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Beamwidth Reduction of Helical Antenna Using Single Layer FSS Structure

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Abstract

In this paper, a 3 X 3 frequency selective surface (FSS) structure consisting of Jerusalem cross-shaped unit cell has been designed to use it as a superstrate above the helical antenna to mitigate the beamwidth of the main beam of the helical antenna. The designed helix is a wideband right hand circularly polarized antenna with 10 number of turns operating in axial mode. The FSS is placed at a distance of 19 mm above the helix. The main radiated beam of the helix possesses a beamwidth of 40 degree which constricts to 26 degrees after placing the FSS. The composite structure is operating at 7.93 GHz where a narrower main beam and a satisfactory gain of 12.42 dB can be achieved sustaining the circular polarization. Due to this property, we can use this composite structure as a filter to select a particular frequency (In this paper, it's 7.93 GHz) from a wide 10 dB bandwidth of the helix where we can obtain a circularly polarized radiation pattern with a relatively high Co-Polarization gain and a much narrower main beam.

1. Introduction

Since a long time, the helical antenna is one of the major areas in microwave research domain where the scientists express their keen interest for its numerous applications in satellite communication and radar technology. The helix antenna provides some advantages in terms of wide bandwidth and high gain compared to monopole, dipole or patch antennas. It also radiates circularly polarized wave over a wide bandwidth. In our day to day life, the demand for mobile phones, smartphones, tablets is increasing rapidly. By virtue of this rising demand, the mobile communication system requires wide bandwidth for accommodating more number of users as to maintain fast communication [1], [2]. So, helix antenna is widely used in mobile communication system [3]. The helical antenna can operate in both axial and normal mode. Depending on its mode of operation, the radiation patterns are different. In normal mode, the radiation beam is perpendicular to the helix axis i.e broadside radiation takes place whereas, in axial mode, the radiated beam is parallel to the helix axis i.e end-fire radiation pattern is obtained [6]. Since 1960, the Frequency Selective Surface (FSS) which is gaining its popularity in microwave field for its extensive applications can be used as a superstrate over antennas for increasing the gain and directivity of the antenna using the reflective property of the FSS [4]. FSS is an array of metallic periodic structure over a dielectric substrate which resonates at a particular frequency which is determined by its capacitance and inductance value. The periodic structure may be either metallic patches or array of an aperture on a metallic sheet which exhibit bandstop and bandpass response respectively [5]. A high directivity resonator antenna which uses a dual-layered FSS superstrate instead of a dielectric Electromagnetic bandgap superstrate in order to increase the dual-band directivity and reduce the height [7]. A wideband FSS comprising of two metallic structures which are separated by a substrate exhibiting a wide stop-band at 60 GHz has been used as a superstrate above a patch antenna to construct a high gain resonant cavity antenna for enhancing the gain by almost 5.9 dB [8]. In [9], A high gain resonant cavity antenna has been formed using FSS which is composed of two different dielectric slabs with different material properties and engraved above a patch antenna as a superstrate operating at 5.8 to 6.2 GHz region.

In this paper, the FSS structure has been utilized as a superstrate above the helical antenna with 10 number of turns. The helix is placed on a metallic circular thin ground plane. This antenna is made to operate in the axial mode which will provide an end-fire radiated beam. The antenna is operating over a wide bandwidth which makes it useful for C band as well as X band communication. This designed helix also provides high gain along the axis of the helix i.e $\theta=0^{o}$. A prototype of 3X3 frequency selective surface (FSS) with Jerusalem cross as the unit cell has been designed also to use it as a superstrate above the helical antenna to improve its performance. The use of FSS as a superstrate helps to mitigate the beamwidth of the main radiated beam of the helical antenna and thus a much narrower beam can be obtained while maintaining the gain and the circular polarization of the helix. The Jerusalem cross which has a parallel LC equivalent circuit makes the FSS a reflective surface, thus the beam radiated by the antenna experiences multiple reflections between the FSS and the metallic ground plane. This property makes the beam much narrower compared to the original radiated beam of the antenna. The design of the FSS and the obtained results are explained below.

