Performance Enhancement of Rectangular Microstrip Antenna with Different Substrate Materials.

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Abstract*: Above 1GHz , Microstrip antenna is extensively used in Wireless communication. The demand of increased wireless communication applications, needs increase in bandwidth, gain and efficiency of microostrip antenna. Microstrip antenna is a low profile antenna but has narrow bandwidth, low gain and efficiency. In this paper amicrostrip antenna is designed with dimensional change technique to improve bandwidth, gain and efficiency. The enhanced performance of proposed design with different dielectric materials designed and are compared with reference Microstrip antenna. A bandwidth enhancement of 230MHz and gain enhancement of 8.4dB are achieved with proposed antenna.

***Keywords* : Bandwidth, Gain, HFSS , VSWR , Wireless communication**

I. INTRODUCTION

COMMUNICATION Engineering Is A Most Rapidly Growing Branch Of Electronics Engineering. Communication Is The Most Basic Need For Progress Of Current Generation Civilization. Antenna Is A Basic Need In Wireless Communication. Above One Ghz Frequency, Wireless Communication, The Microstrip Antenna Is Widely Used.

Microstrip antenna is designed using a dielectric material and two layers of conductors, one on top side and another on bottom side of dielectric material called substrate. The conductive top layer of suitable shape is called patch. The larger area bottom conductive layer is called ground. The different types of patches are rectangular, square, circular and other shapes.[1]

Microstrip antenna has many advantages such as low profile,simple fabrication method, simple to interfacing of ICs.The working of Microstrip antenna can be explained by various methods like Transmission line model and Cavity models[2]. It is used in aircraft, mobile, medical and applications of satellite. The disadvantages of Microstrip Patch Antenna (MPA) are less bandwidth and less gain. Different research groups are working on these issues. The bandwidth enhancement techniques are DGS, Dimensional change, use of different substrates etc.[3]-[16].

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The gain enhancement of MPA is described here. The gain of MPA can be improved by use of negative permeability metamaterial on low temperature co-fired ceramic (LTCC) substrate is described. WLAN Antenna of 5.2GHz [17] is designed with Split Ring Resonator (SRR) and gain improvement of 1.5dB than the conventional antenna is described by authors.

Gain enhancement of MPA using hybrid substrate[18] is described. MPA is designed using substrate with Ferrite ring is described by authors. An antenna with 5-5.6GHz is designed and an enhancement of 4dB gain is achieved by this method. Rectangular microstrip patch antenna Gain and Bandwidth improvement using slot[19] is explained by author. The antenna resonating frequency of 2.5GHz is designed. The gain improvement of 2dBi is achieved by loaded slot using IE3D software. A wideband loop and uni-directional antenna by loading of periodic meta-material[20] is explained by author. Gain improvement by loading meta-material in Loop Antenna with directors of arc shape, are tightly coupled. The antenna is designed with frequency of 0.7 1.07 GHz. A gain of 4.5dBi is achieved.

A superstate single dielectric AR bandwidth and gain improvement of patch antenna is explained by authors for a 11GHz.A superstate loaded with a single dielectric, a single-feed CP patch antenna for a high gain wide band cp radiation [21]. In superstate design prototype compared to conventional design an improvement in 3dB AR bandwidth of 350% is obtained. Also a 7dB in the broadside gain were obtained. A microstrip antenna gain improvement using superstate of cylindrical Shell [22] shape is explained. A microstrip patch antenna gain enhancement by technique of phase compensation is 3.1dB. The resonating frequency is 5.5-5.6GHz and simulated using CST microwave studio for gain enhancement of 48%.Gain improvement of MPA with Ferrite Rings[23] is described.Ferrite ring is used to suppress propagation of Electromagnetic waves. This increases the maximum of gain of MPA placed above EBG layer. The maximum gain of 10.9dB and Average gain of 9.28dB as compared to conventional method maximum gain of 6.37dB and average gain of 4.4dB in 5.5GHz to 6GHz frequency.

