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STUDY AND ANALYSIS OF MICROSTRIP PATCH ANTENNA USING METAMATERIAL STRUCTURE

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ABSTRACT- In this article, we discuss and analyze the microstrip patch antenna performance with and without the use of metamaterial structure. The return loss of a typical patch antenna designed at the 2.4 GHz resonant frequency was compared with the same patch antenna plus the concept of additional stacked metamaterials, which has attracted significant attention in recent decades. Metamaterials are artificially created materials that have properties not easily found in natural materials. A widely accepted property of metamaterials is their ability to control the propagation of electromagnetic waves. Basically, electromagnetic response refers to how a material affects the electric and magnetic fields to which it is subjected. It turns out that there is an improvement in return loss. This rectangular patch antenna was simulated and tested using the CST simulator, where an electromagnetic analysis tool is used.

Keywords: Rectangular Microstrip Patch Antenna, Bandwidth Enhancement, CST Simulator,

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1. INTRODUCTION

Recently, there has been a growing interest in the study of Metamaterials both theoretically and experimentally. Metamaterials (MTM) are man-made materials designed to have properties that may not be found in nature. The invention of the metamaterial started in the late 1960s. In 1967, Victor Georgievich Veselago studied the electrodynamics of substances with simultaneously negative values of dielectric permittivity (ε) and magnetic permeability (μ). materials. Metamaterials are called as double negative materials (DNG) due to the property of negative ε and μ. V. G. Veselago discovered that the Poynting vector of the plane wave is antiparallel to the direction of the phase velocity, which is contrary to the conventional case of plane wave propagation in natural media. Although metamaterial is not present in nature, interesting properties have been theoretically predicted for these substances, such as reversal of Snell's Law, Doppler Effects and Cherenkov radiation, etc. refractive index. A medium composed of non-magnetic conductive elements can form a left-handed frequency band, such as the electric field (E), magnetic intensity The metamaterial structure consists of split ring resonators (SRRs) to produce negative permeability and fine wire elements to generate negative permittivity. SRR is a new design consisting of two concentric rings with a split in each ring. The structure is called a resonator because it exhibits a certain magnetic resonance at a certain frequency. Split-ring resonators can result in effective negative permeability in a specific frequency region. This resonator is an electrically small LC resonator with a high quality factor.3 Left-handed metamaterials (LHM) can be used to build a perfect lens with sub-wavelength resolution.3,4

There are mainly 4 types of metamaterial structures as substrate 1-D Antenna Structure Split ring structure, symmetrical ring structure, and omega structures structure. All Metamaterial antennas are designed around these substrate structures. 1-D structures are easier to manufacture and build.

The framework tends to produce a clean recovery response as there is less ringing effect from the time domain simulation. There is also less coupling between the E field and the H field. The omega-shaped structure is a new metamaterial structure. The increased complexity of the structure is the problem of this structure. There are no more obvious rings or rod parts in the S-frame, so the recovery results are relatively clean. Compared to the other three structures, the Symmetrical-Ring structure has a better directional beam and is easier to adjust its permeability because its rings are symmetrical.5 Metamaterials have a wide variety of applications. Metamaterial Surface Antenna Technology (MSAT) offers an affordable and efficient way to connect multiple mobile clients - airborne broadband communications, broadband Internet services over any rail system, etc. be used together with patch antennas to improve performance parameters. A study on high gain circular waveguide antenna with metamaterial structure is presented in 7. Metamaterials are used for further miniaturization of microstrip antennas. Patch antennas using metamaterials can be used for C-band applications. The size of this antenna reduces by a factor of 2.4 and the gain directivity increases from 4.17 dBi in the conventional design approach to 5.66 dBi in the metamaterial design.

2. LITERATURE SURVEY

Ahsan M.R., Habib Ullah M., and Mansor F. (2014), “Analysis of a Compact Slotted Broadband Antenna for Ku-Band Applications” International Journal of Antennas and Propagation, antenna characteristics are found in terms of return loss, gain, and bandwidth. It is observed that the proposed new configuration can work in two different bands with good amount of bandwidth i.e. 12.05% bandwidth in the 1.25 GHz frequency band and 19.82% bandwidth in the 2 GHz frequency band. The resonant behavior in different frequency bands makes this antenna structure suitable for different types of applications with an antenna gain of 5.509dBi and an antenna efficiency of 89%. The design and simulation of the antenna structure was done with the IE3D simulation software version 15.02. Parabolic reflector, Yagi antenna, Horn antenna are some examples of antenna structures with good bandwidth and gain. There is no doubt that these antennas are sufficient in terms of performance, but the main disadvantage of these types of antennas is the 3D structure that limits the use of these types of antennas, so small antennas are very necessary for these communication devices, and that if we get any antenna structure with 2D structure and small size, we will play an important role in the field of wireless communication.

