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Research Article

A Comprehensive Survey Of Metamaterial Based Microstrip Patch Antenna For Multiband Applications

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ARTICLE INFO **ABSTRACT**

This comprehensive survey is an effort to contemplate disparate kinds of micro-strip patch antennas based on metamaterials for multiband applications, emphasizing the advancement of antenna design. Recent advancements focus on developing miniaturized devices with the integration of multiple functions as per the customer's needs. Mobile systems, smart portable equipment, communication receivers, and wireless networks require antennas that are compact in size, possess good gain, and have multiband functionalities. To improve these antenna parameters, novel artificial materials, known as metamaterials, are blend into antenna designs. The metamaterials can be used to achieve high gain, directivity, and miniaturization from the microstrip patch antenna. The metamaterials permit to diminish the countour volume with antenna gain and directivity enhancement and expand the operating frequency band due to the unused electromagnetic properties of metamaterials. This survey prompts various micro-strip patch antennas based on metamaterials for multiband applications. A comparative analysis of all these metamaterial-inspired micro-strip patch antennas is also included. This survey is delinerate to act as a remarked material for designers of micros-trip patch antennas to be choosen the technology based on the requirements of gain, directivity, bandwidth, and antenna size.

Keyword- *Microstrip Patch Antenna, Metamaterials, Miniature, Gain, Directivity, Bandwidth, Multiband* applications.

Introduction

The recent trend in communication systems in many sectors has been to develop simple, low-profile, light-weight, cost-effective, and compact antennas that can maintain good performance throughout a wide frequency range. This advancement has concentrated on the configuration of micro-strip patch antennas to fulfill the necessity of antennas for modern communication systems. Microstrip patch antennas exhibit several benefits as compared to other antennas, such as being simple, light-weight, low-profile, and cost-effective to fabricate. However, microstrip patch antennas have many limitations, including low gain, low directivity, narrow bandwidth, and low radiation efficiency. The researchers aim to overcome these problems with microstrip patch antennas using various technologies.

A novel approach for overcoming the constraints of the traditional microstrip patch antenna design is the adoption of metamaterial-inspired structures. the only material in the world that has negative permittivity and permeability at the same time, resulting in a negative refractive index that can be used to alter the electric and magnetic properties of electromagnetic waves. These advanced properties for antenna design can result in an enhancement of antenna properties. The electromagnetic properties of metamaterials may be exploited to satisfy the ever-increasing demand for miniaturized, lighter, compact antennas with multiband functionality. Metamaterial antennas are one of the categories of antennas in which we use metamaterials to enhance antenna properties such as size miniaturization, gain, directivity, and radiation efficiency. The metamaterial can provide a great approach for designing antennas to achieve the expected multi-band or frequency-tunable characteristics with high gain and directivity. Metamaterials are a class of such artificial composite structures whose physical properties are different, innovative, and unique from those of natural materials and hence are widely used in antenna design and microwave applications. The first class of metamaterials was studied by V. Veselago way back in 1968 [1]. He labeled these “substances” as left-handed (henceforth referred to as LH) materials owing to their negative values of ε and μ and found that they exhibit peculiar characteristics when an electromagnetic wave is passed through them. The first experimental work on LH materials was done 30 years later by Smith [2] using thin wires and SRR. Smith was motivated by the work engineered by Pendry [3], who proposed SNG (single negative, either ε or μ) materials. Negative ε was achieved using thin wires [4], [5], and negative μ by using the SRR structure [6]. Metamaterials are composed of unit cells whose effective structural size is much smaller than the guide wavelength. Because of the property of unit cells metamaterials are broadly used in antenna design [7].[8], microwave cloaks [9], microwave absorbers, new super layers, and network sensors. In this survey a detailed classification of metamaterials is first presented. Though metamaterials are extensively used in many areas, the survey presented here focuses on their functionality in antenna design. The application of metamaterials in antennas to enhance gain, reduce overall size, and get multi-band characteristics is presented. The purpose of this survey is to highlight the types of metamaterials used for antenna design based on their functionality and help researchers fill the gaps.

I. Classification of Metamaterials

Metamaterial structures are widely classified into a) EGB structures and b) SNG and DNG structures [10]. SNG and DNG materials are divided based on the permittivity and permeability values. The NG index in SNG and DNG means negative, so SNG stands for single negative, where either permittivity or permeability is negative, and DNG stands for double negative, where both of these parameters are negative. NG structures are further classified into ENG (ε <0, μ>0) and MNG (ε >0, μ<0). EGB structures, also known as photonic band structures (PBS), are based on periodic arrangements of the basic structures of which they are made. Fig.1 summarizes the types of metamaterials along with their standard structures.

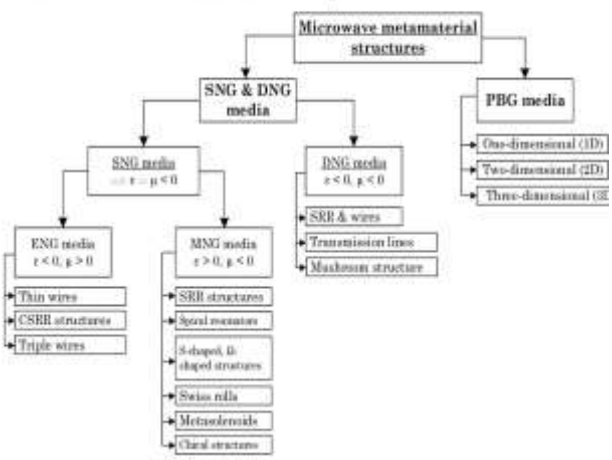


Fig 1. Classification of Metamaterials along with their standard structures

A. ENG Metamaterials

Materials having negative values of permittivity (ε) and positive values of permeability (m) are termed ENG metamaterials. An array of thin metal wires is generally used to get negative values of permittivity [11]. A complementary split-ring resonator structure, the CSRR, has also shown negative permittivity behavior. Hence, such structures also fall under the ENG category. The effective permittivity for such materials is given by the empirical equation [12]:

$Ep=1-wp^{2}/w^{2}$------ (1)

Here, p stands for plasma frequency and is that of the incoming signal. Negative values are achieved when the signal frequency is less than the plasma frequency. Figure 2 (a–d) shows a few ENG structures and the equivalent circuit.