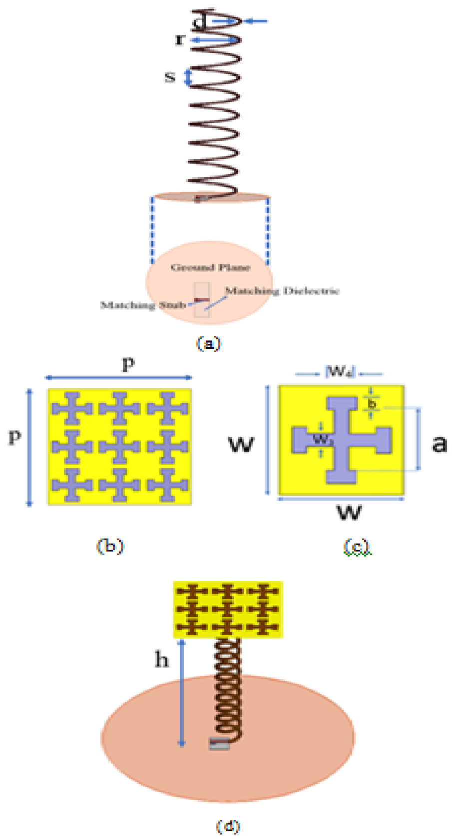

Figure.1. (a) Helix antenna, (b) Prototype of 3*3 FSS, (c) Jerusalem cross (unit cell of FSS), (d) FSS used as superstrate above helix antenna

2. Helical Antenna

2.1 Antenna Design

The helical antenna which is designed is shown in Figure.1. The helix antenna consisting of 10 turns has been designed on a metallic circular ground plane of 100 mm diameter which basically reduces the back radiation. The thickness of the ground plane is very small. The antenna is separated from the metallic ground plane by a dielectric substrate which is composed of Arlon AD320A (ε_r = 3.2) with a thickness of 0.79mm. In this paper the helix antenna is designed to operate in axial mode. So, the helical circumference c (c= 2πr, where r is the radius of the helix which is 4.5 mm) is chosen close to the wavelength λ (C= 0.92λ) corresponding to the resonant frequency 9.81 GHz. The pitch angle α (α= s/c, where s is the spacing between the turns of the helix which is 6.5 mm) should remain within the range between 12° to 14° for the axial mode of operation [10]. In this design, the pitch angle α is kept fixed and its value is taken as 13°. So, the height H of the helical

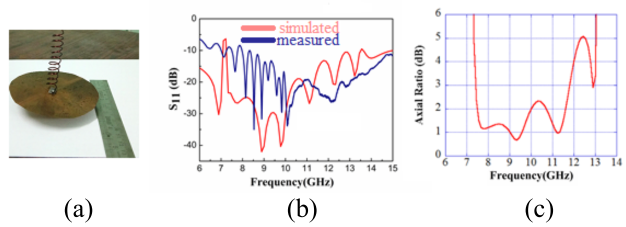

Figure.2. (a) Fabricated Prototype of Helix, (b) Reflection coefficient of the helix antenna, (c) Axial ratio of the helix antenna

antenna containing 10 turns is measured as 6.5cm. The helix wire made of copper has a diameter of 0.05λ i.e 1.5 mm (λ is the wavelength corresponding to 9.81 GHz). The helix is fed by a 50 ohms coaxial connector. A quarter wavelength transformer which is basically a copper stub having a length of 7.5 mm is used to match the impedance of the helical antenna (generally input impedance of helix is resistive and it lies between 100 ohms to 200 ohms) with the 50 ohms impedance of coaxial connector which penetrates through the dielectric substrate and touches the λ/4 transformer.

2.2 Results of Helix Antenna

The simulated results have been obtained in ANSYS HFSS software. The antenna provides a wide band of frequency of near about 6.33 GHz over which it can operate. The 10 dB bandwidth extends from 7.22 GHz to 13.55 GHz yielding almost 61% bandwidth which makes it functional in C band, X band and as well as in Ku band. The axial ratio is less than 3 dB for a wide frequency band extending from 7.3 GHz to 11.9 GHz. This axial ratio plot corroborates the fact that the antenna radiates circularly polarized wave for a wide band of frequency. Since antenna turns are along the right-handed screw, the designed helix is right-handed circularly polarized. The axial ratio plot is shown in Figure.2. The radiation patterns of the helix are shown in Figure.3 for three different frequencies at 7.93 GHz, 8.12 GHz and 8.36 GHz respectively. The antenna is providing a stable gain of approximately 14 dB over the entire bandwidth of 6.33 GHz with a relatively wider beamwidth of near about 40 degrees. The main lobe is aligned along the axis of the helix substantiating the fact that the helix is operating in the axial mode with a negligible back lobe radiation.

