An Ultralow Cross-Polarization Slot Array Antenna in Narrow Wall of Angled Ridge Waveguide

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***Abstract*— A low cross-polarization slot array antenna in the narrow wall of ridge waveguide is presented. A non-angled slot which is created in the narrow wall of the ridge waveguide is considered to be used as radiating resonant slot. The normalized resistance and normalized reactance curves are presented for design purposes. A six element slot array waveguide antenna with ridges on its narrow wall is then designed at frequency of 9 GHz using the normalized conductance of each radiating slot. It is shown that good performance can be achieved even for angled ridge in waveguide. The antenna has the characteristics SLL of -20 dB and cross-polarization equivalent to -60 dB.**

***Index Terms*—** slot array antenna, singled ridge waveguide and cross-polarization.

I. INTRODUCTION

The antenna which is used in the radar technology should be of high power capability, inexpensive in terms of fabrication cost, high gain performance and low loss. The waveguide slot array antenna incorporates the above-mentioned features thus being an appropriate choice to be used in the radar technology and communications.

In the case of the waveguide slot array antenna, the radiating element, i.e. the slots, are made on the broad wall or the narrow wall of a rectangular waveguide taking into consideration the required application [1-4]. Nowadays, considering the limitations of space, there has been much interest in the manufacture of more compact antenna. The creation of a slot on the narrow wall makes this possible. Nevertheless, for this slot on narrow wall to radiate in the TE_{10} mode, it must interrupt the surface currents on the thin wall. To achieve this, the slots should be produced in a slant manner on the antenna wall which causes an increase in the level of cross-polarization and consequently the secondary beam of the antenna. This cross polarization coupled with the variation of the slot admittance with frequency, causes pattern deterioration and loss in array efficiency [5-11]. A strong cross-polarized component, which increases as the slot array scanned at an angle away from broadside, produces interference and jamming problems.

To decrease cross-polarization in the waveguide slot array antenna on the narrow wall of the waveguide various complex methods are employed [12]. One of the most effective methods whereby cross-polarization levels are lowered in this antenna is to change the fields inside the waveguide thus creating untilted slots in the waveguide. In [13], to produce such a field distribution, a probe is inserted tilted near the slot instead of making the slot slope itself. This is done to cause the slot to

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radiate as the excited probe. Another way is to make use of slant wires alongside the slot without any angles. Under this condition, the slant wires are excited by the radiation fields in the waveguide thus producing radiation in the slot. This antenna has a radiation efficiency of approximately 50 percent [14]. Nevertheless, this method encounters difficulty in the case of large-scale arrays as each wire should be drilled in an angular manner in the waveguide wall. In addition, the untilted slot excited by a dielectric plate with conducting strip on both sides has been suggested [15], with radiation efficiency of 22 percent for each radiation element. In this way we can control the coupling more easily and more accurate 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. [16] The slot in excited by to compound iris which produced an 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 abovementioned wires or stripes in [17] the measured result for 16 element slot shows cross-polarization level less than -40 dB.

In this paper, the design of untilted slot array antenna on narrow wall of the ridge waveguide has been presented. Inserting the slant ridge under the slots, the fields are changed in the waveguide in such a manner that the slot is capable of radiating without any angles. Under this condition, considering the omission of the slot angle, the cross-polarization decreases. The normalized resistance and normalized reactance curves are presented for design purposes. A slot array waveguide antenna was designed using ridges on its narrow wall and six radiation elements having a frequency of 9 GHz. The antenna has the characteristics SLL= -20 dB and cross-polarization equivalent to -60 dB. Of course, it possesses radiation efficiency within the range of 95 to 99.5 percent. The proposed array 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

To decrease cross-polarization in the slot array waveguide, the slot angle should be removed. Nevertheless, in case the angles are removed the slots are incapable of intersecting the currents and there will be no radiation. As a result, along with the removal of angles, the field distribution within the waveguide is changed in such a manner as to make radiation possible. The more currents act orthogonal on the slots the less the cross-polarization. One of the best methods where by appropriate field distribution is induced within the waveguide is to use ridges inside it.

This is because the ridges within the waveguide displace the fields in relation to their form and position. Thus, in a ridge waveguide the fields are confined within the ridge and the waveguide.

For this purpose, one can make use of the ridge inside the waveguide to induce appropriate levels of current in the angle-less slot so as to generate appropriate radiation levels with the least cross-polarization fields. In fact, instead of considering angled slots one can angle the ridges in relation to the slots (Fig. 1). Under this condition, the fields residing in the TE_{10} mode begin to move above the ridges. As the ridges move the fields also move. Consequently, considering the location of the slots the fields are not symmetric in relation to the slots and there will be the possibility of radiation. Nevertheless, as the fields pass under the slots, they lead the fields roughly orthogonally towards the slots.

Fig. 1 shows the proposed configuration and the dimensions as the appropriate alternative for tilted slot waveguide antenna where a non-angled slot has been cut in the middle of the narrow wall of the waveguide. The ridge on the narrow wall of the waveguide is placed under the slot. The length of the slot, similar to that of dipoles, is about $\lambda/2$ and the ridges move at an angle α in relation to the slot.

