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Compact Slotted Circularly Polarized Microstrip Patch Antenna with Surface Wave Suppressed Characteristics for WLAN Characteristics

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Abstract

Surface wave propagation in the dielectric substrate is one the dominant factors leading to power loss in microstrip patch antennas. The surface waves are radiated from the edges of the dielectric substrate and does not contribute to the radiation of the antenna. To mitigate this problem discontinuity is required to be introduced in the direction of surface wave propagation. In this paper, surface wave suppressed antenna structures with circularly polarized radiation characteristics have been proposed. A square patch antenna has been designed at 6 GHz. Slotted perturbations for the same patch has been done to achieve compactness and circular polarization in the design. Two variants of the slotted antenna with side patches and PTH pins embedded at specific locations have been presented. For the 1st antenna design the axial ratio bandwidth of 120 GHz, compactness of 32.58 % and gain of 10.5 dB been achieved at resonant frequency of 8.9 GHz. For the 2nd antenna design the axial ratio bandwidth of 110 GHz, compactness of 34.7 % and gain of 9.8 dB been achieved at resonant frequency of 9.2 GHz. The improvement in gain of the proposed designs as compared to simple square patch antenna has been observed to be around 3 - 4 dB.

Keywords: Gold, Nanogratings, Plasmonics, Switching, VO2

Introduction

Planar Micro strip antennas are used in most of the Microwave and Millimeter wave systems. They have many advantages such as low profile, light weight, conformal nature, and lower cost of production. Microstrip patch antennas were invented in 1950s, since then extensive research is being carried out in this field to enhance the radiation characteristics. Microstrip antennas are extensively used in wireless mobile and satellite applications due to the advantageous aspects like economical cost and less weight. Previously, microstrip patch antennas were used in military sector applications like rockets, missiles, satellites and aircrafts. Presently, these microstrip antennas [1-4] are being enormously employed in the commercial sector due to the low cost of dielectric substrate material, circular polarization and mature fabrication techniques. With continued research and development and increased usage, microstrip antennas are ultimately expected to replace conventional antennas for most applications.

The surface waves pose to be a serious hindrance to the radiation mechanism in microstrip patch antennas. The surface wave propagation leads to loss of antenna radiation and leads to undesirable coupling among antenna elements. The zero cut off TM_0 and TE_0 surface wave modes starts propagating along the substrate along with the dominant mode of propagation. The surface waves start propagating when a portion of the radiation from microstrip patch antenna, re-enters the substrate with the angle of incidence in the range of $\pi/2$ to $\sin^{-1}(1/\sqrt{\varepsilon_r})$. These waves once trapped in the dielectric substrate starts following a zig-zag path due to total internal reflection inside the substrate. When the surface waves [5-10] reach the peripheral boundary of the dielectric substrate at the interface of the dielectric and air these waves starts to radiate, if there is any other radiating element beyond this, the waves gets coupled to it. This leads to a considerable amount of loss in radiated power.