3. Frequency Selective Surface

3.1 FSS Unit Cell Design

The FSS unit cell is shown in Figure.1. This is a single layer FSS structure consisting of Jerusalem cross on a dielectric substrate made of Arlon AD320A (ε_r =3.2) with a thickness of 0.79mm. The dielectric Arlon AD320A has a loss tangent of 0.002. The Jerusalem cross is made of copper

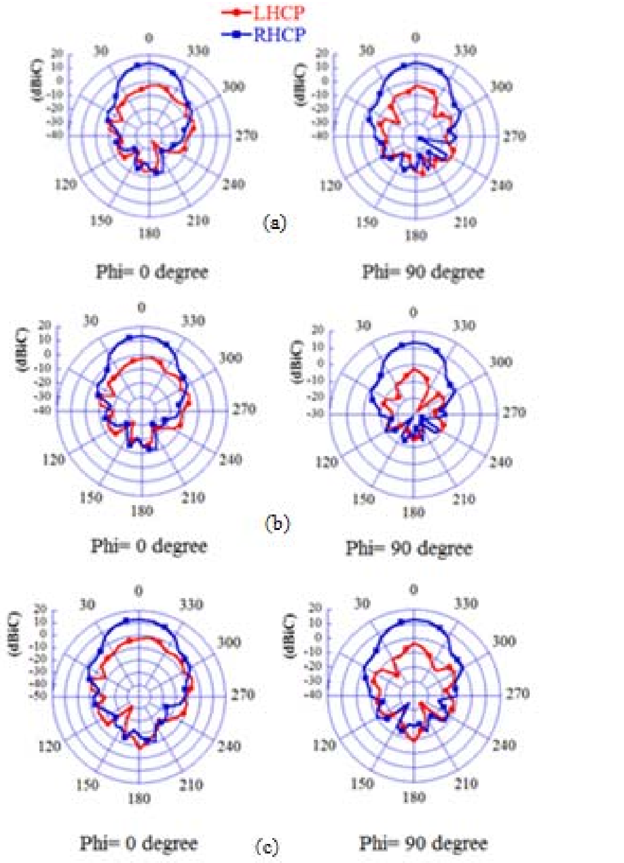

Figure.3. Radiation pattern of the helix at (a) 7.93 GHz, (b) 8.12 GHz and (c) 8.36 GHz

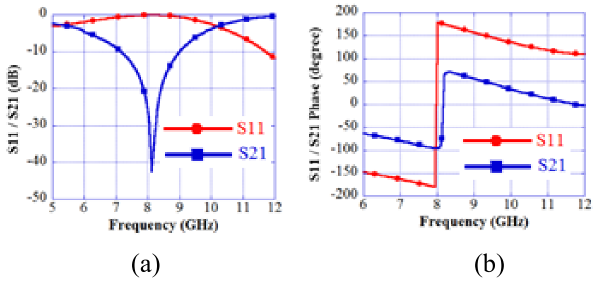

Figure.4. (a) Transmission and reflection coefficient of the FSS, (b) Transmission and reflection phase of the FSS

having a thickness of 0.035 mm. A prototype of 3×3 FSS structure is designed to use as a superstrate above the antenna. The dimensions of the unit cell are listed in Table I.

Table I Unit Cell Dimensions

Parameters	**p**	**w**	**a**
Values	42 mm	14 mm	8 mm
Parameters	b	W_3	W_4
Values	2 mm	2 mm	4 mm

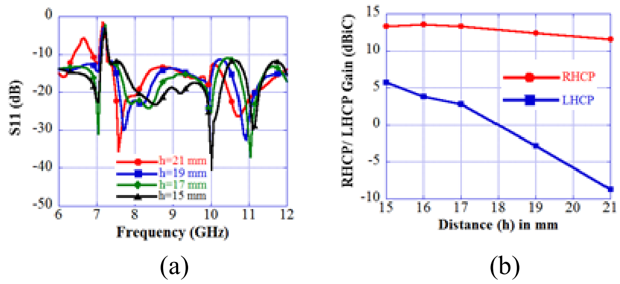

Figure.5. (a) Reflection coefficient plot for different distance between FSS and helix, (b) Variation of RHCP and LHCP gain with distance between FSS and helix at 7.93 GHz

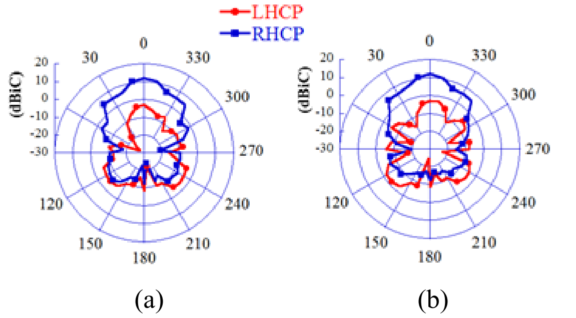

Figure.6. Radiation pattern of helix together with the FSS structure at 7.93 GHz for (a) Phi= 0° and (b) Phi= 90 degree

