UWB KSA Sign Shape Slot Microstrip Antenna Array Mutual Coupling Reduction for Official Applications

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***Abstract*—A novel single element KSA (Kingdom of Saudi Arabia) sign shape, and two element array (Ultra Wide Band) KSA sign shape slot microstrip antennas are presented. A novel KSA sign shape EBG cells are applied to reduce the mutual coupling between array elements with the same shape. The results show that a reduction in mutual coupling of 8 dB is achieved at first band (2.1 - 2.99) GHz and 33 dB at second band (5 – 9.43) GHz. The microstrip array was studied by CST simulator and fabricated by proto laser machine with precision 25µm. The antenna can be used in the military or RFID applications.**

***Index Terms*—Microstrip patch antenna, mutual coupling, EBG, KSA sign shape.**

I. Introduction

Rapid growths of wireless technologies in recent years have made the antennas designs more challengeable. Array antennas can significantly improve the efficiency of wireless application systems. Antennas can satisfy applications, such as digital communication, GPS, GSM, WLAN and RFID. For above mentioned applications smart antenna devices with resonant frequency of 2.4 to 2.485 GHz are used. However, patch antenna arrays have several major drawbacks, in this paper we have analyzed the following problems, 1) Mutual coupling, 2) Size of antenna, and 3) Narrow bandwidth [1]. Mutual coupling in arrays represents a very import problem; hence it is given much attention from antenna design engineers. By placing EBG cells in between the patch antennas mutual coupling loss can be reduced significantly [2]. An EBG structure has the ability of suppressing the surface wave's propagation in the significant frequency band which is known as band gap feature. At the very early stages of EBG research, three dimensional structures were highly focused. Mushroom-like EBG structures are configured by grounding the periodic metallic patches through shorting vias. But due to the manufacturing complexity associated with those three dimensional structure, research concentration has grown on planar configuration e.g. uni-planar compact electromagnetic band gap (UCEBG) structures [3], [4]. A few researches were attempted to achieve wide stop band with planar EBG designs. But the band gaps are positioned at higher frequency bands. The features of EBGs are extended to improve array antenna performance by increasing the directivity such as increasing antenna gain and reducing back radiation. To increase the capacitance effect of the equivalent LC circuit and to improve the compactness in EBG structures, different shapes with significant gaps are designed [5]. The practical applications of EBG structures have difficulties in accommodating their physical sizes. In this paper, the proposed EBG structure is a KSA sign shape which has more gaps and compactness. The technique used in this paper to reduce mutual coupling loss, by increasing the number of EBG cells and by varying the gap distance between cells. The reduction in mutual coupling by means of periodic structure becomes particularly efficient when grating lobes must be avoided [6]. Array antennas are mostly large in size also to improve the performance of the arrays EBG cells are to be placed in between the patch antenna which makes the size much larger. So as to reduce the size of the antenna the proposed method is designing small cells of KSA sign shape for placing EBG cells closer to the patch antenna placed together in the same layer. Another, major drawback of patch antennas array is narrow bandwidth. A possible way to increase the bandwidth is to either increase the height of the dielectric or decrease the dielectric constant. In this paper the first two drawbacks and its approaches are analyzed and the simulated and measured results are also obtained. This configuration is chosen because the KSA sign shape is the official page for any military application. So, this antenna may be used in soldier belts, any commodity for the military application, etc. It should be noted that its main application depends on the range of frequency. According to the chosen ranges of the operating frequency it can be used in RFID [7] or in communication systems.

The antennas were designed and fabricated on a substrate with dielectric constant of 4.4, thickness of 1.6 mm, and tan δ = 0.02. The measuring results were obtained using Anritsu 37297D VNA. The results show that a reduction in mutual coupling of 8 dB is achieved at first band (2.1 - 2.99) GHz and 33 dB at second band (5 – 9.43) GHz. The microstrip array was studied by CST simulator and fabricated by proto laser machine with precision 25µm. The antenna can be used in the military or RFID applications.

