Design of 2.4GHz Low-Profile MIMO Antenna for IOT Applications

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ABSTRACT

In this work a systematic approach for design of 2.4GHz Low-profile MIMO antenna for IoT Applications. The antenna is designed by1.6mm thick FR-4 substrate using HFSS (High Frequency simulation structure) Software. The designed antenna consist of two rectangular microstrip elements and each element dimensions maintained as 27.5x38mm^2 and overall antenna layout maintained at 70x70mm^2 respectively. The designed antenna resonated at 2.4GHz with return loss of -38dB. The antenna parameters such as total peak, gain, bandwidth, and radiation, pattern performances, VSWR, are verified. The designed MIMO antenna results show that it is well suitable for IoT Applications.

Keywords—MIMO Antenna, IOT, Bandwidth, Data Rate

I. INTRODUCTION

The present scenario wireless world relies upon high data rate transmission all over the place. Even after the COVID-19 pandemic situation internet usage become 100% double then previous years because most of the sectors such as corporate sectors, industries, educational organizations, and government institutions, depends on the internet to carry their work smoothly from home. When all digital devices comes across the internet of things, then bandwidth and data rate issues are became to support customers' needs[1-2]. To overcome these issues by adding multiple antennas to MIMO system array configurations are the emerging mechanisms [3-5]. Hence this paper is coordinated as follows; the 2nd section presents the design of MIMO antenna for IOT applications and the results and their discussions are introduced in the 3rd section followed by a conclusion in the 4th section.

II. MIMO ANTENNA DESIGN METHODOLOGY

A. Design of Microstrip Patch Antenna

The Antenna being worked with here is a microstrip rectangular patch antenna using 1.6mm thicker FR-4 substrate material, which lay between microstrip rectangular patch antenna and ground plane. Microstrip feed line is used as an input port which is travelled through Fr-4 substrate material.
The design procedure entails 3 major steps:

- Calculation of dimensions of antenna for the required resonating frequency.
- Simulate the above dimensions using EM simulator such HFSS simulator.
- Continue the parametric study using EM simulator until get the desired results.

The dimensions required include the length, height and width of the substrate, the ground plane and the Patch. The material being considered is FR4 Epoxy whose Dielectric Constant (ε_r) is 4.4, height of the substrate 'h' is 1.6mm and the speed of light c is 3x10^8 are considered. The antenna is being designed to work at 2.4GHz frequency, hence the Resonance Frequency f_0= 2.4GHz. These parameters are substituted in the following formulae [6] to find the antenna dimensions.

$$\text{Patch Width } W_p = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}}$$

$$\text{Patch Length } L_p = \frac{c}{2f_0\sqrt{\varepsilon_r}} - 2\Delta l$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\sqrt{1 - 12\frac{h}{w}}$$

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}}$$

$$\Delta L = 0.412h\frac{(\varepsilon_{eff} + 0.3)(\frac{w}{h} + 0.264)}{(\varepsilon_{eff} - 0.258)(\frac{w}{h} + 0.8)}$$

$$L = L_{eff} - 2\Delta L$$

$$\text{Length of Ground plane } L_g = 6h + L$$

$$\text{Width of Ground plane } W_g = 6h + W$$

The required antenna dimensions are calculated with the formulas given above. However, when simulated in the High-Frequency Structure Simulator (HFSS) with the ideal dimensions, it is observed that the antenna is not perfectly resonating at 2.4GHz; often there are high chances that the external noises and errors are overlooked. So even with the readily available formulas, one has to go through small parametric trials and errors with the values on either side. Those parameters made the antenna to resonate exactly at 2.4GHz. From the above procedure initially designed the single element rectangular microstrip patch antenna (SERMPA) at 2.4GHz, with their dimensions shown in Table.1 and their antenna structure shown in Fig.1 respectively.

