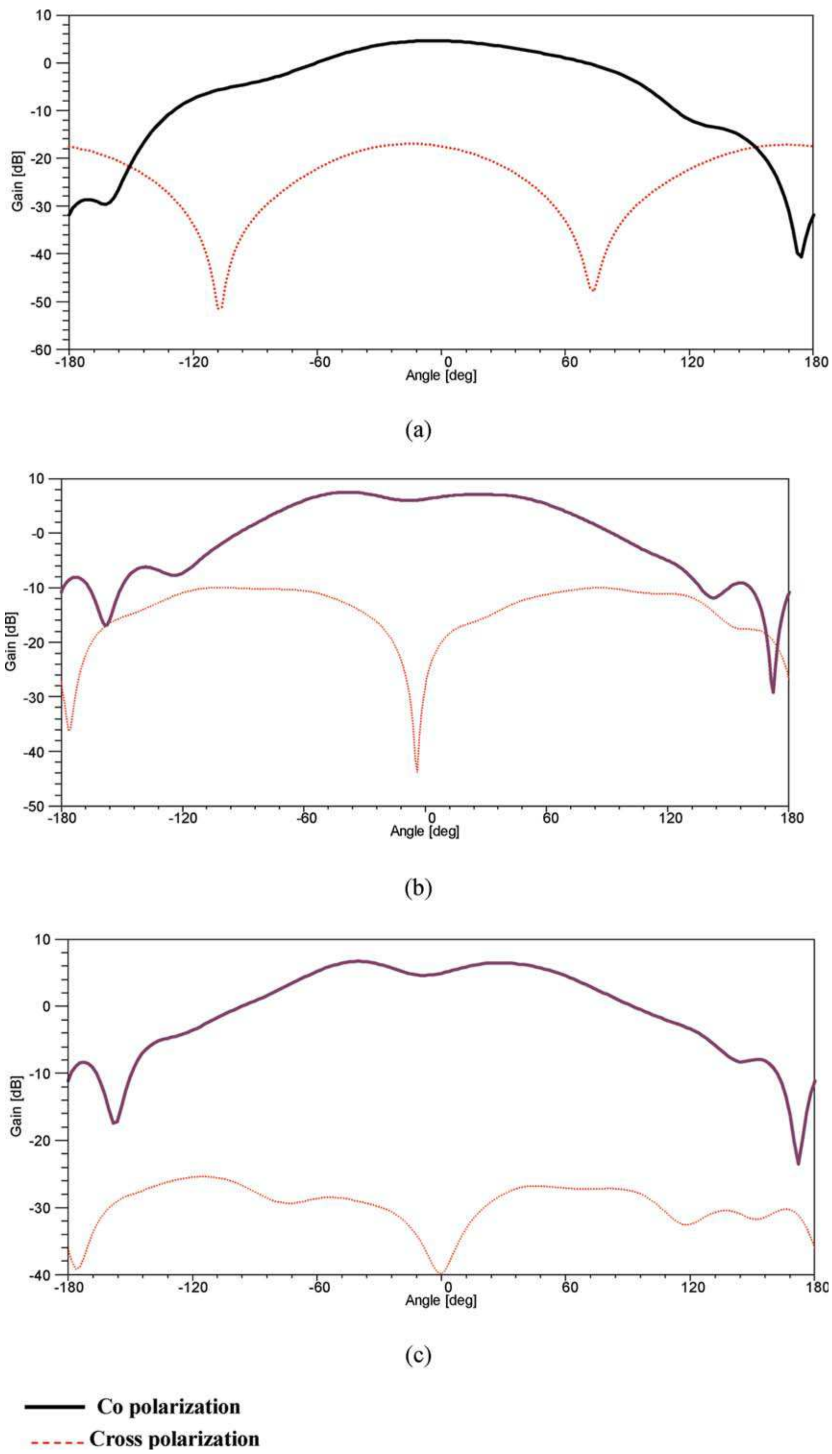


Figure 6 H-plane radiation pattern (a) tilted slot antenna, (b) untilted convex double-ridge slot, (c) untilted concave double-ridge slot. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

waveguides. Some currents are orthogonal to the slots and therefore can replace the tilted slots. The new current distribution and its equivalent surface magnetic current justify the radiation from the slots.

