Design of a Multi-Band 5G Antenna and Machine Learning Approach for Electromagnetic Compatibility

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***Abstract*— A multi band microstrip antenna with diagonal truncated cuts is introduced in this article and the machine learning techniques are introduced to mitigate the antenna electromagnetic interferences. Proposed design consist of (60 X 60) mm^2 FR-4 substrate (ε_r =4.4) substrate with rectangular metal patch along with two 5mm diagonal truncated cuts with line feeding technique. Antenna with line feeding is radiating at 3.3GHz, 5.2GHz & 8.8 GHz frequencies with VSWR of 0.89dB, 3.24dB & 1.32dB, S_{11} of -25.74dB, -24.32dB -21.55dB and gain of 3.5dB, 2.7dB & 6.8dB respectively. Truncated cuts concept is used for the multi band antenna characteristics. The prime factors of electromagnetic interference and its compatibility requirement is mentioned. Machine Learning (ML) approach for the optimization of antenna's interference is discussed at length. The output error and standard deviation for the standard ML model is discussed. The proposed antenna has potential to meet the applications at 5G frequencies with multiple band operation.**

Keywords—Microstrip Patch Antenna, EMC, Machine Learning, truncated cut, HFSS.

I. INTRODUCTION

Antenna is a device used to transmit or receive electromagnetic waves, such as radio or television signals. The intended function and frequency range of an antenna determine the shape and size of the antenna. They can be installed on a tower, a building, a car, and they can be either directional or omnidirectional. Electrical impulses are transformed into electromagnetic waves by antennas, which are then either transmitted into space or picked up from the environment. Modern communication systems, such as radio, television, cell phones, and satellite communications antenna is prime element. There are various antennas available like wire, dipole, horn, microstrip patch and reflector antenna in the market to meet the requirement. The microstrip patch antenna due to its compactness, polarization, and frequency coverage it occupies special place in its domain. A thin, rectangular metallic patch that is positioned over a ground plane makes up a microstrip patch antenna. Due to its small size, low cost, simplicity of integration with electronic circuits, and favourable radiation characteristics, it is a low-profile antenna that is frequently employed in a variety of wireless communication system[1].

The radiating patch is used by the microstrip patch antenna to produce electromagnetic waves that travel through empty space. Basic patch antenna schematic is shown in Fig.1The ground plane beneath the patch serves as a reflector, enhancing the antenna's gain and directivity. The signal is transmitted to the patch through the feed line, where it is then radiated. There exist wide varieties of patch antennas like, slot, truncated cuts, departure ground designs, Multi-Input Multi Output (MIMO), based on design flexibility and to meet the specific application [2]. Though there are various antenna designs are available it is challenging for the antenna engineers to introduce new optimise design to meet the day to day technological requirements of 5G.

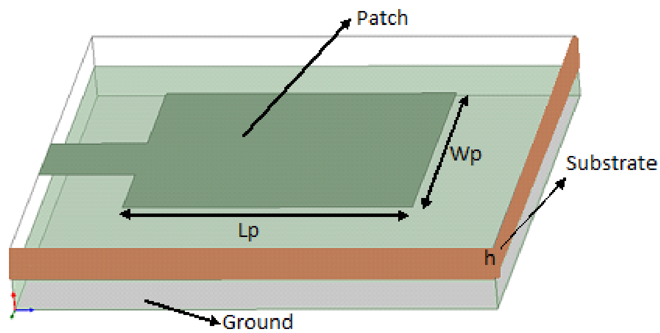

Figure.1 Basic Schematic of Patch antenna

Applications for microstrip patch antennas include wireless local area networks (WLANs), RFID systems, GPS, and mobile and satellite communication systems. They are also utilised in the defence sector for initiatives like electronic warfare and radar. Microstrip Patch Antennas (MPA) are used in mobile communication systems to enable wireless connectivity in smart phones, tablets, and laptops. They are employed in earth stations to interact with satellites in satellite communication systems. They are utilised in RFID systems for the wireless identification and tracking of items. They are utilised for location tracking in GPS systems. They are employed in WLANs to offer wireless connectivity in structures like homes and buildings. Few antenna design in various simulators are available in literature [3].

The fifth-generation wireless network architecture is supported by 5G antennas. These antennas are intended for exceptionally low latency transmission and reception of high-speed data. 5G technology, in contrast to earlier wireless network generations, can produce data rates that are 10-100 times faster than those of the present 4G networks. In order to enable high-speed data connection between devices and the network, 5G antennas are crucial.