3.2 Results of FSS

The single layer FSS is evincing a transmission null of -42.4 dB at 8.12 GHz. The FSS exhibits a 3 dB bandwidth of almost 60% extending from 5.5 GHz to 10.2 GHz. The phase of S_{11} and S_{21} alters from positive value to negative value or vice-versa crossing zero degrees at the respective resonant frequency. So, at resonant frequency there is a large phase transition indicating the fact that maximum reflection or transmission occurs at that frequency. The phase of reflection coefficient differs from the phase of the transmission coefficient by 90° at 7.93 GHz. The S_{11}/S_{21} plot and the phase plot for S_{11}/S_{21} are shown in Figure.4.

4. Results and Discussions of The Composite Structure

The FSS is placed at a different distance (h) above the helix antenna. The distance is varied within the bandwidth of operation of the entire structure (the helix antenna together with the FSS). The 10 dB bandwidth of the helical antenna extends from 7.22 GHz to 13.55 GHz whereas the 3 dB bandwidth of the FSS structure ranges from 5.5 GHz to 10.2 GHz. So, the overlapping range of the antenna and the FSS structure lies between 7.22 GHz to 10.2 GHz. The corresponding wavelength has a range varying from almost 30 mm to 42 mm. The FSS is engraved at a distance of $\lambda/2$ mm above the helix because after travelling $\lambda/2$ distance, the wave experiences a phase reversal of 180º. So, the distance between the FSS and the helix is varied from 15 mm to 21 mm in this paper.The reflection coefficient plots of the composite structure (FSS together with the helix) for four different distances are given in Figure.5. The 10 dB bandwidth of the composite structure remains almost same with the actual bandwidth of the helix. The bandwidth of the entire structure has a range from near about 7.29 GHz to approximately 12.9 GHz exhibiting almost 56% bandwidth.

The RHCP and LHCP gain is plotted against distance (h) between the FSS and the helix in Figure.5. In this paper, RHCP and LHCP are the co and cross polarization respectively. Both LHCP and RHCP gain are decreasing with the increase in distance. For 15 mm distance, the RHCP and LHCP gain are approximately 13.367 dB and 5.8163 dB respectively. Though the RHCP gain (Co-Polarization gain) is maximum for 15 mm distance, the difference between the co and cross polarization is very less (only 7.55 dB). For 21 mm distance, the difference between co polarization and cross polarization is maximum, but the RHCP gain is 11.604 dB. So, we are getting good Co-Polarization and Cross-Polarization separation at the cost of Co-Polarization gain. For 16 mm and 17 mm, the Co-Polarization and Cross-Polarization separation is less than 10 dB. That's why the optimum distance between FSS and the helix is chosen as 19mm because we are achieving satisfactory RHCP gain (12.42 dB) while maintaining more than 15 dB Co-Polarization and Cross-Polarization separation. The beamwidth of the main beam becomes narrower when the FSS structure is used as a superstrate above the helix. The radiation pattern of the composite structure is shown in Figure.6. The beamwidth of the main beam reduces to 26 degrees at 7.93 GHz which is much less than the beamwidth of the actual radiated beam of the helix antenna (40 degrees). So, at this frequency a satisfactory gain of 12.42 dB with a much narrower beam can be achieved. A slightly less amount of gain is obtained than the actual helix which can be compromised for a much narrower radiated beam along the axis of the helix.

5. Conclusion

The reflection coefficient response, axial ratio and radiation pattern of the helix at different frequency have been studied in this paper. The main radiated beam is 40 degree wide. The aberration in the S_{11} plot and the radiation pattern after placing the FSS above the helix have been observed also in this paper. The FSS is kept at various distances ranging from 15 mm to 21 mm and the corresponding reflection coefficient and the LHCP and RHCP gain have been plotted. The best result in terms of gain, beamwidth and the Co-Polarization and Cross-Polarization separation is obtained for 19 mm distance (h). We observe that at 7.93 GHz, we are getting circularly polarized radiation pattern with the satisfactory gain of 12.42 dB and 26-degree beamwidth of the main radiated beam. As the main radiated beam is getting narrower, the designed structure (helix along with the FSS) finds its application in satellite-based cellular communication where many potentially active users are located within a specified area.

6. Acknowledgements

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7. References

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