Abstract—High directive planar antenna made from a one-layer and two-layer metamaterial superstrate has been investigated. Metamaterial are periodic structures and have been intensively investigated due to the particular features such as ultra refraction phenomenon and negative permittivity or permeability. A patch antenna is used as the radiation source. The Ansoft HFSS is used for the simulation. The results show that the gain, directivity and bandwidth of the antenna with metamaterial superstrate are increased at Ku-band (13-17GHz). Compared with the patch feed with the same aperture size but without the metamaterial superstrate, the performance of the antenna is improved obviously.

Index Terms— Metamaterial superstrate, S coupled structure, Double split ring structure, Ultra refraction

I. INTRODUCTION

Compact directive antennas with a single feeding point are highly attractive in practice [1, 2]. Conventional patch antenna has simple feeding mechanisms, whereas its radiated pattern is affected by the surface wave and has low gain and bandwidth [3]. On the other hand, patch array antenna can offer the directive feature, but the complex feeding mechanism and the radiation efficiency limit its application range. Therefore, high directive and wideband antenna with more compact structure and simple feeding is of great interest in recent years.

New artificial materials, such as metamaterial, are introduced to design antennas for enhancing the performance and reducing the profile [1]. Metamaterials are artificial materials synthesized by embedding specific inclusions, for example, periodic structures, in the host media. Some of these materials exhibit either negative permittivity or negative permeability. If both permittivity and permeability of such materials are negative at the same frequency, then the composite possesses an effective negative index of refraction for isotropic medium and is referred to as a left handed metamaterial. The name is used because the electric field, the magnetic field and the wave vector form a left-handed system [4]. These metamaterials are typically realized artificially as composite structures that are composed of periodic metallic patterns printed on dielectric substrates. Metamaterials have been extensively studied in the recent years, in the framework of microwave applications. Several works have been aimed towards the improvement of the performances of antennas in the microwave range of frequencies [5, 6]. It is noted in that some principal properties of waves propagating in materials with negative permittivity and negative permeability are considered and high directivity can be obtained from conventional antenna using metamaterials [7]. In 2000, B. Temelkuran et al. placed a monopole radiation source inside a resonant cavity made of dielectric photonic crystals and obtained high directivity [8]. Furthermore, M. Thévenot and A. R. Weily et al. had designed some antennas by placing a photonic crystals superstrate above a conventional microstrip patch antenna, and also obtained a high directive radiation, respectively [9].

In this paper, two type of metamaterial superstrate antenna with high directivity is introduced for the Ku-band. The metamaterials, which consists of coupled S shaped and Double split rings structures, is used to simulate a low refractiveindex homogeneous medium (n ≈ 0) and placed in front of the feeding source. The simulation results show that the gain and bandwidth of the antenna with metamaterial superstrate is improved and the antenna directivity is enhanced obviously.

II. DESIGN OF ANTENNA WITH METAMATERIAL SUPERSTRATE

A. S coupled metamaterial superstrate

The first metamaterial used in our simulation is composed coupled S shaped structure that they place on substrate with permittivity 2.2 [10]. The unit cell for the coupled S shaped structure medium is shown in Fig. 1. Theoretical and experimental studies have shown that such structures can be taken as a homogenous medium with a low plasma frequency [4]. To obtain refraction index of metamaterial superstrate, a unit cell is identified from the full size structure and placed in a waveguide to collect the S-parameters. The top and bottom surface has PEC boundary conditions, whereas the left and right have perfect magnetic conductor (PMC) boundary conditions and front and back as open boundary condition. A waveguide port is placed at the open boundaries. With the S-parameter data from the waveguide, we can retrieve the effective medium parameter at all frequencies [11]. The
refraction index is shown in Fig. 2a. Using the same method we obtain refraction index for 5×7 array of the coupled S shaped structure. From the Fig. 2b, it is observed the refraction index is near the zero in the frequency range 13.5_17.5GHz. Then one can expect the ultra refraction phenomenon in this range. The radiated energy will be concentrated in a direction close to the normal of the metamaterial superstrate.

