Design and Performance Analysis of a 2*2 Microstrip Patch Array Antenna at 2.45Ghz Using Machine Learning

Mr. A. Srinag[1], M. V. Sangeetha[2], K. Lahari[3], M. Tirupthamma Bai[4], N. Sowmya[5]

Assistant Professor, Dept of Electronics and Communication Engineering, Vasireddy Venkatadri Institute ofTechnology, Andhra Pradesh, India[1]
UG Student, Dept of Electronics and Communication Engineering, Vasireddy Venkatadri Institute of Technology, Andhra Pradesh, India[2,3,4,5]

ABSTRACT

*This project is about developing a 2*2 rectangular microstrip patch array antenna and making a primary analysis of the antenna and introduces the machine learning (ML) technique in order to enhance the antenna performance. The parameters of the antenna, namely, gain and S11 play the key role during the testing process and must be analyzed with the highest degree of accuracy. It is the design process which aims carefully at getting the desirable features to exercise the advantages, being poured in microstrips patch array. The random Forest Algorithm, again the extension, gains in popularity and is used as the part of machine learning to make the design process much better. By the assist of Antenna simulators we got the result in which we have gain and S11 parameters together which is a needed train dataset for the ML model. User interface has been created by using streamlit framework providing user with GUI from that allows inputs of parameters specific to an antenna and return instant responses regarding gain and S11.Machie Learning models are checked accuracy and efficiency in various testing which are known to be in agreement with simulated result. The uses of automation and machine learning are about more than merely speeding up the analysis process, but may also prove valuable in suggesting areas that require improvements or optimizations for future antenna designs.*

Keywords: *Array, Machine Learning, Antenna, Random Forest, Streamlit.*

1. INTRODUCTION

There has been a lot of interest from researchers and the electronic sectors in fabricating antennas using a cost-effective additive manufacturing approach. Due to advancements in wireless and mobile communication, it has become necessary to create effective systems that can function well across a broad frequency range. Operating in the 2.4 – 2.5 GHz frequency range is recommended for wireless local area networks (WLANS).

An effective antenna with low return loss high bandwidth and small size is a common means of communication in this wireless domain 1 – 2 many efforts have been directed into the design and research of the microstrip patch antenna by this technological trend this antenna is well-liked due to its physical attributes which include light weight low profile comfort low manufacturing cost and ease of fabrication strip antennas are often utilized in arrays in addition to being used as single elements because of their great versatility microstrip antennas are used among other things to create needed patterns that are impossible to achieve with a single element such as scanning the beam of an antenna system and increasing gain and directivity.

2. RELATED WORK

The usage of a single element microstrip patch array antenna has already been around for a while. An antenna having a patch of radiation on one side of a dielectric substrate and a ground plane on the other is called a single element microstrip patch array antenna. Since these antennas are compatible with integrated circuit technology, they are commonly employed despite their small size, low profile, and simplicity of manufacture. Some of their drawbacks, meanwhile, are as follows: cross-polarization, power handling capacity, radiation productivity, radiation pattern, bandwidth, and integration difficulties.

The bandwidths of microstrip patch antennas are often smaller than those of other forms of antenna. Due to the resonance phenomenon connected to the dielectric substrate and patch geometry, this limitation occurs. Increased complexity and cost may result from techniques like adding slots, parasitic parts, or thicker substrates that aid in bandwidth improvement. When constructed on inexpensive substrates with large dielectric losses, microstrip patch antennas may have a poorer radiation efficiency than other types of antennas. Diminished radiation efficiency is caused by conductor losses in the patch structure and losses in the substrate material. With major lobes that might not be exactly symmetrical or have uniform gain in all directions, microstrip patch antennas frequently display less-than-ideal emission patterns. For applications that need precision beam shaping or steering capabilities, this non-ideal pattern could be a hindrance. At higher frequencies or when operating in close proximity to conductive surfaces, patch array antennas are susceptible to surface wave stimulation. In addition to decreased efficiency and higher cross-polarization, surface waves can cause distortion in the radiation pattern. Electrical fields produced in orthogonal polarization states are referred to as cross-polarization. In situations where polarization purity is required, like in satellite communication systems, patch antennas may show notable levels of cross-polarization, which can impair system performance. Because of its comparatively large size in comparison to integrated circuit components, microstrip patch antenna integration into small and highly packed RF systems might present special challenges. The complexity of the integration process and system downsizing may be impacted by this restriction, which may limit the arrangement and positioning of additional components on the same substrate.