Figure 3a shows the current distribution in the narrow wall of the waveguide for the dominant mode. As it can be seen the slots must be inclined to interrupt the current distribution; the more inclination, the greater the

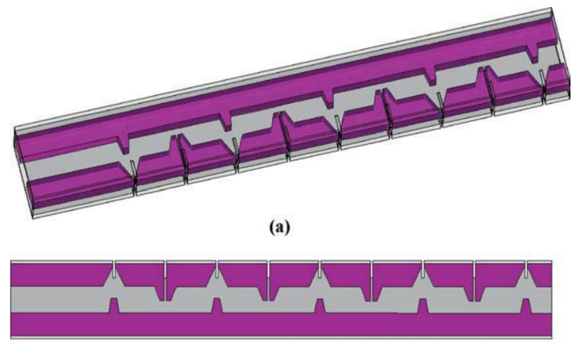


Figure 7 Configuration of the designed array for (a) front view and (b) the top and front views of the designed antenna array of nine uniform resonant untilted slots in a double ridge waveguide. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

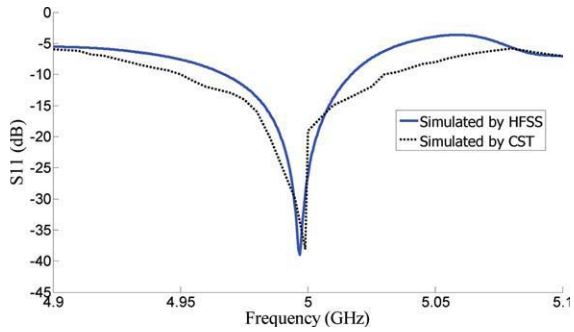


Figure 8 The reflection coefficient designed array antenna with HFSS and CST. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

interruption. Figures 3b and 3c show that the current distribution interrupts with tilted slot and therefore causes a radiation to the outer space.

Figure 4a shows the current distribution in the narrow wall of the convex double-ridge waveguide for the dominant mode. Hence, the untilted slot can interrupt the direct current distribution. Figure 4a shows that the current interrupts the untilted slot and radiates to the outer space.

Figure 5a shows the current distribution in narrow wall of the concave double-ridge waveguide for the dominant mode. Thus, the untilted slot can interrupt the direct current. Figure 5b shows that the current interrupts the untilted slot and radiates to the outer space.

The H-plane radiation pattern of the tilted slot at the frequency of 5 GHz is shown in Figure 6a; in this case the cross polarization level is 20 dB below the main lobe. Figure 6b shows the H-plane radiation pattern of the untilted slot in the convex double-ridge waveguide; the cross polarization level is 25 dB below the main lobe here. Figure 6c shows the H-plane radiation pattern of untilted slot in the concave double-ridge waveguide, as it can be seen the cross polarization level is 30 dB below the main lobe.

III. ANTENNA ARRAY DESIGN

The top and front views of the designed antenna array of nine uniform resonant untilted slots in a double ridge waveguide are shown in Figure 7. First, the normalized conductance of every single radiating slot in the convex double-ridge waveguide and the concave double-ridge waveguide is extracted. The normalized conductance of a