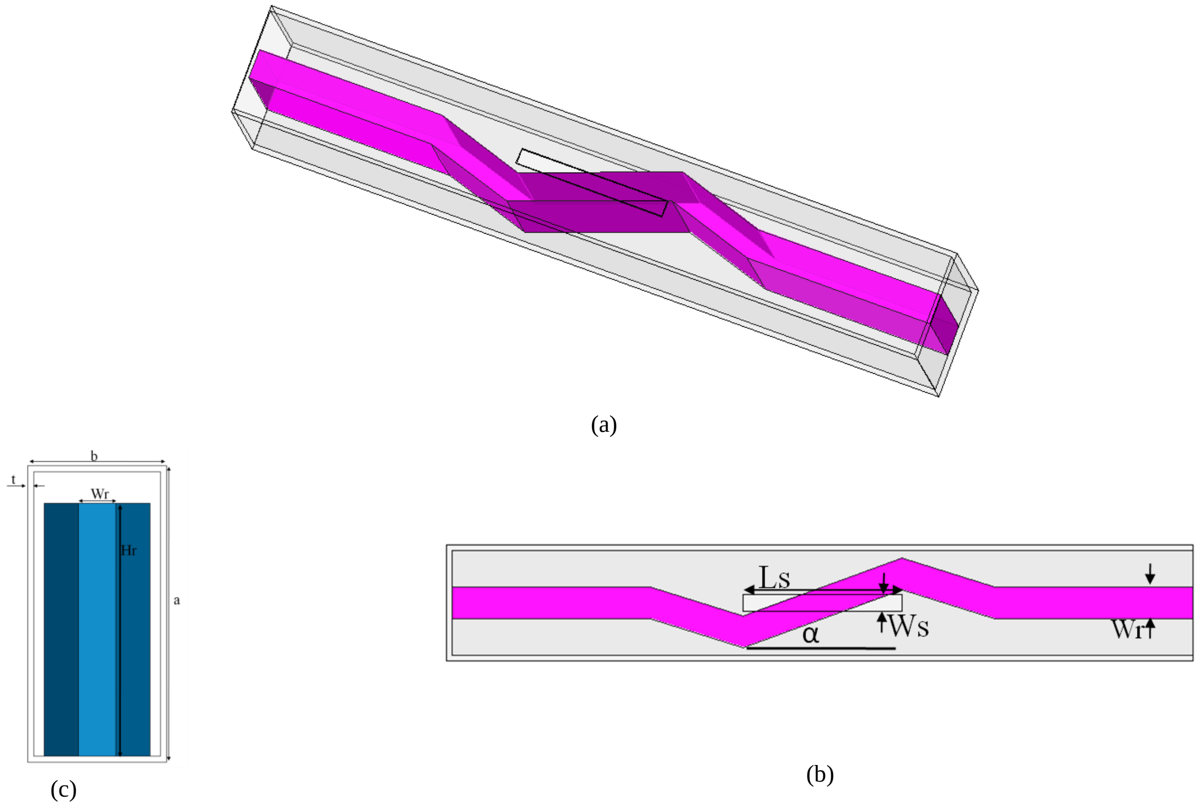
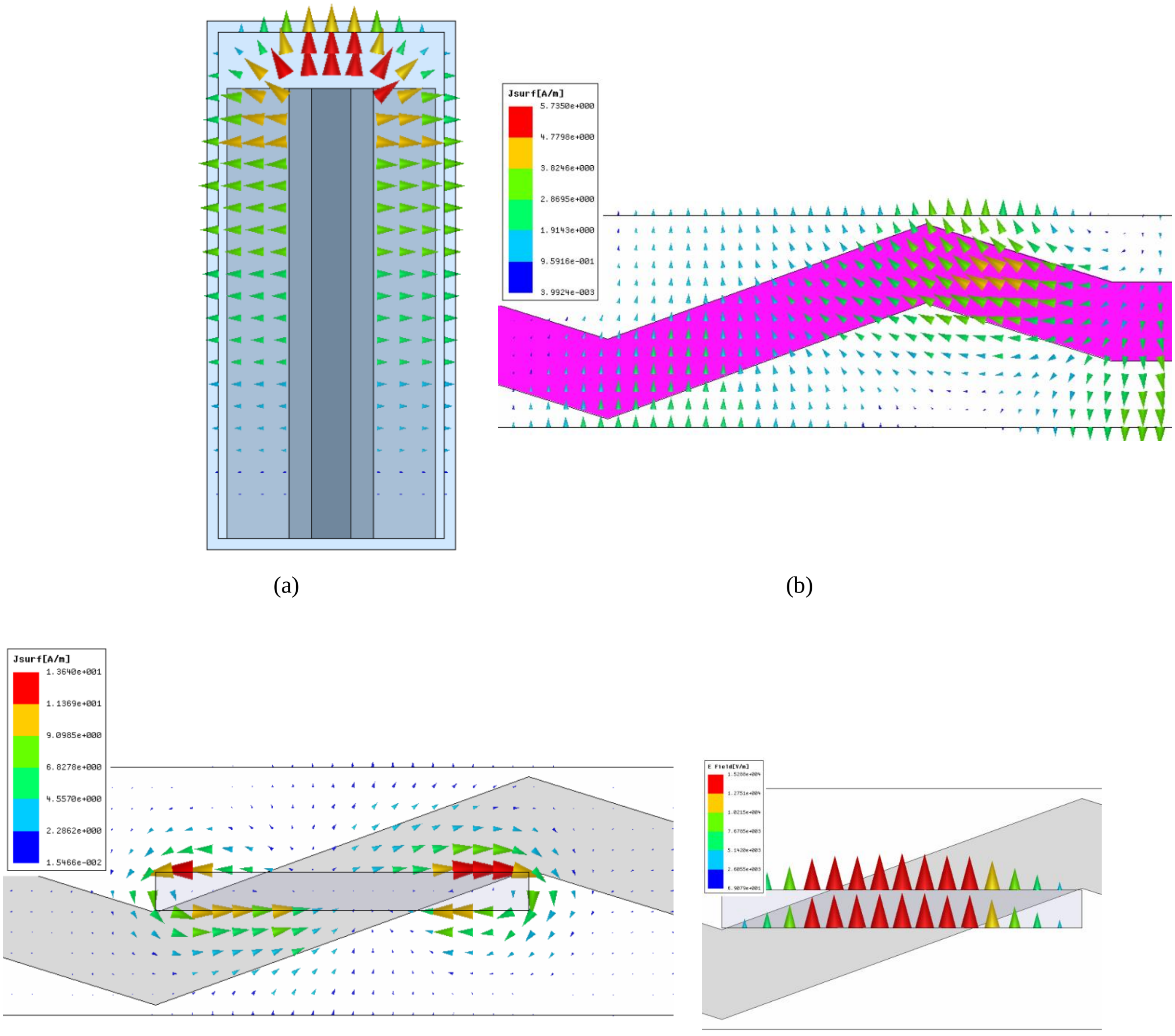


Fig. 1. Proposed structure for excitation of the non-angled slot with angled ridge (a) 3- D view (b) top view (c) side view.

The antenna parameters for resonance at 9 GHz are set as follows: a=22.86mm, b=10.16mm, t=1.27mm, Wr=3.8mm, Hr=20.3mm, Ws=1.58mm, Ls=15.25mm, α=20 deg.

To better understand the behavior of the waveguide slot antenna, the distribution of electric fields and the currents distribution on the surface of the waveguide are shown in Fig. 2. Fig. 2(a) shows the distribution of electric field on the side of the waveguide without slots. As can be seen, most of the fields reside between the ridge and the upper wall of the waveguide.

