ISSN: 2321-8169
268 – 272

Design and Analysis of Wide-Band Planar Antenna using Meta-material for S-Band Applications

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Abstract— A meta-surface inspired patch antenna is proposed and studied for S-band Applications. The proposed antenna has single fed configuration is loaded with an array of meta-surface unit cells for miniaturization and improve the performance of bandwidth. The detailed antenna radiation characteristics are examined and illustrated with simulated results. The antenna is designed for S-band frequency 2.5GHz on FR4 substrate having dielectric constant 4.4 and loss tangent of 0.02 and simulated using Ansoft HFSS software. The simulated results obtained are 10.4% (2.34-2.62 GHz) for 10 dB return loss bandwidth which is 4% more than antenna without meta-surface, 6.7 dBi for gain performance and patch size reduction up to 29% using meta-surface. This antenna will be applicable for S-band Radar applications such as weather radar, surface ship radar and space borne radar (SAR) etc.

Keywords-*Left Handed Materials, Meta-material, Meta-surface, Microstrip Antenna, SRR.*

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I. Introduction

The idea of first Metamaterial was given by J.C.Bose in 1898 using in transmitters, and various microwave components. Then V.G. Veselagoin 1968 first developed a electrodynamic substance having negative permittivity and permeability simultaneously. This work was carried out further by D.M Smith and Pendry in 2001 and discovered meta-material and proved having negative properties. Metamaterialis a periodic material that derives its properties (i.e. Permittivity and Permeability) from its structure rather than its components.Nowadays it is developing field of research at microwave frequencies. This material has not been observed readily in nature; they areformed artificially by their structures and their EM properties.

Various examples of Metamaterial used are Split Ring Resonator (SRR)+ wire, Chiral Materials (Based on polarity), Swiss Roll type. Byusing Metamaterial, antenna reduces its size, increase effciency and Bandwidth at resonance. It also reduces Mutual Coupling of antenna array. Various ways Meta-Material can be used in designingAntenna are: As a Substrate, As a array Feed Network, As a GroundPlane, As a Cloaking Device, As a superstrate, As a Struts in reflector Antenna, As a Radome Structure.Metamaterial (MTM) are the material generated from artificial materials that are not found in nature but can be engineered. In the mid 1960s, Victor Veselago studied the behavior of such materials that shownegative permittivity and permeability and hence are called double negative materials. These materials exhibit negative refractive index, since the structure consists of a Split Ring Resonators (SRR). SRR consists of two concentric rings with a split on opposite sides of rings. These structures provide high quality factor forming an electrically small LCresonator. Metamaterials find their uses in variety of applications.[3-5]

Patch Antenna have a various advantage like low profile, lessweight, easily portable, Small size which are used in many wireless communications, satellite communication and microwave applications etc. Beyond it has advantages, it has disadvantage also of having narrow bandwidth, low gain, small directivity and low efficiency. A Meta-material antenna can be formed by designing Metamaterial unit cell on a substrate of various shapes and feeding that antenna with coaxial feeding, direct feeding or any other feeding mechanism like slot coupling or EM coupling.

Section II describes design of meta-surface unit cell and its array loaded under patch antenna, Section III describes Simulation results of antenna with and without meta-surface, Section IV conclusion.

II. Design of a meta-surface antenna

A. Design of meta-surface unit cell

Meta-surface unit cell has been designed on FR4 substrate having dielectric constant of 4.4, loss tangent of 0.02 and a thickness of 4.8 mm.Meta-surface has been placed at height of

ISSN: 2321-8169
268 – 272

3.2 mm.The design of Meta-surface unit cell is shown in Figure 1.
The dimensions of unit cell has been follows:

- Length/Width of rectangular ring: Lu=8.96 mm ; Wu=5.6 mm
- Length/Width of slot in Rectangular ring:Sl=7.46 mm; Sw=0.85 mm

The meta-surface unit cell has been designed and simulated using Master-slave boundaries and Floquet mode of excitation has been given to unit cell for carrying out analysis using infinite structure.