Gain enhancement of square microstrip antenna with hybrid substrate[24] is explained. A 5.8GHz antenna with conventional substrate of Rogers TMM4 gain and hybrid substrate Rogers TMM4 with ferrite ring are compared. An increase of 2.3 dBi in directivity is achieved.

Gain enhancement of square microstrip antenna with U slot with metallic ring is described in [25]. A 5.8GHz antenna with U slot with & without metal ring are designed and performance in terms of gain are compared. Gain enhancement of 4dB is achieved in the frequency range of 5.5 to 6 GHz. Gain enhancement of MPA for Wi-Fi applications[26] is described. A gain enhancement of 4.13dBi is achieved using Mushroom like Electromagnetic band gap EBG structure. A circular patch antenna gain and Bandwidth enhancement with air as dielectric substrate[27] is briefed . The MPA is fed gain and hybrid substrate Rogers TMM4 with ferrite ring are explained.

A circular patch antenna gain and Bandwidth enhancement with air as dielectric substrate[27] is briefed . The MPA is fed from line between two dielectric substrates by an air. The gain improvement 2.39dB and bandwidth improvement of 1.35% more compared to a conventional circular patch antenna using MOM with FEIKO software. Gain enhancement of MPA using modified U slot antenna[28] is described. A dual band 2.45 to 2.47 GHz and 5.1 to 5.4 GHz modified U slot antenna is designed to achieve peak gain of 6.15dB at 2.45 to 2.57 GHz and 9.1dB at 5.27GHz. The Rogers RT / duroid 5880 dielectric substrate is used which cost more than FR-4 material. Gain improvement of MPA using Near zero index metamaterial lens[29] is explained. For WLAN band antenna broadside gain is improved by using metamaterial unit cell as a superstate. The gain improved by 2 dBi. MPA Gain enhancement by using multiple layer of substrate[30] is explained. A peak gain improvement of 6.5dBi is achieved for an antenna of 6.5GHz resonating frequency. MPA array gain enhancement is described using metallic ring for WLAN / Wi-Fi applications .Rogers Ro 4003 substrate is used. An improvement of 3.1 dB gain is achieved.

Compared to these methods the proposed method is simple, low cost and gives better results. A rectangular microstrip patch antenna (RMPA) is designed with different substrate maaterials. The performance of the RMPA is simulated. The antenna with dimensional change of different substrate materials is designed and simulated using HFSS. The bandwidth and other performance parameters are simulated and compared with that of reference antenna. The organisation of this paper is as given here. Introduction and literature study are described in section I . Section II gives Design, feeding of RMPA and proposed different substrate antenna design. Section III describes modelling and simulation of RMPA and Multiple layer substrate RMPA using HFSS and simulation results. Section IV gives brief comparison of reference RMPA and Enhanced technique of different substrate RMPA and discussion of results. Section V describes conclusion & future scope. Section VI gives acknowledgements

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II. MATHEMATICAL MODEL DESIGN OF PROPOSED ANTENNA

Rectangular microstrip patch MPA configuration is most widely used. The mathematical model of RMPA can be explained using models of Transmission Line and Cavity [2].

A. *Mathematical Model based on Transmission Line*

Transmission line modelling is most accurate for thin dielectric substrates. Fundamentally Transmission model represents the RMPA by two slots, separated by low impedance Zc transmission line having length of L. Mathematical model of RMPA using Transmission model is described here. In this analysis the resonating frequency Fr, Substrate dielectric material dielectric constant and dielectric material thickness or height h of dielectric substrate material are known .The design parameters W - RMPA Width and L Length are calculated.