Fig. 2 (b) shows the currents distribution on the upper surface of the ridged waveguide without the slots. The currents distribution is in such a manner that a non-angled slot intersects the waveguide in the middle of the line and the slot is capable of radiation. Fig. 2 (c) shows the currents distribution on the upper surface of the waveguide slot antenna. The Fig. reveals the fact that the slot intersects the current on the side wall of the ridge waveguide causing the current to move around the slot inducing the field E in the slot. The angle between the ridge and the slot reveals the manner in which current passes around the slot. This current specifies the level of power coupled from the waveguide to the slot and consequently radiation from the slot. Fig. 2 (d) shows the distribution of the electric field in the slot. The field is dependent on the angle between the ridge and the slot.



(a) (b)

(c) (d)

Fig. 2. (a) E field in narrow wall of angled ridge waveguide, current distribution in narrow wall of angled distribution (b) without slot (c) with slot (d) E filed in slot.

The slot waveguide antenna is equivalent to a series impedance circuit. The various angles of the ridge in relation to the slot, the length of the slot and various parameters of ride cause the slot to have various normalized resistance and reactance. For the slot to be in the resonance condition the reactance should be equal to zero. In Fig. 3, the ratio of resistance of maximum resistance for different angles of the ridge with the slot is shown. Fig. shows the effect of changing the angle between the ridge and the slot; increasing the angle increases the ratio of resistance of maximum resistance, because the more the angle causes the more electrical field will radiate outwards the slot. Changing Hr effect on ratio of resistance of maximum resistance is mentioned in Fig. 4. As shown in Fig. by increasing the height of the ridge more electrical field transfers outwards the slot, thus their ratio of resistance of maximum resistance will increase. Fig.s 5-7 shows the effect of changing Ls, Wr, Hr and α on ratio of resistance to resonant resistance and ratio of reactance to resonant reactance. As seen, by increasing Ls, Wr and α, the resonance frequency of slot antenna can be increased.

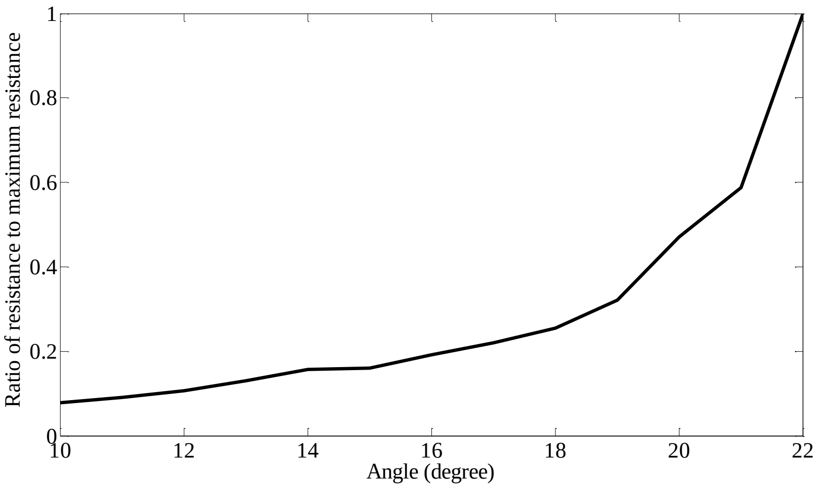
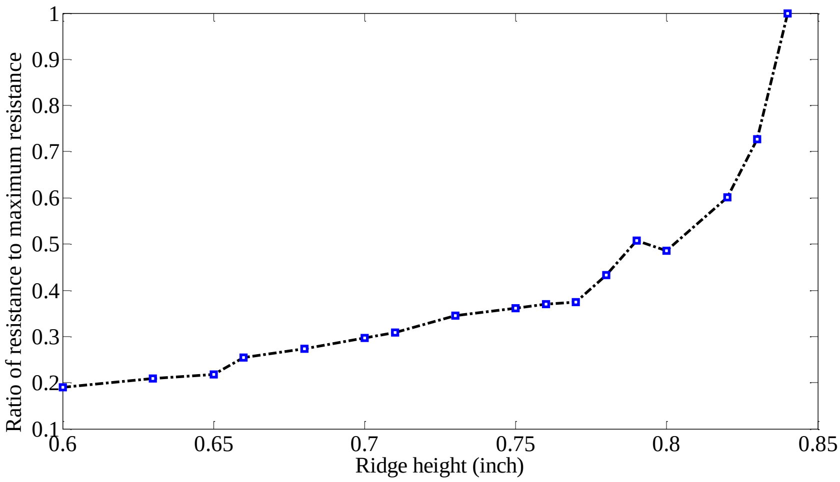


Fig. 3. Normalized resistance of propose slot antenna for different angle.



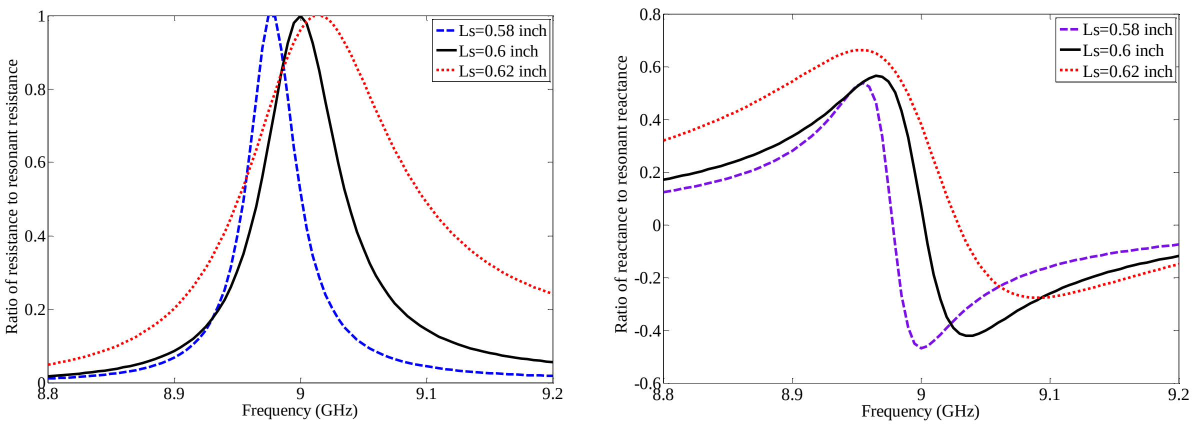
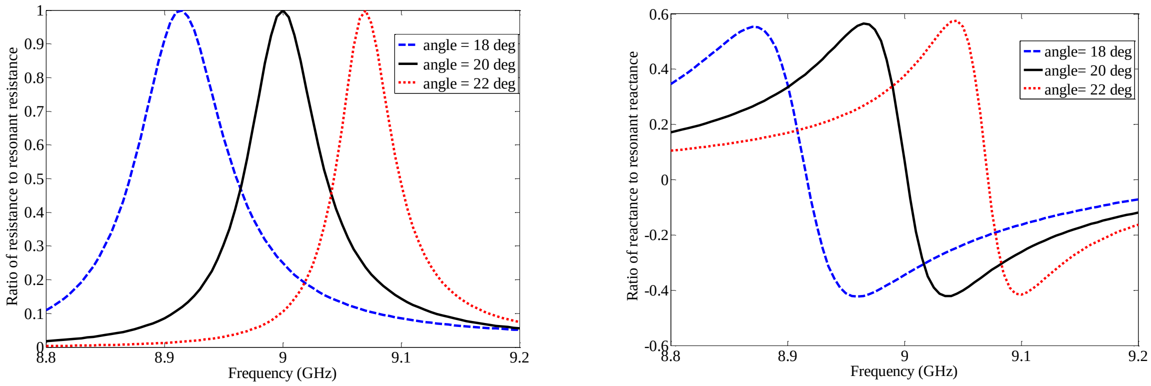


