DESIGN OF HIGH GAIN AND BEAM STEERING ANTENNAS USING A NEW PLANAR FOLDED LINE METAMATERIAL STRUCTURE

A MINOR PROJECT - III REPORT

Submitted by

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BONAFIDE CERTIFICATE

Certified that this **18ECP105L - Minor Project III** report **DESIGN OF HIGH GAIN AND BEAM STEERING ANTENNAS USING A NEW PLANAR FOLDED – LINE METAMATERIAL STRUCTURE** is the bonafide work of **YUVAPRABHA B (927621BEC247), SUJITHA V (927621BEC222), SOBIYA T (927621BEC205), SREVARSHINE S (927621BEC208)** who carried out the project work under my supervision in the academic year **2023-2024 - ODD.**

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PROJECT COORDINATOR

INSTITUTION VISION AND MISSION

Vision

To emerge as a leader among the top institutions in the field of technical education.

Mission

M1: Produce smart technocrats with empirical knowledge who can surmount the global challenges.

M2: Create a diverse, fully -engaged, learner -centric campus environment to provide quality education to the students.

M3: Maintain mutually beneficial partnerships with our alumni, industry and professional associations

DEPARTMENT VISION, MISSION, PEO, PO AND PSO

Vision

To empower the Electronics and Communication Engineering students with emerging technologies, professionalism, innovative research and social responsibility.

Mission

M1: Attain the academic excellence through innovative teaching learning process, research areas & laboratories and Consultancy projects.

M2: Inculcate the students in problem solving and lifelong learning ability.

M3: Provide entrepreneurial skills and leadership qualities.

M4: Render the technical knowledge and skills of faculty members.

Program Educational Objectives

PEO1: **Core Competence:** Graduates will have a successful career in academia or industry associated with Electronics and Communication Engineering

PEO2: **Professionalism:** Graduates will provide feasible solutions for the challenging problems through comprehensive research and innovation in the allied areas of Electronics and Communication Engineering.

PEO3: **Lifelong Learning:** Graduates will contribute to the social needs through lifelong learning, practicing professional ethics and leadership quality

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PO 1: Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

PO 2: Problem analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO 3: Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO 4: Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO 5: Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO 6: The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO 7: Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO 8: Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO 9: Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO 10: Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO 11: Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO 12: Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

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PSO2: Able to solve complex problems in Electronics and Communication Engineering with analytical and managerial skills either independently or in team using latest hardware and software tools to fulfil the industrial expectations.

Abstract	Matching with POs, PSOs
Metamaterials, Beam Steering Antenna, 5.8GHz Microstrip Antenna	PO1, PO2, PO3, PO4, PO5, PO6, PO7, PO8, PO9, PO10, PO11, PO12, PSO1, PSO2

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ABSTRACT

In the last few years, there has been growing interest in employing metamaterials (MTMs) to enhance antenna gain. In this project we proposed a novel structure of planar folded-line left-handed metamaterial (FL-LHM) and applied it to improve the gain of three 5.8GHz microstrip antenna types: a circularly polarized patch antenna, an antenna array, and a beam steering antenna. The planar FL-LHM structure was designed based on transmission line analysis. Their scattering parameters were obtained using a numerical model the negative effective permittivity and permeability were then calculated from these parameters for the assessment of negative refraction index region. The S_{11} and radiation patterns of three fabricated antennas were measured these results matched well with the simulation. We observed that the gain was increased up to 3 dB for all the antennas. In addition, we were also able to maintain the circular polarization as well as the steering of the antenna without changing its dimensions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACRONYM		ABBREVIATION
EMB	-	Electro Magnetic Bandgap
LHM	-	Left handed Material
RHM	-	Right handed Material
ETC	-	Electronic-Toll-Collection
DNM	-	Double-Negative Material
MTM	-	Meta Material
ECC	-	Envelop Correlation Coefficient
CCL	-	Channel Capacity Loss