The size and design of 5G antennas can vary. Small cells mounted on buildings and light poles are one type, while bigger macro cells mounted on towers and rooftops are another. Small cells are made to be used in densely populated regions where they can offer coverage in places that are challenging for conventional macro cells to reach. To enable faster data speeds, 5G antenna technology often operates at higher frequencies, typically above 24 GHz. Smaller antennas are needed for these higher frequencies, which can be installed in more places because they can be installed closer to the ground. Overall, 5G antennas are essential parts of the 5G infrastructure because they allow for quicker and more dependable data transmission. The installation of 5G antennae will be more crucial as the technology develops and grows, ensuring dependable and fast communication.

In this article the design of 5G multi band antenna is proposed. The diagonal truncated cuts are introduced on metallic patch to achieve the multiband characteristics. The antennas electromagnetic interference and its compatibility are discussed. To mitigate the interferences machine learning approach and existing various algorithms are discussed.

II. Antenna EMI/EMC

The fifth generation of wireless communication technology, or 5G, is anticipated to completely change how we access information and communicate. Thoughts have been raised concerning possible health dangers related to electromagnetic radiation released by 5G antennas as a result of the rollout of 5G networks. One of the potential problems with 5G antennas is electromagnetic interference (EMI). When one device's electromagnetic radiation disrupts the operation of another, this is known as electromagnetic interference (EMI). When the electromagnetic radiation emitted by 5G antenna interferes with the operation of nearby electronic devices, this is known as electromagnetic interference (EMI).The EMI of the antenna comprises of many factors like beam scattering in unintended directions, poor channel of data, impedance mismatch etc.

Manufacturers of 5G antennas utilise shielding and other methods to lessen the electromagnetic radiation that the antennas emit in order to reduce EMI. The amount of electromagnetic radiation that 5G antennas can release is also strictly regulated by regulatory bodies like the Federal Communications Commission (FCC). Since 5G antenna systems emit electromagnetic radiation that could interact with other electronic equipment and pose health hazards, electromagnetic compatibility (EMC) is a crucial factor to take into account. EMC for 5G antennas is concerned with reducing electromagnetic radiation levels and making sure the antenna system complies with legal requirements[4].

5G antennas must go through testing and certification procedures to obtain EMC compliance. The testing determines whether the antenna's electromagnetic radiation emissions are within permissible bounds. The installation and design of the antenna must also be optimised to reduce radiation levels and make sure that grounding and shielding are done properly. 5G antenna EMC also entails meticulous site selection and planning[5]. The placement of antennas must assure public safety and reduce their impact on surrounding equipment. Additionally, the venue must abide by zoning laws and other municipal ordinances.5G antenna EMC is essential for assuring the security and dependability of 5G technology. To reduce electromagnetic radiation levels and assure adherence to legal requirements, meticulous planning, design, testing, and certification are necessary.

III. Machine Learning

Due to its mathematical optimisation approaches, artificial intelligence (AI), machine learning (ML), and deep learning (DL) have become buzzwords in daily life. They are not just fancy phrases; they are also highly qualified to hold their positions because of their capacity to automate complex non-linear issues with minimal human involvement. The scientific community is drawn to use machine learning (ML) in high computing electromagnetic applications, particularly in the design of antenna, due to its potential for forecasting the future values of a problem. Due to the abundance of vast amounts of data, there are numerous research articles on image processing, signal processing, and very large scale integration in the literature. The first condition for applying machine learning techniques is the availability of data. It is high for antenna engineers to use ML in antenna design and EMC analysis of antenna. The basic block diagrams of AI,ML, &DL is in Fig.2 and Fig.3 represents the block diagram of ML. Respectively.

In order to forecast and reduce electromagnetic interference (EMI), machine learning techniques are increasingly being applied in electromagnetic compatibility (EMC) applications. Here are several methods that are frequently used in materializing ML techniques.