Fig. 4. Normalized resistance of propose slot antenna for different ridge height.

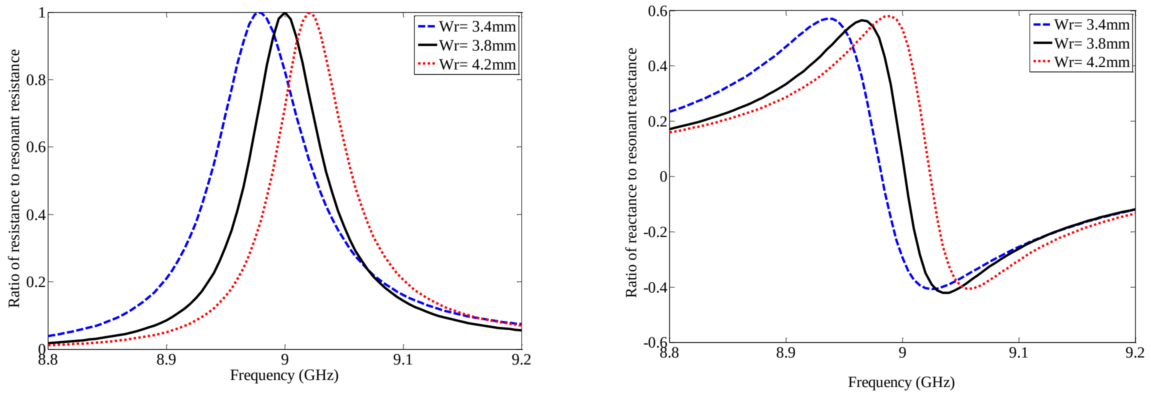
(a) (b)

Fig. 5. Effect of Ls on normalized resistance of propose slot antenna .



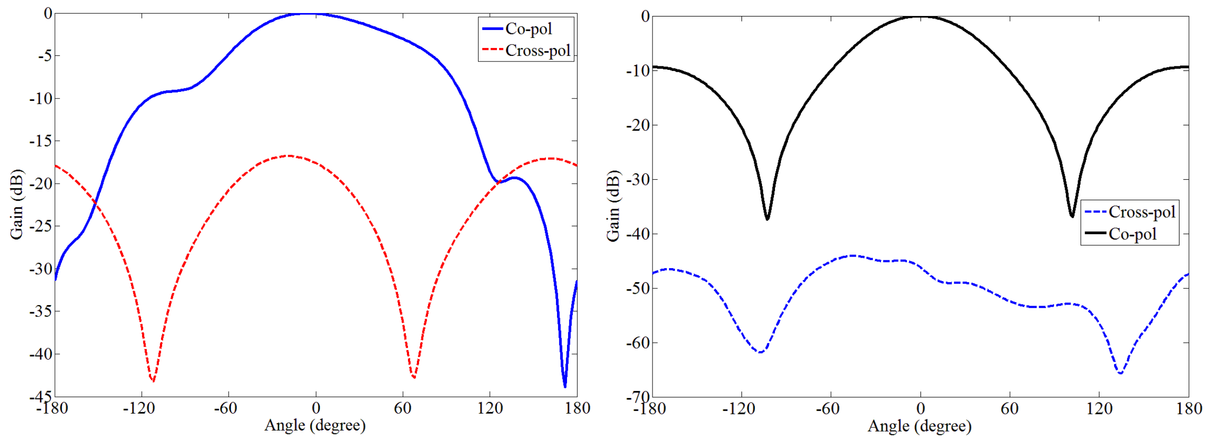
(a) (b)

Fig.6. Effect of angle on normalized resistance of propose slot antenna.



(a) (b)

Fig. 7. Effect of Wr on normalized resistance of propose slot antenna.



(a) *(b)*

Fig. 8. H-plane radiation pattern (a) tilted slot antenna (b) non-angled ridge slot antenna.

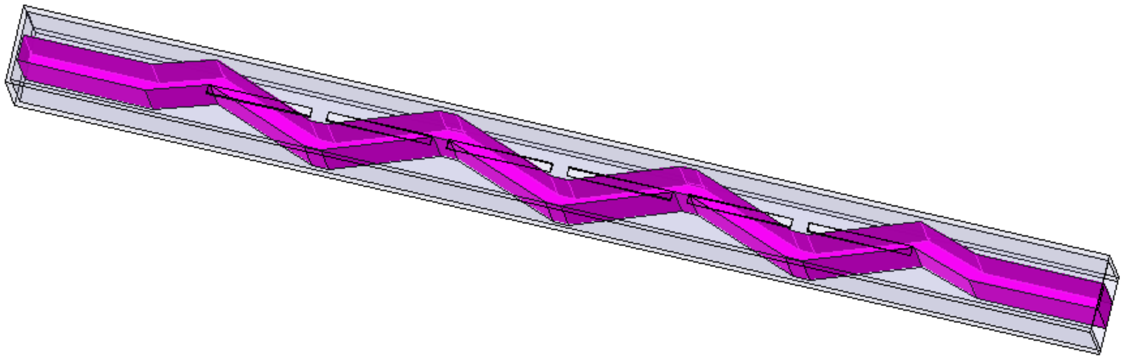


Fig. 9. Configuration of the propose array.