In recent times, electromagnetic band gap (EBG) based dielectric substrates have also been studied for various applications of planar microstrip patch antenna. EBG based substrates are also called as metamaterial substrates. These substrates are specially designed substrates with modified physical behavior. Negative permittivity is being achieved in these substrates by introducing suitable perturbations in the dielectric substrate. In EBGs the substrates are periodically loaded with metallic perturbations which inhibit the path of guided waves and results in suppression of surface wave propagation. The substrates has stop band characteristics in operating bandwidth for of surface wave mode propagation and so these are referred to as EBG structures. The dispersion properties of such substrates are also changed and reflection coefficient reaches unity value and forbidden band gap is also highlighted for wave propagation. Kristensson *et al*. [12] in 2001, proposed his research on enhancement of radiation characteristics and suppression of surface wave modes for patch antennas embedded on anisotropic substrates. In 2004 Iluz *et al*. [13] proposed phased array based microstrip antenna embedded on EBG based substrate. Nikolic *et al*. [14], Veselago [15] and Sievenpiper *et al*. [16] presented suppressed radiation in undesired directions and reduced mutual coupling. In 2007, Boutayeb and Denidni [17] presented cylindrical electromagnetic crystal based bandgap substrate with enhanced gain characteristics. In 2011, Mahmoud and Al-Ajmi [18] presented a circular microstrip patch antenna 2 shorting pins with supressed surface wave excitation. In 2011, Kim and Lee [19] proposed improvement in FBR in micro strip antenna using isolated soft surface with dual-band characteristics. In 2013, Emhemmed *et al*. [20], summarized a review thesis - some investigations on techniques to suppress surface wave propagation in circularly polarized microstrip patch antennas 16 on techniques for surface waves reduction in microstrip antennas. In 2013, Islam and Alam [21] presented electromagnetic surfaces with high impedance for suppression of mutual coupling in array based patch antenna design.

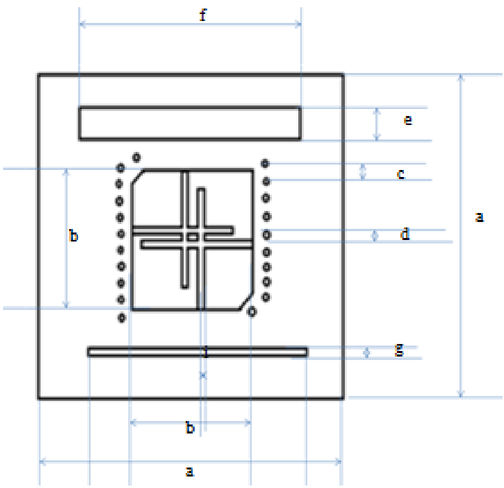
To suppress the surface waves a technique with periodic arrangement of metallic cylindrical pins embedded [22] in the substrate except the area underneath the radiating microstrip patch has been presented in this manuscript. Theoretical analysis of the proposed antenna has been presented. The propagation of TM_0 surface wave modes beneath the patch surface have been observed in simple dielectrics. The suppression of these surface wave modes have been observed in the proposed design. The simulated and theoretical results have been validated using EBG characteristics. The suppression of surface waves has been validated by improvement in gain and radiation efficiency characteristics.

Materials and methods

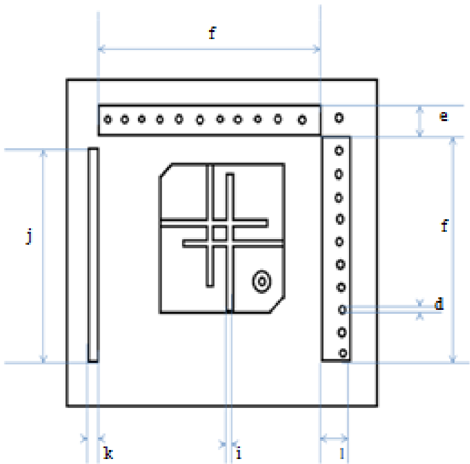
Antenna design

In this manuscript antenna structures with circularly polarized radiation characteristics have slotted microstrip patch antenna geometry embedded on a linear array of cylindrical pin bed structure are presented. The antenna structures are designed at 8.9 and 9.2 GHz for WLAN applications. The proposed antenna is exhibiting enhanced radiation characteristics, improved matching characteristics and axial ratio bandwidth of around 120 and 110 MHz. This manuscript illustrates the parametric study of dimensions of embedded cylindrical pin substrate for improving the radiation characteristics of the microstrip patch antenna. The simulation results are postulated by using Ansoft HFSS.

The antenna structures are shown in **Figures 1**(**a**) and **1**(**b**). The dimensions of the patch antenna are same as that of the circularly polarized patch antenna considered earlier. The length of side patch 1 is 35 mm and width is 5 mm. The length of side patch 2 is 35 mm and width is 2 mm. The metallic cylindrical pins are having the radius of 0.75 mm and spacing of 1 mm.