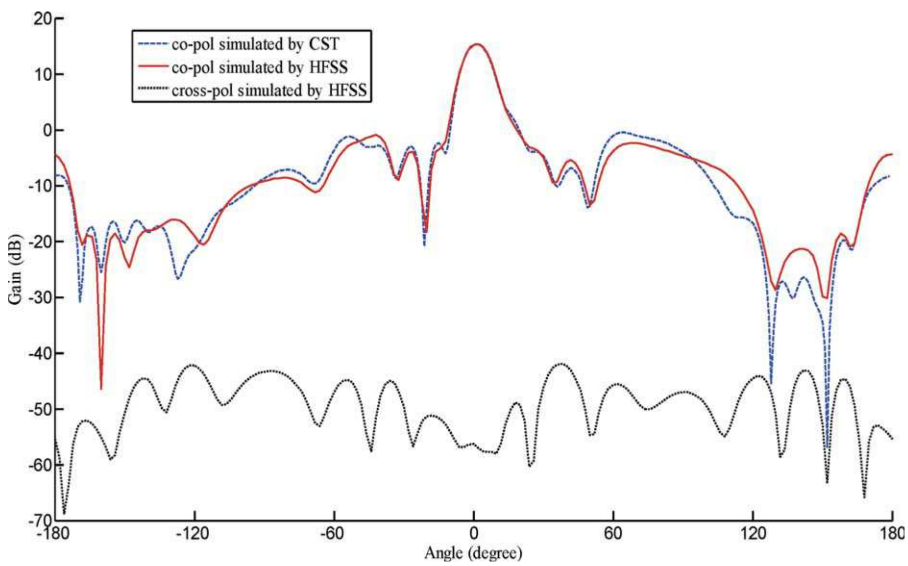


Figure 9 Simulated co and cross polarization of H-plane radiation pattern of the array with HFSS and CST. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

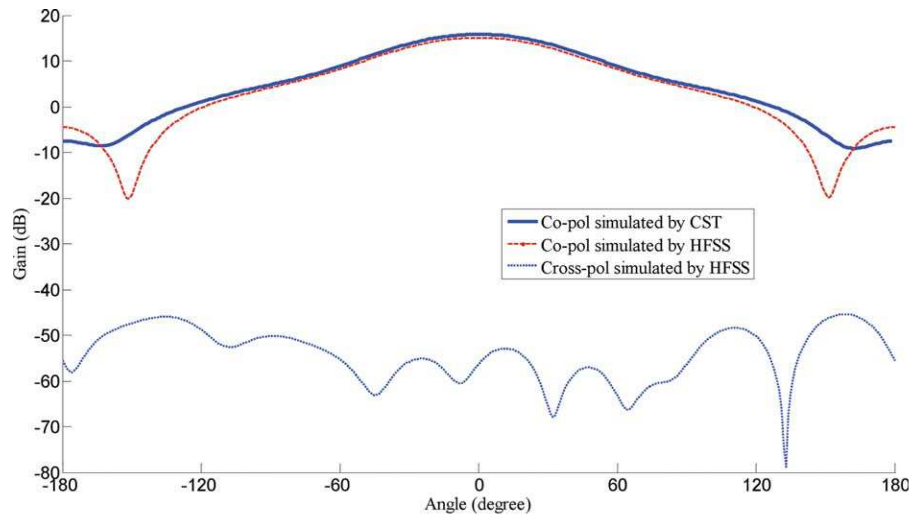


Figure 10 Co and cross polarization of E-plane radiation pattern of array. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

slot depends on the length of the slot, width of the slot, depth of the slot, height of the convexity and concavity of the ridges and width of the convexity, and concavity of the ridges. In the next step, based on the normalized conductance of each slot the array is designed neglecting the mutual coupling. The array was designed so that to have a normalized input admittance of $y = 1$ at the operational frequency. The optimal antenna parameters for resonance at 5 GHz are set as follows: $a = 50.4$ mm, $b = 30$ mm, $t = 2$ mm, Wr = 10 mm, hr = 16 mm, Ws1 = Ws2 = 1.55 mm, hr1 = hr3 = 26 mm, hr2 = 2 mm, Ls1 = Ls2 = 12 mm, L01 = L02 = 15 mm.