II. Antenna Design and Simulations

This section is divided into three parts. The first part discusses the single element geometry of the novel KSA sign shape microstrip patch antenna. The second part presents the two elements of UWB KSA sign shape slot microstrip patch array arranged on substrate without EBG and study the effect of spacing between elements on the mutual coupling. The last part of this section shows the two elements of UWB KSA sign shape slot microstrip patch array arranged on substrate with EBG elements which have the same shape like array patches (KSA sign shape). The E- and H-plane radiation patterns are discussed for each antenna model.

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Antenna structures were modeled in CST Design Suite 2010 in which extensive full-wave analysis is performed.

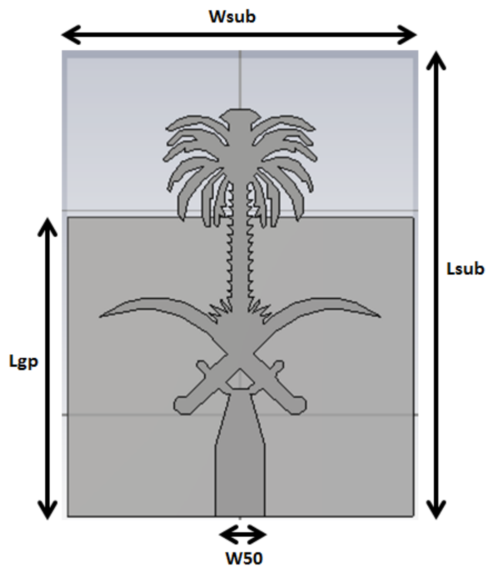


Fig. 1. The novel KSA sign shape microstrip patch antenna.

A. Novel KSA Sign Shape Single Element

CST numerical simulation was used to simulate the KSA sign shape microstrip patch antenna on a dielectric substrate with ε_r = 2.2, h = 1.5748 mm, and tan δ = 0.001. To obtain the resonant frequency at 2.563 GHz, the patch's size was 9.5 mm × 30 mm. The ground plane is $W_{sub} \times L_{sub}$ = 34 mm ×45 mm ($0.3\lambda_0 \times 0.4\lambda_0$). The patch is fed by a matched microstrip line feed with width W_{50} = 4.8 mm, and L_{gp} = 29.3 mm as shown in Fig. 1. The simulated reflection coefficient $|S_{11}|$ is presented in Fig. 2. The band width is extended in the frequency range (2.38 - 2.76 GHz). The E- and H-plane radiation patterns are shown in Fig. 3. In Table I, single patch antenna parameters are presented. It is observed that novel antenna gives good matching, acceptable gain, and good radiation efficiency.

TABLE I: NOVEL KSA SIGN SHAPE MICROSTRIP PATCH ANTENNA.

Parameters	Results
Frequency (GHz)	2.563
$\|S_{11}\|$ (dB)	-40.5
B.W.	15 %
Gain (dBi)	3.4
Radiation efficiency	89 %
Antenna efficiency	88 %

B. UWB Single Element

Fig. 4 shows the single element of UWB KSA sign shape slot microstrip patch antenna on a dielectric substrate with ε_r = 4.4, h = 1.6 mm, and tan δ = 0.02. To obtain the ultra-wide band response, the patch's radius was 10 mm. The ground plane is 42 mm x 50 mm ($0.4\lambda_0$ x $0.47\lambda_0$). The patch is fed by a matched microstrip line feed with width W_{50} = 3 mm. The optimum values of the structural parameters are W_{sub} = 42 mm, L_{sub} = 50 mm, and L_{gp} = 19.6 mm. The simulated reflection coefficient $|S_{11}|$ is presented in Fig. 5. Ultra-wide band of frequencies are obtained (2.3 – 10) GHz. The E- and H-plane radiation patterns are shown in Fig. 6 and Fig.7 at two frequencies 2.818 GHz and 8.668 GHz, respectively. In Table II, single patch antenna parameters are presented. It is observed that novel antenna gives good matching, acceptable gain, and good radiation efficiency.