Systems may learn through data as well as generate forecasts and conclusions despite having to be explicitly programmed owing to the use of machine learning algorithms. One of these methods was random forest, that comes within the collaborative learning family. Its dependability and also its efficacy provide an excellent alternative both regressive as also as categorization algorithms. The random forest technique is being applied across multiple sectors, such biological data technology, medical care, finance, marketing, and computer science for tasks namely choosing out attributes, regression analysis, and segmentation. With minor tweaks, it typically provides excellent outcomes, even though it is capable of handling vast volumes of information despite delivering judgements regarding attribute relevance, presenting it as an interesting alternative.

With the following study, we hope to overcome those constraints using improved design methodologies, innovative substances, and combination tactics. Through utilizing developments in machine learning algorithms and standardisation approaches, we expect getting superior outcomes in the efficiency study of 2*2 microstrip patch array antenna for diverse frequency bands, inclination and phasing. Eventually enhancing the reliability of the characteristics of the antenna that include the bandwidth and S parameters.

3. DATASET DESCRIPTION

For constructing machine learning prediction algorithms to forecast the probable outcomes of antenna parameters normally we must have an information set consisting of both gain and S-parameter observations in addition to essential attributes. With a machine learning predictive approach, the dataset should generally contain attributes, gain and S-parameters, the metadata. Characteristics were the source elements required to forecast gain and S-parameters. The goal characteristics which we anticipate comprise the gain and S-parameters, their result values are assessed throughout a variety of frequencies as well as under varied operational conditions. Such information might be acquired by simulations or real measurements in a monitored laboratory environment. And the metadata comprises the supplementary details regarding each data point, which includes the kind of antenna, measurement established calibration information etc. It might be beneficial for pre-processing and analysis. After the gathering of dataset, the information is beforehand processed subsequently recover significant traits, and training a machine learning model to estimate gain and S-parameters on the basis of the input characteristics. Famous machine learning methods like random forests are utilized for problems related to regression. While estimating gain (DB) parameter data of frequencies [GHz], inclination (Theta [DEG]), phases (Phi [DEG]) are necessary, to foresee S-parameter information of frequencies [GHZ] is needed. For constructing this mathematical framework roughly 400 values have been incorporated in the dataset of gain and S parameters.

	A	B
1	Freq [GHz	dB(S(1,1)) []
2	1	-0.065691527
3	1.01	-0.065885822
4	1.02	-0.066113286
5	1.03	-0.066373177
6	1.04	-0.066664801
7	1.05	-0.066987509
8	1.06	-0.067340695
9	1.07	-0.067723796
10	1.08	-0.068136289
11	1.09	-0.06857769
12	1.1	-0.069047553
13	1.11	-0.06954547
14	1.12	-0.070071066
15	1.13	-0.070624005
16	1.14	-0.071203982
17	1.15	-0.071810728
18	1.16	-0.072444006
19	1.17	-0.07310361
20	1.18	-0.073789368
21	1.19	-0.07450114
22	1.2	-0.075238816
23	1.21	-0.076002319
24	1.22	-0.076791602
25	1.23	-0.07760665
26	1.24	-0.078447479
27	1.25	-0.079314138
28	1.26	-0.080206706
29	1.27	-0.081125295
30	1.28	-0.08207005
31	1.29	-0.08304115
32	1.3	-0.084038807
33	1.31	-0.085063267

S Parameter Plot

a) S-parameter

	A	B	C	D
1	Freq [GHz]	Phi [deg]	Theta [deg]	dB(GainTotal) []
2	2.45	-180	-180	-25.61058929
3	2.45	-180	-178	-24.80228091
4	2.45	-180	-176	-22.9537628
5	2.45	-180	-174	-20.98619249
6	2.45	-180	-172	-19.23037633
7	2.45	-180	-170	-17.72960931
8	2.45	-180	-168	-16.45517395
9	2.45	-180	-166	-15.36945557
10	2.45	-180	-164	-14.43989803
11	2.45	-180	-162	-13.64061499
12	2.45	-180	-160	-12.95134631
13	2.45	-180	-158	-12.35613034
14	2.45	-180	-156	-11.84220041
15	2.45	-180	-154	-11.39915368
16	2.45	-180	-152	-11.0183424
17	2.45	-180	-150	-10.69242947
18	2.45	-180	-148	-10.4150621
19	2.45	-180	-146	-10.18063005
20	2.45	-180	-144	-9.984085242
21	2.45	-180	-142	-9.820806399
22	2.45	-180	-140	-9.686497981
23	2.45	-180	-138	-9.577115691
24	2.45	-180	-136	-9.488813505
25	2.45	-180	-134	-9.417908664
26	2.45	-180	-132	-9.360862083
27	2.45	-180	-130	-9.314272228
28	2.45	-180	-128	-9.274880675
29	2.45	-180	-126	-9.23958755
30	2.45	-180	-124	-9.20547474