B. Double split rings metamatrial superstrate

The second metamaterial superstrate is made of Double split rings structure [12]. Same method, as mentioned before, is used to obtain refraction index of metamaterial superstrate. The unit cell of structure is shown in Fig. 3 index has shown. For confirmation of result for array of these structures, refraction index of 6×7 array of them, that it shows in Fig. 3, is extracted with same method. The refraction index of unit cell and 6×7 array of Double split ring metamaterial superstrate has shown in Fig. 4.
III. DESIGN OF MICROSTRIP ANTENNA WITH METAMATERIAL SUPERSTRATE

Microstrip antenna with square patch (5.6mm×5.6mm) on the Roger RT/duroid substrate with permittivity 2.2 and with 40 mm×46 mm dimensions and height 1.575mm is used in the simulation process. The Square patch feed by 50 $\Omega$ coaxial probe is positioned 1.25mm off-center. The operation frequency of antenna is 15.23 GHz. Metamatrial superstrate places above the patch of antenna for concentrating of radiation energy normal to itself. Adjustment of first superstrate layer is the most important stage in antenna design and it is about one third of operation wavelength ($\lambda/3$) above ground plane which cause to gain increase. The second layer, improve beam shaping and bandwidth. The distance of second layer from first layer is between $\lambda/3$ to $\lambda/2$. Fig. 5a shows configuration of microstrip antenna with S coupled metamatrial superstrate. The first layer is about 9.225mm above the ground plane and the optimized distance of second layer is 11.60mm. Also Configuration of Antenna with Double split ring metamaterial superstrate has been shown in Fig. 5b. The first layer is about 9.225mm above the ground plane and the optimized distance of second layer is 10 mm.

The Ansoft HFSS is used for simulation. Fig. 6 shows return loss of antenna with metamaterial superstrate. The results shows that the bandwidth of antenna with two layer metamatrial superstrate has improved. Fig. 7 shows the gain of antenna with metamaterial superstrate in comparison with simple microstrip antenna. It is observed Gain of antenna increases significantly with metamaterial superstrate. The first layer has important role in this increase. Fig. 8 shows gain pattern of antenna with metamaterial superstrate at frequencies that antenna has maximum Gain. Except antenna with one layer Double split ring that its maximum Gain occurs at 13.7GHz, maximum gain of the rest occur at 15.23GHz.

![Fig. 5. Configuration of antenna with metamaterial superstrate (a) S coupled structure (b) Double split ring structure.](image)

![Fig. 6. Comparison of return loss of antenna with and without metamaterial superstrate.](image)

![Fig. 7. Comparison of Gain of antenna with and without metamaterial superstrate.](image)

![Fig. 8. Gain pattern (a) simple microstrip antenna (b) One layer S coupled (c) two layer S coupled (d) One layer Double split ring (e) Two layer Double split ring.](image)
IV. SIMULATION RESULTS

Fig. 6 shows the bandwidth of antenna (S11<-10 dB) with two layers metamaterial superstrate has increased. The bandwidth of antenna with two layers S coupled increases about 1 GHz, whereas the bandwidth of antenna with two layers Double split ring has increased about 2.2 GHz. Although the bandwidth of antenna with one layer Double split ring increase as same as two layers, but there is a narrow frequency notch band around 14.1 GHz. Also Gain of antenna has increased by using metamaterial superstrate. It is observed from Fig. 7, maximum Gain is obtained by two layers S coupled metamaterial superstrate about 15 dB. Although from Fig. 7 is observed that one layer Double split ring intensively reduces Gain of antenna at frequencies upper than 14.3 GHz, two layers double split ring improve Gain of antenna.

Finally, Fig. 8 displays Gain pattern of the microstrip antenna with metamaterial superstrate. It is obvious the metamaterial superstrate cause to increase the directivity of the antenna, particularly when two layers metamaterial superstrate are used.

V. CONCLUSION

In conclusion, metamaterial structures help to improve some features of microstrip antenna. The near zero refraction index of these structures concentrate radiation energy of patch of antenna, consequently, they increase Gain of antenna and beam shaping of antenna radiation pattern. Also, they help to improve bandwidth of antenna when two layers metamaterial superstrate are used.

REFERENCES