The microstrip antenna with 2D structure meets this requirement. The microstrip patch antenna is a two-dimensional planar antenna configuration with all the advantages of PCB, such as simple design and layout, low cost, etc. profit, low efficiency etc. and to overcome this disadvantage several researches are in progress. The shape of the leaflets on these antennas affects the performance of these antennas. Several ways to improve antenna performance are suggested by researchers, such as cutting notches and gaps in regular rectangular, square, etc. , introducing slits in the patch geometry, using different dielectric materials, using different feed methods, using air gap formation, using stacked configuration, etc. antenna is calculated,

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consider the VSWR curve which will help determine if this antenna structure can. operate in the frequency bands shown on the return loss curve. Another important parameter gain is also considered to analyze the antenna gain, besides another important parameter i.e. directionality is shown. Finally, efficiency, including antenna efficiency and radiation efficiency, is considered. All these results are analyzed in this article. The coaxial probe feeding method is used for feeding.

Kevin Ming-Jiang Ho and Gabriel M.Rebeiz. (2014), "Dual-band Circularly Polarized Microstrip Antenna for Ku/Ka-Band Satellite Communication Arrays" in IEEE Antenna and Wireless Propagation, A Compact Microstrip Antenna for Automatic Dependency Surveillance System (ADS-B) is presented. The antenna is provided with a 50Ω transmission line. A T-slot is carved into the ground plane to achieve a certain degree of design miniaturization. The proposed antenna has a compact size of 82 mm x 65 mm and a frequency of 0.297λ0 x 0.23λ0 at 1.09 GHz. The antenna resonates at 1.09 GHz, which is common in ADS-B systems. The predicted gain of an ADS-B antenna ranges from 1dB to 5dB and the measured gain is around 3.10dB. The proposed antenna is expected to comply with the ADS-B specification. The design is validated by manufacturing and measuring the prototype. Simulated and measured results are available and compared. Microstrip patch antennas (MPAs) have gained a lot of attention in the microwave community. MPAs are typically designed using different shapes and images etched onto a dielectric substrate. Deployment techniques depend on antenna design and location specifications. The most commonly used MPA is the rectangular patch. A rectangular patch antenna has approximately half the rectangular wavelength of a rectangular microstrip transmission line. Microstrip patch antennas with a completely flat plane are characterized by high directional gain. However, they suffer from low bandwidth. For compact and small MPAs, slots are often carved into the ground plane so that the electrical size of the antenna is reduced. MPAs are lightweight, low-cost, low-volume, and generally have a flat, low-profile arrangement. They are also easy to design and manufacture with low manufacturing costs. Several MPAs have been introduced with different geometries in an attempt to improve antenna performance characteristics such as radiation pattern, gain, efficiency, size and directivity. However, the proposed MPA is designed for the operation of the Automatic Dependency Surveillance System (ADB-S).

M. Vinoth, J. Belbin Lijjo, S. Allen, Dr. M. Sugadev (2020) "Design and analysis of reconfigurable insert-fed antenna for 5g (sub-6ghz) applications", Solid-state technology, in this paper, a rectangular dual-band antenna with defects integrated into a metallic ground plane is proposed. Originally, a rectangular patch antenna was designed that resonated at 5.2 GHz. With the introduction of DGS in metallic ground plane, the microstrip antenna is available with 3.5GHz and 5.2GHz frequency simultaneously, suitable for both WiMAX and WLAN applications. Therefore, the proposed antenna behaves as compact and active in dual frequency band. The antenna is made of RT-Duriod substrate with a dielectric constant of 2.2 and a length of 0.762 mm. This procedure is experimentally verified and the measured results agree with the simulated results.