CHAPTER 1

INTRODUCTION

Antenna is an important component that affects the performance of wireless communication systems. Antennas with low profile, low manufacturing costs, and high gain are more desirable for the system. To satisfy the requirements, microstrip antenna is a good candidate for the antenna design. How ever it is difficult to obtain a high gain using a normal microstrip antenna. To resolve this issue, some traditional technologies for enhanced-gain antenna are used such as reflectors, directors, dielectric lenses, superstrates, or array techniques. In recent years, electromagnetic bandgap (EBG) structures and metamaterials have been demonstrated to enhance the antenna gain. This paper will be focused on the high gain antenna using MTM technique. Metamaterials denote artificial constructed materials that may not be found in nature. Metamaterials has negative permittivity ($\varepsilon < 0$) and/or negative permeability ($\mu < 0$). The MTM is called double-negative material (DNM) or lefthanded material (LHM) when it has double-negative ε and μ. With the same incident wave, the reflected wave through a LHM is in opposition to the reflected wave through a positive permittivity and permeability material. LHM acts like lenses to focus wave in the same direction thus it is usually placed above an antenna to increase its gain. In general, LHM uses a periodic structure and is modeled as an infinite array of MTM unit-cells. Therefore, in this paper, a single LHM unit cell will be studied instead of the entire array of unit-cells. The dimension of a LHM unit-cell is very small compared to λ_0 where λ_0 is the wavelength in free space at the operating frequency. In this paper, we concentrate on the design of a new LHM and its applications in gain enhancement for low profile antennas. In the context of improving the antenna gain, two types of MTM are usually found: the left-handed materials or double negative materials and evanescent materials. LHMs have both negative permittivity and permeability that were mentioned by Veselago in 1968.His paper introduced the propagation of waves in LHMs that is opposite to the wave vector in the right-handed materials (RHMs),LHM possess the negative refraction index (n) and their wave vector k is also called the "backward wave." Evanescent materials are the other type of MTMs with single negative $\varepsilon < 0$ or $\mu < 0$ which were considered by Prendry and his colleagues thirty years later. He found out that thin metallic wire lattices (TMWs) had effectively negative permittivity and split ring resonators (SRRs) had effectively negative permeability in specified frequency bands. The first practical LHM unit-cell structure was proposed by Smith and his colleagues based on SRR of Prendry in. It is constituted of TMW and SRR which have dimension in 3D of d = λ0/7.5(dx×dy×dz).Ziolkowskithen successfully investigated and realized some slabs of planar LHM structures that comprised a substrate Duroid 5880 (h sub = 0.8 mm)with embedded strip line operating at the X band. This one is more compact than the first LHM structure in3Dandsuitable for low-profile antenna application. The dimension of these planar LHM unit-cells in 2D is around$d$ = λ0/6 (dx×dy×h sub). The other LHM structure, the "Ω shaped," was first suggested in 1992 by Saadoun and Eng heta. In 1997, Simovski et al. presented "Ω" shaped LHM unit-cell in 3D with the dimension of d =λ0/9 (dx×dy×dz), application for antenna gain enhancement .This LHM unit-cell is smaller than the LHM unit-cell of Prendry and Smith. At the same time, they also designed the "Ω" shaped LHM unit-cell in 2D in ; then the "Ω" shaped LHM unit-cell in 2D was fabricated in 2008 with the dimension of $d = \lambda_0/x\times d_y\times h$ sub) using Roger Duroid substrate. The new planar "S" shaped LHM unit-cell was investigated by Chen et al. with the dimension of $\lambda/5 \times \lambda/9.7 \times h$ sub, but this LHM could not be smaller thanλ0/6,5 In addition, the negative effective permittivity, permeability, and refraction index can be extracted from average H-field and E-field of each LHM unit-cell or from their reflection and transmission coefficient parameters. These methods have been researched and validated by many researchers, especially matched results between the simulation and the experimental S parameters which have been demonstrated. For this reason, our new planar “folded-line” LHM (FL-LHM) unit-cell structure will retrieve their effective ε and μ from$S$ parameters based on the numerical LHM unit-cell model.This FL-LHM unit-cell has a smallest dimension of $\lambda_0/9.5$ compared with the published unit-cell structures .we show the methodology to design and to obtain this FL-LHM at defined operating frequency.The design of novel high gain and beam steering antennas using FL-LHM substrate will be presented more in detail in Section 3. When a LHM substrate covers a reference antenna, it enhances the gain of that antenna and also maintains its performance. This performance can be circular polarization or beam steering.This one is a major advantage of LHM substrate which will be presented. As we have reported in our previous work, the operating frequency of FL-LHM as well as FL-LHM antenna was defined at 5.8GHz in order to satisfy the operation-range requirement for reader antenna of electronic-toll-collection (ETC) free-flow system application on the highway in Europe. The ETC free-flow system allows automatic fee payments of vehicles without stopping on the highway. It is composed of a reader and transponders (badges) where the reader is fixed on a gantry of the road and the badge is mounted on a vehicle.Each badge stores all information of each vehicle, such as the class, the owner of vehicle, his address, and his bank account. Reader detects and then communicates with badge to collect all vehicle information when a vehicle enters its operating zone.Physical layer of the equipment (the reader and the badge) uses the microwave communication at the spectrum of 5.795GHz–5.815GHz or 5.875GHz–5.905GHz according to European dedicated short-range communication (DSRC) standard. In this DSRC system, an antenna with higher gain gives a longer distance of communication and hence vehicles can be allowed to pass faster

1.1 OBJECTIVES

To satisfy the requirements, microstrip antenna is a good candidate for the antenna design. However it is difficult to obtain a high gain using a normal microstrip antenna. To resolve this issue, some traditional technologies for enhanced-gain antenna are used such as reflectors, directors, dielectric lenses, superstrates, or array techniques. In recent years, electromagnetic bandgap (EBG) structures and metamaterials have been demonstrated to enhance the antenna gain. This main objective will be focused on the high gain antenna using MTM technique (New planar folded line-Left handed metamaterial).

CHAPTER 2

LITERATURE SURVEY

2.1 Direct Calculation of Permeability and permittivity for a Left – Handed metamaterial by D.R.Smith

Smith et al. presents an electromagnetic metamaterial was fabricated and demonstrated to exhibit ‘‘left-handed’’ (LH) propagation band at microwave frequencies. A LH metamaterial is one characterized by material constants—the permeability and permittivity—which are simultaneously negative, a situation never observed in naturally occurring materials or composites. While the presence of the propagation band was shown to be an inherent demonstration of left handedness, actual numerical values for the material constants were not obtained. In the present work, using appropriate averages to define the macroscopic fields, we extract quantitative values for the effective permeability and permittivity from finite-difference simulations using three different approaches. The standard procedure is to discretize a unit cell of the structure and apply periodic boundary conditions, allowing a phase advance in one of the directions. In the case where we are looking for an effective magnetic response from the rings, we focus on electromagnetic modes polarized such that the magnetic field is parallel to the ring axes. The resulting dispersion curve, which displays a frequency band gap. The effective refractive index n(v) is related to both the permeability and permittivity thus, the band gap of characterized by imaginary values of n(v), only indicates that one or the other material parameter has fallen below zero.