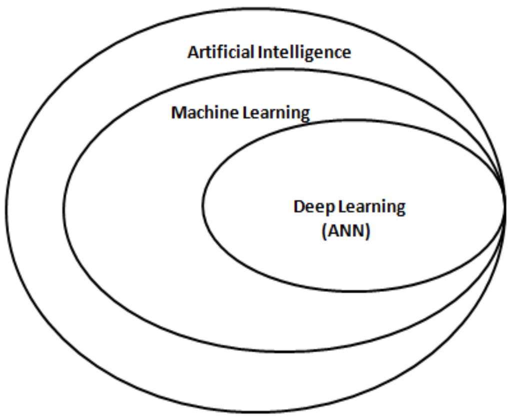

Fig.2 Block Diagram of AI, ML &DL

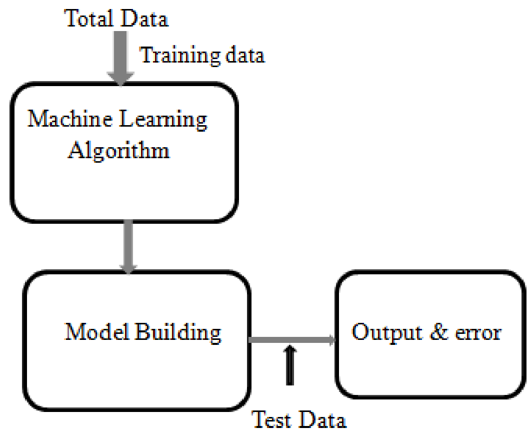

Fig.3 Block diagram of ML

Supervised Learning: Input-output pairs of labelled data are used to train an algorithm. For instance, a model can be trained to forecast the EMI level based on input variables like the electromagnetic signal's frequency and voltage.

Unsupervised Learning: In this method, the model learns from data that has not been labelled and finds patterns and structures. It can be used to recognise and categorise various EMI signal types.

Reinforcement Learning: This entails teaching a model to base decisions on input from the outside world. It can be used to create EMI mitigation plans that change as the EMI environment does.

Deep Learning: Deep learning is a branch of machine learning that makes use of deep neural networks to discover and examine intricate data patterns. It can be used to look for hidden patterns in huge datasets of EMI signals. By offering more precise and effective EMI prediction and mitigation solutions, machine learning approaches have the potential to enhance EMC applications. It is crucial to remember that the calibre and volume of the data used to train the models determines how effective these strategies are.

IV. ANTENNA DESIGN PROCEDURE

Due to its low profile, light weight, and simplicity of integration with printed circuit boards, microstrip patch antennas are frequently employed in wireless communication systems. The steps mentioned below make up the design process for the microstrip patch antenna.

a. Establish the antenna's operational frequency and bandwidth needs.
b. Based on the intended frequency and bandwidth, choose the substrate material and thickness. Low loss tangent and dielectric constant should be characteristics of the substrate material.
c. Based on the intended resonance frequency and substrate characteristics, determine the patch antenna's dimensions. Equations or simulations can be used to determine the patch's size.
d. Identify the patch antenna's feed point location. The feed point ought to be situated at the maximum current and voltage

e. Creating the transmission line and matching for the feed network. The feed network needs to match the source and antenna's impedance and have a minimal loss.

The basic antenna design equations are mentioned in Eq. (1) to Eq. (5). The dimensions are optimized in such a way that to match the port impedance of 50Ω. Dimensions of the proposed antenna are mentioned in table.1, and the antenna is Fig. 4[8].The proposed antenna is designed in full wave electromagnetic solver High Frequency Structural simulator (HFSS) which uses the Finite Element Method and requires less memory space on computer [14].

$$w = \frac{C}{2f_0\sqrt{\varepsilon_r}} \quad (1)$$

$$l_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} \quad (2)$$

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2} \quad (3)$$

$$\Delta l = \frac{\varepsilon_{reff} + 0.300}{\varepsilon_{reff} - 0.258}\left[\frac{l/h + 0.262}{l/h + 0.813}\right] \quad (4)$$

$$l = l_{eff} - 2\Delta l \quad (5)$$

Table.1 Antenna Design Parameters

k	a	b	*l*	*w*	r
5mm	60mm	60mm	27.66mm	21.44mm	5mm

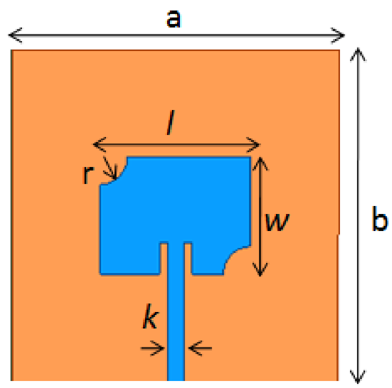

Fig.4 Proposed antenna design

V. MACHINE LEARNING TECHNIQUES IN ANTENNA EMC

Process of designing an antenna takes into account a variety of factors, including radiation patterns, impedance matching, polarisation, and frequency response. The performance of antennas has been improved by using machine learning (ML) approaches to optimise antenna design. The antenna performance parameters needs be optimized for better EMI limits are listed below followed by machine techniques available in contemporary literature.