(a)



(b)

Figure 1 Top view of circularly polarized antenna: (a) (antenna 1) with 2 side patches embedded on cylindrical pin bed structure and (b) (antenna 2) with 3 side patches embedded on cylindrical pin bed structure.

The dimensions of the side patch 1 are length is 30 mm and width is 2 mm. The side patch 2 is having length of 40 mm and width of 5 mm. The side patch 3 has the length of 35 mm and width of 5 mm. The Cylindrical Pin Array on left side of the patch has the metallic pins with radius 0.75 mm and spacing 1 mm and the Cylindrical Pin Array on the right side of the patch has the pins with radius 1 mm and spacing 1 mm. The antenna design parameters have been tabulated in **Table 1**.

Table 1 Antenna design parameters.

S. No.	Parameter	Dimension (mm)
1	**a**	50
2	**b**	23
3	**c**	1
4	**d**	0.75
5	**e**	5
6	**f**	35
7	**g**	2
8	**h**	35
9	**i**	1
10	**j**	32
11	**k**	2
12	**l**	5

The surface wave suppression using cylindrical pin bed structure is followed for 2 proposed antenna structures. One structure has cylindrical pins embedded near the radiating edges from where the fringing fields radiate. And the 2 non radiating arms are supported with 2 patch geometries so that the radiation can be inhibited from those locations. The antenna shown in **Figure 1**(**a**) is provided with cylindrical pins embedded at the locations specifically where there is maximum radiation loss. The side patch has been etched to reduce the radiation loss from other sides. The parametric study has been done for selecting the dimensions of the metallic pin and metallic rectangular patches. The antenna structure shown in **Figure 1**(**b**) has been designed by etching a side patch along with the main circularly polarized patch antenna.

This structure allows the coupling of fields toward the major radiation lobe of the antenna. The slotted patch has been etched at location where maximum radiation loss is observed in the form of surface waves.

Effect of parameter dimensions on antenna performance

The reduced surface wave theorem [9] has been studied which follows that the effective dielectric constant should be such that it satisfies the following condition:

$$\varepsilon_{r_{eff}} = (\beta_{TM_0}/k_0)^2 \quad (1)$$

These proposed antenna structures satisfy this theorem. The zero cut off TM_0 surface wave modes propagates in the transverse direction to that of the patch antenna plane thus to inhibit its propagation we have to introduce the obstacle or discontinuity to its flow. The dielectric substrate is embedded with metallic cylindrical pins in longitudinal. These pins acts as metallic reflectors which reflects the surface waves towards the main radiation lobe of the microstrip patch antenna. This way we can solve the problem of surface wave radiation loss.

The anisotropic dielectric medium acts as artificial dielectric substrate. The dielectric constant or relative permittivity and relative permeability tensors are given below:

$$[\varepsilon] = \begin{bmatrix} \varepsilon_x & 0 & 0 \\ 0 & \varepsilon_y & 0 \\ 0 & 0 & \varepsilon_z \end{bmatrix}; [\mu] = \begin{bmatrix} \mu_x & 0 & 0 \\ 0 & \mu_y & 0 \\ 0 & 0 & \mu_z \end{bmatrix} \quad (2)$$

The parametric analyses of different design parameters as defined in **Figures 1**(**a**) and **1**(**b**) and their effect on antenna performance parameters like gain, radiation efficiency and return loss is shown.