2.2 Left- Handed materials composed of only S-Shaped resonators by H.Chen, L.Ran, J.Huangfu

.Chen et al presented about S-shaped inclusion for the realization of metamaterials exhibiting left-handed properties. Unlike most of the conventional inclusions used so far that are composed of two separate geometries- typically a split ring and a rod-the inclusion proposed in this paper is made of only one S-shaped element which yields an overlapping negative permittivity and negative permeability response over a frequency band of about 2.6 GHz. By adopting this geometry, we manage to lower the negative permittivity frequency band down to the level of the negative permeability frequency band, thus allowing the overlapping to occur. Therefore, the structure works as a stand alone and does not require the use of an additional rod. In this paper, we propose a design of SRR for which these two frequency bands (corresponding to a negative permittivity and a negative permeability) do overlap in a wide frequency range. This is achieved by properly tuning the geometry of the rings into an S-type structure associated with an inverted image. The theoretical analysis, the numerical simulations and the experimental results confirm the left-handed property of the meta material.They had proposed a metamaterial only composed of S-shaped SRRs which, by themselves, i.e., without the need of additional rods, yield metamaterials that exhibit lefthanded properties.

2.3 Robust method to retrive the constitutive effective parameters of metamaterials by X.Chen, T.M.Grzegorezyk

Chen et al presented a method to retrieve the effective constitutive parameters (permittivity and permeability) of a slab of metamaterial from the measurement of S parameters. Improvements over existing methods include the determination of the first boundary and the thickness of the effective slab, the selection of the correct sign of effective impedance, and a mathematical method to choose the correct branch of the real part of the refractive index. The sensitivity of the effective constitutive parameters to the accuracy of the S parameters is also discussed. The method has been applied to various metamaterials and the successful retrieval results prove its effectiveness and robustness. Left-handed (LH) structures have been realized so far as metamaterials and very quickly, researchers have been working on retrieving their effective permittivity and permeability to better characterize them. On each side of the resonance, the branch of n8 can be obtained by a Taylor expansion approach considering the fact that the refractive index n is a continuous function of frequency.

CHAPTER 3

EXISTING SYSTEM

Microstrip Patch Antennas (MPA) are becoming increasingly useful and are widespread within the communication systems. Besides, they have some disadvantages such as small bandwidth, low efficiency, etc. To overcome these drawbacks, the metamaterials (MTM) have been used as a technique to increase the performance of the antenna. Some papers proposed using different types of MTM for gain enhancement of antenna. However, the shape of MTM is limited, commonly used are Split ring resonator. Omega shape, U shape, S shape. Therefore, the purpose of this research is to design a new shape of MTM unit cell to improve the gain of the MPA. Recently, the designed antenna using the algorithm has been greatly introduced. The advantages are automatic design and simulate in the simulation software.

$$L_t = L_{self} + 2L_{mutual} \quad \text{------------} \ (1)$$

$$C_t = C_{self} + C_{mutual/2} \quad \text{-------------} \ (2)$$

The gap s between two conductors of two adjacent unit-cells determines their mutual coupling level. The closer the unit cells are, the larger the current magnitude is thus the resonant frequency will be increased.We found that these components define resonant frequency like effective permittivity and permeability. For easier understanding and designing, each unit-cell is represented by a symmetrical circuit model,where the total inductance L_t has been split into series (L_s) and parallel(L_p) components, similarly for the total capacitance C_t.L_s depends on the total length of conductor line $l$and its value is dominant in series impedance (Z_s).

On the other hand, C_p depends on area of parallel surface between two conductor faces; its value is dominant in shunt admittance (C_p) and depends on the "common" parallel area. As consequence, we can change the total length of line (l) or the "common" parallel area to achieve desired resonant frequency. This means the higher the l or "common" parallel area is, the lower the resonant frequency.

Table 3.1: Parameters of new FL-LHM

Symbol	**Values**
T	0.25 (mm)
P	28.25 (mm)
R	0.25 (mm)
Q	2 (mm) (gap between two folded lines)
O	4.3 (mm)
L	1.4 (mm)
N	5.3 (mm) (dimension of a unit-cell in x direction)
M	5.3 (mm) (dimension of a unit-cell in y direction)
εr	3.55 permittivity of substrate (3.55 + j0.0027)
μr	Permeability of substrate