a. Beam forming Optimisation
b. Antenna Selection
c. Channel Prediction
d. Interference Mitigation
e. Energy Efficiency

Neural Networks: Antenna design frequently makes use of the well-liked machine learning method known as neural networks. They are especially helpful for forecasting antenna behaviour based on input characteristics. Neural networks, for instance, can be used to forecast an antenna's radiation pattern, impedance matching, and frequency response. This can be accomplished by using a dataset of input parameters and associated antenna behaviour to train a neural network [6-7].

Genetic algorithms: Another machine learning method that has been used in antenna design is genetic algorithms. They are very helpful for optimising the antennas' geometry and structure to boost their performance. By emulating the method of natural selection, where the best solutions are chosen and used to generate new ones, genetic algorithms function. Genetic algorithms can be used in antenna design to determine the best shapes and sizes for antennas in order to increase their effectiveness and reduce their losses [9-10].

Support Vector Machines: Another machine learning method that has been used in antenna design is support vector machines (SVM). They are very helpful for categorising antennas according to their features. SVM, for instance, can be used to categorise antennas according to their frequency response, polarisation, and emission patterns. SVM divides the data into various groups by locating a hyper plane. SVM can be used in antenna design to categorise various antenna designs based on their traits and to determine which design is optimal for a given application.

Particle Swarm Optimization: Another machine learning technology that has been used in antenna design is particle swarm optimisation (PSO). It is very helpful for positioning and orienting antenna elements optimally to produce a desired radiation pattern. In order to discover the best answer, PSO simulates the movement of a swarm of particles in a search space. PSO can be used in antenna design to optimise the placement and inclination of antenna elements in order to produce the desired radiation pattern and reduce interference from outside sources.

Decision Tree Technique: A decision tree is a supervised learning technique used in machine learning that is utilised for classification or regression tasks. It is a hierarchical model that resembles a flowchart, with each internal node standing in for an attribute test, each branch for the test's result, and each leaf node for a class label or a numerical value. The decision tree algorithm divides the training data into smaller groups according to the chosen attributes in a recursive manner, doing so until the subsets are homogeneous or a predetermined stopping threshold is satisfied. By following the path from the root to a leaf node, the resulting tree can be utilised to forecast the class label or numerical value of subsequent instances[11].

Random Forest Technique: A common machine learning method for classification, regression, and other problems is called random forest. It is an ensemble learning technique that mixes various decision trees to increase prediction accuracy. Using randomly chosen portions of the training data, multiple decision trees are independently constructed in Random Forest. A randomly chosen subset of the dataset's features is used to build each decision tree. This lessens over fitting and enhances generalisation ability. Output of each decision tree is combined to get the final forecast during prediction. The decision trees' majority vote is used for classification jobs while their average output is used for regression tasks [12-13].

In comparison to other machine learning methods, Random Forest has a number of advantages, including the capacity to handle big datasets with numerous characteristics, excellent accuracy, and resistance to over fitting. It is frequently employed in many different applications, such as fraud detection, picture classification, and recommendation systems. Random Forest is a strong and adaptable machine learning method that can produce precise predictions in a variety of applications. The basic procedure for any ML optimization is represented in Fig.5.