Table 1: Dimensions of SERMPA

Parameters	Lp	Wp	L	W	FR-4
Dimensions (*mm*)	27.5	38	70	70	4.4
Parameters	1	2	3	4	h
Dimensions *(mm)*	10	0.5	2.8	32	1.6

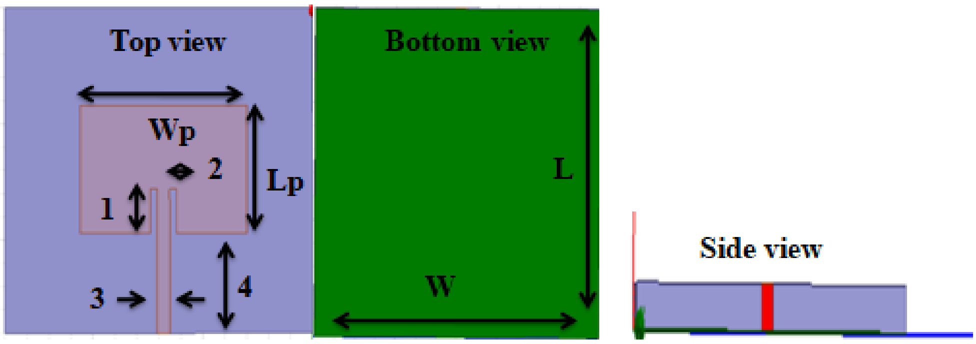

Fig -1: Geometry of SERMPA

B. **Two Element MIMO Microstrip Patch Antenna**

After the realization of the SERMPA, the duplication feature of the HFSS software helps in creating a 2 Element MIMO microstrip antenna. The structure of 2 element MIMO microstrip antenna consists of two identical SERMPA with the separation of $\lambda/4$ (where λ is the free space wavelength) to avoid poor diversity and it is named as proposed two element rectangular MIMO microstrip antenna (PTERMMA) with their antenna structure shown in Fig.2 respectively.

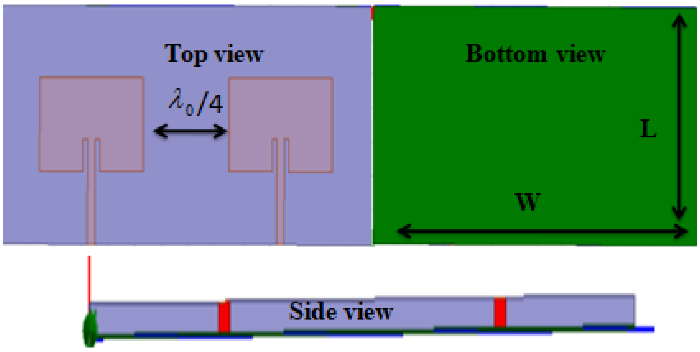

Fig -2: Geometry of PTERMMA

III. RESULTS AND DISCUSSIONS

The return loss (RL) characteristics of single element rectangular microstrip patch antenna (SERMPA) are shown in Fig.3. The antenna gives resonance at 2.4GHz with a return loss of -36.09dB. By marking with a marker at return loss graph at -10dB then mark as m_1= 2.14GHz and m_2=2.513GHz with the subtraction of m_2-m_1 with that bandwidth of 373MHz is obtained.

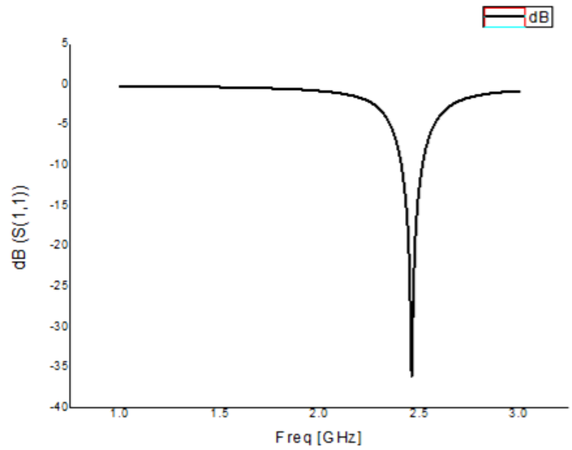

Fig -3: RL characteristics of SERMPA

Similarly, the return loss (RL) characteristics of the proposed two element rectangular MIMO microstrip antenna (PTERMMA) are shown in Fig.4. The antenna gives resonance at 2.4GHz with a return loss of -31.59dB and bandwidth of 373MHz simultaneously.