Gain Plot 2

b) Gain-parameter

***Fig 1**: Dataset of gain and S parameters*

4. PROPOSED METHODOLOGY

Using the design which we had imagined we constructed microstrip 2*2 patch array antenna in HFSS (high frequency structure simulator. We open up fresh possibilities like gain booster, beam steering control, directivity, beam shaping, polarizing inclusion, spatial multiplexing. Utilizing machine learning models for forecasting we may acquire antenna parameters like gain, and S parameters without heading for the simulation each time

In the proposed array of antenna we will have access to electronic management of phase shifts in the array enables us to “steer” the signal beam despite having to move the antenna, focusing on certain directions. The cohesive combining commands coming from every component significantly boosts overall gain, guiding greater power in the direction we want, and directivity that is a measurement of how effectively an antenna is focused radiation within a certain direction tends to be greater in a 2*2 patch array antenna. This happens owing to the capacity to modify the radiation pattern through altering the phase and amplitude of the signals entering every patch element, the array’s structure offers extra freedom in tailoring the radiation pattern. With altering the corresponding amplitude and phase of the signals sent to every patch element the beam shape may be customized to satisfy certain goals including eliminating side lobes or obtaining a greater coverage area, a 2*2 patch array antenna may enable polarisation diversity in which every component is able to be supplied with signals of various polarizations. This offers improved efficiency in contexts in which signal polarisation can fluctuate or when several polarizations are necessary to communications. The numerous components of the array may be employed for spatial multiplexing that provides more data throughput and enhanced connection dependability by harnessing geographical variety.

With the help of HFSS, an antenna design for a microstrip 2*2 patch array is created. It is a form of design that is included in AEDT. With a wide range of uses, HFSS provides a number of solutions. It offers a broad range of analyses to aid in the comprehension of electromagnetism principles, including 2D rectangle plots and 3D field plots within complicated geometries. HFSS provides a number of cutting –edge solution techniques that are built on the tried-and-true finite elements technique. We many choose the optimal solution for each problem as well as, in several cases, get better results when you use numerous solutions in a connected application.

Building a machine learning prediction model that accurately forecast antenna properties at various frequencies, angles, as well as phases was the next step for this the projects expansion. The gain and S parameters, which are antenna parameters, may be accurately predicted with the aid of this prediction model. A number of library resources, including thonny, visual studio, numpy, pandas, and joblib were employed in the development for this framework.

Among its limited uses involves planning optimizing, which the ML model might do by allowing users to investigate different antenna configurations. By entering alternative combinations of design variables through the framework, we can easily anticipate their associated S and gain values. This data could assist you find optimum design combinations which satisfy their targeted performance objectives. It may possibly lessen the dependence upon lengthy simulations for design exploration, enabling to have a quicker method of design. Performance prediction – if you have developed a good ML model, then may employ it to forecast the gain and S parameters of newly developed antenna designs without performing simulations for every iteration. This may be very handy while encountering substantial parameter fluctuations. Quick design cycles – investigate design choices and discover optimum configurations utilizing the ML model, eliminating dependency on simulations. Improving efficiency – acquire insights into the correlations among design parameters as well as performance measures, resulting in better antenna design.

