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Design and Analysis of Wideband Metamaterial Patch Antenna

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***Abstract* – A design and investigation of Microstrip patch antenna for X and Ku band operation has been recommended. A square patch metamaterial antenna was designed and fabricated using Arlon AD 1000 (tm) substrate. This was designed as a compact size antenna with high frequency and for high gain applications. The antenna ground layer is imposed by metamaterial structure, the top radiating layer have square patch with square shape reflector. The dimension of the radiating patch is 5.4 mm5.4 mm and the square reflector is 9.8 mm9.8 mm and 14 mm14 mm. The proposed antenna has been modeled with square patch and square reflector methods have been adopted for proper wideband operation. The measured results shows that the square patch metamaterial antenna has a return loss of -15.5dB at 11.2GHz, -24.8dB at 13.9GHz, -18.5dB at 16GHz and -13.8dB at 16.7GHz, meanwhile it has a gain of 2.2dB and directivity of 2.5dB. This antenna was designed for the radar, live broadcasting and naval satellite downlink application.**

***Keywords*– Square patch metamaterial antenna, radar, live broadcasting application, naval satellite downlink application, X and Ku band.**

I. INTRODUCTION

At present, the wireless communication is the rising and lively technological area in the modern communication world. Satellite communication play a major role in the wireless communication especially in radio and microwave application and also play an essential role to step-up the availability of high speed internet services. With rapid development of modern communication and radar technology, capability to transmit signals simultaneously in X, Ku, Ka band is considered to be of great significance for military and meteorological satellite [18]. Remote sensing satellite, Communication satellite, LEO, MEO, HEO, GPS, GEO, Drone satellite, Ground satellite, Polar satellite and navigation satellite are some type of satellite communication applications.

The Microstrip antenna was proposed by G.A.Deschamps in 1953. The practical concept of Microstrip antenna to transmit radio frequency signals could not gain much ground till 1970 by Howell and Munson. Further, the development of the printed circuit board (PCB), microwave techniques, and many kind of low-attenuating media materials made the use of Microstrip antennas more practical. High gain and wide bandwidth are often desirable requirements for antennas [10]. There are three layers and four types of feeding involved in microstrip patch antenna (i) Ground layer (ii) Substrate layer (iii) patch layer (radiating element). The feeding methods are classified as (i) Aperture coupling (ii) Proximity coupling (iii) Microstrip line feeding (iv) Co - axial feeding.

Narrowband radio technology offers that the operating range is typically greater than the unlicensed; spread spectrum radio system is the function of RF power, receiver sensitivity, frequency of operation, antenna gain and system loss and also the FCC brings order out of chaos. Where a wide bandwidth allows more number of users to transmit and receive large amount of data. Wide bandwidth results in faster transfer speed resulting in less frustration and greater customer satisfaction. Frequency Selective Surface (FSS), which can transmit or reflect different frequencies of electromagnetic (EM) wave, are used in different applications [18].

Metamaterial is a Greek word, in which meta means beyond normal or something advance and it is designed to obtain the physical properties that do not exist in natural material Metamaterial is an artificial material, in which any materials permittivity and permeability values are converted into most negative value then that material act like metamaterial and are usually arranged in an repeated patterns. The composition of metamaterial is metal, plastics and it is otherwise called as negative-index material; focuses on the electromagnetic radiation by a flat lenses. SRR (Split Ring Resonator) is an artificially produced structure familiar to metamaterial, which generate the magnetic response up to 200 terahertz over various type of metamaterial.