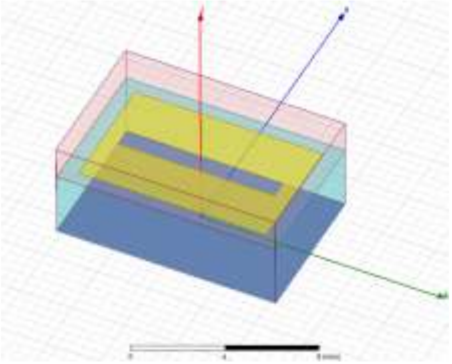

Figure 1: Meta-surface Unit Cell

It has been observed that the reflection phase of the unit cell crosses through the range of +90 degree to -90 degree across a wide frequency range. The frequency range of meta-surface unit cell is within ±90 degree reflection phase variation from 2.47 to 5.5 GHz. This is shown in Figure 2.

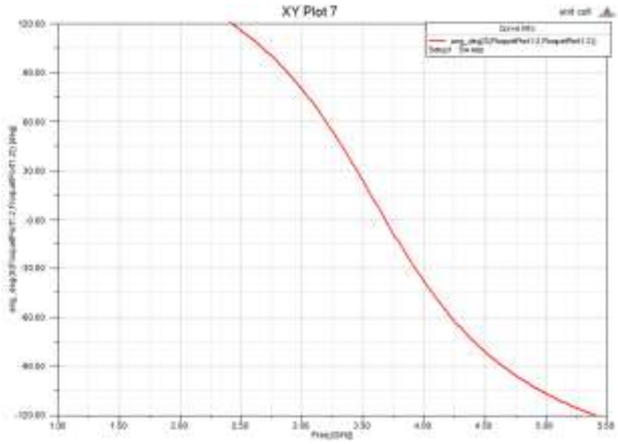

Figure 2: The reflection phase diagram of meta-surface unit cell

B. Design of antenna with and without meta-surface

After designing a unit cell, a rectangular patch antenna has been designed initially at 2.5 GHz frequency on FR4 substrate having dielectric constant of 4.4, loss tangent of 0.02, at a thickness of 4.8 mm. The dimensions of patch antenna are as follows:

- Length and width of ground plane:90 mm *180 mm
- Size of patch: $0.207\lambda_0$ * $0.483\lambda_0$ where $\lambda_0$is the free space wavelength at 2.5 GHz.
- Coax-feed location: x_p=-11 mm ; y_p=-15 mm
- Overall antenna size: 90 mm *180 mm *4.8 mm.

The above antenna is feed with Coaxial-feeding technique and simulated in HFSS.The simulation result of this antenna configuration is shown below.

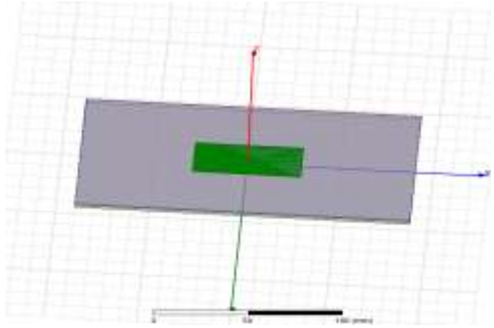

Figure 3: Rectangular patch antenna without meta-surface

Antenna with meta-surface:

After the unit cell and the conventional antenna has been designed and simulated, the conventional antenna has been loaded with an 7*7 array of meta-surface unit cell at a height of 3.2 mm and the antenna is placed at 1.6 mm above the meta-surface. The overall dimensions are as follows:

- Length and width of ground plane:90 mm *180 mm
- Size of patch: 0.155 λ_0 *0.454 $\lambda_0$where $\lambda_0$is the free space wavelength at 2.5 GHz.
- Coax-feed location: xp=-8 mm ; yp=-8 mm.
- Overall antenna size: 90 mm *180 mm *4.8 mm.

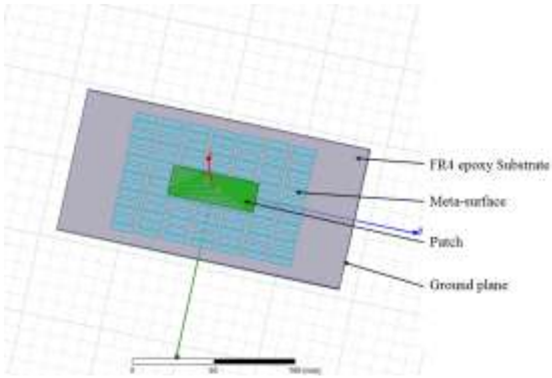

Figure 4: Rectangular patch antenna with meta-surface

III. Simulation Results of antenna with and without meta-surface

The antenna is simulated using Ansoft HFSS and the simulated results are shown as below. Figure 5 shows the return loss of an antenna which is about -14 dB at the resonant frequency. The 10 dB return loss bandwidth is about 150 MHz(6%). Figure 6 shows the far _eld radiation property that

ISSN: 2321-8169
268 – 272

is gain (dBi) which is about 7 dBi at 0 degree. Figure 7 shows the cross-pol discrimination which is about -13 dBi and Figure 8 shows the radiation pattern of the same above antenna configuration.