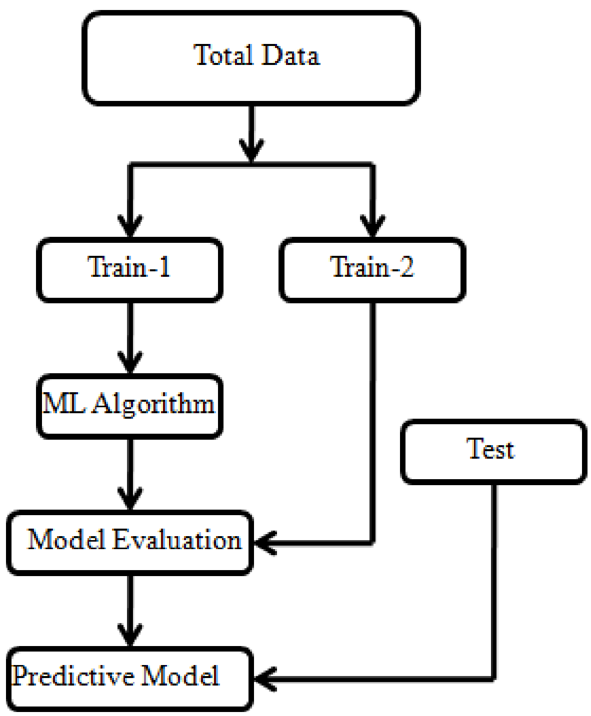

Fig.5 ML Optimization Procedure

$$Output\ Error(OE) = required - predicted \quad (6)$$

$$Mean\ square\ error = \frac{1}{N}\sum_{N=1}^{N}(OE)^2 \quad (7)$$

VI. Discussion of Results

The proposed antennas mentioned in Fig. 4 of 60 X 60 mm^2 size is designed and simulated in full wave electromagnetic solver High Frequency Structural Simulator (HFSS) with frequency sweep from (1-10) GHz. Presence of two truncated diagonal cuts are useful to obtain the multiband characteristics. The S_{11} of the designed antenna is shown in Fig.6, which clearly indicates antenna is radiating at three frequencies around 3.3 GHz, 5.2 GHz & 8.8 GHz with -25.74dB, -24.32db, & -21.55dB respectively. Corresponding VSWR at three bands are 0.89 dB, 1.32dB &3.2dB. The designed antenna with reasonable bandwidth characteristics has applications at 5G sub bands Wi-Fi applications. The antenna has the reasonable gain values of 3.5dB, 2.9dB & 6.8dB respectively at three bands of operation. The S_{11}, VSWR & Gain data points from the full wave simulator are represented in Fig.6, 7&8. And the performance characteristics are mentioned in table.2. Further various ML techniques to mitigate the EMI/EMC characters of the antenna and their performance parameters interims output error and standard deviations are in Eq.6 &7.

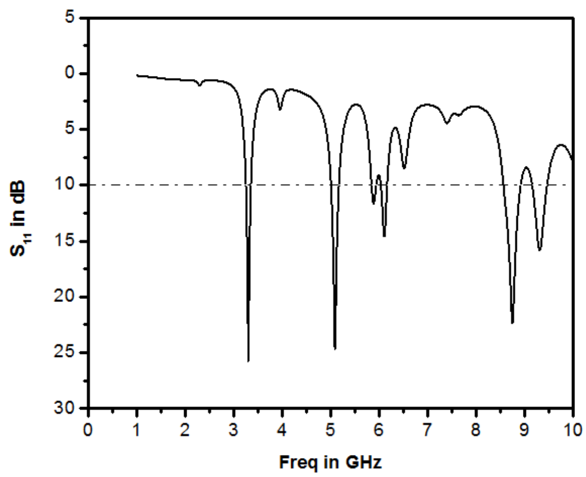

Fig.6 S_{11} of Antenna with truncated cuts

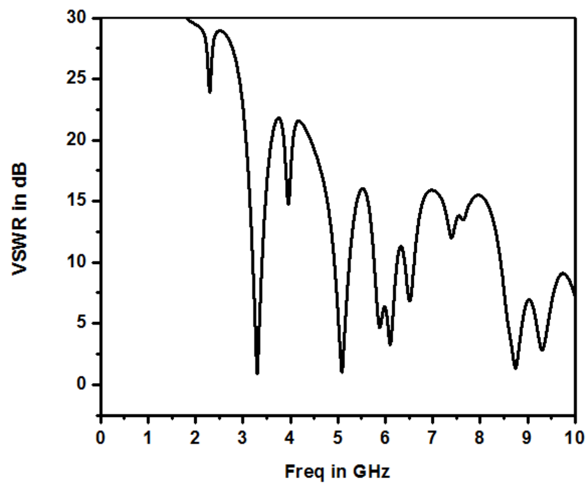

Fig.7 VSWR of Designed antenna.