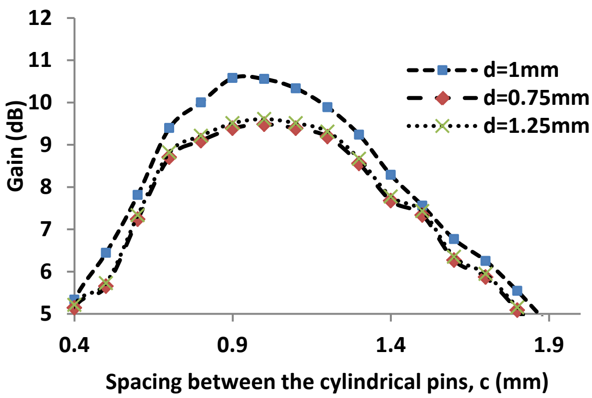


Figure 2 Parametric analysis of spacing between cylindrical metallic pins (c), diameter of cylindrical pin (d) versus frequency keeping other parameters constant.

The dimensions represent the spacing between metallic cylindrical pins. This has been varied from 0.4 m to 1.9 mm. The diameter of cylindrical metallic pins is varied from 0.75 to 1.25 mm. As per the simulation results shown in **Figure 3** the spacing of 1 mm shows highest gain and the diameter of the metallic cylindrical pins at which maximum gain is observed is 1 mm.

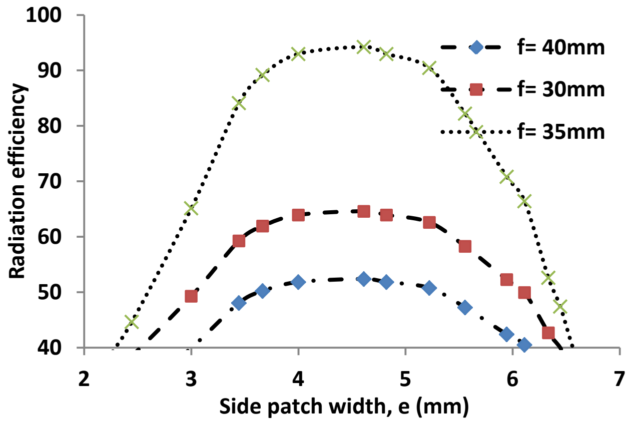


Figure 3 Parametric analysis of side patch width (e, k) and length (f) keeping other parameters constant.

The parametric analysis of width of side patch ‘e’ and ‘k’ is done. The variation of ‘e’ is plotted with respect to radiation efficiency. The graph is plotted for different values of side patch length ‘f’ varying from 30 to 40 mm. As per the simulation results the maximum value of radiation efficiency is obtained at ‘e’ and ‘k’ varying from 4 to 5 mm with optimum value of side length as 35 mm.

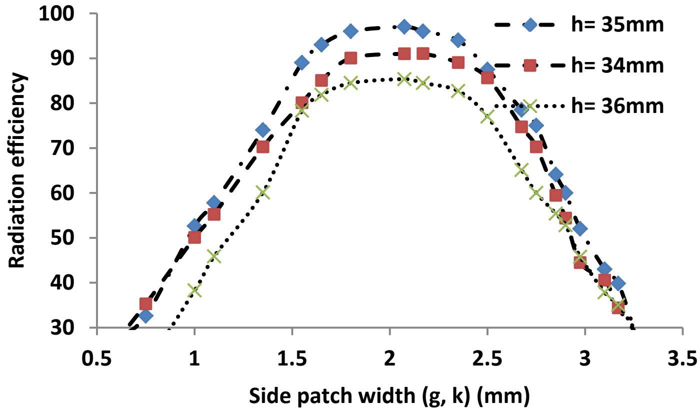


Figure 4 Parametric analysis of side patch width (g, k) keeping other parameters constant.

The parametric analysis of width of side patch ‘g’ and ‘k’ is done. The variation of ‘g’ and ‘k’ is plotted with respect to radiation efficiency. The graph is plotted for different values of side patch length ‘f’ varying from 30 to 40 mm. As per the simulation results the maximum value of radiation efficiency is obtained at ‘g’ and ‘k’ to be 2 mm with optimum value of side length as 35 mm.