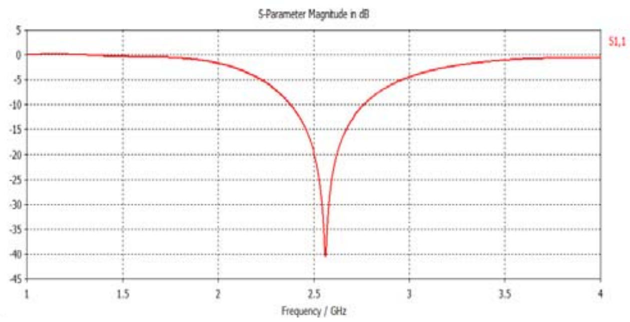


Fig. 2. Reflection coefficient $|S_{11}|$ of the novel KSA sign shape microstrip patch antenna.

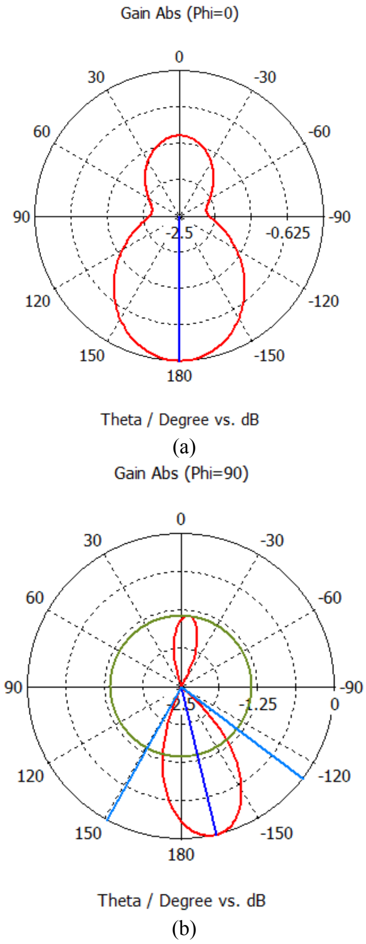


Fig. 3. Radiation pattern of novel KSA sign shape microstrip single element antenna at frequency 2.563GHz (a) E-plane, and (b) H-plane.

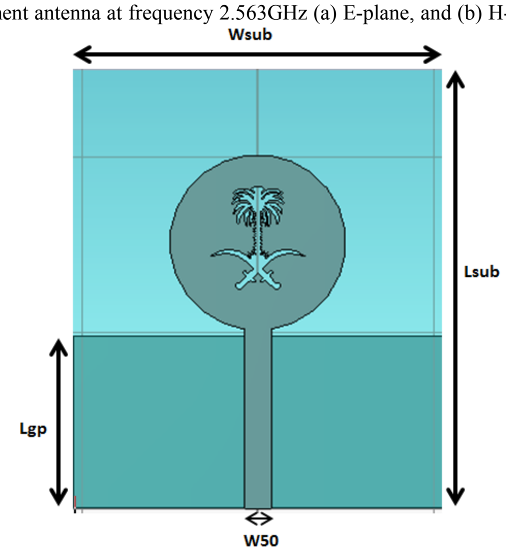


Fig. 4. UWB KSA sign shape slot microstrip patch antenna.

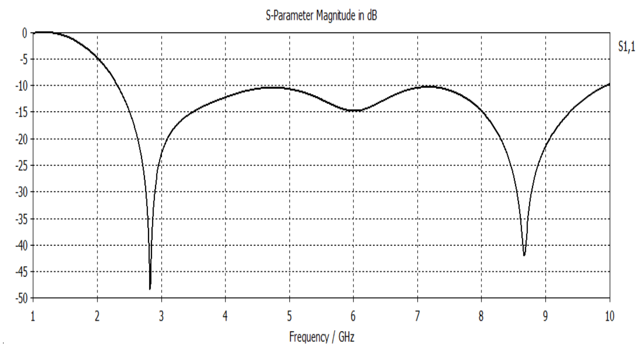
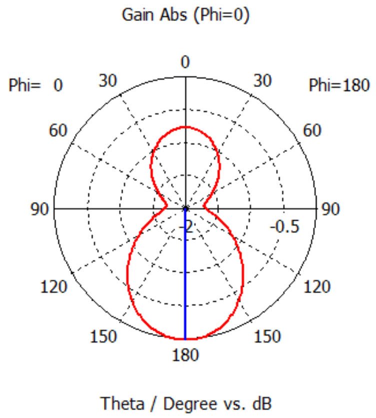


Fig. 5. Reflection coefficient $|S_{11}|$ of UWB KSA sign shape slot microstrip patch antenna.