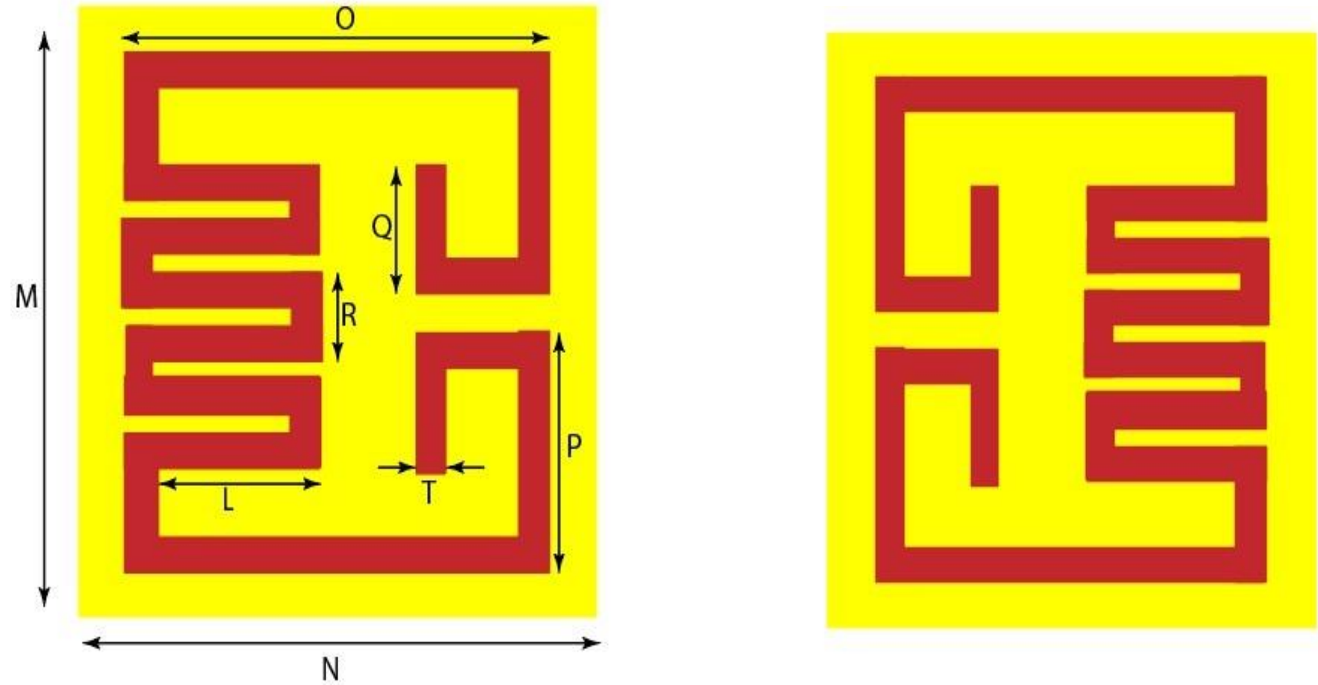

Figure .3.1 Front and back view of the unit cell

The series impedance and shunt admittance of a unit-cell can be obtained from

$$Zs = \frac{-j\omega L_s - 1}{j\omega C_s} \qquad \text{------------- (4)}$$

$$Y_p = \frac{-j\omega C_p - 1}{j\omega L_p} \qquad \text{------------- (5)}$$

The effective permittivity and permeability of unit-cell in this model can be calculated using the Bloch theorem. We start from the relation of the current and the voltage that passes thought a unit-cell as the following equation

$$I_n + 1 = In\ e^{j\beta} \qquad \text{------------- (6)}$$

$$V_n + 1 = V_n e^{j\beta} \qquad \text{------------- (7)}$$

where β is the phase crossing through unit-cell n

$$\beta = k_p, \qquad \text{------------- (8)}$$

where k is the wave vector in the unit-cell and p is the dimension of the periodic unit-cell p=dx=dy=d. Involving the spatial dispersion in these effective parameters, according to the effective permittivity and permeability of a unit-cell can be calculated from the following

$$\mu_{eff} = \frac{\omega L_s - (1/\omega C_s)}{2\omega_p \beta \tan(\beta/2)} \qquad \text{-------------} \ (8)$$

$$\varepsilon_{eff} = \frac{2\beta \tan(\beta/2)}{\omega Ls - (1/\omega Cs))\ \omega p} \qquad \text{-------------} \ (9)$$

Where Z_s' , Y_p' are real numbers they can be negative or positive depending on the values of L_s, C_s and L_p, C_p as follows

$$Z'_s = \frac{\omega L_s - 1\omega}{C_p} \qquad \text{-------------} \ (10)$$

$$Y_p' = \frac{\omega C_p - 1\omega}{L_p} \qquad \text{-------------} \ (11)$$

we can summarize that a LHM unit-cell can be obtained by choosing suitable values of Ls, Cs and Lp, Cp under the condition combined with

$$\omega L_s < \frac{1}{\omega C_s} \qquad \text{-------------} \ (12)$$

As presented, the total length of the conductor line increases, while the resonant frequency increases. This way we can tune the FL-LHM to any operating frequency. For convenience, at the frequency of 5.8GHz of LHM unit-cell 5.8×109. we suppose that L_t and C_t are defined as L_s= 32.73 nH, C_s= 0.018 pF, and C_p= 0.95pF with ωC_p< $1/\omega L_p$. The investigated FL-LHM unit cell consists of two conductor lines etched on

Roger 4003 substrate and has the following dimensions.Each conductor face is created by a line with the width of w = 0.25mm and the total length of l = 28.25mm (around $\lambda_0/2$) to satisfy conditions and above to have resonant frequency at 5.8GHz.This line is folded in one unit-cell with dimensions of 4.3×4.3mm^2 ($\lambda_0/9.5$) by using meander line structure in y direction to reduce the dimension .The separation between two unit-cells is of s = 2mm.Two conductor lines are maintained parallel to each other by the substrate dielectric Roger 4003 that has thickness of hsub = 0.8 mm, permittivity of ε_r= 3.5,permeability of μ_r= 1, and loss tangent of tanδ =0.0027.

CHAPTER 4

PROPOSED SYSTEM

The proposed antenna is printed on a low cost FR-4 substrate having a loss tangent and relative permittivity of 0.02 and 4.4, respectively.The proposed design has two patches excited using a 3 mm wider microstrip lines with a 50 Ω characteristic impedance. Edge to edge separation between the radiating elements of the MIMO antenna is kept as 0.135λ0 (7 mm).

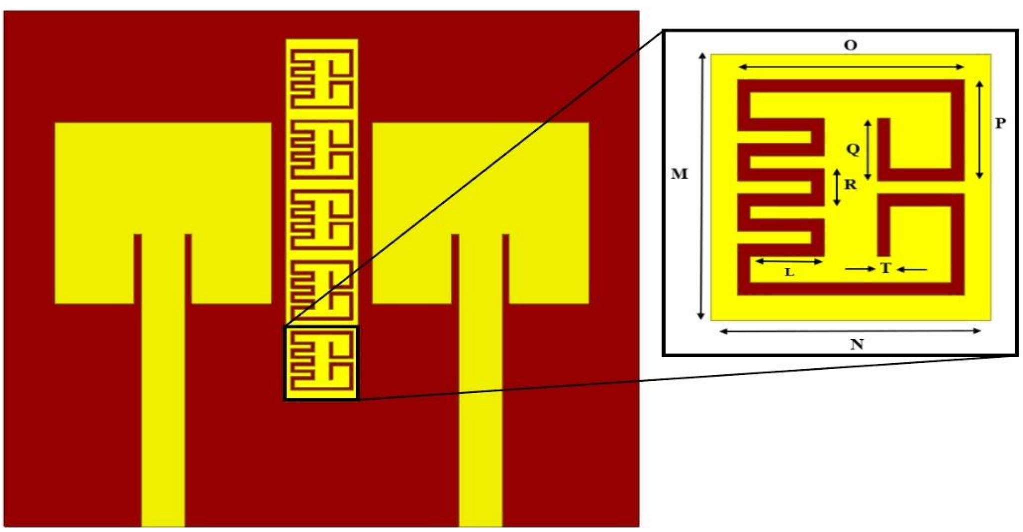

Figure 4.1. Top view of the proposed Multiple Input Multiple Output (MIMO) Antenna.