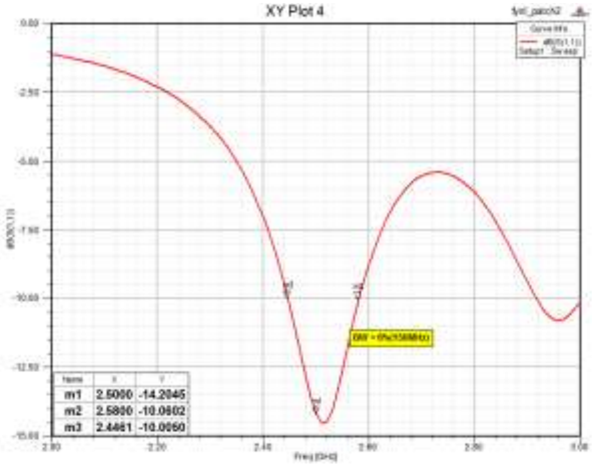

Figure 5: Return loss(dB) of an antenna without meta-surface

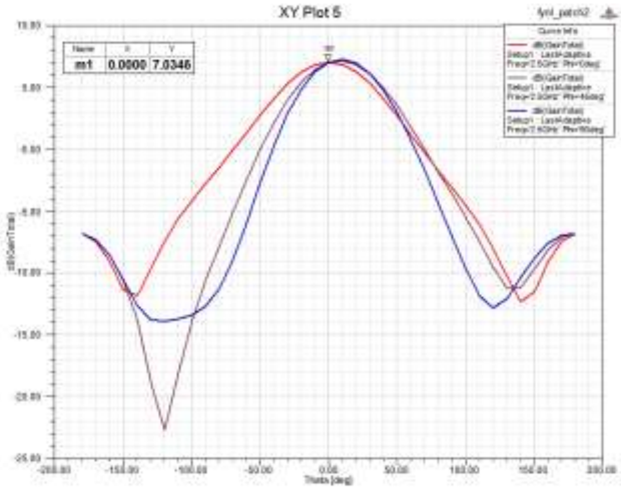

Figure 6: Gain(dBi) versus theta(deg)

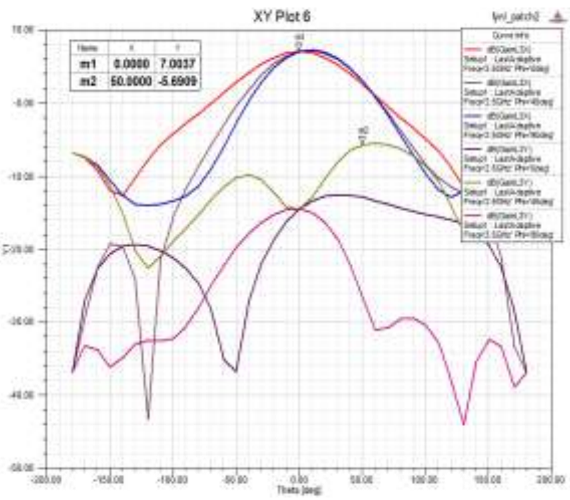

Figure 7: Cross-pol discrimination

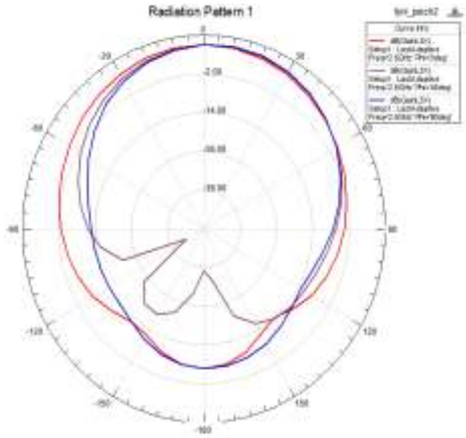

Figure 8: Radaiation Pattern

Simulation results of antenna loaded with meta-surface

In Figure 9, 10, 11 shows the 10 dB return loss, gain(dBi)and radiation pattern of a meta-surface antenna. In Figure 4.9,return loss upto -26 dB is obtained at resonant frequency 2.5 GHz. The 10 dB return loss bandwidth of meta-surface antenna is 10.4%(2.34 GHz - 2.62 GHz). Also comparison has been shown in this _gure between return loss of conventional antenna and meta-surface antenna.