TABLE II: UWB KSA SIGN SHAPE SLOT MICROSTRIP PATCH ANTENNA.

Parameters	first resonant	second resonant
Frequency (GHz)	2.818	8.668
$\|S_{11}\|$ (dB)	-48.3	-42.1
Gain (dBi)	2.915	4.688
Radiation efficiency	94%	87%
Antenna efficiency	93%	84%



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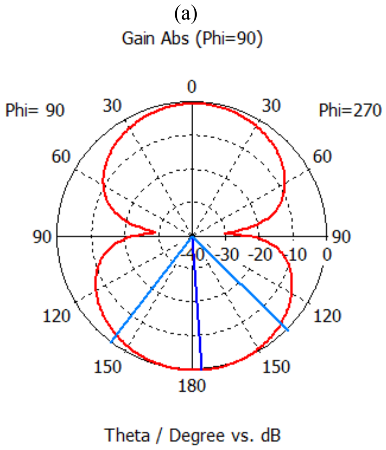

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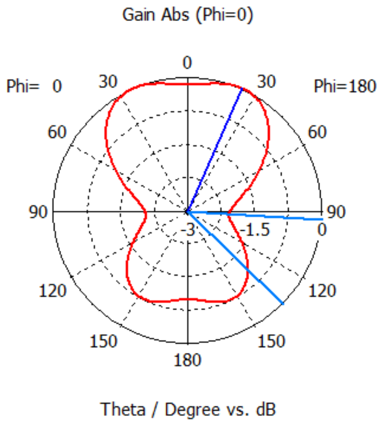
Fig. 6. Radiation pattern of UWB KSA sign shape slot microstrip single element antenna at frequency 2.818GHz (a) E-plane, and (b) H-plane.

C. Two Elements Array without EBG

As shown in Fig. 8, the two elements of UWB KSA sign shape slot microstrip patch antenna on a dielectric substrate with ε_r = 4.4, h =1.6 mm, and tan δ = 0.02. The optimized distance between the patches is 34 mm ($0.32\lambda_0$) to get the best reflection coefficient. Fig. 9 shows the effect of the separation between the two elements on both $|S_{11}|$ and $|S_{21}|$. The ground plane is 80 mm x 50 mm ($0.75\lambda_0$ x$0.47\lambda_0$) at resonant frequency. Each patch is fed by a matched microstrip line feed with width W_{50} = 3 mm. The reflection coefficient and the mutual coupling are presented in Fig. 10. From Table III, it is noticed that the mutual coupling in the first and second resonant frequencies are -11.5 dB and -13.2 dB, respectively. This difference is due to the effect of relative distance to wavelength between elements in the two frequency bands. The simulated gain and radiation efficiency are also presented in Table III. The E-and H-plane radiation pattern for two elements array without EBG is shown in Fig. 11 and Fig. 12.



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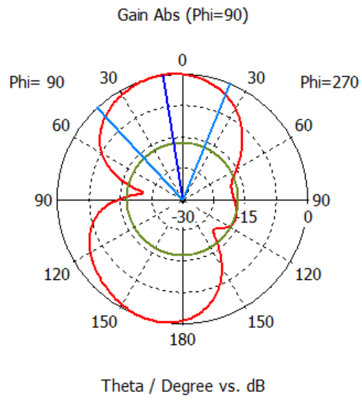

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Fig. 7. Radiation pattern of UWB KSA sign shape slot microstrip single element antenna at frequency 8.668GHz (a) E-plane, and (b) H-plane.