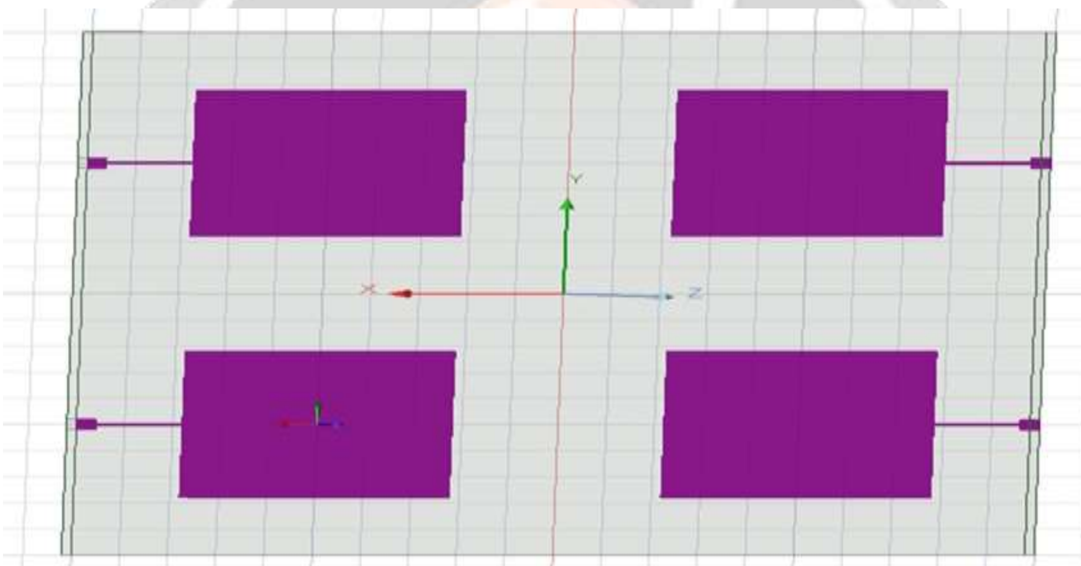


***Fig 2**: Design of 2*2 microstrip patch array antenna in HFSS*

5. METHODOLOGY

Designing the 2*2 microstrip patch array antenna in HFSS

- **Define Specifications:**

  Evaluate the characteristics associated with your antenna, considering operation frequency, gain parameters, polarization, beamwidth, etc.

- **Geometry Setup:**

  In the study of geometry setting up, the initial step was building the substrate – defining a substrate made of dielectric substance along with its measurements, subsequently design patch elements- design the microstrip patches and feedlines in accordance with your intended requirements, immediately following is scheduled patches- layout the 2*2 array configuration using the correct spacing and measurements, then add the plane of ground underneath each patch.

- **Feed Network Design:**

Construct a feeding system with the array to attain the appropriate radiation parameters. Select the feeding approach (corporate feed, serial feed, etc.) depending upon the required performance.

- **Simulation Setup:**

In simulation configuration initially it's necessary to specify the simulation frequencies ranges. After that, define the boundary conditions of use, mesh parameters and solvers choices. Following putting out the radiation boundaries as well as sources of excitation to create the array.

- **Verification:**

During validation, compare the simulation findings against mathematical computations or observations where applicable. Verify that the antenna fits the necessary specifications.

Developing Machine Learning Prediction Model

- **Dataset Collection:**

Obtain information gathered from HFSS simulations or observations for different configurations with the 2*2 microstrip patch array antenna. Includes factors including patch size, substrate qualities, operation frequency, feedline design and array shape.

- **Feature Engineering:**

Obtain key characteristics using the dataset that may properly reflect the antennas characterisation. Normalize or scale the characteristics as required to achieve consistency.

- **Target Variables:**

Specify the desired variables to forecast employing the machine learning model. This might contain factors as gain, radiation pattern, impedance matching etc.

- **Model Selection, Training and Evaluation:**

Select suitable machine learning algorithms with regression workloads, like regression, decision trees, random forests, or neural networks. Separate the dataset into training and testing sets. Train the model on the training dataset then tweak hyper parameter values as appropriate. Validate the training models efficiency utilizing measures includes mean squared error (MSE), root mean squared error (RMSE), R- squared, etc., employing the testing dataset. Evaluate the model's predictions using HFSS simulations or observations to verify its correctness.

- **Model Deployement:**

Having satisfied with the models performance, deploy it to forecast the antenna's performance for modifications or design factors. Incorporate the model within the process of design to aid in quick prototyping and optimisation.

6. OUTPUT AND RESULTS:

The gain analysis displays the highest gain attained from the antenna, often in the direction of greatest radiation. Radiation patterns demonstrate the geographic distribution of gain, revealing beamwidth and sidelobe levels. S-parameter plots indicate the antenna's matching of impedance and reflection properties, enabling effective power transmission among the antenna and the feeding network. Evaluations comparing simulated and theorized outcomes are done to assess the correctness of the design and simulation process. A sensitivity evaluation might be done to analyze the influence of modifications in design parameters on gain and S- parameters. A sensitivity evaluation might be done to analyze the influence of modifications in design parameters on gain and S- parameters. The trained ML model displays good results in predicting antenna characteristics like gain and S-parameters. Metrics for evaluation reveal great accuracy and correlation among the projected and actual outcomes. Visualization methods that involve scatter plots or regression plots might be utilized to emphasize the level of agreement with expected and actual outcomes. The accuracy of the model is tested against baseline techniques or conventional methods of analysis to measure its efficacy.