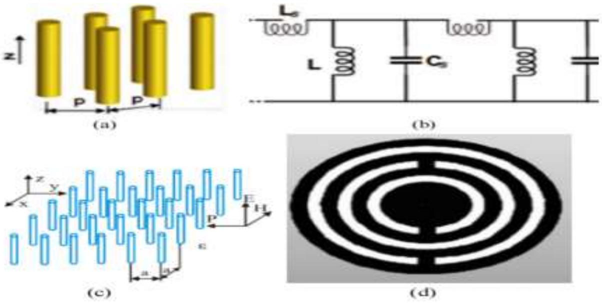


Fig 2. Sample ENG Structures

B. MNG Metamaterials

MNG materials are known as Mu-negative materials because the permeability values are negative. For such materials, ε >0 and μ < 0. The most commonly used MNG structure is the split ring resonator, or SRR. SRR consists of two concentric metal rings of any shape (which can be square or circular) split by a gap. The electrical equivalent circuit of an SRR unit cell is an LC circuit because the gap between the rings acts as a capacitor and the rings act as inductors. The permeability of negative materials is a function of the signal frequency and geometry of the SRR [13]. The radius of rings, the width between them, slit widths, etc. are the design parameters that need to be taken into consideration.

Figure 3(a-d) shows a few MNG structures and the equivalent circuit.

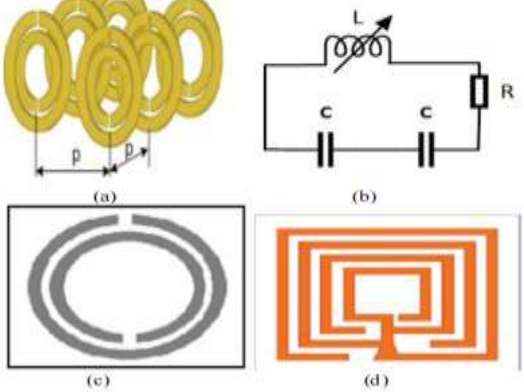
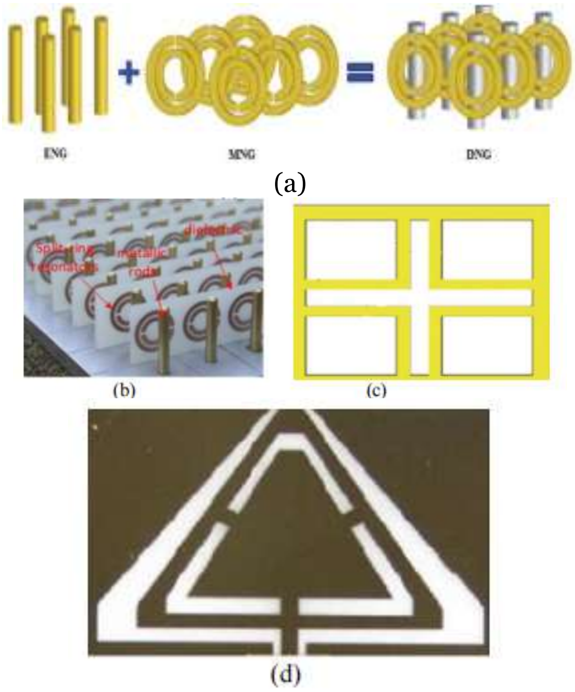


Fig 3. Sample MNG Structures

C.DNG Metamaterials

Double-negative materials are known as DNG materials. They are sometimes also referred to as negative refractive-indexed NIM materials or LH MTM (an acronym for metamaterials). In the rest of the survey, the MTM acronym is used. The materials are artificially designed from an application perspective and are not available naturally. DNG structures can be viewed as an coalescence of ENG (thin wire-based) and MNG (SRR) materials, which were initially reported in [14]. The necessity of combining these two structures was to get negative values for both permittivity and permeability. Such materials exploit the advantages possessed by both ENG and MNG structures and hence prove to be a right fit in many applications. With respect to antennas, such DNG structures are used to subside the mutual coupling within the elements, aid in enhancing antenna quantities, and help in downsizing the antenna structures. Figure 4(a-d) shows a few DNG structures [15].



(a)

(d)

Fig 4. Sample DNG Structures

D. EGB Metamaterials

Electromagnetic band gap structures are known as EGB structures. They are also known as photonic band gap structures (PBG) [16]. These components possess regular patterns of dielectric or metals or are an amalgamation of both in one, two, or three dimensions. An important property of these structures is the forbidden nature of waves in a prescribed range of frequency and signal propagation in other ranges. These forbidden areas are popularly known as band gaps. This band gap feature of EGB materials is very useful in suppressing surface waves when used with antennas, and hence such structures are very commonly used in many microwave applications. Figure 5(a–d) shows a few EGB structures.