The distance between centers of two adjacent slots is 35.046 mm with the quarter wavelength terminal slot, terminating in the last wall at the frequency of 5 GHz. Design of asymmetric double-ridge waveguide slot radiator is based on the determination of the guides cut-off wavelength using HFSS software:

$$\gamma = \alpha + \beta \tag{1}$$

TABLE III Summary of the Proposed Antenna Characteristics

Frequency	*S*11	Gain	SLL	Crosspolarization	HPBW
5 GHz	38 dB	15.1 dB	15.6 dB	−68 dB	11.8 dB

$$\lambda_g = 2\pi/\beta \tag{2}$$

The half wavelength in the double-ridge waveguide is smaller than the half wavelength in nonridged waveguide; therefore, the distance between successive untilted slots in the double-ridge waveguide is smaller than the distance between the tilted slots in an ordinary waveguide. This fact is due to the effect of the double-ridges on raising the propagation constant of the dominant mode in the double-ridge waveguide. The slotted convex double ridge waveguides and the slotted concave double ridge waveguides are placed successively to produce the required phase inversion between adjacent slots. The simulation of the designed array was done using Ansoft HFSS and CST Microwave Studio software.

The calculated input reflection coefficient is shown in Figure 8. The reflection coefficient is less than 40 dB at design frequency. Since the reflection from slots is suppressed well, a good agreement was observed between the simulation results from HFSS and CST software.

Figure 9 shows the H-plane radiation pattern of the array. The simulation results show that cross polarization level is −68 dB below the main lobe. The cross polarization in proposed structure is omitted in some extent and improvement of the cross polarization is −38 dB. There is also a good agreement between simulation

TABLE IV Comparison of the Characteristics of the Tilted Slot Array Antenna and the Designed Untilted Slot Array Antenna

	Tapering Model	Number-Element	Crosspolarization (dB)	SLL (dB)	HPBW (Deg)	Gain (dB)
Untilted double ridge	Uniformly	9	−68	15.6	11.8	15.1
tilted	Uniformly	9	−30	13	15	13

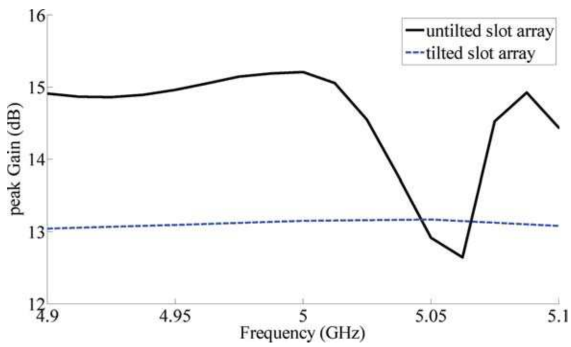


Figure 11 Simulated peak antenna gain for untilted and tilted slot array. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

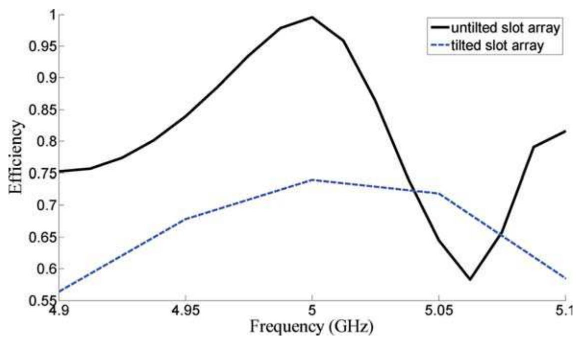


Figure 12 Simulated efficiency of antenna for untilted and tilted slot array. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