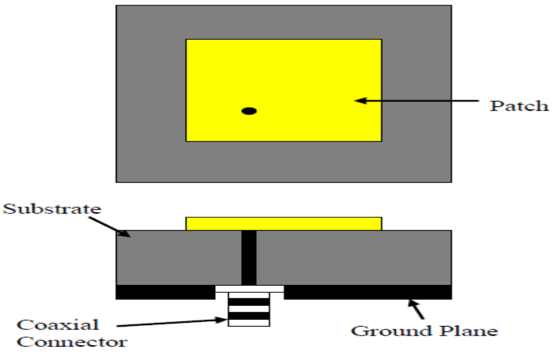

Fig. 1. Probe Feed MPA structure

The RMPA Width W and Length L are is calculated as given in by the equations [2],[3]. After calculations, the dimensions of rectangular microstrip patch antenna (RMPA) with different dielectric material are as given in the Table1.

TABLE I
RMSA DIMENSION WITH DIFFERENT DIELECTRIC MATERIALS

Sl No	Material	Width (mm)	Length (mm)	Dielectric Constant
1	Silicon	15.85	11.38	11.9
2	Glass	22	16.2	5.5
3	FR-4	22.4	16.4	4.4
4	Hard Rubber	26.2	21.03	3.0
5	Quartz	26.6	18.8	3.78
6	Polythene	29.4	24.4	2.25
7	RT Duroid	30	24.9	2.23

B. *Feeding techniques :*

There are two types of feedings for MPA as given below.
1) Contact feeding 2) Non-contact feeding.
In contact feeding there are 2 methods. Line feeding and Probe feeding. In Non- contact feeding Aperture feeding and Proximity coupling feeding are well known methods.

The simple feed method is Microstrip Line feed for RMPA, In this line feeding we have 3 types . They are centre feeding,
Offset feeding and inset feeding. This method provides good impedance matching without use of additional matching device.

The second method is probe feed for RMPA. This method very popular and frequently used for feeding microstrip patch antenna

The third method is Aperture coupled method of feeding RMPA. It is also known as Electro-magnetic coupling. The advantage of Electro-magnetic copuling is low spurious feed radiation, higher reliability, easy matching of impedance.

Proximity coupling technique for RMPA is fourth method. The advantage of Proximity coupled / indirect feed is less spurious feed radiation. The matching of impedance is simple with good reliability. Up to 13% bandwidth can be obtained. The fabrication is tedious process which also requires alignment.

In proposed RMPA, Probe feed is used.

III. RESUTLS AND DISCUSSIONS

Figure 2 shows the modelling and simulation of RMPA using HFSS.

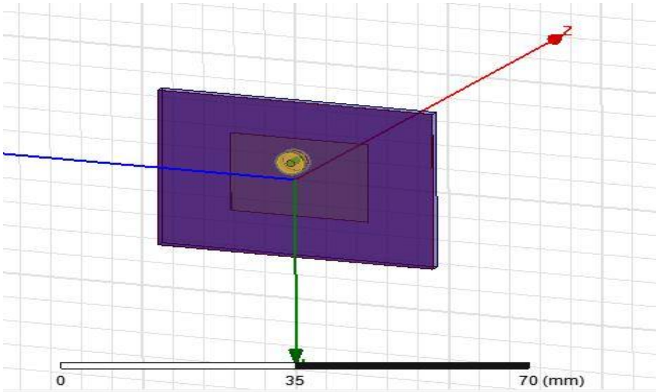

Fig. 2. Proposed MPA Modeling using HFSS

Design of FR-4 microstrip antenna is modeled and simulated by HFSS is shown in figure 2. This reference antenna has single layer substrate of FR-4 material with thickness of 1.6mm. This antenna has resonating frequency of 4.08GHz and bandwidth of 105 MHz and maximum gain of 2.9dB. To improve gain and also bandwidth another antenna is designed with dimensional change technique.