Table 4.1. Different parameters and values of the antenna

Parameters	**Dimension (mm)**
L_s	37
W_s	22
L_p	13
W_p	15
L_f	22
W_f	3
L_I	5

The iterative design process of the proposed MIMO antenna that includes three steps is presented in Figure 4.2 .Firstly, a single radiating element patch antenna with microstrip feed is designed and optimized to operate efficiently. Width and length of the optimized antenna were chosen as 15 mm and 13 mm respectively. Secondly, another patch antenna is designed near to the first one as shown in Figure 4.3(step 2). The unit cell of the proposed metamaterial structure is shown in Figure 4.1 is used as decoupling structure. The unit cells are used between the antennas for a good isolation between the two antenna elements (step 3).

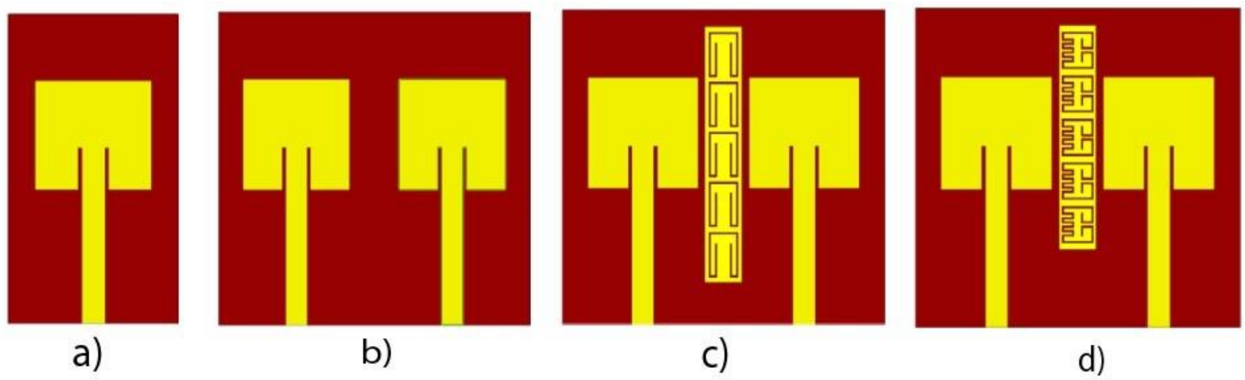

Figure 4.2. Steps for the design of proposed MIMO antenna.

The resonant frequency of MIMO antenna without metamaterial is observed at 5.7 GHz while the resonant frequency of the proposed MIMO antenna using metamaterial is observed at 5.8 GHz. It is worth highlighting that very low mutual coupling is constantly preferable for efficient MIMO antennas. Figure 5.1 shows that antenna without having metamaterial has poor isolation in the whole operating band. A very high isolation is achieved by employing metamaterial between the radiating elements.

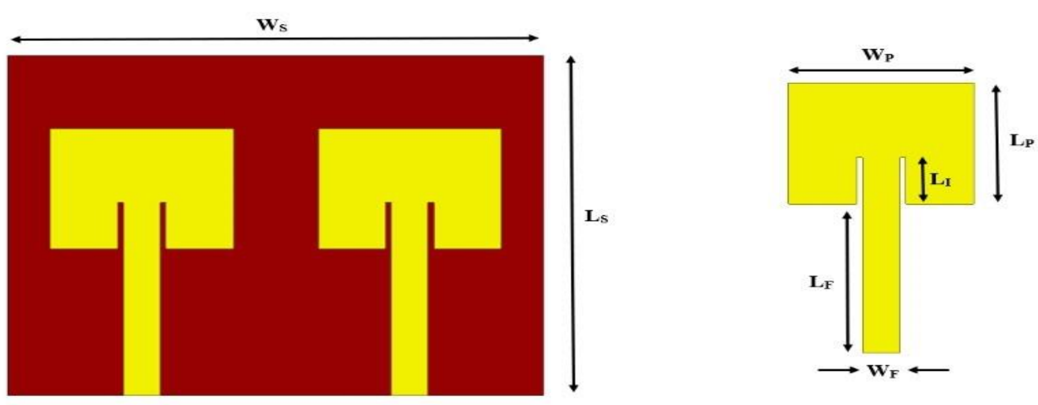

Figure 4.3. Before loading the unit element.

The isolation behavior can also be explained through the analysis of the antenna's surface current distribution at the frequency of interest. The current distribution at 5.8 GHz in both cases (with and without using metamaterial) is presented in Figure 4.1. Upon excitation of port 1 of two port antenna, a high mutual coupling is obtained between the monopoles, because the current is strongly coupled to another radiator. It is obvious from the Figure 4.3 that mutual coupling is diminished by the insertion of metamaterial unit cells between the two radiating elements. Thus, a very low mutual coupling is achieved. To give a profound comprehension of the global configuration, the equivalent circuit model is provided in Figure 1.1. Three resonating structures are cascaded together. The patches of the proposed antenna are modeled by a resonator structure with Lp1, Cp1, Lp2, and Cp2. The decoupling structure of metamaterial is modeled as L_cR, C_cR, and R_cR. C_c and L_c are coupling structures and help in the coupling of the two patches, which is always undesirable in MIMO antenna.