Dual-band antennas are interesting for wireless communication systems that use two frequency bands, such as WLAN and WiMax, because they can replace two individual antennas. Furthermore, the miniaturization of antennas has also become more important due to the increasing demand for smaller antennas with the rapid development of wireless communications.

Both methods reduce size, cost and complexity. The microstrip antenna is widely used in wireless communication due to its light weight, low profile, low cost, simplicity and low cost. Efforts are being made to design an integrated microstrip antenna with a high percentage of miniaturization, as the need for smaller antennas at lower frequencies has been driven. Many efforts have been made to achieve size reduction, such as the use of a high permittivity dielectric substrate, Defective Microstrip Structure (DMS), PBG etched onto a substrate based on limited numbers of defects, known as Defective World Structure (DGS).), or a combination thereof. As a result of these processes, various effects on the microstrip antenna were observed, which allowed the antenna to operate in the low frequency band. Likewise, many methods have been reported to design low-cost, small-profile, active dual-band notation. Other techniques have used a patch antenna in a higher-order mode with a radiation pattern that is the quasi-fundamental mode. Parasitic element next to radiating element, emitter elements, stub attached to radiating element. Microstrip antenna with DGS can also support this purpose with multiband that can operate on different frequencies from a single device.

Paolo Squadrito, Shuai Zhang and GertFrolund Pedersen. (2018), "Wideband or Dualband Low Profile Circular Patch Antenna with High Gain and Sidelobe Suppression" in IEEE Transaction on Antennas and Propagation, A rectangular microstrip patch antenna is presented in this paper for Ku-band satellite communication applications. The proposed E-shaped patch antenna is designed to cover various applications such as broadcasting, remote sensing and space communication. To include the high-frequency effect in the process, the concept of a microstrip-based Cole-Cole diagram is adopted to create a frequency-dependent characteristic impedance (loss). The simple method proposed in this study is compatible with Computer Aided Design (CAD), therefore; the Ku Band satellite microstrip antenna design in this study will be fast and easy to use.

In recent years, the need for small antennas for wireless communication has increased significantly, which has led to extensive research on compact microstrip antenna design among microwave and RF engineers. Compact microstrip antennas such as VSAT systems are one of the most suitable applications for supporting advanced satellite communication equipment. Ku-band (12-18 GHz) is one of the preferred options for VSAT applications. VSAT can be received by satellite television and satellite television broadcasts. Also, VSAT is one of the best emergency support systems during disasters. Microstrip patch antenna is a two-dimensional planner antenna configuration that has all the advantages of a printed circuit board, including but not limited to simple design, easy fabrication, and low cost. Although these antenna structures have several advantages over other methods, they also have the main disadvantages of low bandwidth, low gain and low efficiency. There is a lot of research going on to overcome these disadvantages in order to make the most of the advantages such as simple design, ease of fabrication and low cost in manufacturing these small microstrip antennas. The performance of these antennas depends on their physical configuration. Several ways to improve the performance of the antenna in its physical configuration are suggested by the researchers. Microstrip patch antennas are powered by means that are divided into contact and non-contact. In communication systems, RF energy is delivered directly to the radiating surface using a linear microstrip link.

Rayuan Deng, ShenhengXu and Fan Yang. (2018), "An FSS backed ku/ka quad band reflect antenna array for satellite Communications" in IEEE Transaction on Antennas and

Propagation, A new microstrip patch antenna loaded with high-gain broadband H-shaped slot is presented in this article. The antenna is printed on a dielectric substrate, supported by a metallic plate, and fed directly by a 50 Ω coaxial cable. Using the ADS software package according to the specified size, the antenna is simulated. The combined effect of combining these techniques and introducing a new mounted clip provides a low profile, wide bandwidth, high gain, and compact antenna characteristic. Computer simulation results show that the antenna can detect wideband characters. With the parameters adjusted, it shows a wide impedance bandwidth at the 2.42 GHz frequency.