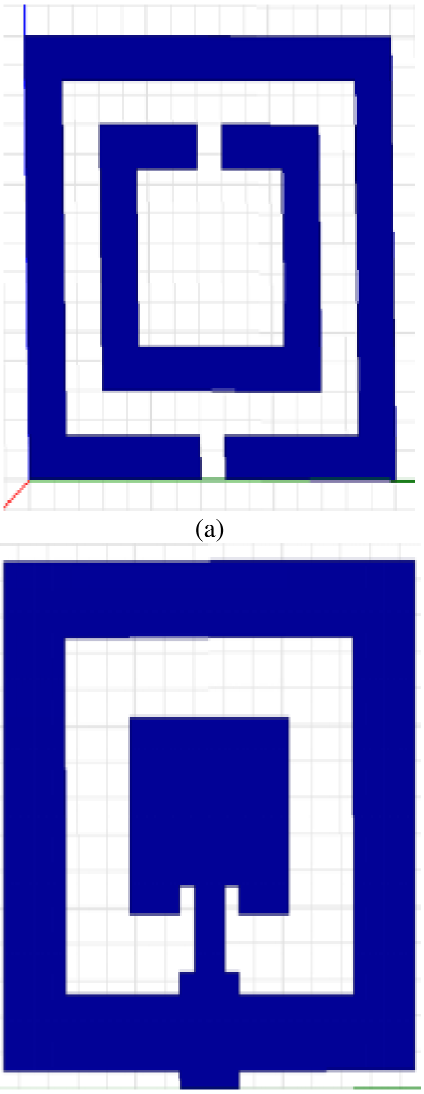
A perforated dielectric substrate structure has been adopted to construct full dielectric metamaterial with gradient permittivity distribution for the required reflection phase for [22] antenna design. The radiation properties of this antenna remains stable [22] within 11-17GHz. Maxwell's equations are used to describe the electromagnetic property of metamaterial. The SRR act as an artificial magnetic dipole. where the gap between inner and outer ring act as a capacitor while the ring themselves act as an inductor resulting in an LC resonant circuit. A metamaterial loaded transmission line has more advantages over conventional delay transmission line, it can achieve positive or negative phase shift. Wireless communication, space communications, GPS, satellites, space vehicle navigation and airplanes are some applications for metamaterial antennas.

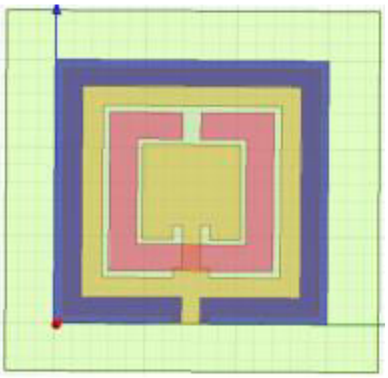
Widely rectangular and circular microstrip patch antennas are used for wireless communication applications. But above X-band frequency the antenna operates with high heat emission, so in order to reduce or controlling the heat emission rectangular patch will be modify in to square patch. This work involves transmission line model is a specialized structure used to transmit high frequency signal over short or long distances with minimum power loss and also act as a pulse generator. Reflector is a stand-alone device used for reflecting the electromagnetic waves (or) redirecting the radio frequency (RF). The most common stand-alone reflector types are corner reflector and flat reflector. Here a flat reflector will act as a mirror, reflect the radio signal and is used as a passive repeater. The primary antenna and reflecting surface are in plane reflector antenna and is used to radiate the EM energy in desired direction.
Extensive simulation work has been done using HFSS to find optimum patch dimension and their resonance frequencies for bandwidth operation [15]. The top radiating layer is designed by a square patch antenna with square shape reflectors and the bottom ground structure is imposed by the metamaterial structure. Here using ARLON AD 1000 (tm) material as a substrate material for designing the antenna. The antenna is fed by a user defined lumped port "applies a uniform electric field between two metallic boundaries" and that "the excitation at the port can be expressed as a voltage or as a current, or via the connection to the circuit interface".

II. ANTENNA STRUCTURE & ANALYSIS

A compact size microstrip patch antenna is designing with high frequency and for high gain application is the main objective. A square patch metamaterial antenna is operated in X and ku (Kurtz - under) band. The proposed antenna is designed by three layers such as ground layer, substrate layer, radiating layer (square patch, square shape reflectors). This design involves ARLON AD 1000 (tm) material for substrate has the dielectric constant (εr) of 10.2, thickness (h) of 1.6 and loss tangent ($\tan\delta$) of 0.0014. The proposed antenna involves transmission line model is a specialized structure used to transmit high frequency signal over short or long distances with minimum power loss.
The design specifications of the antenna are calculated using the transmission line formulas given below,
Wavelength, λ , (c= 3*10^11 mm/s) …(1)

For square patch, Length and width are equal value, ...(2)
Where dielectric constant, r = 10.2
The length (Lg) and width (Wg) of the ground is calculated by using the formulas (3) (4),
Ground length, $Lg=L+6h$ ...(3)
Ground width, $Wg=W+6h$ ...(4)
Where height (thickness), $h=1.6$
Effective dielectric constant, ...(5)
Effective length, ...(6)
Designed square patch metamaterial antenna is shown in fig. 1. The antenna parameters have been summarized in table I.