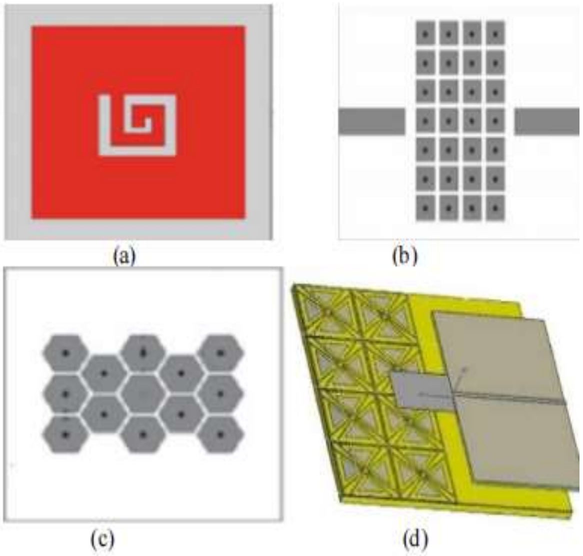


Fig.5. Sample EGB Structures

III. Metamaterials in Antenna Structures

MTMs are employed in antenna structures by assembling an array of unit cells or a single unit cell. Resonant frequency, permeability, and permittivity are the prime factors considered while designing the antenna. The geometry of the MTM unit cell directly influences these parameters; hence, it is paramount to first design and simulate the unit cell that satisfies the requirements of the resonant frequency. Based on the resonant frequency, the geometry of the unit cell can be altered. Optimization in MTM refers to adjusting the size of the unit cells. An optimal algorithm for the design of a unit cell is proposed in [17]. Many times, the simulations were done based on calculations that were not in agreement with the desired results. Hence, for satisfactory results, the dimensions of the unit cells can be extracted employing the optimal algorithm. Figure 6 shows the flow of the algorithm used in designing the unit cell. MTM is used in antenna design either as a chunk of the antenna environment or as a segment of the antenna structure, depending on the applications. MTMs are used in antennas primarily for enhancing gain, antenna miniaturization, multi-band characteristics, and increasing the frequency bandwidth [18].

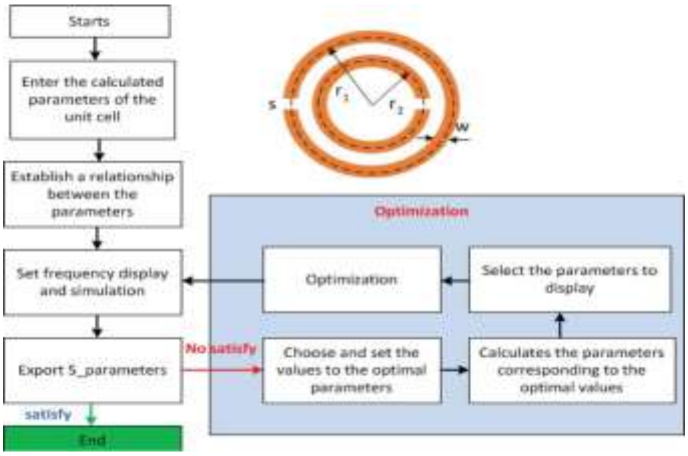


Fig 6. Optimal Algorithm for the design of unit cell

IV.The Microstrip Antennas Based on Metamaterials

Mahyoub et al. have proposed a study of microstrip antenna characteristics with controlled metamaterials [19]. The double-open resonator metamaterial has been studied for the proposed antenna design. The meta-surface is used as a substrate for the design of the proposed antenna, which results in a reduction in the geometric size of the microstrip antenna due to the negative permittivity and permeability values of the metamaterial. This proposed antenna also enhances its directional properties. The synthesized results of this micro-strip antenna with meta-material as a substrate and a split-ring resonator have been presented. The SRR resonator-based metamaterial layer has been used as a substrate to shift the operating strip at low frequencies. For the chosen sort of resonator, the geometric size can be decreased by up to 40% as compared to the traditional microstrip patch antenna. [19] Mahesh et al. have reported a meta-material-based high-performance circular microstrip patch antenna [20]. This circular microstrip patch antenna has been designed for use with and without meta-material structures.