The rapid development of wireless communication systems has increased the demand for compact microstrip antennas with high gain and wideband operating frequencies. Microstrip patch antenna has advantages such as low profile, conformal, light weight, simple realization process and low production cost. However, conventional microstrip patch antennas have some disadvantages, such as small bandwidth, etc. Performance improvements are needed to cover the required bandwidth. There are many well-known ways to increase the bandwidth of antennas, including increasing substrate thickness, using a low dielectric substrate, using various matching and feeding methods, and using various resonators in this article. A printed broadband antenna fed by a coaxial probe is presented. The antenna is modeled using Agilent Advanced Design System (ADS) technology. The results show that the impedance bandwidth achieved a good match. The dielectric constant of the substrate is closely related to the size and bandwidth of the microstrip antenna. A low substrate dielectric constant produces a large bandwidth, while a high substrate dielectric constant results in a small antenna size. There is a trade-off between antenna size and bandwidth.

S. D. Mahamine, R. S. Parbat, S. H. Bodake and M. P. Aher (2016) "Effects of different substrates on S-band rectangular microstrip patch antenna", 2016 International Conference on Automatic Control and Dynamic Optimization Techniques In this paper, a simple RMPA is designed and its performance parameters are compared with an RMPA with a deformed ground plane. The antenna is simulated at 2.4 GHz using CAD-FEKO simulation software. This work mainly involves the modification of the ground plane called Defected Ground Structure (DGS). Antenna parameters such as reflection coefficient, gain, VSWR and bandwidth, with and without DGS, are measured using Network Analyzer. The main focus of this article is to improve the bandwidth for the patch antenna to be used for broadband applications and the effect of DGS polling on antenna parameters. Microstrip patch antennas are widely used today due to their many advantages, such as lightness, small volume, compatibility.

These antennas are used in different portable communication devices. A simple Microstrip Antenna patch. The radiation patch is on one side of the dielectric substrate and the ground plane is on the other side of the substrate. The metal patch can assume any geometric shape such as rectangle, triangle, circle, helical, ring, elliptical, etc. The patch size corresponds to the antenna ring frequency. However, microstrip patch antennas have a small bandwidth and bandwidth enhancement is required in many practical applications, so bandwidth enhancement has been used in different ways. Faulty ground structure is one of them. Also, most applications that use microstrip antennas are in communication systems, such as portable communication devices that require a small antenna size. Several tools developed for the design of highly compact microstrip patch antennas have been introduced in recent years. The definition of DGS is that at the bottom of the patch antenna a certain shape with a defect is introduced, and depending on the different size, shape and size of the defect, the protected current distribution will be disturbed. Incoming interference and antenna current flow will be affected due to interference with shielded current distribution. It can also control excitation and electromagnetic waves propagating through the substrate layer.

Sadiya Afrin Swarna, Salma Faria, Sakhawat Hussain & Anis Ahmed (2019) "Novel Microstrip Patch Antenna with Modified Ground Plane for 5G Wideband Applications", Global Journal of Researches in Engineering, This article presents a broadband microstrip patch antenna for wireless communication. In its most basic form, a microstrip patch antenna consists of a radiant patch on one side of a dielectric substrate with a ground plane on the other side. The patch is usually made of a portable material, such as copper or gold, and can take any shape possible. A rectangular patch is used as the main radiator. The advantages of this type of broadband antenna are many, such as planar, small size, simple structure, low cost and easy manufacturing, making it attractive in practical applications. This rectangular microstrip antenna patch is designed for wireless communication applications operating at 2.4 GHz with 11 dB gain outdoors. It also has a wide beam angle for its radiation pattern. The results show that the microstrip patch antenna can be used as a computer client antenna and an effective wireless antenna. One of the types of wireless communication at 2.4 GHz is Wireless Fidelity (WiFi). A WiFi-enabled device, such as a personal computer, video game console, smartphone, or digital audio player, can connect to the Internet if it is within range of a wireless network connected to the Internet.

The coverage of one or more (connected) access points (hotspot) can cover an area as small as a few rooms or as large as several square kilometers. With the development of MIC and advanced semiconductor devices, microstrip has attracted a lot of attention from the electronics community in recent years. Despite its many attractive features such as light weight, low cost, simple construction, compatibility on curved surfaces and so on, the microstrip feature suffers from the inherent limitation of low impedance bandwidth.

The transmission line model represents a microstrip antenna with two slots of width W and length h, separated by a transmission line of length L. The microstrip is actually a constant line of two dielectrics, usually a substrate and air. most electric field lines reside in the substrate and parts of some lines in the air. As a result, this transmission line cannot support a pure electromagnetic transmission (TEM) mode, since the phase velocities can be different in air and substrate. Instead, the dominant mode of propagation will be the quasi-TEM mode. Therefore, the effective dielectric constant (εreff) must be found to account for melting and wave propagation on the line.