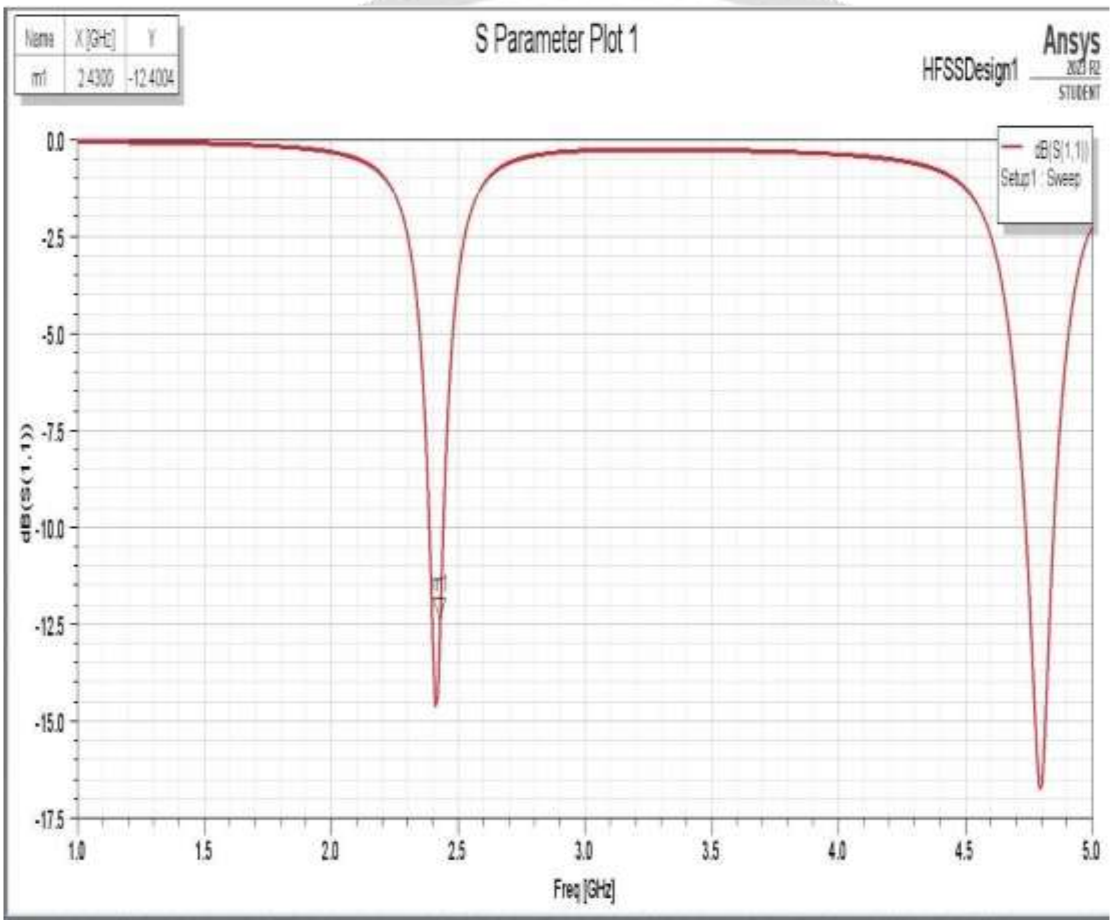


***Fig 3**: S parameter plot in HFSS*