(a)
(b)



(c)

Fig. 1.Antenna geometric structure (a) Metamaterial imposed ground layer (b) Radiating square patch with square shape reflector (c) Overall design of proposed antenna

Table –I:Antenna parameters

PARAMETER DESCRIPTION	CALCULATED VALUES
Resonant Frequency (fr)	11.8 GHz
Substrate Material	Arlon AD 1000 (tm)
Relative Permittivity (?$_r$)	10.2
Thickness	1.6mm
Loss tangent (tand)	0.0014
Ground dimension (L_g*W_g)	15*15mm
Substrate dimension (L_s*W_s*h))	15*15*1.6mm
Patch dimension (L_p*W_p)	5.4 * 5.4 mm
Feed dimension (L_f*W_f)	2*1.6mm
Air box dimension	20.5*20.5*7mm

The proposed antenna is operated over X, Ku band for radar and satellite downlink application such as live broadcasting and naval satellite application. IEEE defined the X band ranges from 8 to 12GHz, Ku band ranges from 12 to 22.5GHz and is widely used for satellite TV and VSAT systems on ships. The resultant use of smaller patch antennas for VSAT application due to the wide spacing between satellites allows for very high powered transmission. X band not have much interference than other higher frequency bands, Ku band incurs lesser terrestrial interference. Above X band frequencies the microstrip patch antennas are operated under high heat emission. So, for reduce (or) control the heat emission of antenna, the rectangular patch is modified into square patch antenna then the heat emission will be quite rectified. In the square patch edge is cornered for achieving wide band antenna. Our antenna has to perform as a sharp node with wide bandwidth. For achieving wide bandwidth we introduce metamaterial structure is imposed on the ground and it results in wide bandwidth.

The design strategy of the metamaterial loaded transmission line can be introduced with the original length of microstrip line to make a dispersion-compensating segment of transmission line. So in order to overcome the problem radiating ring structure (square shape reflector) is mounted on the top radiating layer. Arlon AD 1000(tm) is a high dielectric constant material/substrate that permits circuit miniaturization, compared to other traditional low loss materials. The important features of Arlon AD 1000 (tm) are best in class of thermal conductivity; high copper peel strength allows for thinner etched line widths; lowest insertion loss; larger panel sizes available and low moisture absorption.

In general the high frequency signal cannot void directly, hence the ring structure (square shape reflector) is separated from the square patch. The separated distance acts as a capacitor and produces capacitance. The ring structure (square shape reflector) act as an inverse tank circuit. For normal tank circuit the passive elements of inductor (L) and capacitor (C) are connected parallel with the power supply. But in proposed antenna design the top radiating layer patch with the ring structure produces inverse tank circuit, in which the passive element of inductor (L) and capacitor (C) are connected in serious with the power supply as well as the whole circuit.

By the metamaterial surface the antenna performance was improved, because the conducting area of the ground is reduced compared to the defected ground structure antenna. If the conduction area is minimized means then the power consumption of the antenna is also reduced. The antenna power consumption was reduced over 48% and the accuracy of the antenna is improved around 48%. Due to less power consumption the antenna heat emission was also reduced.

The ground uses SRR (Split Ring Resonator) which produces the tank circuit, where in ground the inductor (L) and capacitor (C) are connected parallel with the power supply. Tank circuit produces the most negative electrical value in other words return loss results in most negative value. Satellite communication ranges from 1GHz to 40GHz, it deals with L, S, C, X, Ku, K, Ka bands. Here the X band frequencies are used for data uplink and ku band is full of downlink frequency application. The designed antenna is suitable for both uplink & downlink (transceiver) application, which achieves the frequency of 11.2GHz, 13.9GHz, 16GHz and 16.7GHz.

The antenna is used as a transmitter and receiver in space station sectors, transceiver in the live broadcasting and under water transceiver antenna in naval communication application. A live broadcasting is also called as live transmission and live reception of microwave signals and these types of media that are broadcast without a significant delay. Our proposed antenna act as a transceiver antenna used to determine their location to high precision using time signals transmitted along a line of sight by radio from satellites. In ANSYS HFSS software needs radiation boundary (air box) for analyzing the antenna performance in particular area or finite calculation domain. This minimizes reflections from outer surfaces, ensures maximum absorption and is very much similar to an anechoic chamber. Due to physical configuration antenna its performance will be varied.