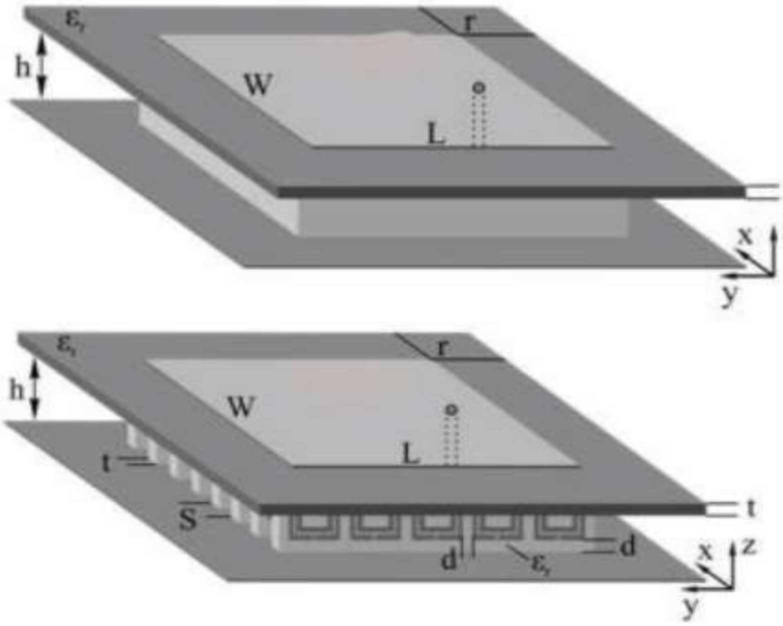


Fig. 7. Micro-strip antenna with Meta-surface

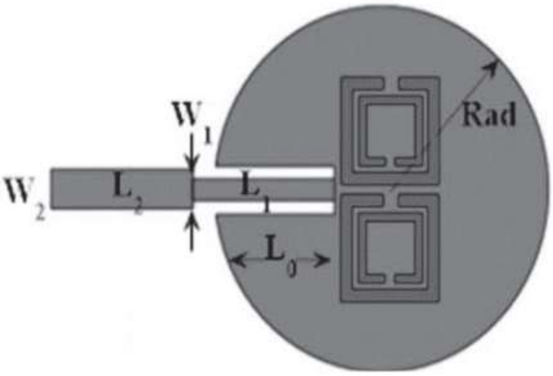


Fig. 8. Circular patch antenna with resonator material

Mahyoub et al. have proposed a metamaterial-based microstrip antenna using LTCC technology [21]. This survey narrates the outcome of research and modeling for the properties of metamaterials consisting of single-ring open square annular resonators. The SR helical resonator is introduced to reduce the size to a higher degree compared with the double-ring SRR and single-ring SRR. Calculations for the mathematical model can be performed using the reflection and transmission coefficients for permittivity and the permeability of the SR spiral resonator metamaterial. Metamaterial-based microstrip antennas with LTCC technology can reduce patch geometry, enhance efficiency, and have a wide working frequency range. The outcomes of this study show the performance of a metamaterial-based antenna. Negative dielectric values and permeability values of the metamaterial can be used to decrease the dimension of the designed antenna and also improve its directional characteristics. This microstrip antenna has a 40% size reduction as compared to standard traditional antennas. However, there is no modification to the obtained gain. [21]

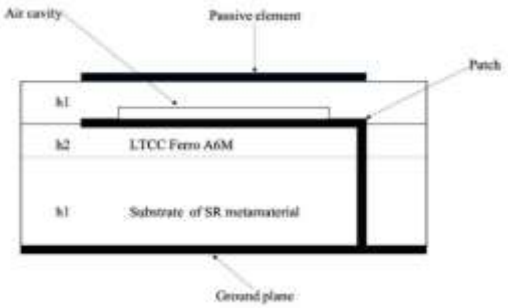


Fig. 9. Meta-surface with Microstrip antenna

Diptiranjan Samantaray et al. have reported slotted microstrip patch antennas using meta-surface as a substrate for enhancement of gain [22]. A substrate-based metasurface antenna has gain and directivity enhancements. This microstrip patch antenna includes fractal-shaped slotted patches with the shape of a square having a shorting via at the designed antenna geometric center and a few slots with the shape of a rectangle around the ground plane structure.

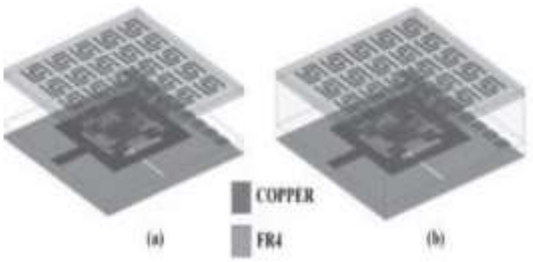


Fig. 10. 3-D view of meta-surface antenna

A micro-strip patch antenna with a meta surface as a superstrate has been designed with a slotted patch. This proposed antenna construct has a squared-shaped patch organized in a chaotic pattern in which the short is in the core of the patch and the line-up of squared patches is uniformly arranged on the patch. Two rectangular slots are designed on the ground plane to improve the bandwidth of the proposed antenna. This antenna has a 7.6 percent bandwidth, 24 dB return loss, and 7.6 dB gain at a frequency of 10.44 GHz [23]. Niamat Hussain et al. have proposed a circular polarized meta-surface-based micro-strip patch antenna for 5G applications [24]. This survey narrates the design and comprehension of a broad-band patch antenna having circular polarization with a meta-surface for 5G applications.