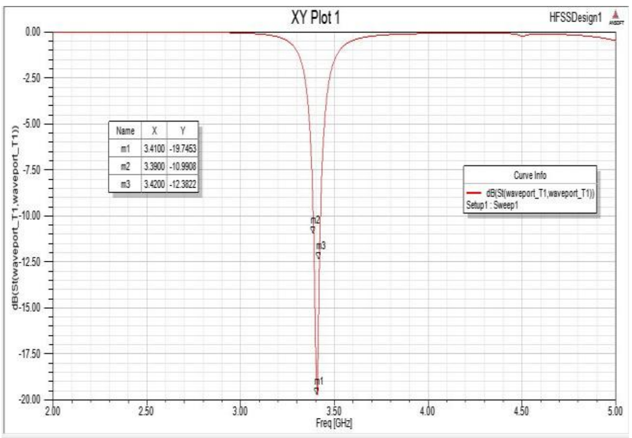

Fig. 3. S11 of Silicon MPA

The S11 characteristics for diffrent substrate materials are shown in Figure 3 to Figure 9. The gain , VSWR and other characteristics are shown in Figure 11 to Figure 18 . From the

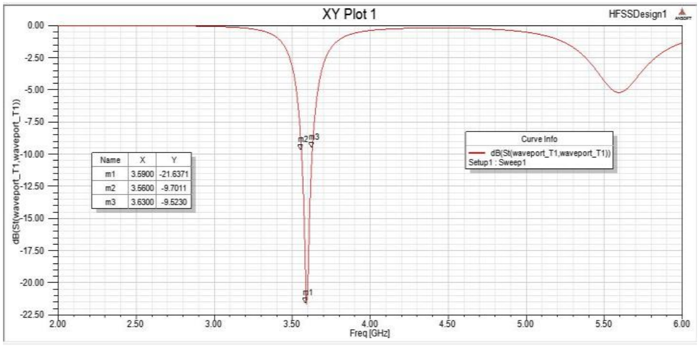

Fig. 4. S11 of Glass MPA

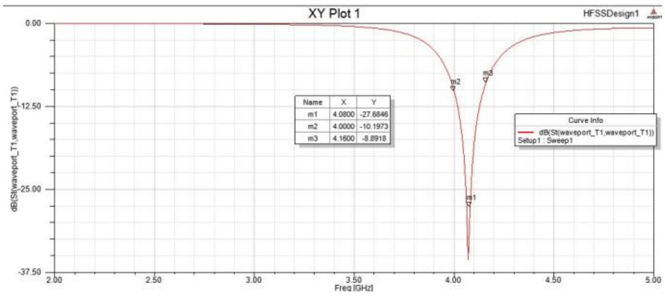

Fig. 5. S11 of Reference MPA

characteristics the value of the maximum S11 , gain & VSWR are given in Table 2. The -10dB bandwidth are given in Table 3. All these parameters are taken as reference antenna parameters. Since these values are less, so performance enhancement of parameters is achieved by means of proposed dimensional change technique of different substrate material RMPA. The S11 characteristics of Enhanced characteristics different materials substrate is shown in Figure . The Enhanced values are given in Table 4 and Table 5 . From the table we observe there is considerable amount of improvement with proposed technique for different dielectric substrate material.

TABLE II
RESULTS OF ANTENNA PARAMETERS WITH DIFFERENT DIELTRIC SUBSTRATE FOR REFERENCE RMPA

Sl no	Material	Frequency	Gain	VSWR
1	Silicon 2 3 4 5	3.4GHz	2.13dB	2
2	Glass	3.59GHz	3.8dB	1.9
3	FR-4	4.08GHz	2.9dB	1.5
4	Hard Rubber	3.74GHz	4.52dB	1.38
5	Quartz	3.7GHz	4.5dB	1.1
6	Polythene	3.75GHz	5.36dB	1.9
7	RT Duroid	3.4GHz	4dB	1.8