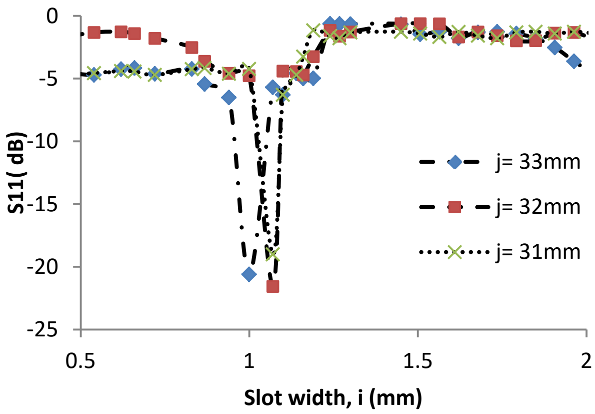


Figure 5 Parametric analysis of slot width (i) keeping other parameters constant.

The parametric analysis of width of slot ‘i’ is done. The variation of ‘i’ is plotted with respect to return loss. The graph is plotted for different values of side patch length ‘f’ varying from 30 to 40 mm. As per the simulation improved result for the value of return loss is obtained at ‘i’ to be 1 mm with optimum value of side patch length is 32 mm.

The design parameters like diameter of the metallic cylindrical pins, side patch length and width, slot width are calculated using parametric analysis.

The textured surfaces or the artificial dielectric substrates having embedded wire medium are used to change the surface impedance, and control the reflection characteristic, and tailor the properties of surface waves.

Suppression of surface waves is observed in both the structures. The reflection characteristic of the artificial dielectric substrate effectively represents the suppression of surface waves.

The reflection coefficient of the substrate can be represented as,

$$\rho = -(\beta_h \beta_p{}^2 \tan(\beta_h L) - k_{\parallel}{}^2 \gamma_{TM} \tanh(\gamma_{TM} L) + \varepsilon_h \gamma_0 (\beta^2 + k_{\parallel}{}^2))/(\beta_h \beta_p{}^2 \tan(\beta_h L) - k_{\parallel}{}^2 \gamma_{TM} \tanh(\gamma_{TM} L) - \varepsilon_h \gamma_0 (\beta^2 + k_{\parallel}{}^2)) \quad (3)$$

The calculated value of reflection coefficient ρ comes out to be 0.115536 – j0.994633 and 0.114436 – j0.992533 for antenna structures shown in **Figures 1** and **2** respectively. The magnitude of the reflection coefficient comes out to be approximately equal to 1 for both the structures, which supports 100 % reflection of surface waves.

The surface impedance for the dielectric substrate with embedded cylindrical pins medium is given by,

$$Z_s = j\eta_0 \tan(\beta h L)/\sqrt{\varepsilon_h} \quad (4)$$

The calculated value of Z_s are –j44.0746 Ω and –j74.0675 **Ω** 992533 for antenna structures shown in **Figures 1**(**a**) and **1**(**b**) respectively, which are capacitive in nature, this shows the suppression of TM_0 surface wave modes.

Results and discussion

The proposed antenna structures are showing suppression of surface waves. The TM_0 surface waves are suppressed when the reflection characteristics of the EBG substrate is also well in accordance. The novelty of these structures is that they are suppressing surface waves to a great extent of around 4 - 5 dB as shown in **Figure 6** and along with it these structures are circularly polarized radiation characteristics with axial ratio bandwidth of around 100 MHz as shown in **Figure 7**. The propagation of surface waves affects the gain of the microstrip antenna which gets degraded due to power loss in the form of surface waves. The antennas are designed at the frequencies 8 - 9 GHz which could be used for RADAR communication applications which is novel for this surface wave suppressed circularly polarized antennas. The gain characteristics are shown in **Figure 8**. The surface wave suppressed structure illustrated in [6] does not showcase compactness characteristics which are considered in this paper. Apart from this the theoretical base of results is also provided in this paper. The mutual coupling reduction and gain enhancement in circularly polarized patch array is considered in [7], the theoretical proof is not provided in that paper for improvement in results. In [8] the gain improvement and circular polarization has been concentrated upon but the improvement in gain is not much significant.