III. SIMULATED RESULTS & DISCUSSION

The antenna design and optimization is done using the 3-D full wave simulation software ANSYS HFSS 13.0. Typically, the 3-D mode antenna simulator is used to model, simulate the high-frequency components, such as antennas, RF/microwave components. Through the diligent simulation, the antenna results in dual band frequencies of X band (8GHz to 12GHz), Ku band (10GHz to 22.5GHz) and analyzed numerous antenna parameters including return loss (RL), VSWR (Voltage Standing Wave Ratio), radiation pattern, gain, directivity and efficiency.

The practical circuit realization suffers with the mismatch between the available source power and the power delivered or in other words it is the negative value of magnitude of the reflection coefficient and measured in decibels (dB). The designed antenna return loss is maintained as more negative value hence, the antenna has very low returned signals and is given by -15.5dB at 11.2GHz, -24.8dB at 13.9GHz, -18.5dB at 16GHz and -13.8dB at 16.7GHz using the ANSYS HFSS tool.

$$\text{Return loss} = -20\log () \qquad \text{...(7)}$$

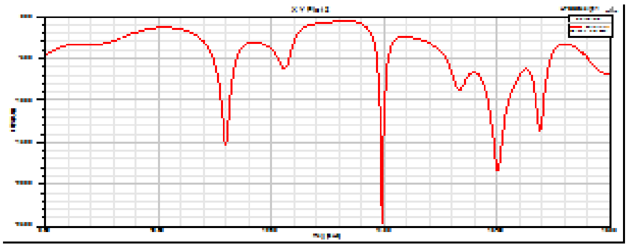


Fig.2. Return loss of the proposed antenna.

The designed antenna presents good gain with minimum losses at the specified frequency. Fig. 2.shows the reflection coefficient of the Microstrip patch antenna, obtained from the simulation using the HFSS software. The antenna is operating at two resonance frequencies. VSWR is a numerical measurement that describes how well the antenna is impedance matched to the transmission line or the formation of standing waves due to impedance mismatch.

If the given input signal is equal to the resultant output signal, then the antenna has a unit value and has no impedance mismatch. The numerical range of VSWR is ranges from 0 to 1, but practically it ranges from 0 to 5.The VSWR of proposed antenna is kept below 2 (<2) for both X and Ku band frequencies of 11.2GHz, 13.9GHz, 16GHz and 16.7GHz. Fig. 3. shows the VSWR of the square patch metamaterial antenna.

$$\text{VSWR=}, \qquad \text{Where, } = \ln(-) \qquad \text{…(8)}$$

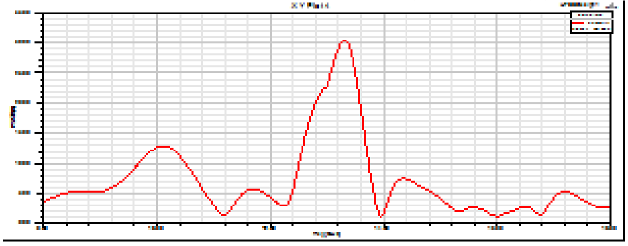


Fig.3. VSWR of proposed square patch metamaterial antenna

Radiation pattern refers to the strength of the radio waves from the antenna or other source depends on direction (front end, back end). In every antenna azimuthal and elevation angle, the near end radiation is always zero far end forms the fan shape radiation pattern. The radiation pattern of the proposed antenna is formed with different angle (0 to 360 degree) by using the solution frequency of 11.8 GHz and is shown in Fig. 4.

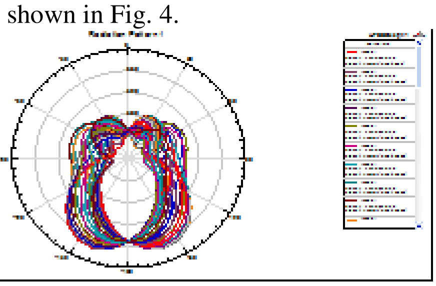


Fig.4. Radiation pattern of the proposed antenna.

The Smith chart can be used to solving problems with transmission lines and matching circuits, simultaneously display various parameters including impedances (Z-parameters), admittances (y-parameters), reflection coefficients (Γ), scattering parameters. The frequencies of 11.2GHz, 13.9GHz, 16GHz and 16.7GHz are present near to the unit circle, where the mathematical calculation of impedance and admittance are easily found using the smith chart. The smith chart plot for the proposed antenna is shown in fig. 5.