CHAPTER 5

RESULTS AND DISCUSSIONS

To validate the proposed design, an antenna prototype is fabricated and measured. The antenna's simulations were conducted using ANSYS High-Frequency Structure Simulator (HFSS) software. Comparing the simulated and the measured results, we can notice that there is a slight frequency shift. This may be due to several factors which include the SMA connector loss, cable loss, limitation of milling machine as well as radiating boundaries during the measurement process. The measured frequency band of the proposed MIMO antenna is within the range of 5.61–5.93 GHz with $S_{11}/S_{22} < -10$ dB and $S_{21}/S_{12} < -20$ dB.

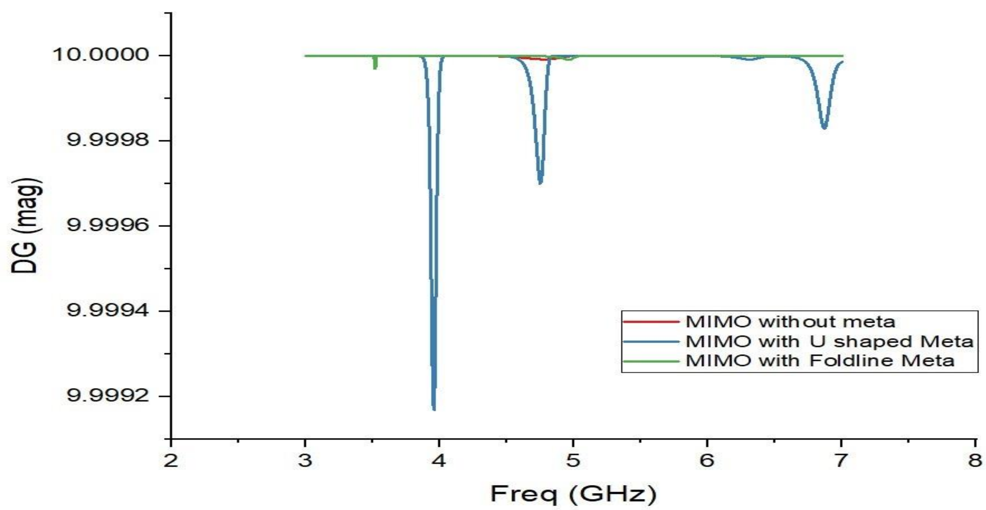

Figure 5.1 Plot between Frequency (GHz) and Directive Gain(mag)

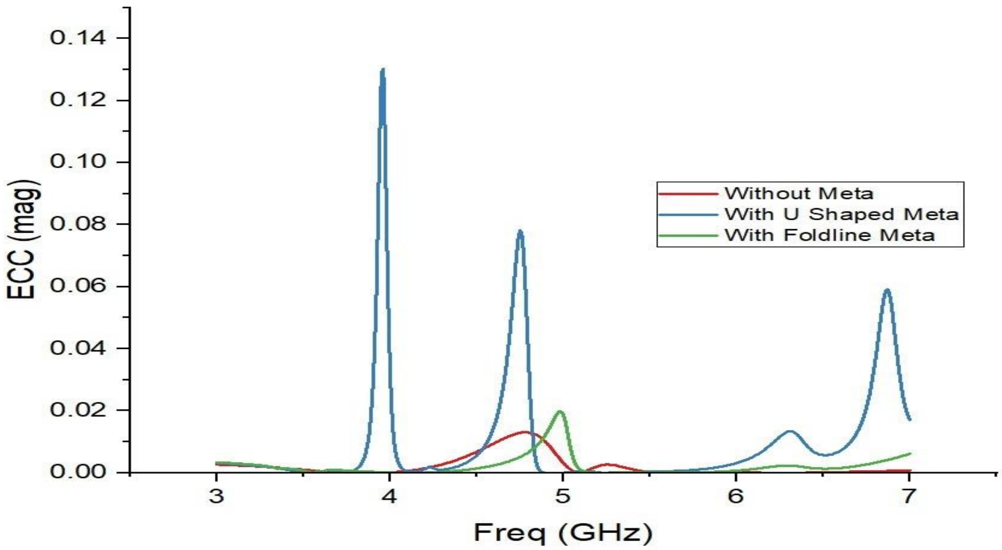

Figure 5.2 Plot between Frequency (GHz) and Envelope Correlation Coefficient(mag).

Further study mainly, in terms of the MIMO antenna’s radiation characteristics in both cases (with and without metamaterial) have also been conducted. As appeared in the figure, the introduction of metamaterial has a slight effect on the deviation of the radiation pattern.The simulated peak gain of the proposed MIMO antenna with and without metamaterial as well as the measured peak gain is portrayed in Figure 5.1. As shown in the figure, the antenna gain is enhanced when metamaterial unit cells are used and hence, the maximum realized peak gain of 4 dB is obtained at 5.8 GHz.The simulated peak gain of the proposed MIMO antenna with and without metamaterial as well as the measured peak gain is portrayed in Figure 5.2. As shown in the figure, the antenna gain is enhanced when metamaterial unit cells are used and hence, the maximum realized peak gain of 4 Db is obtained at 5.8 GHz.

$$\textbf{ECC} = \frac{|\iint_{4\Pi}\left(\vec{F}_i(\theta,\pi)\right)\times(\vec{F}_j(\theta,\pi))d\Omega|^2}{|\iint_{4\Pi}|\left(\vec{F}_i(\theta,\pi)\right)|^2 d\Omega \iint_{4\Pi}|(\vec{F}_j(\theta,\pi))|^2 d\Omega} \quad \text{------------- (13)}$$

where Fi (θ, Φ) describe the 3D radiation pattern when antenna i is excited and Fj (θ, Φ) describe the 3D radiation pattern when antenna j is excited. Solid angle in above the ECC ought to have zero value in the ideal case. However, practical limit for an uncorrelated MIMO antenna is ECC < 0.5. The ECC is around the ideal value and it is equal to 0.02 at 5.8 GHz. Furthermore, it is clear from the same figure that the ECC is less than 0.1 over the operating frequency band. The Diversity Gain (DG) is another fundamental parameter, which characterizes the MIMO antenna. The DG can be calculated using the following equation.

$$\textbf{DG} = 10\sqrt{1-(ECC)^2} \quad \text{------------- (14)}$$

The DG versus frequency. At 5.8 GHz, the proposed MIMO antenna attained a DG of 9.1 dB. Yet, the proposed antenna has a DG > 9.992 dB over the entire operating band.