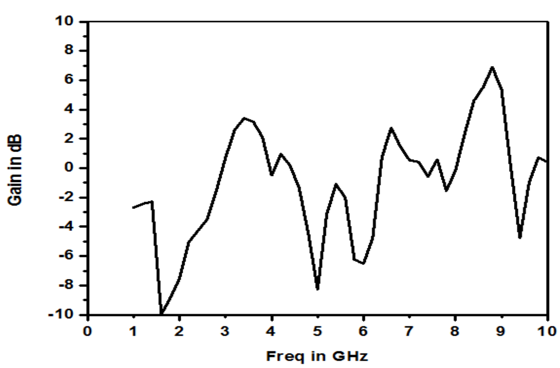

Fig.9 Gain of the antenna

S. No	Freq(GHz)	S11(dB)	VSWR(dB)	Gain(dB)
1	3.3	-25.74	0.89	3.5
2	5.2	-24.32	3.24	2.7
3	8.8	-21.55	1.32	6.8

Table.2 Antenna Performance Characteristics

VII. Conclusion

The Designed antenna with two diagonal truncated cuts is radiating at three bands with reasonable return loss, VSWR, gain and bandwidth which are suitable for multiband 5G applications like WLAN, RADAR altimeter etc. Application of machine learning techniques for the antenna design is need of the hour and which reduces the dependency on conventional electromagnetic simulators. The operation in unintended directions results EMI in terms of electromagnetic beam scattering, interference impedance mismatch, and poor channeling of the signal. Effective ML prediction model with low root mean square error and output error is needed. The introduction of more robust multi variable ML algorithms over large amount of data from Computational Electromagnetic simulators is essential for the antenna community to mitigate the EMI. The application of high end algorithms like random forest algorithm and obtaining of huge data records is suggested for the future scope of study for better EMC of the antenna to improve the efficiency.

References

[1] CA Balanis, “Antenna Theory: Analysis and Design”, John Willey & Sons, New York -1989.

[2] G. Garg, P. Bhartia, I. Bahl and A. Ittipiboon, “Microstrip Antenna Design Handbook,” Artech House, Canton, 2001.

[3] V A Sankar et al.., “A Study on Scilab Free and Open Source Programming for Antenna Array Design”, IEMTRONICS-2020.

[4] J. Zhang, X. Yang, and Y. Liu ,”Design and EMC analysis of a dual-polarized microstrip antenna for LTE applications" Radioengineering, 21(3)-875-880-2012.

[5] J. Chen, C. Liang, and K. Pan, “Radiation Efficiency and EMC of Antennas for Wireless Communication Systems" , IEEE Transactions on Electromagnetic Compatibility, vol. 56, no. 5, pp. 1125-1132, Oct. 2014.

[6] Umut Ozkaya & Leveny Sefyi, “ Dimensions Optimization of microstrip patch antenna in X/Ku band via Artificial Nueral Network.”, Procedia, Science direct, 2015, 195, 2520-2526.

[7] K Vasu babu et al, “Design and Dvelopment of Miniaturized MIMO antenna using Parasitic elements and ML Techniques for lower Sub 6GHz 5G Applications.”, Int. J.Electrinics.Comm-, 2022-154281.

[8] V A Sankar et al..,”Design of Elliptically Etched Circular And Elliptical Printed Antennas For Dual-Band 5G Mobile Applications”, Microstrip Antenna Design for Wireless Applications CRC PRESS-August-2021

[9] Hilal M. El Misilmani, Tarek Naous, and Salwa K. Al Khatib, “A review on the design and optimization of antennas using machine learning algorithms and techniques”, International Journal of RF and Microwave Computer-Aided Engineering · October 2020.

[10] Hilal El Misilmani & Tarek Naous “Machine Learning in Antenna Design: An Overview on Machine Learning Concept and Algorithms”, IEEE-HPCS July- 2019.

[11] Md. Samiul Islam Sagar et al.., “Application of Machine Learning in Electromagnetic:Mini-Review”, MDPI Electronics-2021.

[12] N Sheshu Kumar & U D Yalavarthi,”A Comprehensive Review on Machine Learning Based Optimization Algorithms for Antenna Design”, Journal of physics, ICACSE 2020.

[13] Christoph Maeurer et al.., “Antenna Design Exploration And Optimization Using Machine Learning”, IEEE-09-2020

[14] Ansys HFSS simulator v.22-2022.