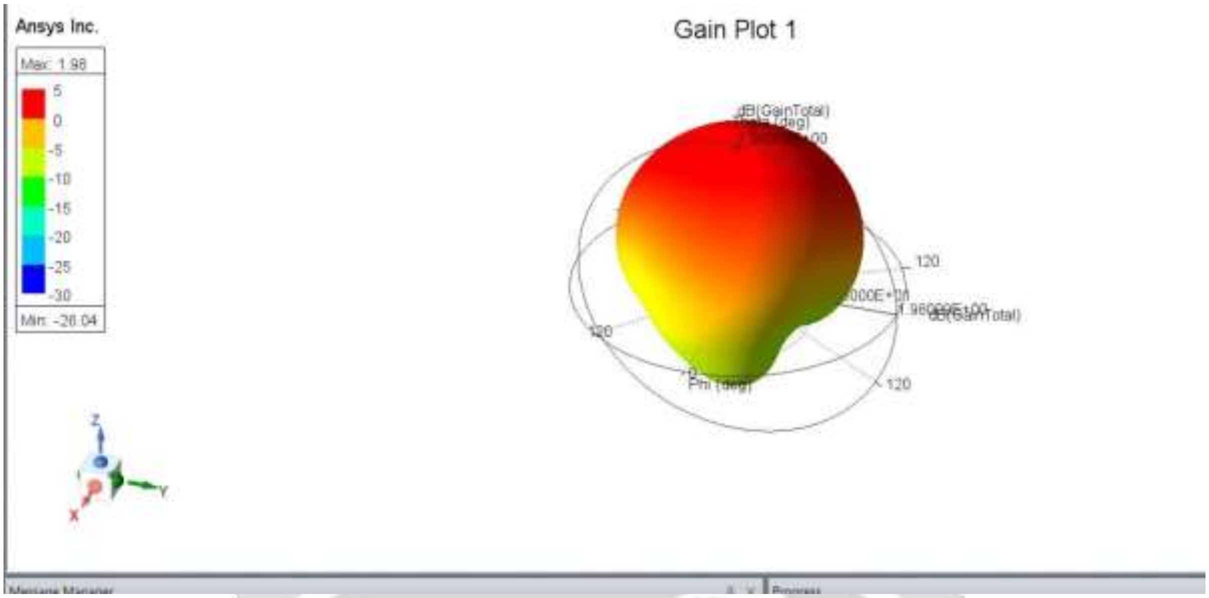
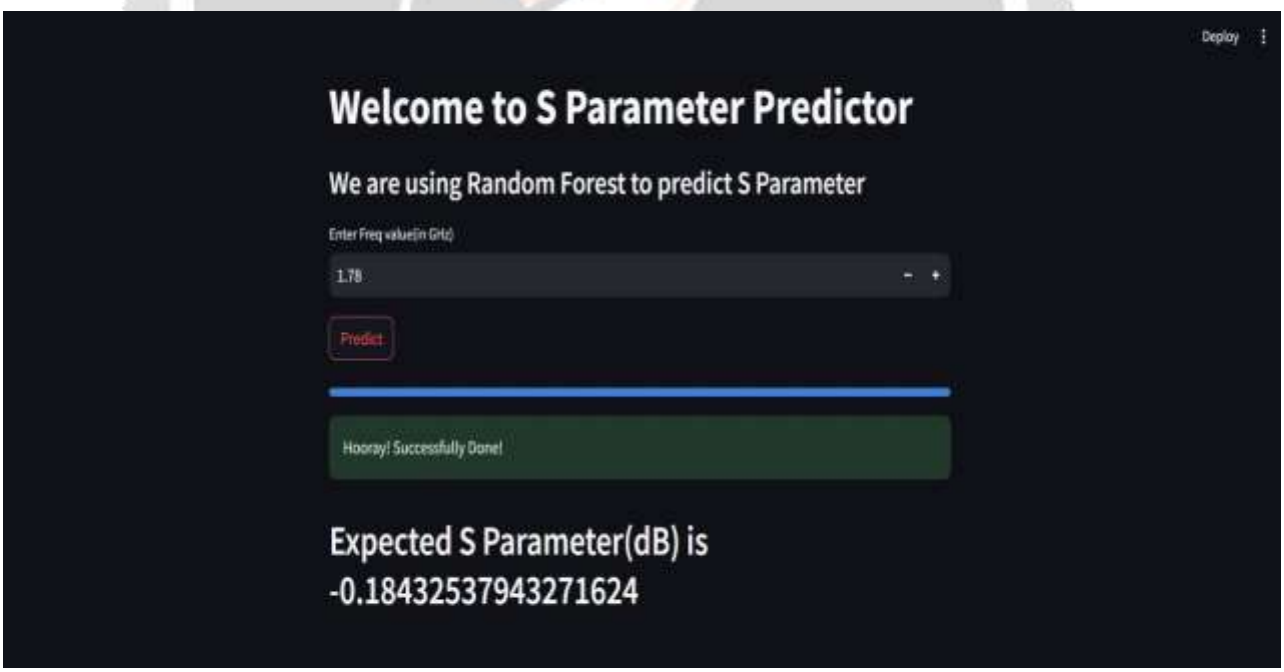