3. ANTENNA DESIGN

The dielectric constant of the substrate is closely related to the size and bandwidth of the microstrip antenna. A low substrate dielectric constant produces a large bandwidth, while the result is a high substrate dielectric constant. The basic design features of patch antenna on FR-4 substrate with dielectric constant 4.4, The main advantage of this type of power supply scheme is that the power supply can be placed at any desired location within the patch to match its input impedance. This feeding method is easy to manufacture and has low spurious radiation.

An antenna is a device that radiates and receives radiated electromagnetic waves. There are several important antenna characteristics that should be considered when choosing an antenna for our application, as follows:

1. Antenna radiation pattern
2. Return loss
3. VSWR

The radiation pattern of an antenna is a graph of the relative field strength of the radio waves emitted by the antenna at different angles. Return loss is the loss of signal power due to reflection caused by the discontinuity of a transmission line. VSWR is the voltage standing wave ratio defined as power reflected from the transmission line. The microstip patch antenna is increasingly used because the patch can be printed directly onto the circuit board. In the mobile phone market, microstrip antennas are widely used.

4. MICROSTRIP PATCH

The following diagram shows a patch antenna in its basic form: a flat plate on top of a ground plane (usually a printed circuit board). The center conductor of the coax acts as a power probe to couple the electromagnetic force into and/or out of the patch. The electric field distribution of a rectangular patch excited in its fundamental mode is also shown. The electric field is zero at the center of the patch, maximum (positive) on one side and minimum (negative) on the other side. It should be mentioned that the minimum and maximum change direction continuously according to the fast phase of the used signal. The electric field does not suddenly stop in a patch like in a hole; Rather, fields extend the outer periphery to some extent.

5. METHODS OF ANALYSIS OF MICROSTRIP PATCH ANTENNA

The most popular methods for analyzing patch microstrip antennas are the transmission line model, the cavity model, and the full wave model (mainly including the integral/transient method). The power line model is the simplest and provides a good physical understanding, but is less accurate. The cavity model is very accurate and provides good physical understanding, but it is complex in nature. Full-wave models are extremely accurate, versatile, and can handle single elements, finite and infinite arrays, stacked elements, arbitrarily shaped elements, and intersections.

6. RETURN LOSS AND VSWR

The reflection coefficient at the antenna input is the ratio of the reflected voltage to the incident voltage and is the same as S11 when the antenna is connected to port 1 of the network analyzer. It is a measure of the impedance difference between the antenna and the source line. Contrast level is usually defined in terms of return loss or VSWR.

7. ANTENNA GAIN AND DIRECTIVITY

Antenna gain is a measure of the antenna's radiation intensity on the stronger side than the reference, when both antennas are fed the same input power. If the reference is an isotropic rod, the gain is usually expressed in dBi units. The advantage of the antenna is that passive incident power is not added to the antenna but is redistributed to deliver radiated power in specific areas rather than being transmitted by an isotropic antenna.

8. RADIATION PATTERN

The radiation pattern represents the spatial distribution of the electromagnetic field emitted by the antenna. The pattern will be obtained in two planes, the E plane and the H plane. The E plane is the plane that contains the electric field vector and the maximum radiation direction and the H plane is the plane that contains the magnetic field vector and the maximum direction. By placing the antenna in receive mode inside an anechoic chamber, the radiation patterns of the E and H planes will be captured using the antenna calibration setup and network analysis. The antenna radiation pattern in various frequency bands can be measured with a rotation of the antenna test position and the calibration software.

9. POLARISATION AND RADIATION OF MICROSTRIP ANTENNA

The polarization of the antenna is determined by the wave radiating in a certain direction corresponding to the direction of the electric field. The instantaneous electric field vector tracks a number in time. If the path of the electric field vector follows a line, the antenna is said to be linearly polarized. If the electric field vector rotates in a circle, it is called circularly polarized. To characterize the polarization, the axial ratio is used. It is defined by the following relationship:

$$T = \frac{\text{Large diameter of the ellipse}}{\text{Small diameter of the ellipse}}$$

Polarisation is said to be linear if T → ∞ or T = 0, and circular if T = 1.