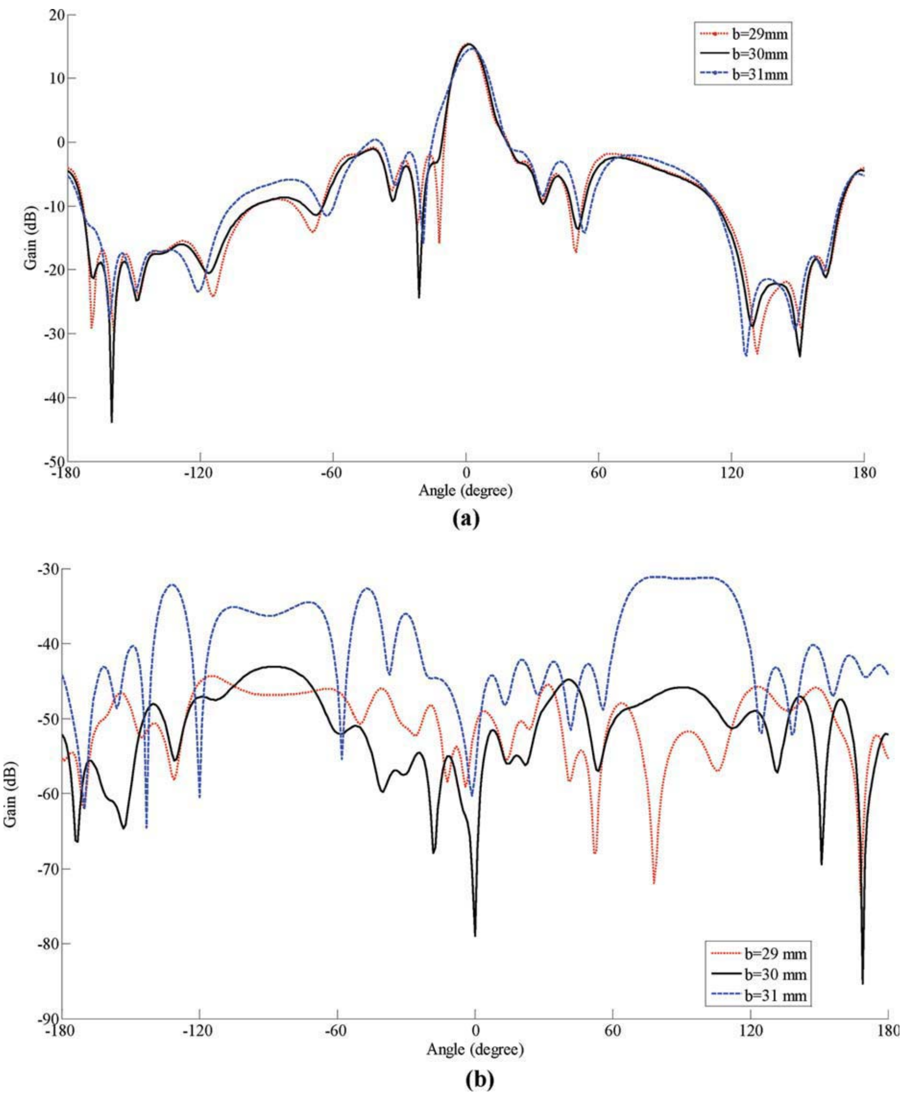


Figure 13 Simulated results of radiation patterns for various width waveguide b (a) co-polar, (b) cross-polar. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