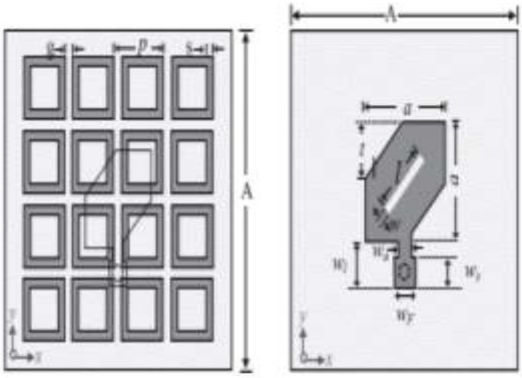


Fig. 11. Aerial view of the patch on meta-surface

A proposed microstrip antenna was designed with patch having different shape between 4*4 squared shape ring array of meta-surfaces and ground surface, and the inherent bandwidth of the standard patch antenna was extended with rectangle shaped slot. By effectively stimulation of surface waves propagating over the meta-surface, different resonances and circular polarized radiations were created enabling performance of impedance and axial ratio. The reduced size of designed antenna 1.1λo× 1.1λo × 0.093λo is achieved by stacking meta-surface on the adjusted patch without air gap structure. This antenna design has been tested and simulated. This antenna has 11 dB gain and a 3-dB axial ratio bandwidth for frequency of 24.1 to 29.5 GHz. In the specified frequency range, the designed antenna has simulated gain in the range of 9.5–11 dBi. [24] Meng Guo et al. have reported a double-layer meta-surface based microstrip antenna for X-Band [25]. This antenna having a linear polarization and circular polarization for X-band with a two-layer meta-surface is simulated to extend the bandwidth of micro-strip antennas. Two resonance modes, TM10 and TM20, are developed in these suggested designs by adding an extra meta-surface between the patch and the ground surface. The F4B substrate, having a permittivity of 2.2, is populated with a two-layered meta-surface for a linear polarized meta-surface antenna having a dimension of 0.8 λ0 × 0.8 λ0 × 0.058λ0. This designed antenna has an impedance matching bandwidth of 32.47 percent, 32.44 percent, and 19.72 percent at 8.41 to 11.67 GHz, 8.29 to 11.5 GHz, and 9.6 to 11.7 GHz, respectively. [25]

Amruta et al. have proposed a patch antenna based on split-ring resonator metamaterial [26]. This patch antenna is based on the compound right-left-handed transmission technique and is meant to improve its properties. It depicts a simple patch antenna by tailoring its patch to increase gain and bandwidth, resulting in a higher quality factor.

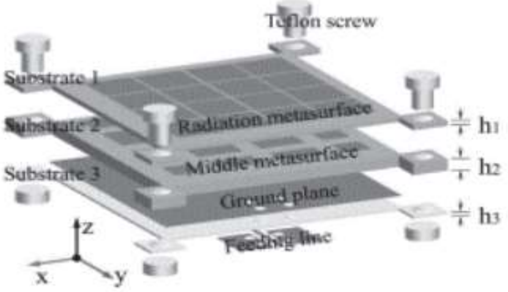


Fig. 12. Side view of the double layer meta-surface antenna

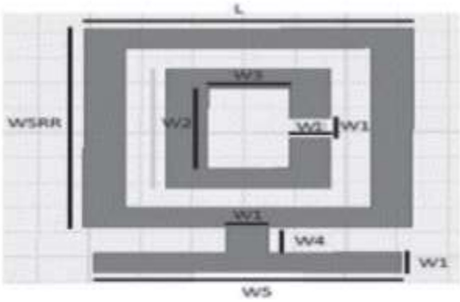


Fig. 13. Single SRR Unit

A patch antenna was created utilizing a split-ring resonator, which was refashioned slightly from the original pattern and utilized in conjunction with capacitively loaded strips. The gain and return loss of this proposed antenna have been simulated. For a single SRR unit, the suggested microstrip antenna's simulated gain is enhanced from -13dB to -20dB. [26] Varun Setia et al. have reported a triple-band meta-material inspired micro-strip patch antenna for WLAN and WiMAX applications [27]. The lower ground plane has two meta-material unit cells and micro-strip patch having a rectangular shape in the fore-ground. This suggested microstrip antenna and ground surface is fabricated on a FR4 substrate. The suggested microstrip antenna covers the triple frequency bands of 2.65 GHz–2.9 GHz, 3.17 GHz–3.75 GHz, and 5.55 GHz–6.1 GHz having omnidirectional radiation patterns.

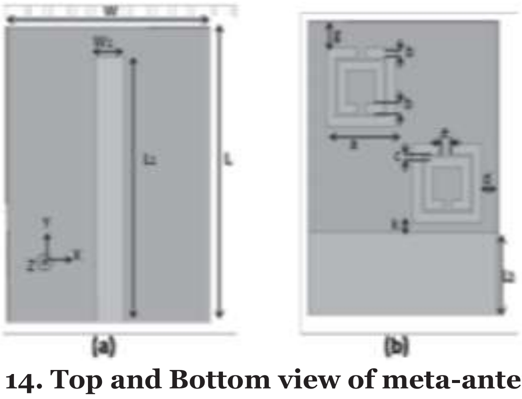


Fig. 14. Top and Bottom view of meta-antenna

It has been proposed to design antennas with a chaotic ground surface and double square SRR unit cells. The frequency bands 2.8 GHz and 5.8 GHz are created in this suggested antenna layout by placing SRR unit cells opposite each other diagonally. The reflection coefficient for this suggested antenna is less than -10 dB in three frequency bands: 2.65 to 2.9 GHz, 3.17 to 3.75 GHz, and 5.5 to 6.1 GHz, with a total usable band-width of 1.38 GHz. For the frequencies of 2.8 GHz and 3.4 GHz, the suggested antenna's radiation pattern is omnidirectional, with 0 dB and 1.4 dB peak gains of 0 dB, respectively. At 5.8 GHz, with a 4.2 dB peak gain, the radiation pattern of this proposed antenna is nearly omnidirectional. [27] Pinsakul et al. have proposed a microstrip patch antenna using an artificial magneto-dielectric metamaterial [28]. A complete investigation of the design and simulation of an artificial magneto-dielectric substrate has been published and is being utilized to create microstrip antennas for wireless applications. The unit cell is made up of numerous quadrilateral loops that have been proposed and placed on a dielectric substrate with a FR4 surface on which each antenna element is located. A frequency of roughly 2.45 GHz was found in this metamaterial. The primary benefit of the proposed antenna design is that it is unique. Furthermore, the proposed antenna has good radiation qualities at the material level, making it appropriate for WLAN applications. This study establishes, measures, and tests the magneto-dielectric metamaterial for quality. This study compares dielectric material on a microstrip antenna with an artificial magneto-dielectric substrate. This magneto-dielectric is often created by embedding particular inclusions.