10. Analysis

1. Width (*W*):

$$W = \frac{\mathrm{C}}{2\mathrm{fo}\sqrt{({}^{\varepsilon}\mathrm{r}+1)/2}}$$

W = 82mm

2. Effective Dielectric constant (ε*reff*):

$${}^{\varepsilon}reff = \frac{({}^{\varepsilon}r+1)}{2} + \frac{{}^{\varepsilon}r-1}{2}[1+12\left(\frac{h}{w}\right)]\hat{}\left(\frac{1}{2}\right)$$

E*reff* = 4.4

3. Effective length (*Leff*):

$$Leff = \frac{c}{2fo\sqrt{^{\varepsilon}reff}}$$

Leff = 65mm

4. Length Extension (Δ*L*):

$$\Delta L = 0.412h * \frac{(^{\varepsilon}reff + 0.3)\left(\frac{W}{H} + 0.264\right)}{(^{\varepsilon}reff - 0.258)\left(\frac{W}{H} + 0.8\right)}$$

Δ*L* =20.25mm

5. Actual length of patch (*L*):

$$L = Leff - 2\Delta L$$

L = 24.5mm

Table 3.1 Dimensions of the Antenna

Sl.No.	Parameters	Size(mm)
1.	W	82
2.	L	65
3.	Wt	2.8
4.	Lt	32
5.	W1	69
6.	L1	20.25
7.	Ws	8.5
8.	Ls	24.5
9.	a	16.5
10.	b	16.5
11.	c	24.5
12.	d	27.1
13.	e	5.6