The H-plane radiation pattern of the tilted slot at the frequency of 9 GHz is shown in Fig. 8(a); in this case the cross polarization level is 17 dB below the main lobe. Fig. 8 (b) shows the H-plane radiation pattern of the non-angled slot in the ridge waveguide; the cross polarization level is 45dB below the main lobe here.

III. ANTEENA ARRAY DESIGN

In the preceding section, the slot waveguide antenna was designed. In this section the slot array waveguide antenna is designed. In the first section general dimensions of the antenna, the design parameters and also the uniform tapering antenna design are presented. In the second section design with chebyshev tapering is presented to get better SLL.

A. Waveguide Slot Uniform Array Antenna

Fig. 9 shows the front view of the uniform slot array waveguide antenna using ridges together. For the slots to be in the resonance condition each should reveal a resistance load. Calculating normalized resistance and reactance for the slots on the basis of the lengths of the slots one can find the optimal length for the slots where normalized reactance equals zero (i.e. roughly $\lambda_0/2$). The slots are spaced $\lambda_g/2$ and ridge angle are placed successively to create the required phase inversion between adjacent slots. The distance between centers of slot and S.C end waveguide wall is the half wavelength at the frequency of 9 GHz as the $\lambda_g/2$ line is short circuited. As each slot reveals real impedance the line is short circuited not exerting an effect on impedance eventually turning Z_{in} to be a real value as the circuit equivalence (Fig. 4).

It has to be mentioned that the presence of the ridge within the waveguide causes the wavelength of the design frequency to be shorter as compared with the simple waveguide. To calculate λ_g, HFSS software and the following formulae were used:

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

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

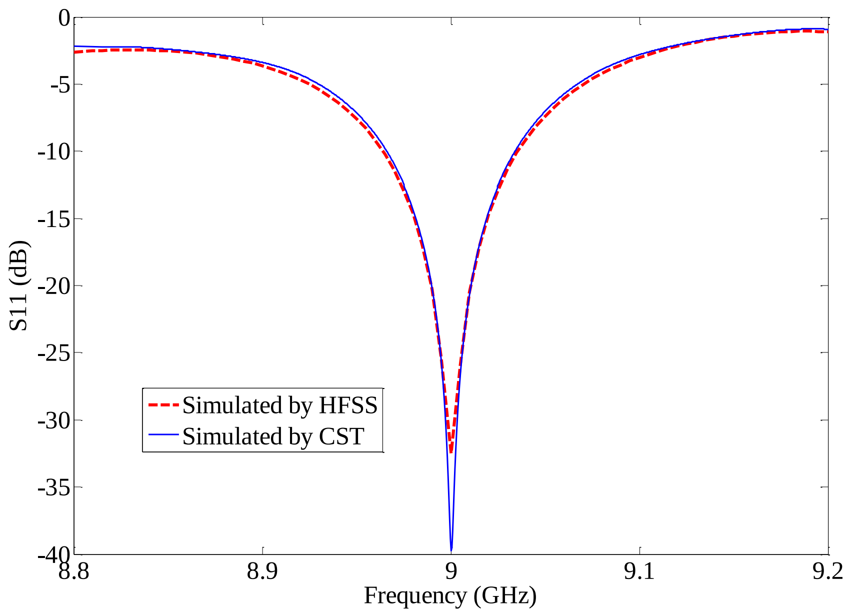


Fig. 10. The reflection coefficient designed array antenna with HFSS and CST.

The antenna was designed for the frequency 9 GHz with six non-angled slots. Taking into consideration the effect of coupling among the slots, limited optimization was achieved with the following dimensions for the antenna. Array analysis is performed based on two different methods of analyzing, i.e. CST method which is time domain and analyses using the numerical method of finite integral technique, and the HFSS method which is frequency domain and analyses using the numerical method of finite element. Besides, results from these two different analyzing methods which are also in compatibility with the fabrication.

The optimal antenna parameters for resonance at 9 GHz are set as follows: a=22.86mm, b=10.16mm, t=1.27mm, Wr=4mm, Hr=15.24mm, Ws=1.27mm, Ls=15.25mm, α=20 deg.

The calculated input reflection coefficient is shown in Fig. 10 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.

Fig. 11 shows the H-plane radiation pattern of the array. The simulation results show that cross polarization level is -65 dB below the main lobe. The cross polarization in proposed structure is omitted in some extent and improvement of the cross polarization is -40 dB. There is also a good agreement between simulation results from HFSS and CST software. The simulated E-plane radiation pattern at the 9 GHz frequency is shown in Fig. 12. Using the ridge the secondary beam was removed as the cross-polarization was reduced substantially. As a result, the secondary beam in the angled slot antenna is non-existent here.

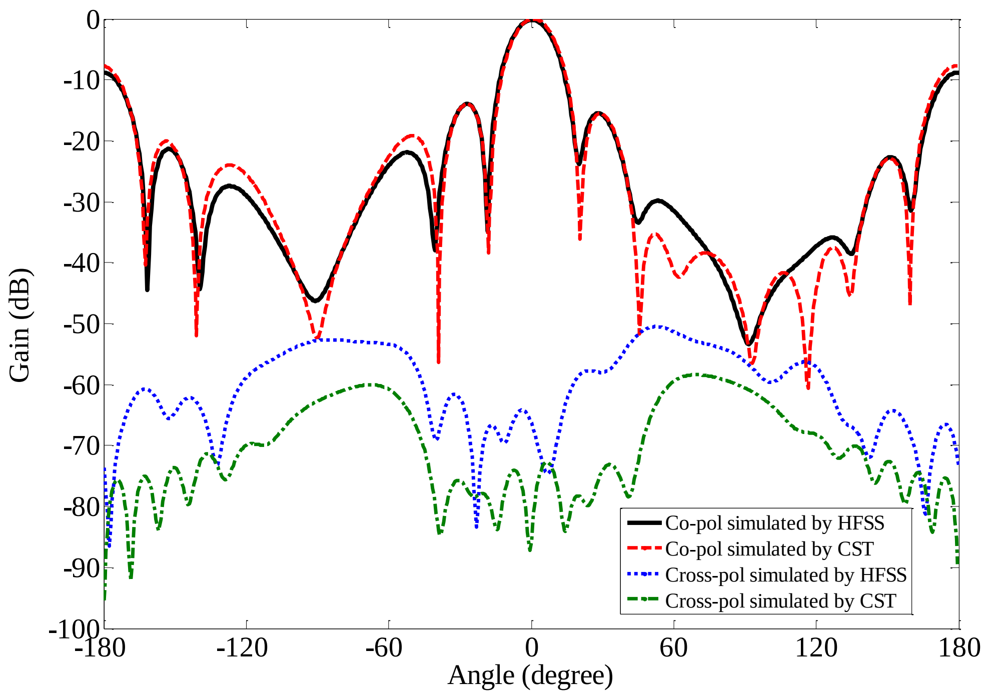


Fig. 11. Simulated co and cross polarization of H-plane radiation pattern of the array with HFSS and CST.