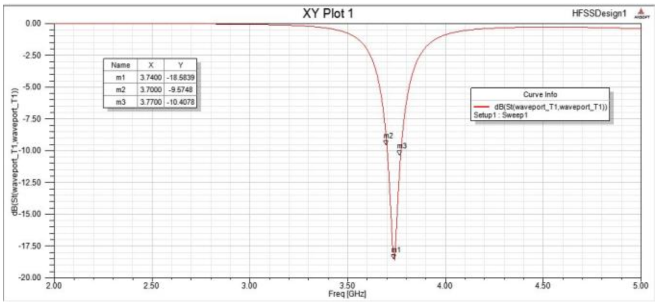

Fig. 6. S11 of Hard Rubber MPA

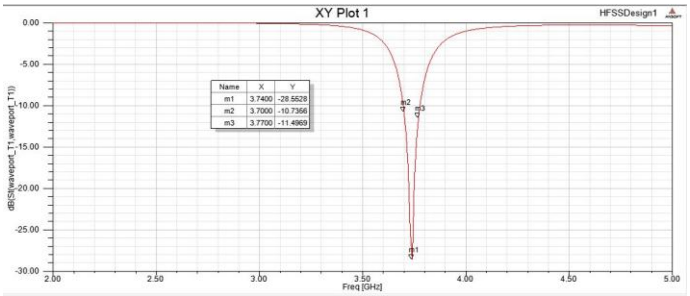

Fig. 7. S11 of Quartz MPA

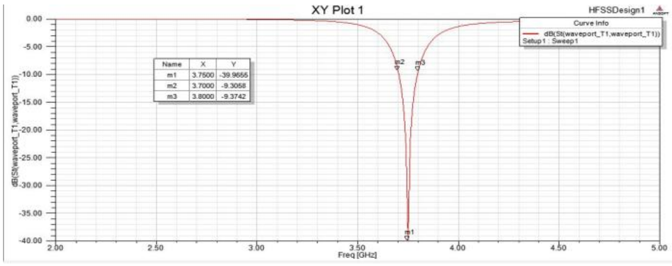

Fig. 8. S11 of Polythene MPA

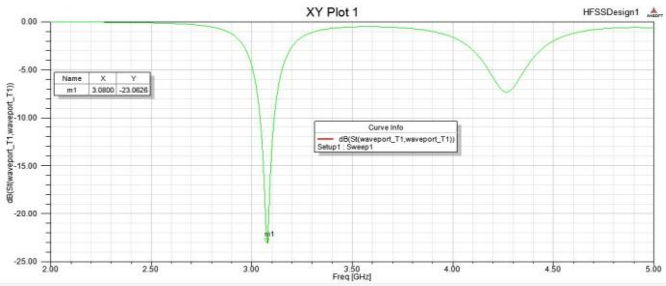

Fig. 9. S11 of RT Duroid MPA

TABLE III

RESULTS OF ANTENNA BANDWIDTH WITH

DIFFERENT DIELTRIC SUBSTRATE FOR REFERENCE RMPA

Sl no	Material	Frequency	S11	Bandwidth
1	Silicon	3.4GHz	19.7dB	30MHz
2	Glass	3.59GHz	22dB	70MHz
3	FR-4	4.08GHz	27.68dB	110MHz
4	Hard Rubber	3.7GHz	18.58dB	70MHz
5	Quartz	3.74GHz	28.55dB	70MHz
6	Polythene	3.75GHz	28.6dB	72MHz
7	RT Duroid	3.4GHz	23.63dB	100MHz

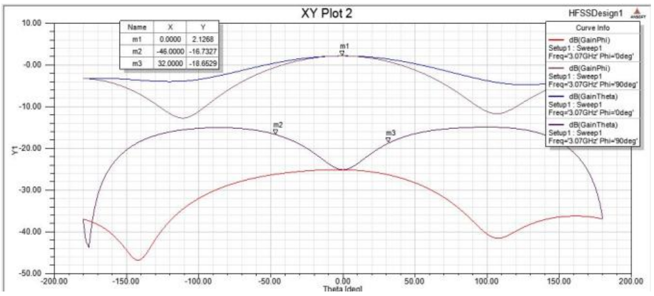

Fig. 10. Gain of Silicon MPA

Fig. 11. Gain of Glass MPA

TABLE IV
RESULTS OF ANTENNA PARAMETERS WITH DIFFERENT DIELTRIC SUBSTRATE FOR PROPOSED RMPA

Sl no	Material	Frequency	Gain	VSWR
1	Silicon	3.45GHz	3.23dB	1.7
2	Glass	3.63GHz	4.8dB	1.7
3	FR-4	4.1GHz	3.95dB	1.2
4	Hard Rubber	3.76GHz	5.52dB	1.05
5	Quartz	3.78GHz	5.6dB	1.2
6	Polythene	3.75GHz	6.36dB	1.6
7	RT Duroid	3.6GHz	8.4dB	1.2