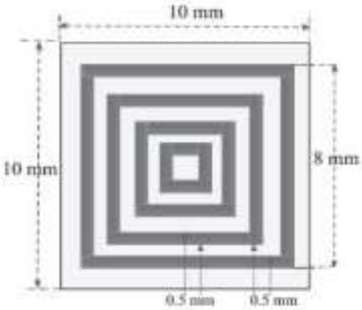


Fig. 15. Single loop meta cell

At the same frequency, the suggested meta-material antenna has an 11.5 percent reduction in patch area. In the suggested design of the microstrip patch, the quadrilateral loop unit cell with 4.8 permittivity and 2.2 relative permeability is realized and adjusted. The proposed artificial magneto-dielectric meta-substrate antenna shows results such as a radiation efficiency of 89 percent and a gain of 6.90 dB, compared to 83.27 percent and 5.23 dBi for the conventional antenna. [28] Singh et al. have reported a micro-strip patch antenna design for multi-band 5G communication systems with a metamaterial-inspired structure. [29]. Using the characteristics of meta-material split-ring resonators, this research provides a design for an optimum multi-band MIMO antenna appropriate for 5G wireless communication. The meta-material structure is generated by placing split-ring resonators on the antenna substrate's backside. Copper is used to make the periodic rectangular rings on the FR4 substrate, with r = 4.4, r = 1, and loss tangent tan = 0.02. The suggested antenna's metamaterial rings improve its performance by allowing it to modify the nature of electromagnetic wave transmission media at the expense of the antenna's power efficiency.

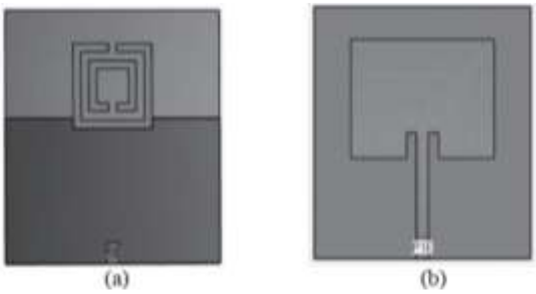


Fig. 16. Designed Antenna Structure, (a) Back View Showing the SRR Rings, (b) Front View

Two bands of 2.61 GHz and 7.1 GHz, i.e., the frequency range indicated for the next generation of communication systems, are included in the developed framework. This dual-band antenna structure has a 300 MHz and 490 MHz bandwidth at 2.61 GHz and 7.1 GHz, respectively, with return losses of -39.35 dB and -21.36 dB at the respective frequencies. [29] Nathapat Supreeyatitikul et al. proposed an s-shaped metasurface-inspired circularly polarized patch antenna design in the c band. The suggested patch antenna has a low profile and is made up of three substrate layers: upper, middle, and lower. The upper substrate had four periodic S-shaped meta-surface components; the middle substrate had a rectangular-shaped slot in the center; and the lower substrate had a coplanar waveguide with microstrip and ground. The linearly polarized CP wave was transformed by the S-shaped meta-surface elements. An antenna has been designed and built. The suggested antenna has a gain of up to 6.16 dBic at 5.6 GHz. [30] Huanhuan Yang et al. have presented micro-strip patch antennas using meta-surface. An anisotropic metasurface has been proposed to replace the traditional patch and act as the antenna's radiating structure directly without increasing the antenna's initial size. The suggested antenna's radiation and scattering mechanisms have been simulated. To achieve a reduction in radiation performance, a 4x4 array was created. The suggested antenna element and array both have gains of 7.5 dB and 17.8 dB, respectively. [31]

From the above comparative analysis, microstrip patch

antennas can be reduced by up to 40% with the use of metamaterials, but antenna miniaturization can be obtained at the expense of degradations in gain and bandwidth. Various proposed meta-material-based microstrip antennas with different technologies can be used to achieve maximum gain up to 11 dB and wide bandwidth, but there is no such significant reduction in antenna size. The maximum antenna size reduction and gain enhancement cannot be achieved simultaneously through the above-mentioned proposed meta-material-based microstrip patch antenna.

IV. Proposed Solution

Metamaterial antennas are a type of antenna that uses metamaterials to improve the performance of tiny antenna systems in terms of gain, directivity, and efficiency. The metamaterial may be useful in assisting antennas in achieving multiband or frequency-adjustable properties with high gain and directivity.

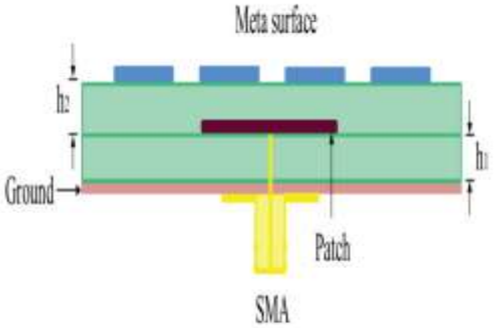


Fig.17.Proposed design of Metamaterial based Microstrip patch Antenna

A patch is sandwiched between a meta-surface and a ground surface substrate in the suggested antenna. The metamaterial structure is loaded over the substrate to create a metamaterial antenna. Metamaterial substrates come in a variety of shapes and sizes. Any alterations to the metamaterial substrate will have an impact on the antenna's characteristics. To obtain a low antenna profile, the meta-surface layer is immediately placed above the patch with no air gap. metamaterial structure is loaded over the substrate to create a metamaterial antenna. Metamaterial substrates come in a variety of shapes and sizes. Any alterations to the metamaterial substrate will have an impact on the antenna's characteristics. To obtain a low antenna profile, the meta-surface layer is immediately placed above the patch with no air gap.