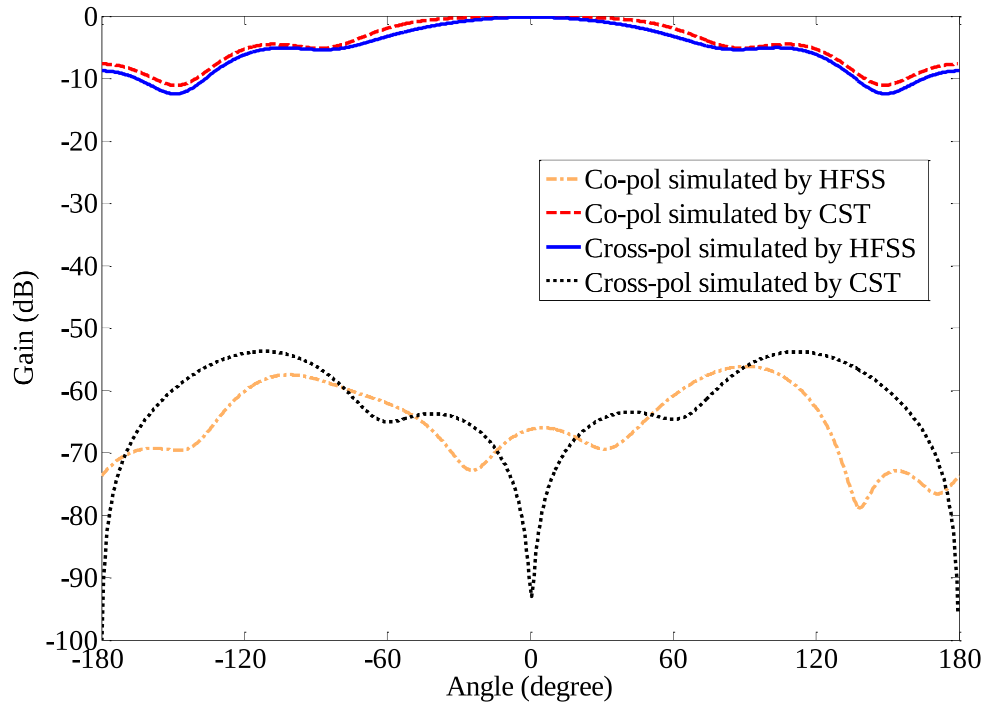


Fig. 12. Co and cross polarization of E-plane radiation pattern of array.

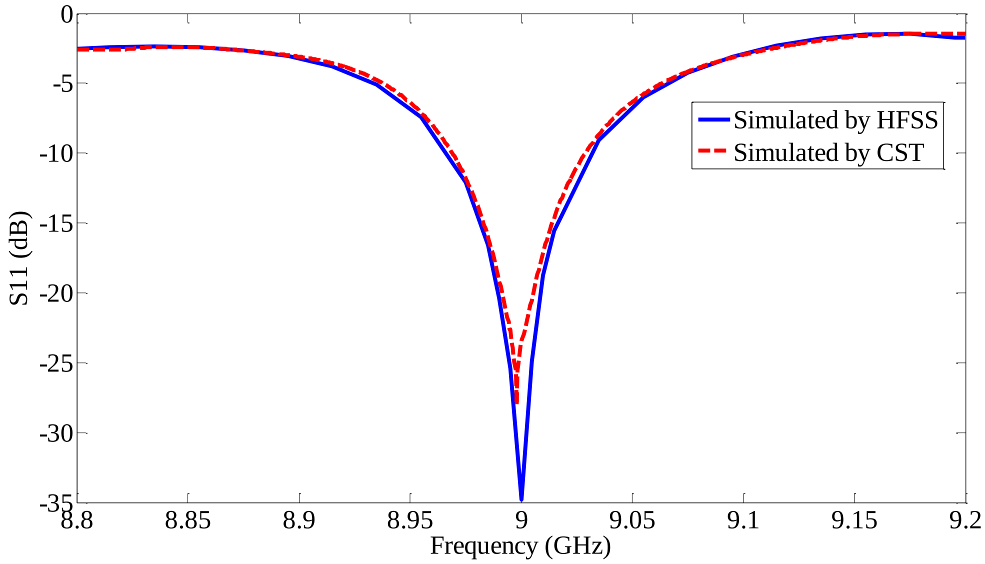


Fig. 13. The reflection coefficient designed chebyshev array by using different angles with HFSS and CST.

TABLE 1. DESIGNED SIZE OF ANGLE AND LS OF CHEBYSHEV ARRAY FOR SLL=20 DB

	X1,6	X2,5	X3,4
Angle (degree)	18	20	22
Ls (inch)	0.625	0.59	0.575

B. Waveguide Slot Chebyshev Array by Using Different Angles

In this section the design of Chebyshev array antenna for 6 elements using major to minor lobe level of 20 dB in frequency of 9 GHz based on the change of the angle between ridge and the slot is presented.

The ridge angles of x_n (n=1, 2… 6) which control the resistance and excitation level of each slot, are determined from the resistance curve described in Fig. 3.The designed parameters for 20 dB SLL are listed in table 1.

The optimal antenna parameters for resonance at 9 GHz are set as follows: a=22.86mm, b=10.16mm, t=1.27mm, Wr=4mm, Hr=15.24mm, Ws=1.27mm.

The calculated input reflection coefficient is shown in Fig. 13 the reflection coefficient is less than 30 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.

Fig. 14 shows the H-plane radiation pattern of the array. The simulation results show that cross polarization level is -60 dB below the main lobe. There is also a good agreement between simulation results from HFSS and CST software.