This kind of pin bed structure also acts as a Surface Integrated Waveguide and a waveguide as we know acts as a high pass filter. The S11 plot shows for the structures that it acts the high pass filter as there is a dip in S11 plot at the higher values of frequency the dip in S11 values is showing the pass band characteristics.

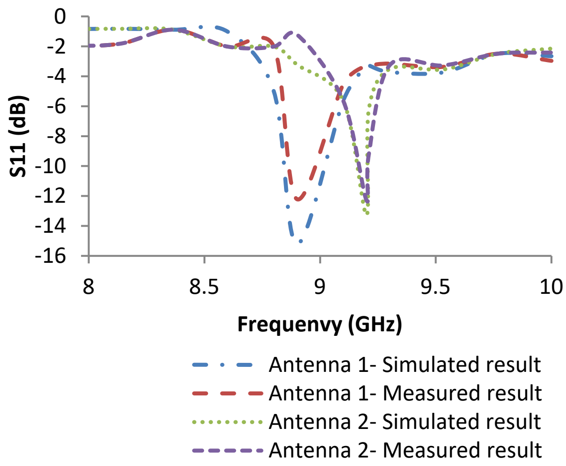


Figure 6 Graph showing the simulated and fabricated results of gain characteristics for the 2 modified antenna structures.

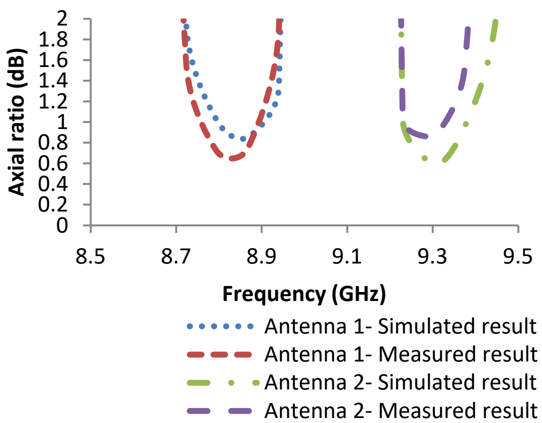


Figure 7 Graph showing the simulated and fabricated results of axial ratio characteristics for the 2 modified antenna structures.

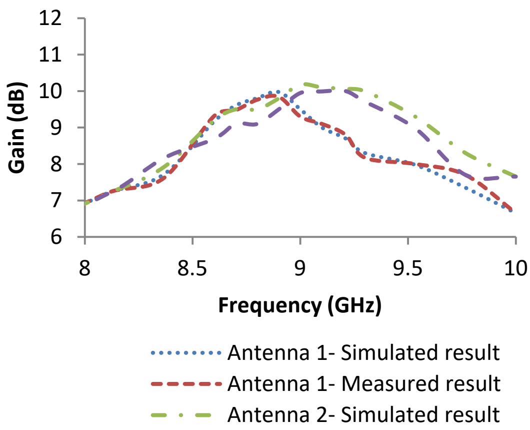


Figure 8 Graph showing the simulated and fabricated results of gain characteristics for the 2 modified antenna structures.

Conclusions

The ill-effects of Surface Wave propagation are minimized using array of cylindrical metallic pins embedded in the dielectric substrate in close proximity of the metallic patch antenna. Two circularly polarized surface wave suppressed antenna designs have been proposed. The antenna designs are slotted for achieving compactness. The modified structures are suitable for satellite and RADAR applications. The theoretical background confirming the propagation and suppression of surface wave propagation has been proved. The simulation has been performed on HFSSv14. The measured results comply well with the simulation results.

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