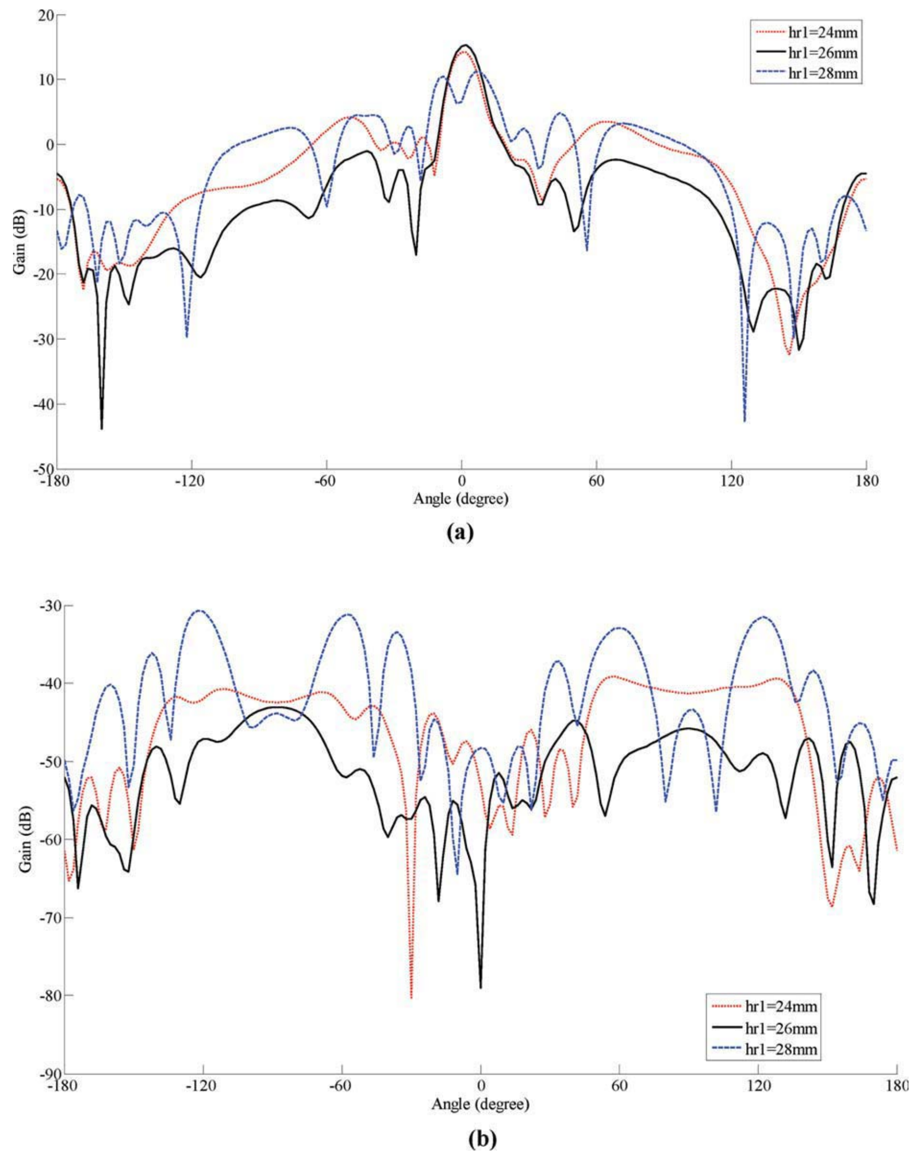


Figure 14 Simulated results of radiation patterns for various height convex hr1 (a) co-polar, (b) cross-polar. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

results from HFSS and CST software. The simulated E-plane radiation pattern at the 5-GHz frequency is shown in Figure 10.

Table III highlights a summary of the characteristics of the proposed antenna.

In Table IV the characteristics of the tilted slot array antenna are compared with those of the untilted one. Clearly, the cross polarization of the designed array antenna is much lower compared to that of the tilted slot array antenna.

Figure 11 presents the simulated peak antenna gain for untilted slot array and tilted slot array. The peak gain of untilted slot array over the 5 GHz is 15.25 dB, which is developed 2-B peak gain of tilted slot array antenna.

Figure 11 presents the simulated peak antenna gain for untilted slot array and tilted slot array. The peak gain of untilted slot array over the 5 GHz is 15.1 dB, which is developed 2-dB peak gain of tilted slot array antenna.

Figure 12 shows the simulated radiation efficiency for untilted slot array and tilted slot array. The radiation efficiency of untilted slot array exceeding 0.95 at 5 GHz is improved by 0.25 efficiency of tilted slot array antenna. This good radiation efficiency is due to the use of the double ridge into waveguide. The radiation efficiency is obtained by calculating the total radiated power (TRP) of the antenna with HFSS over the 3D spherical radiation first and then dividing that total amount by the input power of 1 W.