TABLE III: TWO ELEMENTS OF UWB KSA SIGN SHAPE SLOT MICROSTRIP PATCH ANTENNA WITHOUT EBG

Parameters	first resonant	second resonant
Frequency (GHz)	2.539	8.668
$\|S_{11}\|$ (dB)	-32.29	-16.1
$\|S_{21}\|$ (dB)	-11.5	-13.2
Gain (dBi)	3.1	5.2
Radiation efficiency	97%	71%
Antenna efficiency	91%	63%

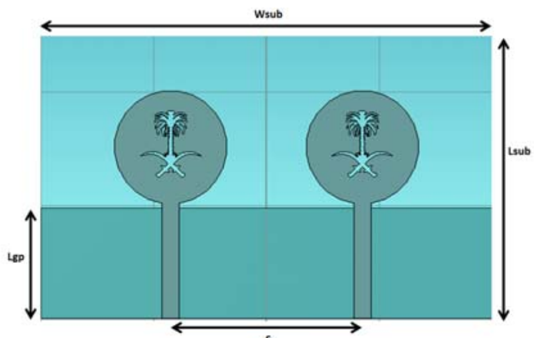
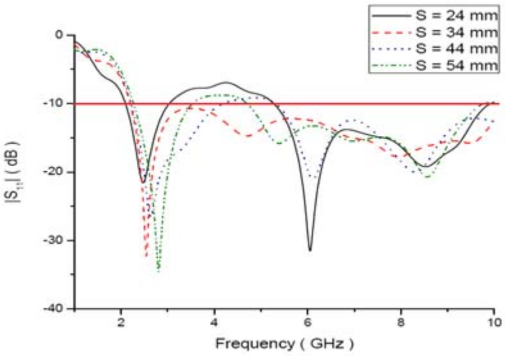


Fig. 8. The two elements of UWB KSA sign shape slot microstrip antenna array.



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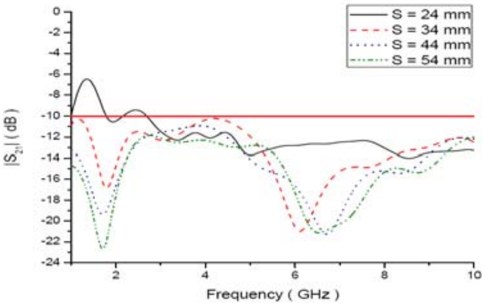

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Fig. 9. The effect of varying the distance between the two patches of the array (a) $|S_{11}|$, and (b) $|S_{21}|$.

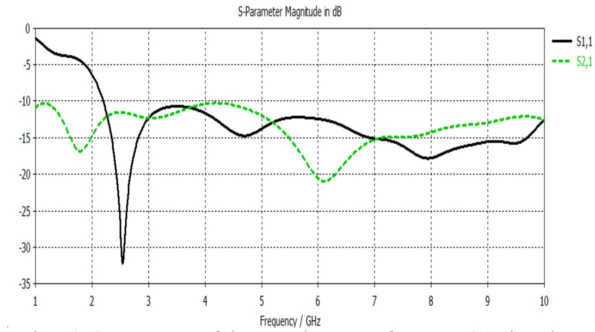


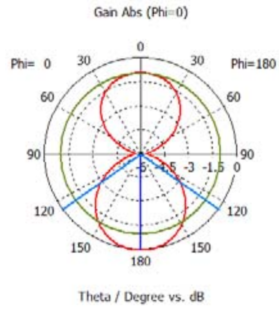
Fig. 10. S-parameter of the two elements of UWB KSA sign shape slot microstrip antenna array without EBG.

TABLE III: TWO ELEMENTS OF UWB KSA SIGN SHAPE SLOT MICROSTRIP PATCH ANTENNA WITHOUT EBG

Parameters	first resonant	second resonant
Frequency (GHz)	2.539	8.668
$\|S_{11}\|$ (dB)	-32.29	-16.1
$\|S_{21}\|$ (dB)	-11.5	-13.2
Gain (dBi)	3.1	5.2
Radiation efficiency	97%	71%
Antenna efficiency	91%	63%