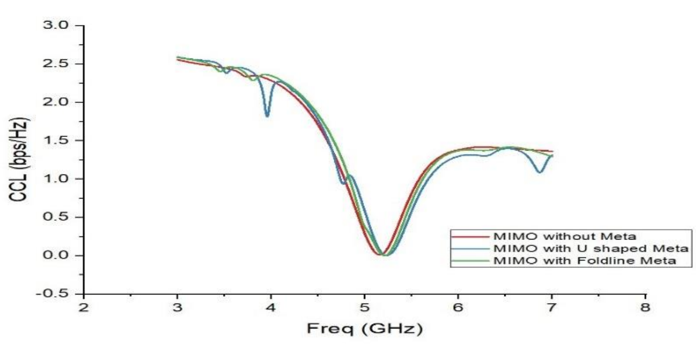

Figure 5.3 Plot between Frequency (GHz) and channel capacity loss(bits/Hz)

Another critical parameter for realizing the performance of MIMO antenna is its channel capacity loss (CCL). The CCL for any MIMO antenna can be computed. Where i,j = 1,2.The CCL calculated from S-Parameters. The proposed antenna achieves CCL values less than 0.5 bits/s/Hz.

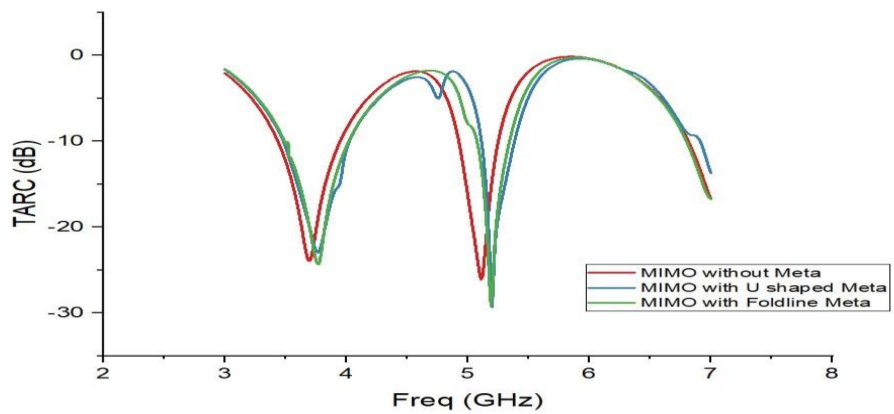

Figure 5.4 Plot between Frequency (GHz) and TARQ(dB)

CHAPTER 6
CONCLUSION

In this project, a new planar FL-LHM structure is presented. An equivalent circuit is useful for understanding and designing a FL-LHM substrate for an arbitrary operating frequency. In addition, the FL-LHM modeling is created for easy simulation using electromagnetic software and for enhancement antenna gain. In consequence, the new FL-LHM substrate is used to increase the gain of three types of low-profile antennas which are the circularly polarized rectangular patch antenna, the antenna arrays, and the beam steering antenna. These three low-profile FL-LHM antennas operate at the frequency according to the DSRC standard for ETC free-flow system application. The gains measured are 9.5 dB, 15.3 dB, and 11 dB in measurement. The gain of any RA is increased up to around 2.5–3 dB by using this planar FL-LHM substrate. The S_{11} and radiation pattern results in measurement of three FL-LHM antennas are well fit with simulation results.