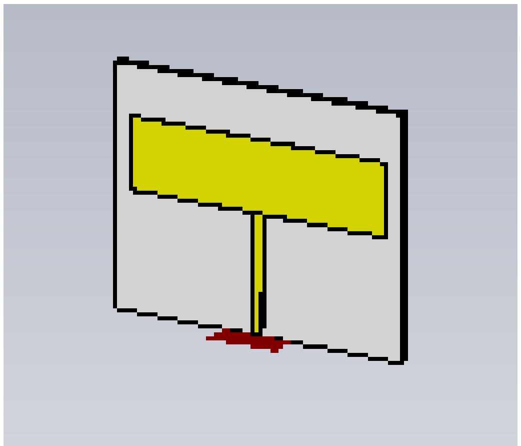


Figure.1. Model of Antenna

11. Result and Discussion

Simulation

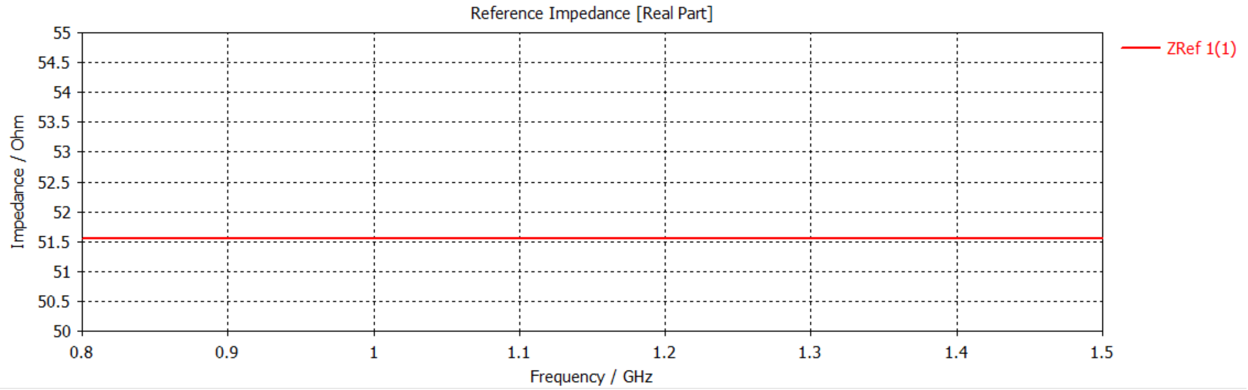


Figure.2. Reference Impedance

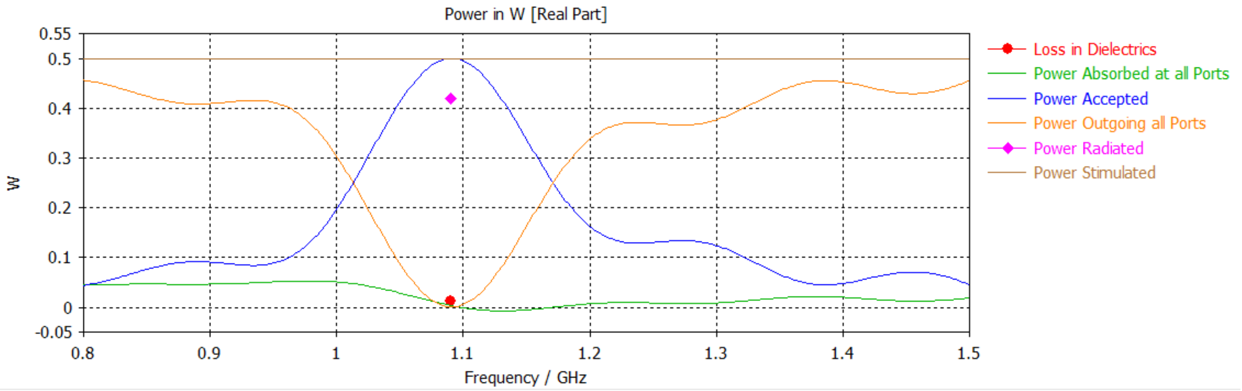


Figure.3. Power in W

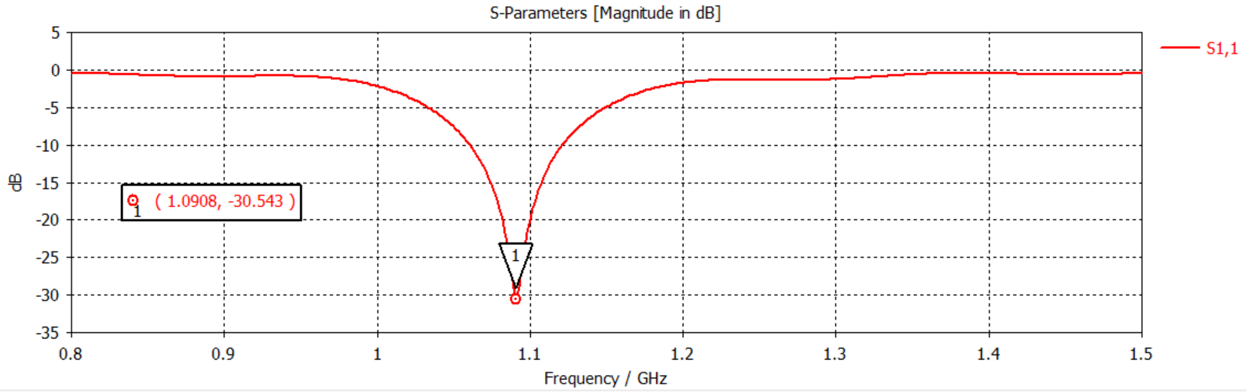
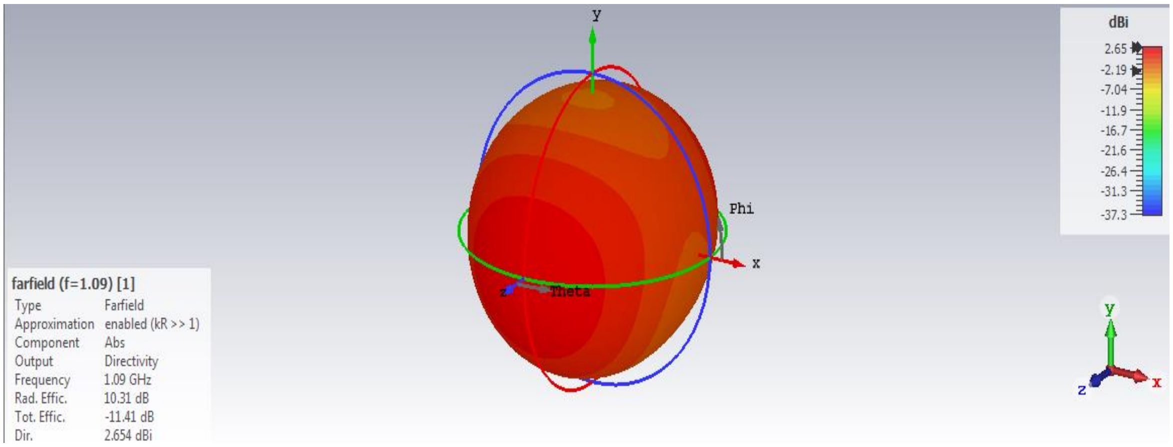