D. Two Elements Array with EBG

The two elements of UWB KSA sign shape microstrip patch antenna with the same patch shape EBG cells on a dielectric substrate with ε_r = 4.4, h = 1.6 mm, and tan δ = 0.02 is shown in Fig. 13. The distance between the patches is 34mm ($0.32\lambda_0$) which is optimized the distance for the case without EBG to avoid grating lobes. The ground plane is 80 mm x 50 mm ($0.75\lambda_0$ x$0.47\lambda_0$) at resonant frequency. Each patch is fed by a matched microstrip line feed with width W_{50} = 3 mm. The S-parameters are presented in Fig. 14. From Table IV, it is noticed that the mutual coupling in the first and second bands is improved with comparison to the two elements without EBG. This difference is due to the effect of the EBG cells between elements in the two frequency bands. The simulated gain and radiation efficiency are presented. The E-and H-plane radiation pattern for two elements without EBG is shown in Fig. 15 and Fig. 16, respectively. Comparing the results introduced in Table III and Table IV, for the case of two antenna array without and with EBG, one can conclude that EBG reduces the antenna size by more than 4% for the lower frequency band and by more than 11% for the higher frequency band. The gain, radiation, and antenna efficiency are slightly increased. This is due to reducing the surface waves as a result of locating the waves as a result of locating the EBG cells in the separation between the antenna array elements. The most important achievement is the coupling reduction between the two elements by more than 3.1 dB in the lower band of frequency and by 7.02 dB in the higher band of frequency.



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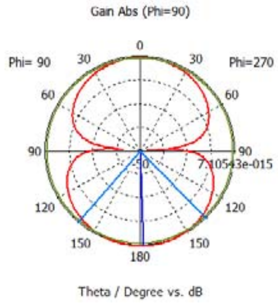

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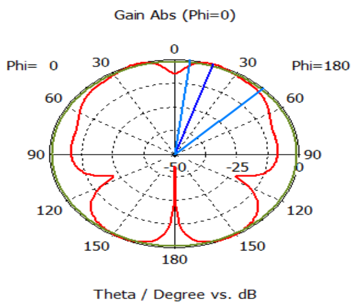
Fig. 11. Radiation pattern of UWB KSA sign shape slot microstrip antenna array without EBG at frequency 2.539GHz (a) E-plane, and (b) H-plane.



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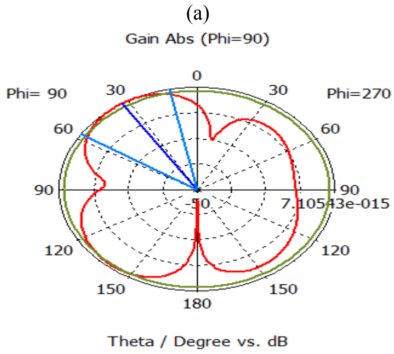

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Fig. 12. Radiation pattern UWB KSA sign shape slot microstrip antenna array without EBG at frequency 8.668GHz (a) E-plane, and (b) H-plane.

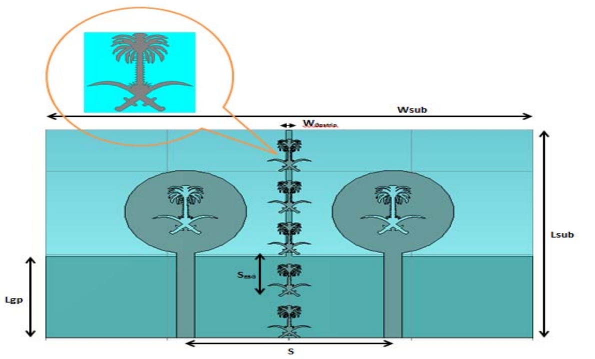


Fig. 13. The two elements of UWB KSA sign shape slot microstrip antenna array with EBG cells.

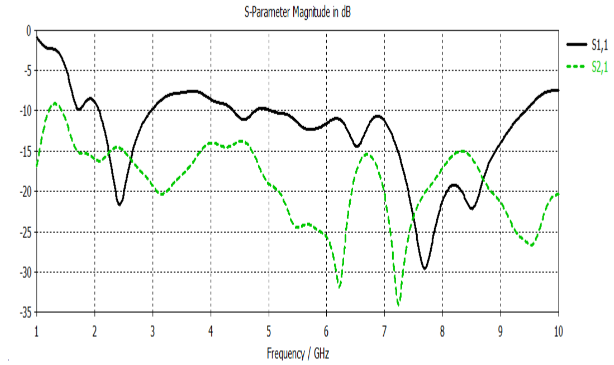


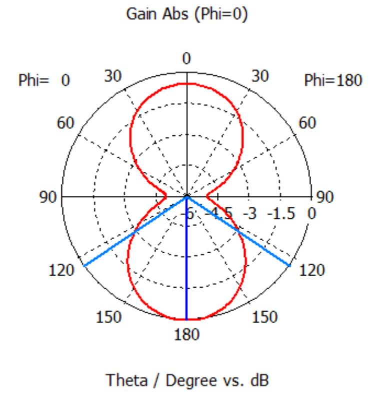
Fig. 14. S-parameter of the two elements of UWB KSA sign shape slot microstrip antenna array with EBG.