TABLE V
RESULTS OF ANTENNA BANDWIDTH WITH DIFFERENT DIELTRIC SUBSTRATE FOR PROPOSED RMPA

Sl no	Material	Frequency	S11	Bandwidth
1	Silicon	3.45GHz	-21.7dB	75MHz
2	Glass	3.63GHz	-23dB	110MHz
3	FR-4	4.1GHz	-31.1dB	230MHz
4	Hard Rubber	3.78GHz	-24.71dB	112MHz
5	Quartz	3.76GHz	-30.5dB	107MHz
6	Polythene	3.75GHz	-26.55dB	110MHz
7	RT Duroid	3.4GHz	-29.72dB	205MHz

Fig. 12. Gain of FR-4 MPA

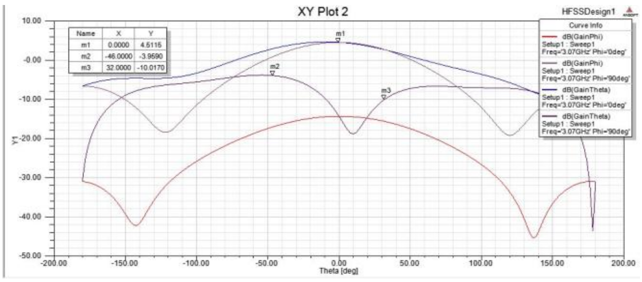

Fig. 13. Gain of Hard Rubber MPA

IV. PERFORMANCE COMPARISON OF REFRENCE AND PROPOSED ANTENNA

The comparison of different dielectric substrate materials reference and proposed RMPA , are given in Table No. 5 to 11.

TABLE VI
PERFORMANCE COMPARISON OF SILICON REFERENCE AND PROPOSED RMPA

Sl no	Parameter	Reference RMPA	Proposed RMPA
1	Resonance Frequency	3.4GHz	3.45GHz
2	S11	-19.7dB	-21.7dB
3	Bandwidth	30MHz	75MHz
4	Gain	2.13dB	3.2dB
5	Input impedance	50 ohms	50 Ohms
6	Radiation pattern	Hemisphere	Hemisphere
7	VSWR	2.0	1.7

The comparison of Silicon reference and proposed RMPA with dimensional change are shown in Table No. 6. From comparison, it is found resonance frequency is more in proposed RMPA and bandwidth is also more. The bandwidth is enhanced by 150% The gain is enhanced from 2.9 to 3.8dB. There is 38% enhancement in gain. The directivity and Radiation pattern are comparable with improvement of 1dB. The total resistance of patch and input resistance are also comparable. The VSWR of reference RMPA is around 1.9 and is acceptable. The VSWR of Proposed RMPA is 1.7 is and it is good matching of antenna with transmission line. From comparison the bandwidth and gain are enhanced by 150% and 38% in proposed and has better performance enhancement

TABLE VII
PERFORMANCE COMPARISON OF GLASS REFERENCE AND PROPOSED RMPA

Sl no	Parameter	Reference RMPA	Proposed RMPA
1	Resonance Frequency	3.59GHz	3.63GHz
2	S11	-22dB	-23dB
3	Bandwidth	70MHz	110MHz
4	Gain	3.8dB	4.8dB
5	Input impedance	50 ohms	50 Ohms
6	Radiation pattern	Hemisphere	Hemisphere
7	VSWR	1.9	1.6

The comparison of Glass reference and proposed RMPA are shown in Table No. 7. From comparison, it is found resonance frequency is more in proposed RMPA and bandwidth is also more. The bandwidth is enhanced by 57.14%.The gain is enhanced from 2.13 to 3.8dB. There is 78.4% enhancement in gain. The directivity and Radiation pattern are comparable with improvement of 1.1dB. The total resistance of patch and input resistance are also comparable. The VSWR of reference RMPA is around 1.9 and is acceptable. The VSWR of Proposed RMPA is 1.6 is and it is good matching of antenna with transmission line. From comparison the bandwidth and gain are enhanced by 57.14% and 78.4% in proposed and has better performance enhancement.