Figure.4. S- Parameter



farfield (f=1.09) [1]

Type	Farfield
Approximation	enabled (kR >> 1)
Component	Abs
Output	Directivity
Frequency	1.09 GHz
Rad. Effic.	10.31 dB
Tot. Effic.	-11.41 dB
Dir.	2.654 dBi

Figure.5. Farfield

12. CONCLUSIONS

A compact microstrip antenna with an improved bandwidth using a metamaterial substrate has been presented. For the characterization of microstrip antennas on metamaterial substrates, the effective medium approach was employed. The new design helps achieve antenna size reduction and bandwidth improvement for microstrip patch antennas. The results presented in this work are promising for the design of compact antennas, achieving a size reduction without sacrificing the antenna bandwidth, which makes the antenna useful for several applications. The antenna resonates at 1.09 GHz typical for ADS-B applications. The predicted gain of the ADS-B antenna is 1dB to 5dB, W1 = 69 mm, the return loss of -30.543 dB.

REFERENCE

1. Ahsan M.R., HabibUllah M. and Mansor F. (2014), "Analysis of a compact wideband slotted antenna for ku band applications" in International Journal of antennas and propagation, Vol 2014, pp.1-6.

2. Kevin Ming-Jiang Ho and Gabriel M.Rebeiz. (2014), “Dual band circularly polarized microstrip antenna for ku/ka band satellite communication arrays” in IEEE Antenna and wireless propagation, Vol 14, pp.1831-1833.
3. Khandelwal MK, et al,"Analysis and design of dual band compact stacked Microstrippatch antenna with defected ground structure for WLAN/WiMax applications", Int J Electron Commun (AEÜ) (2014),http://dx.doi.org/10.1016/j.aeue.2014.07.018.
4. M. Vinoth, J. Belbin Lijjo, S. Allen, Dr. M. Sugadev, “Design and Analysis of Insert-fed Reconfigurable Antenna for 5g (sub-6ghz) applications”, Solid State Technology Volume: 63 Issue: 6 Publication Year: 2020, pp 5509-5519..
5. Paolo Squadrito, Shuai Zhang and GertFrolund Pedersen. (2018), “Wideband or dual band low profile circular patch antenna with high gain and sidelobe suppression” in IEEE Transaction on antennas and propagation, Vol 66, pp. 3166 – 3171.
6. Rayuan Deng, ShenhengXu and Fan Yang. (2018), “An FSS backed ku/ka quad band reflect array antenna for satellite communications” in IEEE Transaction on antennas and propagation, Vol 66, pp.4353-4358.
7. S. D. Mahamine, R. S. Parbat, S. H. Bodake and M. P. Aher, "Effects of different substrates on Rectangular Microstrip patch Antenna for S-band," 2016 International Conference on Automatic Control and Dynamic Optimization Techniques (ICACDOT), Pune, 2016, pp. 1142-1145, doi: 10.1109/ICACDOT.2016.7877765.
8. Sadiya Afrin Swarna, Salma Faria, Sakhawat Hussain & Anis Ahmed, "Novel Microstrip Patch Antenna with Modified Ground Plane for 5G Wideband Applications", Global Journal of Researches in Engineering: Electrical and Electronics EngineeringVolume 19 Issue 1 Version 1.0 Year 2019 , Online ISSN: 2249-4596 & Print ISSN: 0975-5861, pp 8-15.
9. Shengying Liu, Kaibo Jiang and GuobingXu. (2019), “A dual band shared aperture antenna array in ku/ka bands for beam scanning applications” in IEEE Access - open access journal, Vol 7, pp.78794-78802.
10. Sugadev M, Logashanmugam E , “Quad band U-Slot microstrip antenna design for C, X and Ku band wireless applications”, Hikari Journal of Contemporary Engineering Sciences, Vol. 8, no. 16,pp. 737-745,July 2015.