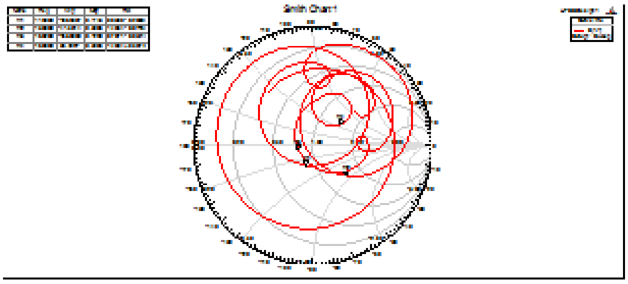


Fig.5. Proposed antenna smith chart.

The power or amplitude of a signal from the input to the output port by adding energy called gain and it converted from some power supply to the signal. The gain of the proposed antenna is shown in fig. 6. A plot of the gain as a function of direction is called gain pattern or radiation pattern. Here the gain of the proposed antenna 2.21dB and is measured using 3D polar plot.

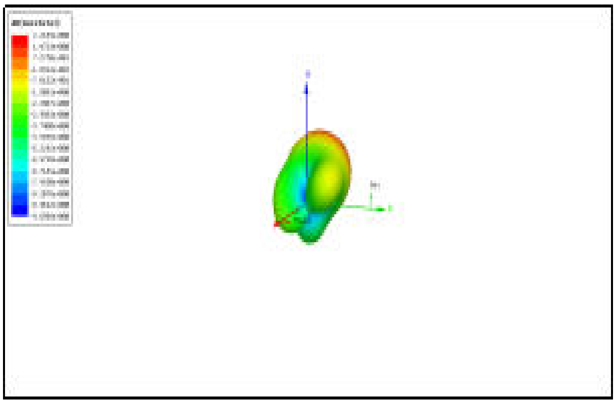


Fig.6. Gain of the square patch metamaterial antenna.

Directivity of an antenna is expressed in decibels (dB), is the measure of degree to which the antenna radiates in a single direction and is plotted in the 3D polar plot using HFSS. The directivity of an antenna is 2.53dB. The directivity of the antenna is shown in the fig. 7. The directivity (D) of the antenna can be calculated using the formula (9).

$D = Ae4 / \lambda 2$ ...(9)

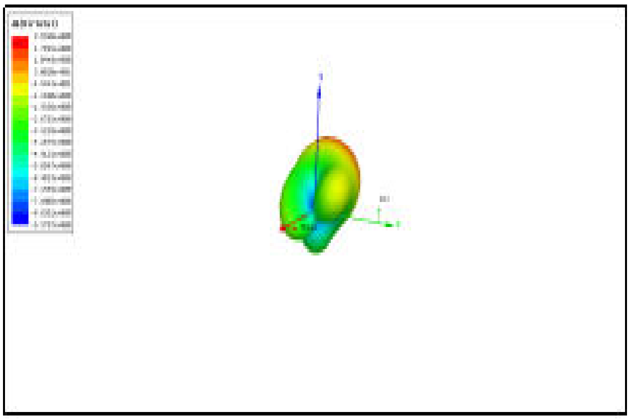


Fig.7. Measured directivity of the proposed antenna.

The efficiency of antenna can be calculated as using,

$\eta = G \lambda 2 / Ae4$ ...(10)

From those results the efficiency of the antenna is calculated by using the measurements of gain and directivity. Antenna efficiency is calculated by using the formula (10). The efficiency is expressed in terms of percentage (%). The proposed square patch metamaterial antenna efficiency is 88 %.

Table- II: Simulated results of proposed antenna

DESCRIPTION	SIMULATED RESULTS
Solution frequency	11.8GHz
Sweep type	Fast
Start frequency	8GHz
Stop frequency	18GHz
Step size	0.01GHz
Return loss	-15.5dB at 11.2GHz, -24.8dB at 13.9GHz, -18.5dB at 16GHz, -13.8dB at 16.7GHz
VSWR	11.2GHz is 1.2 13.9GHz is 1 16GHz is 1 16.7GHz is 1.2
Gain	2.21dB
Directivity	2.53dB
Efficiency	88 %

IV. CONCLUSION

Our proposed antenna design shows the advantage of antenna size, frequency usage and support for transceiver application on radar, space station, live broadcasting and underwater uplink and downlink naval satellite applications. The frequencies of X and Ku-band are efficiently utilized in this antenna. From the simulation results, the VSWR is kept below two (<1.5), the gain of the antenna is 2.2dB while operating in both X, Ku band and the resultant efficiency of the proposed antennas are 88%. The simulation results shows that proposed antennas has achieved better gain and efficiency with comparatively smaller dimension than some of the reported antennas.

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