***Fig 4**: Gain parameter plot in HFSS*



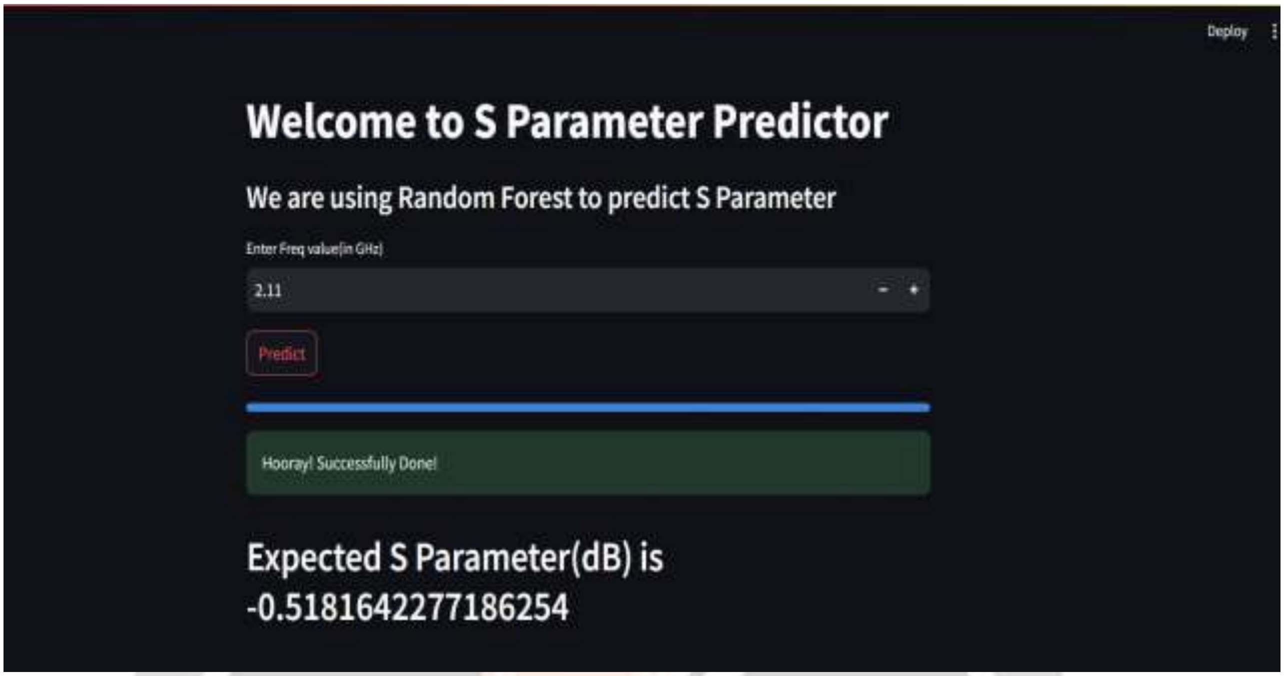
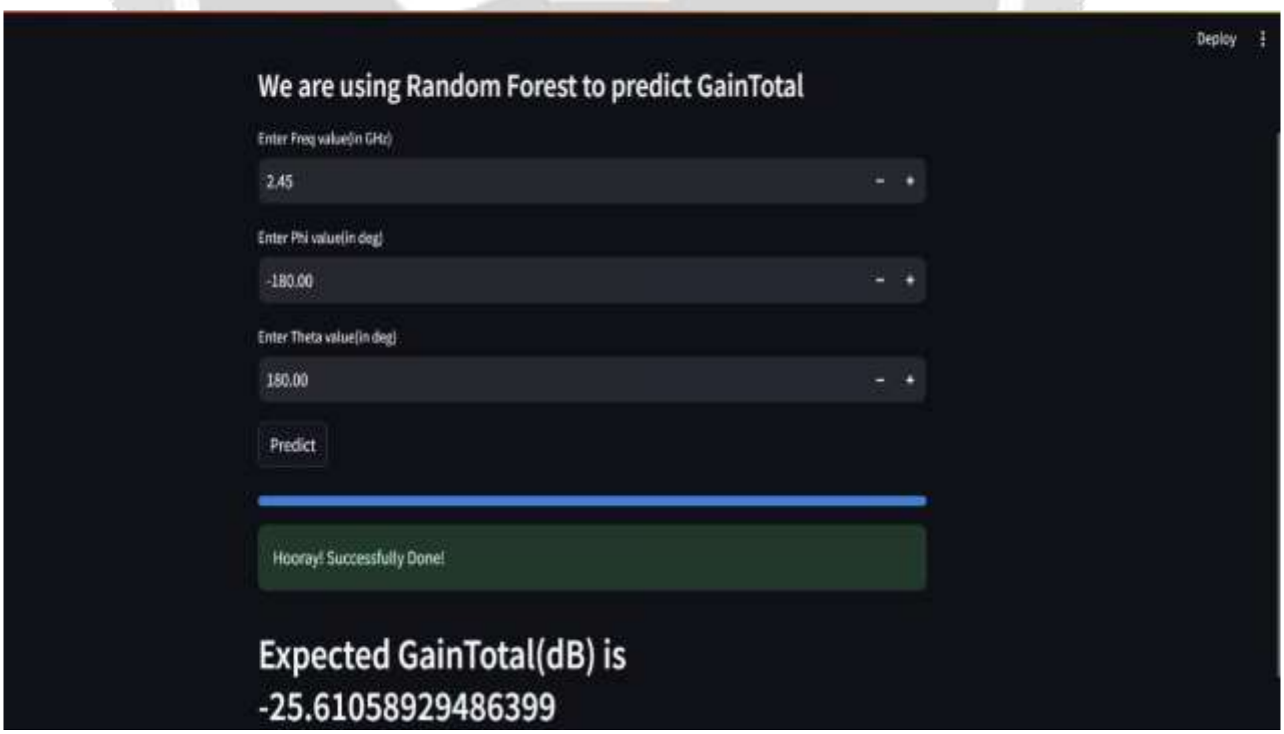