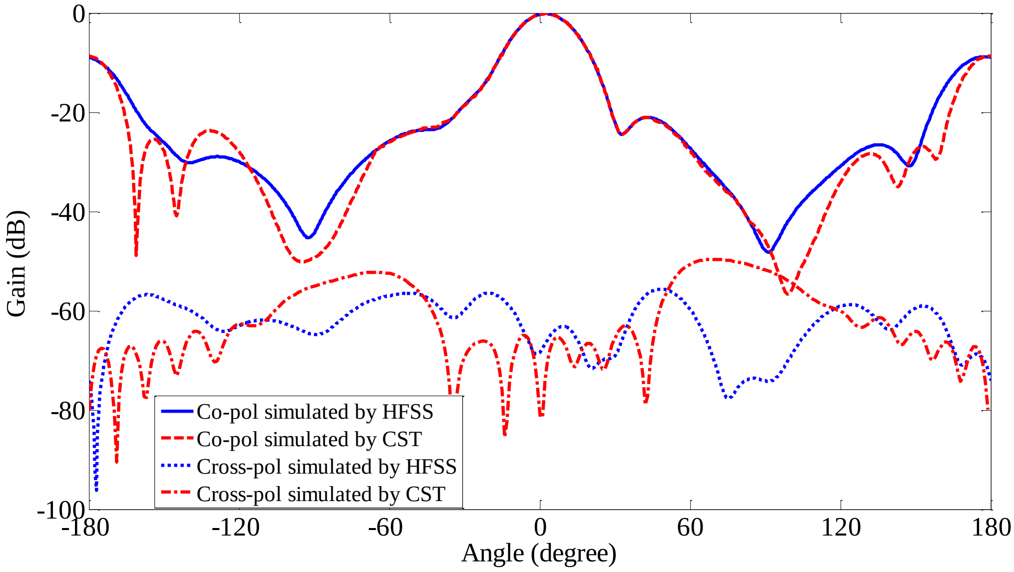


Fig. 14. Simulated co and cross polarization of radiation pattern of the chebyshev array by using different angles with HFSS and CST.

TABLE 2. DESIGNED SIZE OF RIDGE HEIGHT AND LS OF CHEBYSHEV ARRAY FOR SLL=20DB

	X1,6	X2,5	X3,4
Ridge height (inch)	0.7	0.78	0.81
Ls (inch)	0.565	0.585	0.605

C. Waveguide Slot Chebyshev Array by Using Different Ridge Heights

The Chebyshev array antenna is presented in this section, with 20 dB SLL for 6 radiating elements by using Fig. 4 (changing height of the ridge). The ridge angles of xn (n=1, 2… 6) which control the resistance and excitation level of each slot, are determined from the resistance curve described in Fig. 4.The designed parameters for 20 dB SLL are listed in table 2.

The optimal antenna parameters for resonance at 9 GHz are set as follows: a=22.86mm, b=10.16mm, t=1.15mm, Wr=3.7mm, Ws=1.27mm, α=20 deg.

The calculated input reflection coefficient is shown in Fig. 15 the reflection coefficient is less than 25 dB at design frequency.

Fig. 16 shows the H-plane radiation pattern of the array. The simulation results show that cross polarization level is -65 dB below the main lobe. There is also a good agreement between simulation results from HFSS and CST software.

In table 3 the characteristics of the tilted slot array antenna are compared with those of the agreement was observed between the simulation results from HFSS and CST software.

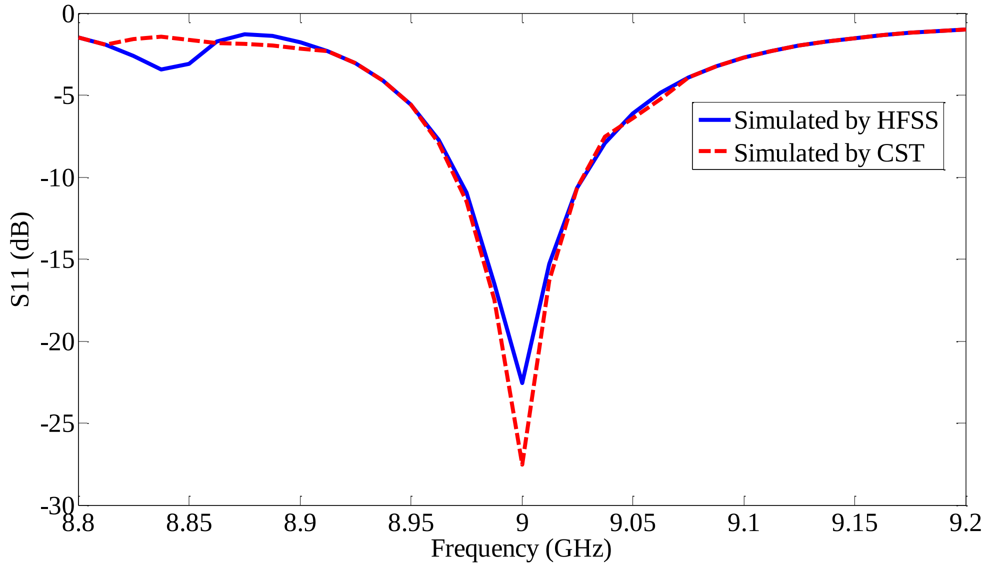


Fig. 15. The reflection coefficient designed Chebyshev array by using different ridge height with HFSS and CST.

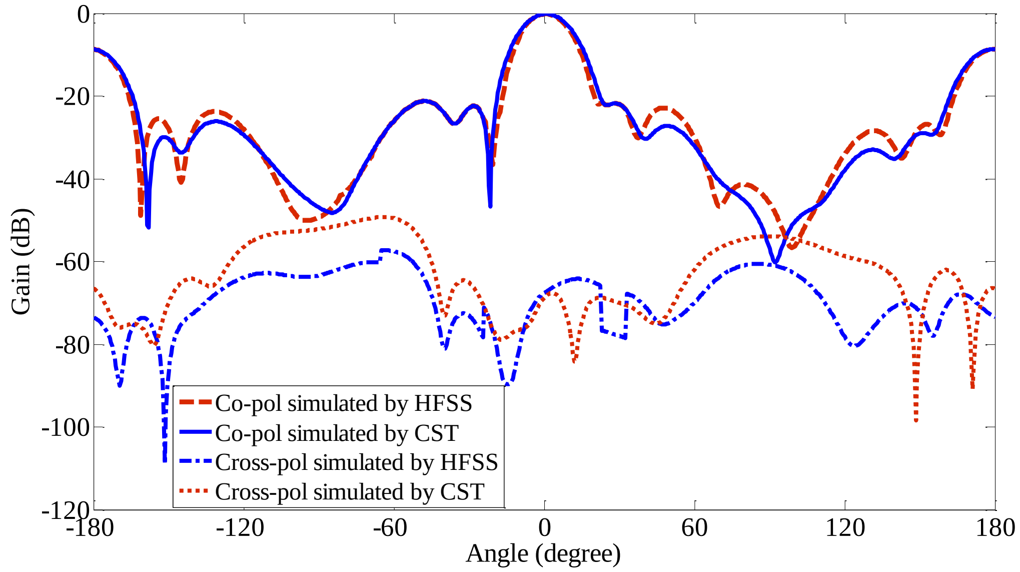


Fig. 16. Simulated co and cross polarization of radiation pattern of the chebyshev array by using different ridge angle with HFSS and CST.