TABLE I. Comparison of Micro-Strip Antenna Based on Metamaterials

. No	Research	ear of Publish	Authors	Advantage	Disadvantage	Summary
1.	Study of the Micro-Strip Antenna Characteristics with Controlled Metamaterials.	2020	Mahyoub et. a	Reduced size, enhanced efficiency, wide frequency band	Low bandwidth	Reduction in antenna size of up to 40%, Gain up to 6 dB
2.	Design and Development of Metamaterial Based High Performance Microstrip Antenna. In Emerging Trends in Photonics, Signal Processing and Communication Engineering.	2020	Mahesh et al	Minimize the dimensions of a patch, No degradation of directivity after reduction in patch size	Low bandwidth, Low gain performance	Reduction in antenna size by 25%, Directivity up to 6 dB
3.	Evaluation of the Efficiency of the Metamaterial in the Development of Microstrip patch Antennas using LTCC Technology.	2020	Mahyoub et. a	Higher degree of minimization, bandwidth of 3.3 and 5.9 % at 4.5 and 3.5 GHz	Reduced operating band, No gain enhancement	Reduction in antenna size of up to 40%
4.	A Gain-Enhanced Slotted Patch Antenna Using Meta surface as Superstrate Configuration	2020	Diptiranjan Samantaray et al	Gain enhancement Directivity enhancement Good efficiency	Low reduction factor in terms of antenna size	7.6 % bandwidth, Return loss up to 24 dB at 10.4 GHz, 7.6 dB gain
5.	A meta surface-based low-profile wideband circularly polarized patch antenna for 5G millimeter-wave system	2020	Niamat Hussain et	Gain enhancement Wide impedance bandwidth	Low reduction factor in terms of antenna size	Bandwidth of 24.1 - 29.5 GHz, Gain of 11 dB
6	Double-layer meta surface based low profile broadband X-band microstrip antenna	2020	Meng Guo et al.	Broad bandwidth Good reduction factor in terms of antenna size	No gain enhancement	Bandwidth of 8.29 - 11.5 GHz, Antenna size 0.8×0.8×0.058 λo
7.	Enhancing the Performance Characteristic of Patch Antenna using Split-Ring Resonator	2020	G. Amruta et al.	Gain enhancement	Low reduction factor in terms of antenna	Return loss up to -20 dB

	Metamaterial				size	
8	Triple-Band Metamaterial Inspired Microstrip Antenna using Split Ring Resonators for WLAN/WiMAX Applications	2019	Varun Setia et al.	Operate at three frequency bands 2.65 GHz to 2.9 GHz, 3.2 GHz to 3.8 GHz, and 5.5 GHz to 6.1 GHz, Reduced size	No gain enhancement	Return loss of less than -10 dB, Bandwidth of 1.38 GHz
9	Artificial Magneto Dielectric Metamaterial with Microstrip Antenna for Wireless Applications	2019	P insakul et al.	Better efficiency of radiation, Gain enhancement, Reduced size	Low reduction factor in terms of antenna size	11.5% reduction in antenna size, 88.87% efficiency, 6.8 dB gain, Bandwidth of 163 MHz
1	Multiband Microstrip Patch Antenna Design for 5G Using Metamaterial Structure	2018	Singh et al.	Multiband 2.61 GHz and 7.1 GHz, Good impedance matching, good reflection coefficient and bandwidth	Low antenna efficiency	Bandwidth of 300 MHz, Return loss up to -39.35 dB at 2.61 GHz and -21.36 dB at 7.1 GHz

V.To Enhance Antenna Gain

This section discusses how gain is improved due to MTM. Many planar antennas suffer from the disadvantage of low gain, which hence affects their performance when such antennas are used in various applications. To enhance the gain, MTMs are employed. Many arrangements are possible, such as having the unit cells arranged around the radiated elements or having one or many superstrates at a certain distance from the radiated element. One more possibility is employing MTMS, as the loading for the antennas is shown Fig.18.

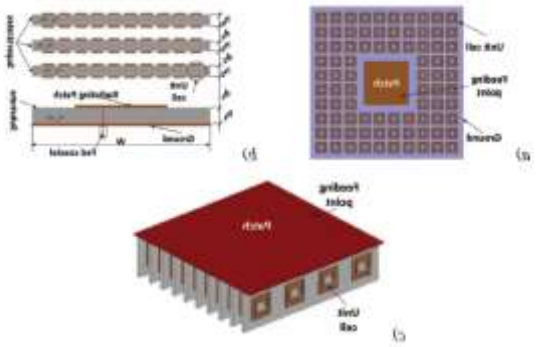


Fig 18. MTM Structures to improve gain

TABLE II. Survey on increase in Antenna Gain due to MTM

S.No	Antenna structure and methodology	Principal findings		Type of MTM used	Frequency
		Gain Without MTM	Gain With MTM		
1.	MTM super state is placed above EGB substrate	9.2 dB	21.6 dB	EGB	14.6 GHz
2.	3D SRR embedded in LTCC substrate	5.73 dBi	6.93 dBi	MNG	5.2 GHz
3.	MTM super state placed very close to patch and horn antenna	4.1 dB	14.1 dB	DNG	2.3 GHz
4.	MTM unit cell is placed above UWB microstrip	8.7 db increase in gain		DNG	3.1 – 10.6 GHz
5.	Dualband MTM Unit cell placed above patch	2.6 dBi	6.6 dBi	DNG	5.7 GHz
6.	Array of 3*6				