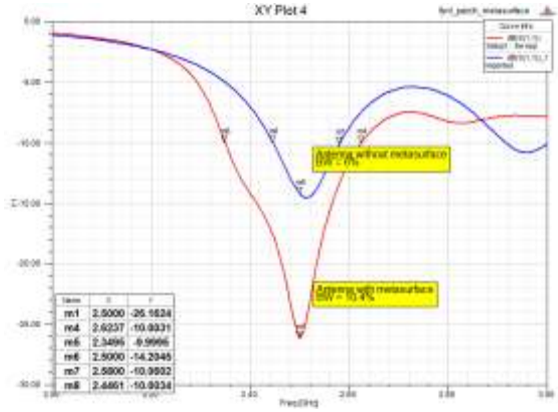

Figure 9: Return loss(dB) of a meta-surface antenna

The Figure 4.10,shows the graph of gain versus angle in degree. The gain obtained through meta-surface antenna is about 6.74 dBi.

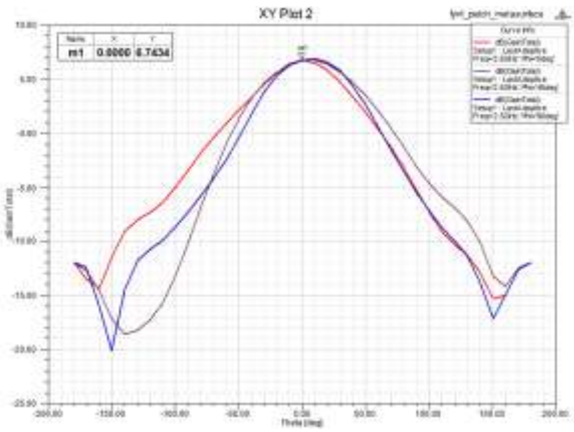

Figure 10: Gain(dBi) versus theta(deg)

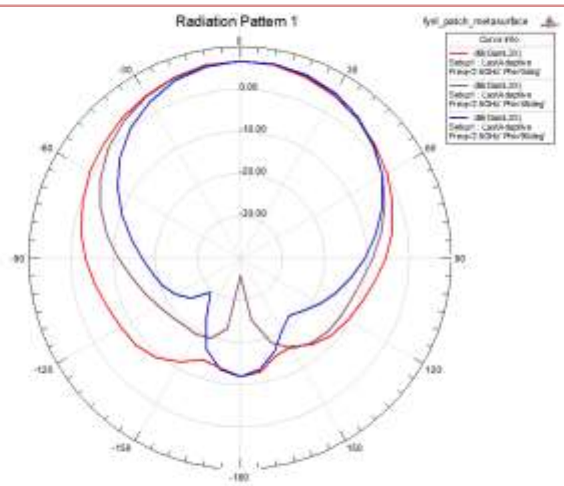

Figure 11: Radiation Pattern

IV. Conclusion

A systematic and detailed study has been done on metamaterials and its properties to achieve it. Various types of meta-materials that is EBG(Electromagnetic bandgap structures), SRR(Split Ring Resonator), RIS(reactive impedance surfaces)etc. has been studied through the literature survey. Microstrip antennas and its feeding techniques has also been studied with its method of analysis. A patch antenna has been designed and simulated on FR4 epoxy substrate and its performance is observed by using meta-surface and without meta-surface. It has been observed that 10 dB return loss bandwidth with and without meta-surface is 10.4% and 6.2% respectively, gain in dBi is about 7.2dBi without meta-surface and 6.7dBi with metasurface. It has also been observed that while using meta-surface coupling between patch and meta-surface increases leads to increase in bandwidth. Size reduction of patch antenna is observed upto 29% compared to antenna size without meta-surface.

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268 – 272

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