TABLE 3. COMPARISON OF THE CHARACTERISTICS OF THE TILTED SLOT ARRAY ANTENNA AND THE DESIGNED NON-ANGLED SLOT ARRAY ANTENNA

	Tapering model	Number element	Cross-polarization (dB)	SLL (dB)	HPBW (Deg)	Peak Gain (dB)
tilted	Uniformly	6	-25	12	15	11.5
Non-angled ridge	Uniformly	6	-65	14	11.8	12.5
Non-angled ridge	Chebyshev by using ridge height	6	-65	20	17	12.5
Non-angled ridge	Chebyshev by using angle	6	-60	20	20	12.4

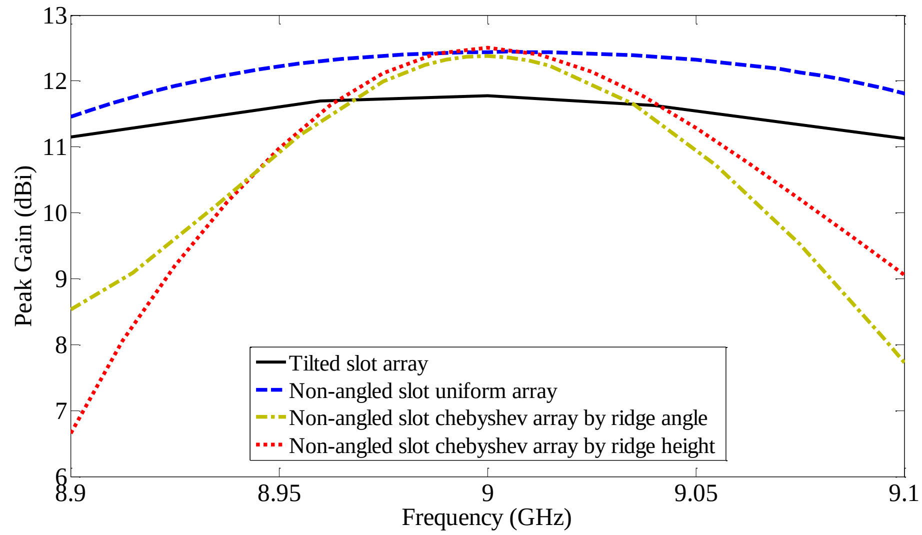


Fig. 17. Simulated peak antenna gain for non-angled ridge slot and tilted slot array

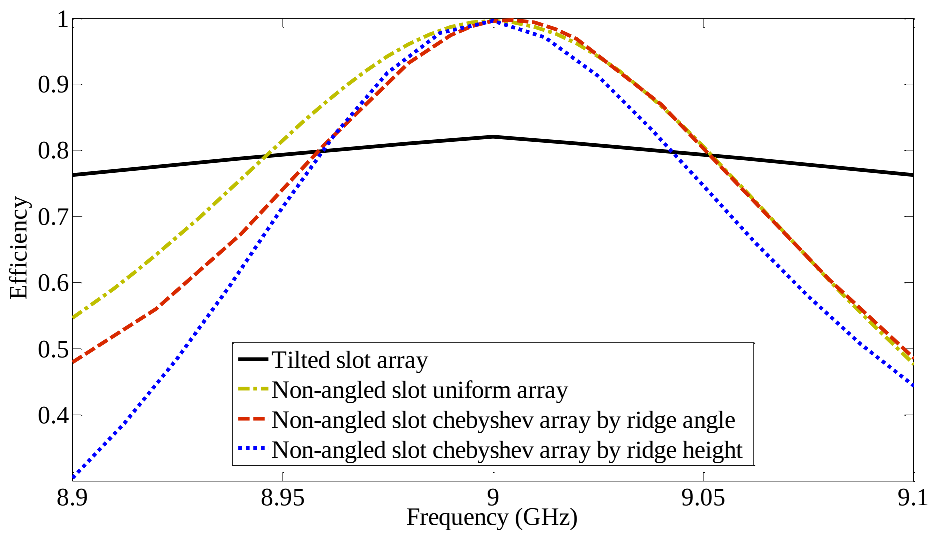


Fig. 18. Simulated efficiency of antenna for non-angled ridge slot and tilted slot array

non-angled one. Clearly, the cross polarization of the designed array antenna is much lower compared to that of the tilted slot array antenna.

Fig. 17 presents the simulated peak antenna gain for non-angled slot array and tilted slot array. The peak gain of non-angled slot array over the 9 GHz is 12.5 dBi, which is developed 1 dBi peak gain of tilted slot array antenna.

Fig. 18 shows the simulated radiation efficiency for non-angled slot array and tilted slot array. The radiation efficiency of non-angled slot array exceeding 0.995 at 9 GHz. which is improved 0.19 efficiency of tilted slot array antenna this good radiation efficiency is due to the use of the ridge into waveguide. The radiation efficiency is obtained by calculating the total radiated power of the antenna with HFSS over the 3-D spherical radiation first and then dividing that total amount by the input power of 1watt.

IV. CONCLUSION

A novel array antenna composed of non-angled slots in the narrow wall of the ridge waveguide, with significantly improved cross-polarization, is presented. The proposed structure works by inserting angled ridges in waveguide. It is shown that the angled ridge can produce an orthogonal current distribution in the place of the slots. The linear array consists of six uniformly resonant non-angled slots in the ridge waveguide at the frequency of 9 GHz. The simulated results show that the antenna has an excellent cross-polarization smaller than -60 dB and a side lobe level of about -20 dB.

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