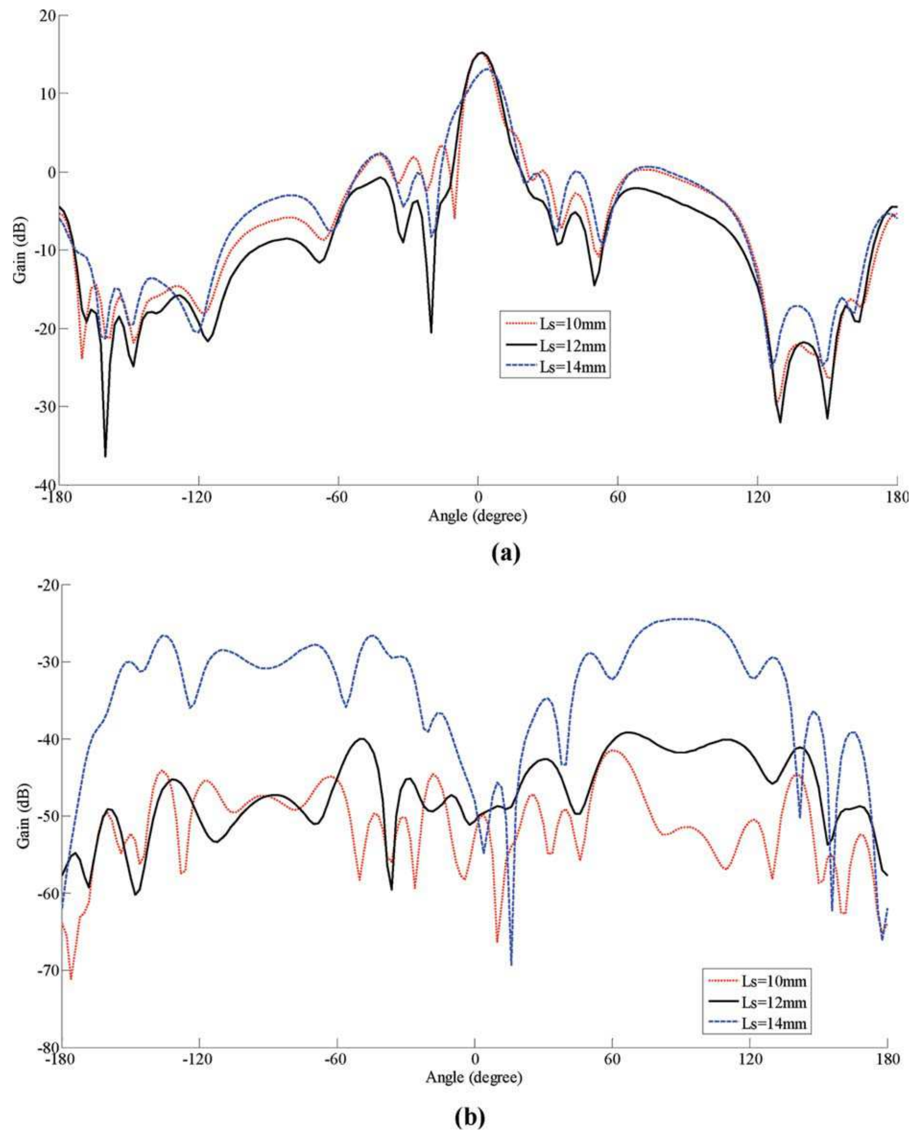


Figure 15 Simulated results of radiation patterns for various depth slot Ls (a) co-polar, (b) cross-polar. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

In Figures 13–16 the effect of changing different parameters on the antenna radiation pattern is investigated.

Figure 13 shows the co and cross polarization of the designed array antenna for various waveguide widths (b) showing that increasing b causes the cross polarization to increase.