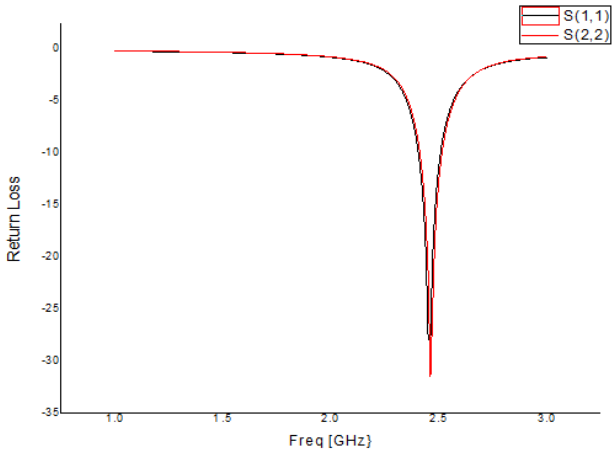

Fig -4: RL characteristics of PTERMMA

The 3D polar plot tells about the gain characteristics of the antennas. Hence gain parameter can define the link budget and area of coverage. The SERMPA gives a peak gain of 4.16dB and PTERMMA gives a peak gain of 4.53dB. 3D polar plots of SERMPA and PTERMMA are shown in Fig.5 and Fig.6 respectively.

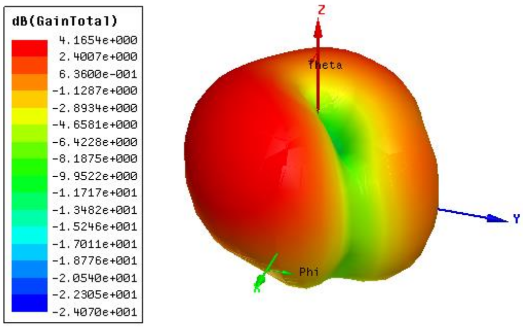

Fig -5: 3D Polar Plot characteristics of SERMPA

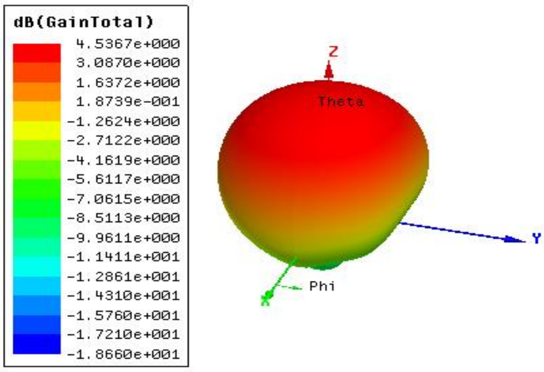

Fig -6: 3D Polar Plot characteristics of PTERMMA

The data rate of the system mainly depends on the channel capacity [7-9]. As per a single antenna transceiver system shown in Fig.7, we can use the Shannon equation to find the data rate of SERMPA as shown below. Here we consider the SERMPA bandwidth as 373MHz and signal to noise ratio is 32dB so that it gives 10.37Gb/s/Hz.

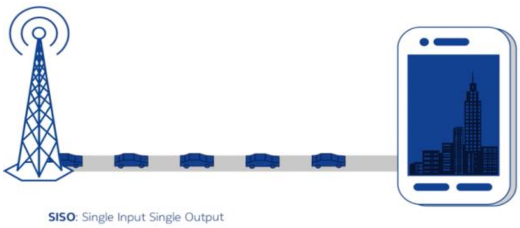

Fig -7: Single antenna transceiver system

$$C = Blog_2(1 + \frac{S}{N})$$
$$= 373x10^6 log_2(1 + 32)$$
$$= 1881.5 Mb/s/Hz$$

The MIMO system takes the advantage of multipath propagation effect, and considering the multi-antenna transceiver system shown in Fig.8, can give high data rate than the basic Shannon equation by without increasing bandwidth and SNR. Hence PTERMMA data rate can be found by using a modified Shannon equation as shown below. Here we consider the PTERMMA bandwidth as 373MHz and signal to noise ratio is 32dB so that it gives 21.36Gb/s/Hz. Hence it proved that the MIMO system supports a higher data rate than any other system by increasing multiple antenna rather than increasing bandwidth and SNR.