	MTM t cells placed on both sides of substrate	8.7 db increase in gain		-	3.88 GHz
7.	SRR structure placed at half wavelength away from patch	Gain increased by 7.6 dB		DNG	5.9 GHz
8.	SRR structure placed at half wavelength away from patch	7.46 dB	12.46 dB	DNG	9.89GHz to 10.24GHz
9.	Double layer EBG structure on FR4 substrat	6 dBi	8.5 dBi	EGB	2.8 GHz to 4.4 GHz
10.	3 layer MTM structure used as substrate	7.8 dBi improvement		ENG	10 GHz
11.	Cross spilt ring resonators used	5.15 dB	6.24 dB	MNG	-

VI. Miniaturization

Size reduction is a very important aspect owing to the demand for multiple functionalities in a device. Existing techniques like fractal geometry, shorting pins, and high-dielectric substrates pose disturbances to the structure of the antenna. MTM is preferred because of the peculiar properties of their unit cells at a resonant frequency. In many structures, MTM acts as defected ground structures to miniaturize the antenna size.

TABLE III. Survey on the use of MTM for miniaturization

S.NO.	**Antenna structure and methodology**	**% Reduction in size due to MTM**	**Type of MTM used**	**Frequency**
1.	SRRs structure is used as bottom layer along with fractal portion.	40%	DNG	2.5 GHz
2.	Wire spilt multi spilt resonators are placed on each side of the antenna	50%	DNG	2.03 GHz
3.	Patch antenna loaded with 2 DNG unit cells	54.6%	DNG	2.52 GHz
4.	Rectangular CSRR structure is used as metamaterial	46.8%	ENG	2.9 GHz, 5.2 GHz
5.	9 SRR embedded in lower section of antenna	33%	MNG	2.4 GHz
6.	SRR structure used to design magneto dielectric substrate	65%	DNG	2.4 GHz

7.	CSRR land interdigital capacitor used	55%	ENG	3.67-3.93 GHz
8.	Partial loading MTM ring on to patch resonator	-	DNG	1800MHz
9.	Radiating Element of ESA is placed above the conducting layer	76.9%	-	1.8 GHz

VII.To get Multi-Band Characteristics

Integrating multiple functions on a single device is in prime demand, and to cater to this, multiband antennas need to be designed. At resonant frequencies, MTM supports negative refraction indexes and symmetric pairs in the unit cell structures. This helps in designing multiband antennas either by using MTM as radiating components or as a loaded part. This summarizes a few MTM-based multiband antennas operating at different frequency bands for multiple applications.

TABLE IV. Survey on multiband structures using MTM

Antenna structure and methodology	**Type of MTM used**	**Operating Frequency**	**Operating bands**
Circular shaped SRR used with 5 rings	MNG	2.1 , 2.5 , 3.5 , 4.5 , 5.9 , 6.9 GHz	UMTS, WLAN, WiMAX (IEEE 802.11ax)
MTM EBG structure used	EGB	2.4 , 5 GHz	WLAN
Modified square SRR used to produce a negative refractive index.	MNG	2.18–2.5, 3.21–3.76, 4.1–7.89 GHz	UMTS, WLAN, WiMAX
Triangular SRR structure is used	MNG	2.4, 5.2, 5.8, 3.5, 8.2 GHz	WLAN, WiMAX, ITU

TABLE V. Design specifications of proposed microstrip antenna based on meta-material

S.NO.	**Parameters**	**Proposed Value**
1.	Targeted Frequency Band	S/C band
2.	Targeted Frequencies	2.4-2.8 GHz 3.3-4.0 GHz 5.1-5.8 GHz
3.	Gain	8-10 dB
4.	Size Reduction Factor	30-40%

This proposed meta-material-based microstrip patch antenna has high gain, directivity, and bandwidth with a reduction in size for single-band and multi-band applications. This proposed microstrip patch antenna based on metamaterials can be beneficial for NISAR-NASA ISRO Synthetic Aperture RADAR, 5G Wireless Communication, WiMax, and WLAN applications.

V. Conclusion

A microstrip patch antenna is a light-weight, simple, low-profile, and cost-effective antenna, but its main drawbacks are the low gain, narrow bandwidth, and reduced radiation efficiency. To overcome the disadvantage of a standard microstrip patch antenna, meta-material-inspired structures have been widely used in various fields. Metamaterial is an unreal or artificial material. The characteristics of metamaterials are defined by the structure of the metamaterial. The structure of metamaterials can be rectangular, circular, elliptical, triangular, or any perpetual shape. Metamaterials presence provides enhancements in the design of antennas.Metamaterials are very useful for low-profile antennas for RF and microwave bands. Various types of microstrip patch antennas based on metamaterials are available. The various techniques mentioned in this review survey can be utilized to improve some of the problems with conventional microstrip patch antennas. This survey shows techniques and methods for enhancing the gain, efficiency, directivity, radiation pattern, and bandwidth performance of micro-strip patch antennas. It is proposed that the antenna gain and directivity can be improved by using various metamaterials. This survey highlighted the recent progress within the literature on designing microstrip patch antennas using metamaterial. It is concluded that microstrip patch antennas based on metamaterials may provide gain enhancement and significant miniaturization with a wide bandwidth for multiband frequency in the future. A deeper understanding of the meta-materials will result in more applications for designing microstrip patch antennas, various RF components, and similar kinds of structures in various fields. This survey attempts to highlight the importance of meta-materials and the design technologies of meta-material-based microstrip patch antennas.

VI. References

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