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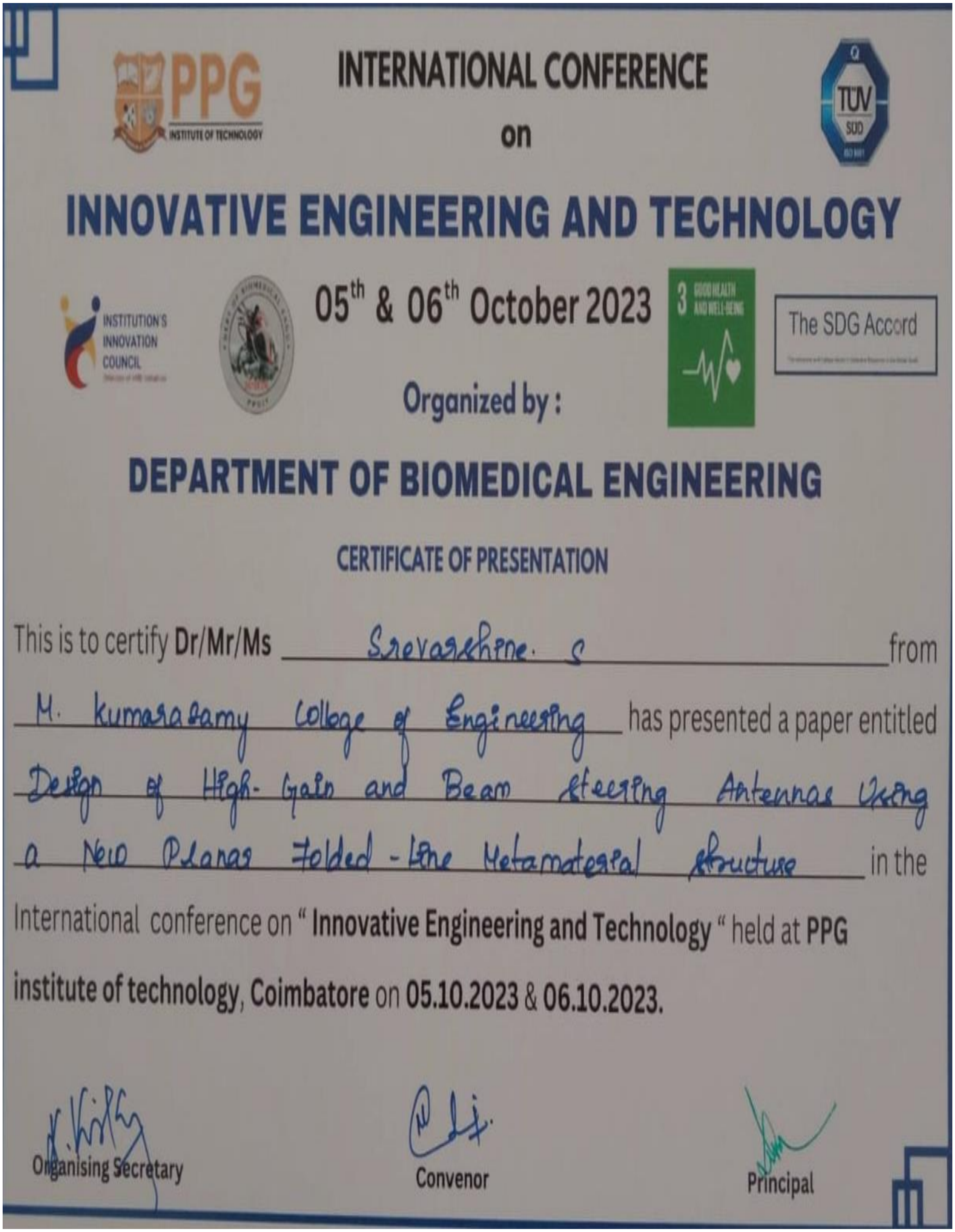
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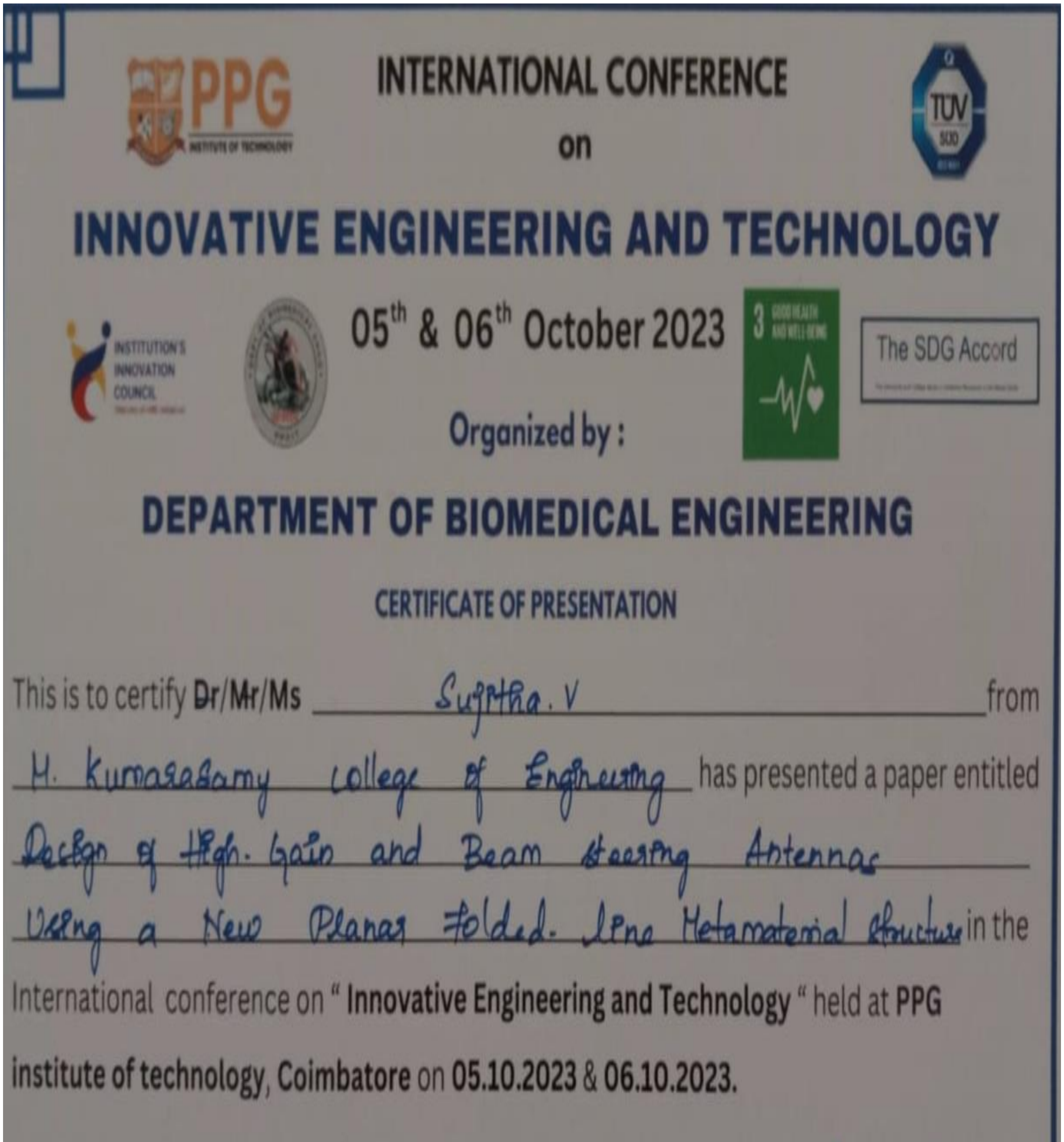

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