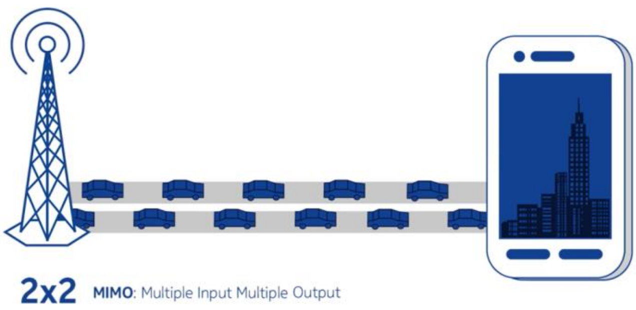

Fig -8: Multiple antenna transceiver system

$$C = Blog_2(\det\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix} + 32\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix})$$

$$= 373\ X10^6 log_2(\det[\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix} + 32\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix} X \begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}])$$

$$=373\ X10^6 log_2(1089) =3763.11 \text{Mb/S/Hz}$$

The VSWR tells about the voltage standing wave ratio characteristics of the antennas. Hence VSW parameter can define the effective power transmission from the power source to the radiating element. The SERMPA gives a VSWR of 0.4 and PTERMMA gives a VSWR of 0.2, are shown in Fig.9 and Fig.10 respectively.

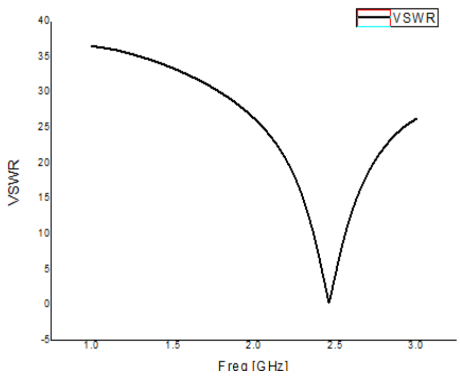

Fig -9: VSWR Plot characteristics of SERMPA

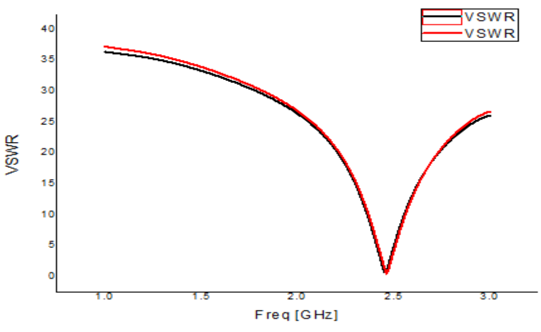

Fig -10: VSWR Plot characteristics of PTERMMA

The radiation pattern shows the distribution of radio waves. Both SERMPA and PTERMMA patterns are shown in Fig.11 and Fig.12 respectively

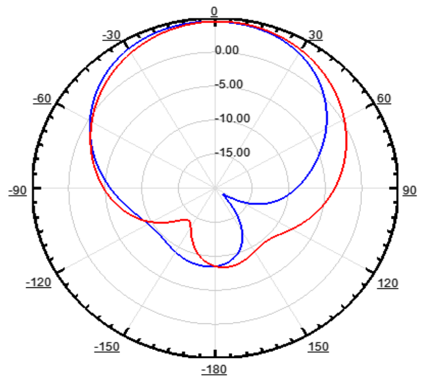

Fig –11: Radiation Pattern of SERMPA

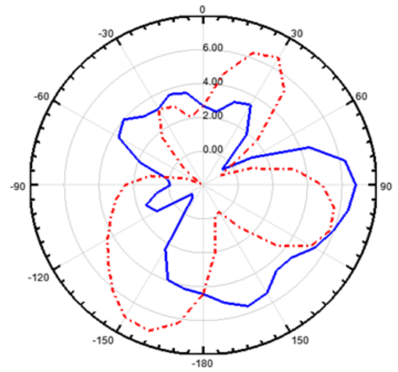

Fig –12: Radiation Pattern of PTERMMA

The results of both SERMPA and PTERMMA are recorded in Table.2 to analyze the outputs and the impact of MIMO on the Data Rate.

Table 2: Summarized results of SERMPA and PTERMMA

Parameters	SERMPA	PTERMMA
Resonant Frequency GHz	2.4GHz	2.4GHz
Bandwidth	373MHz	373MHz
Return Loss	-36.09dB	-31.59dB
Gain	4.16dB	4.53dB
Data Rate	1881.5Mb/s/Hz	3763.11Mb/s/Hz
VSWR	0.4	0.2

IV. CONCLUSION

This work presented the single element rectangular microstrip patch antenna (SERMPA) and proposed two element rectangular MIMO microstrip antennas (PTERMMA) respectively using FR-4 substrate and both antenna resonated at 2.4GHz. The PTERMMA has a decent scope and provides satisfying results such as wide bandwidth, gain, high data rate and VSWR as compared to SERMPA such that PTERMMA is well acceptable to the IOT applications.

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