__Fig 5__: S parameter predictor using machine learning



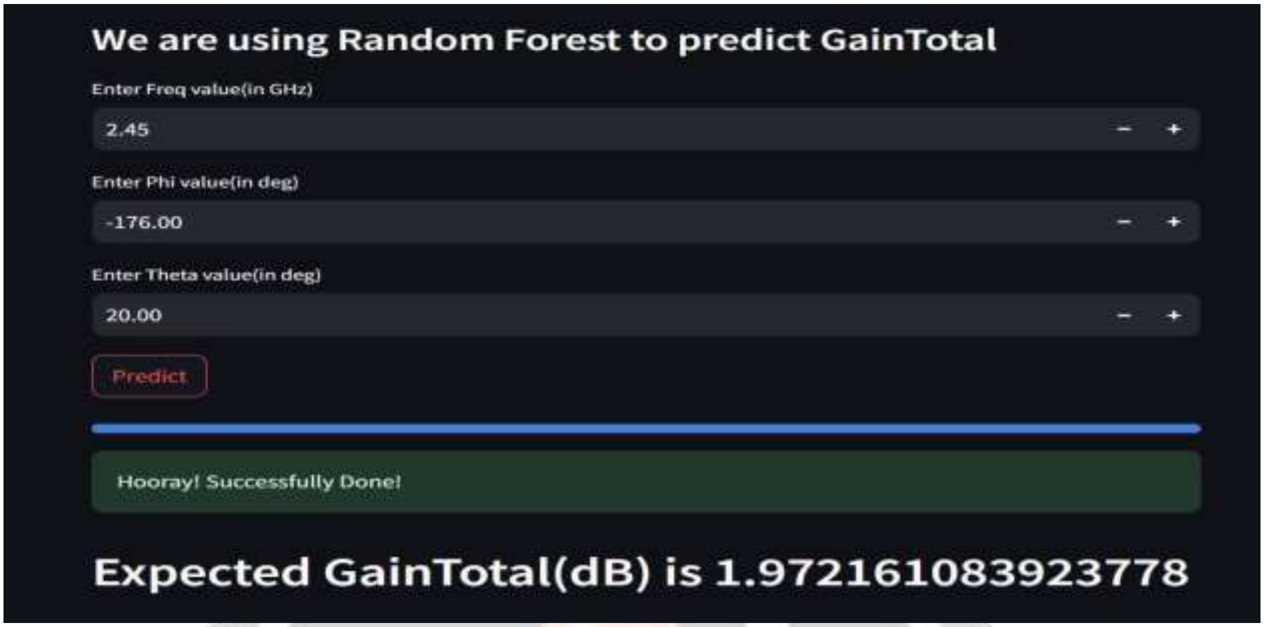


***Fig 6**: Gain parameter predictor using machine learning*

7. CONCLUSION

Finally, in this project the gain analysis shows the antenna's capacity to emit electromagnetic energy effectively in the intended directions. S-parameter analysis guarantees optimal impedance matching and the transmission of signals features, critical for system efficiency. Paired with the machine learning prediction model, precise forecasts of gain and S-parameters may be produced, supporting quick prototyping and optimizing the design. The ML prediction model precisely represents the intricate interactions among antenna characteristics and design variants. It offers a helpful tool for antenna designers to swiftly assess and improve antenna designs according to desired performance criteria. Further study might concentrate on strengthening the model's accuracy, scalability, and applicability to real- world datasets.

8. REFERENCES

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