TABLE IV: TWO ELEMENTS OF UWB KSA SIGN SHAPE SLOT MICROSTRIP PATCH ANTENNA WITH EBG

Parameters	first band	second band
Frequency (GHz)	2.431	7.696
$\|S_{11}\|$ (dB)	-21.66	-29.61
$\|S_{21}\|$ (dB)	-14.6	-20.22
B.W. %	37	58
Gain (dBi)	3.263	5.587
Radiation efficiency	98%	78%
Antenna efficiency	95%	77%

III. EXPERIMENTAL RESULTS AND DISCUSSION

To verify the conclusions drawn from the simulation, two microstrip antennas were fabricated on FR4 substrates by proto laser machine with precision 25μm. The permittivity of the substrate is 4.4, the substrate thickness is 1.6 mm (63 mil), and tan δ = 0.02. The measuring results were obtained using Anritsu 37297D VNA. Fig. 17 shows a photograph of the fabricated UWB KSA sign shape microstrip patch antenna. Comparison between measured and simulated results is presented in Fig. 18. In Fig. 19, the fabricated two elements of UWB KSA sign shape microstrip patch antenna array without EBG photograph is presented. The measured and simulated results of the two elements of novel flag shape microstrip antenna array without EBG are compared in Fig. 20. The fabricated two elements of UWB KSA sign shape microstrip patch antenna array with EBG photograph is shown in Fig. 21. The measured results of the two elements of UWB KSA sign shape microstrip antenna array without and with EBG are compared in Fig. 22. The results show that a reduction in mutual coupling of 8 dB is achieved at first band (2.1 - 2.99) GHz and 33 dB at second band (5 – 9.43) GHz. This result agrees well with the simulated results. From this experimental demonstration, it can be concluded that the EBG can be utilized to reduce the antenna mutual coupling between array elements.



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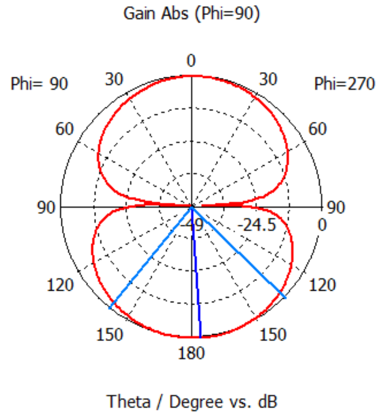

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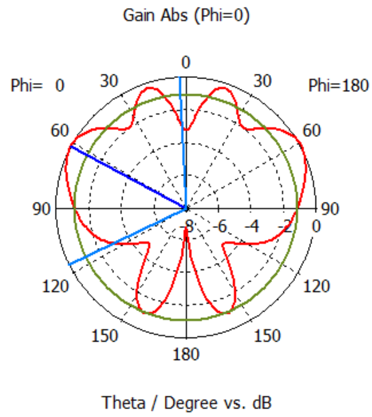
Fig. 15. Radiation pattern of UWB KSA sign shape slot microstrip antenna array with EBG at frequency 2.431GHz (a) E-plane, and (b) H-plane.



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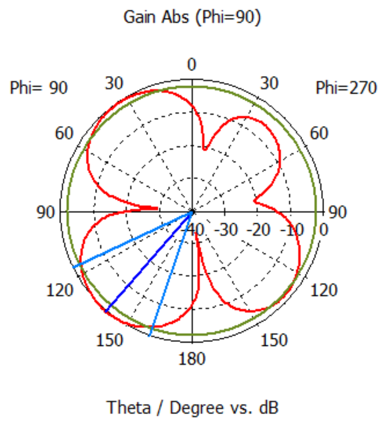

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Fig. 16. Radiation pattern of UWB KSA sign shape slot microstrip antenna array with EBG at frequency 7.696GHz (a) E-plane, and (b) H-plane.