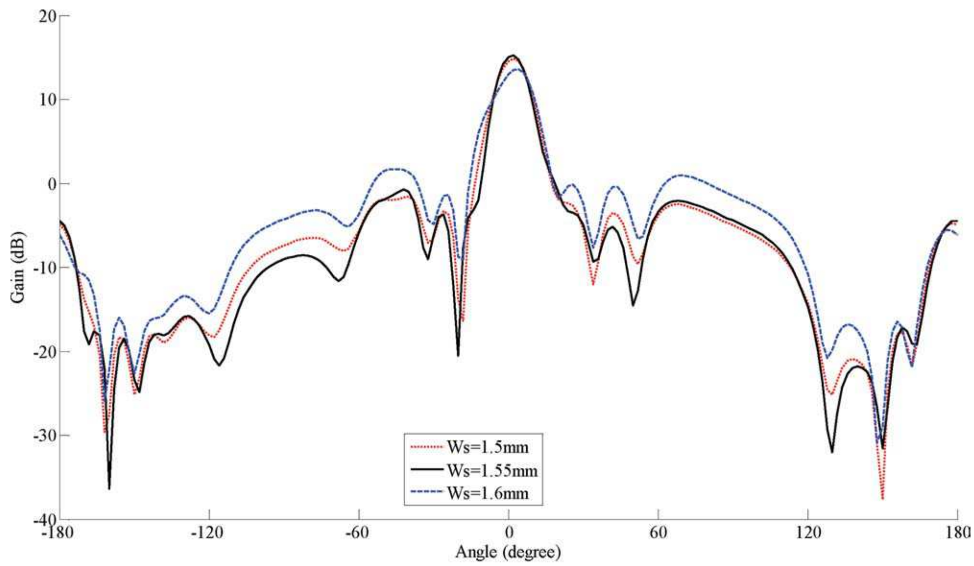
Figure 14 shows radiation patterns of the antenna for various heights of the convexity in the waveguide ridge (hr1) showing that the cross-polarization is increased as a result of increasing the hr1 parameter.

SLL and cross-polarization are slightly increased as a result of the decreasing Ws parameter from 1.6 to 1.5, as shown in Figure 15.

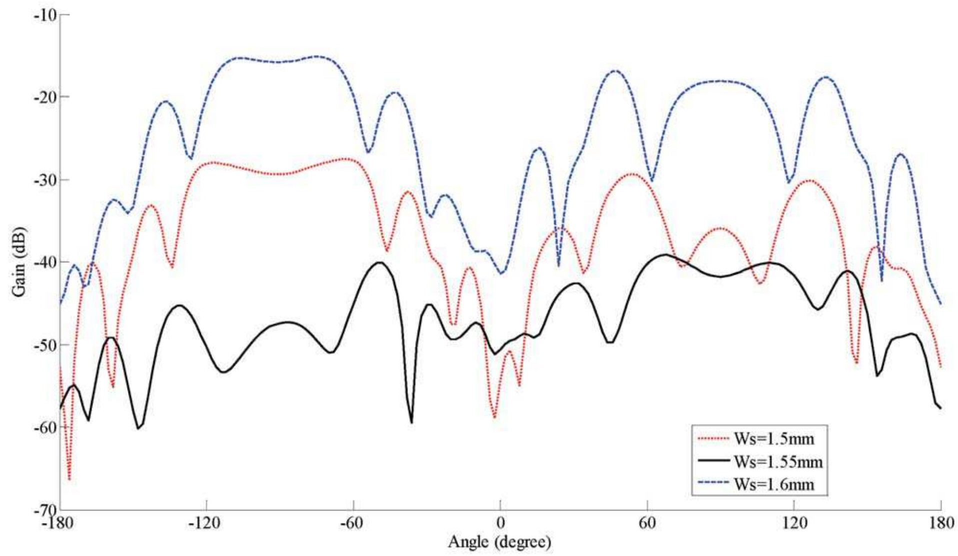
Figure 16 shows the simulated co and cross polarization of the antenna for various resonance slot depths; it can seen that by increasing the Ls parameter, cross polarization is increased.

IV. CONCLUSION

A novel array antenna composed of untilted slots in the narrow wall of the double-ridge waveguide reducing cross-polarization is presented. The proposed structure works by inserting a convexity or reducing the concavity of one of the ridges of the double-ridge waveguide. The linear array consists of nine uniformly resonant untilted slots in the double-ridge waveguide at the frequency of 5 GHz. The simulated results show that the antenna has an excellent cross-polarization smaller than -65 dB and a side lobe level of about -16 dB.



(a)



(b)

Figure 16 Simulated results of radiation patterns for various width slot Ws (a) co-polar, (b) cross-polar. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

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BIOGRAPHIES

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