A. Single Element

Fig. 17. The fabricated UWB KSA sign shape slot microstrip patch antenna.

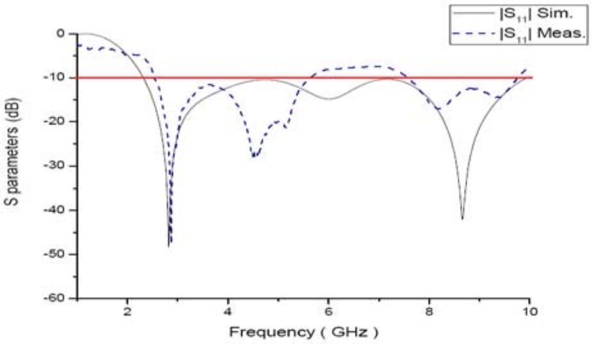

Fig. 18. Comparison between measured and simulated reflection coefficient of UWB KSA sign shape slot microstrip antenna.

B. Two Elements Array without EBG

Fig. 19. The fabricated two elements of UWB KSA sign shape slot microstrip patch antenna array without EBG.

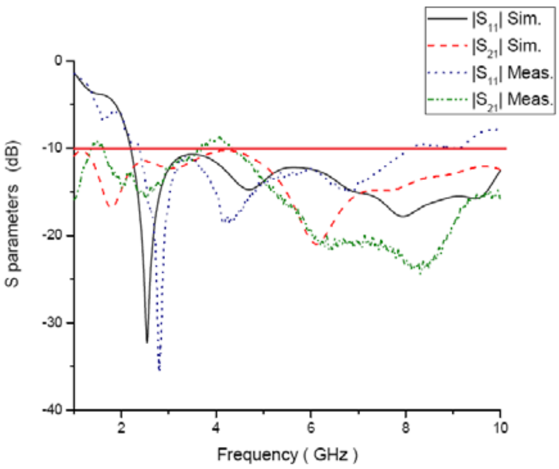

Fig. 20. Comparison between measured and simulated results of the two elements of UWB KSA sign shape slot microstrip antenna array without EBG.

C. Two Elements Array with EBG

Fig. 21. The fabricated two elements of UWB KSA sign shape slot microstrip patch antenna array without EBG.

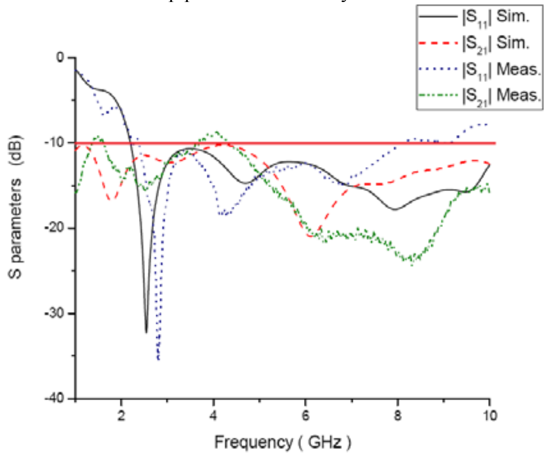

Fig. 22. Comparison between measured results of the two elements of UWB KSA sign shape slot microstrip antenna array with and without EBG cells.

IV. Conclusions

In this paper, a UWB KSA sign shape slot microstrip antenna is presented. The single and two element antenna were designed and fabricated on a substrate with dielectric constant of 4.4, thickness of 1.6 mm, and tan $\delta = 0.02$. The microstrip array was studied by CST simulator and fabricated by proto laser machine with precision 25µm. The antenna can be used in the military or RFID applications. This configuration is chosen because the KSA sign shape is used in the official page for any military application. So, this antenna may be used in soldier belts, any commodity for the military application, etc. The EBG cells in the shape of small size KSA sign are inserted between the adjacent coupled elements in the array to suppress the pronounced surface waves. A reduction in mutual coupling of 8 dB is achieved at first band (2.1 - 2.99) GHz and 33 dB at second band (5 – 9.43) GHz. The measured results agree well with those obtained by the CST.

Acknowledgment

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