TABLE VIII
PERFORMANCE COMPARISON OF FR-4 REFERENCE AND PROPOSED RMPA

Sl no	Parameter	Reference RMPA	Proposed RMPA
1	Resonance Frequency	4.08GHz	4.1GHz
2	S11	-27.7dB	-31.1dB
3	Bandwidth	110MHz	230MHz
4	Gain	2.9dB	3.95dB
5	Input impedance	50 ohms	50 Ohms
6	Radiation pattern	Hemisphere	Hemisphere
7.	Patch Resistance	218 ohms	217 ohms
7	VSWR	1.5	1.2

The comparison of FR-4 reference and proposed RMPA with multiple substrate , multilayer are shown in Table No. 7. From comparison, it is found resonance frequency is more in proposed RMPA and bandwidth is also more. The bandwidth is enhanced by 104.5% The gain is enhanced from 2.9 to 3.95dB. There is 36.2% enhancement in gain. The directivity and Radiation pattern are comparable with improvement of 1dB. The total resistance of patch and input resistance are also comparable. The VSWR of reference RMPA is around 1.5 and is acceptable. The VSWR of Proposed RMPA is 1.1 is and it is perfect matching of antenna with transmission line. From comparison the bandwidth and gain is enhanced by 104.5% and 36.26% in proposed antenna and has better performance enhancement.

TABLE IX
PERFORMANCE COMPARISON OF HARD RUBBER REFERENCE AND PROPOSED RMPA

Sl no	Parameter	Reference RMPA	Proposed RMPA
1	Resonance Frequency	3.74GHz	3.78GHz
2	S11	-18.58dB	-24.7dB
3	Bandwidth	70MHz	110MHz
4	Gain	4.5dB	5.52dB
5	Input impedance	50 ohms	50 Ohms
6	Radiation pattern	Hemisphere	Hemisphere
7	VSWR	1.5	1.1

The comparison of Hard Rubber reference and proposed RMPA are shown in Table No. 9. From comparison, it is found resonance frequency is more in proposed RMPA and bandwidth is also more. The bandwidth is enhanced by 57.15% The gain is enhanced from 4.5 to 5.52dB. There is 22.7% enhancement in gain. The directivity and Radiation pattern are comparable with improvement of 1dB. The total resistance of patch and input resistance are also comparable. The VSWR of reference RMPA is around 1.5 and is acceptable. The VSWR of Proposed RMPA is 1.1 is and it is perfect matching of antenna with transmission line. From comparison the bandwidth and gain are enhanced by 57.15% and 22.7% in proposed antenna and has better performance enhancement.

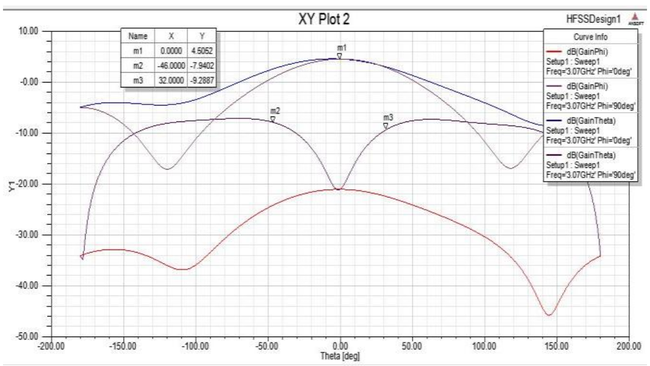

Fig. 14. Gain of Quartz MPA

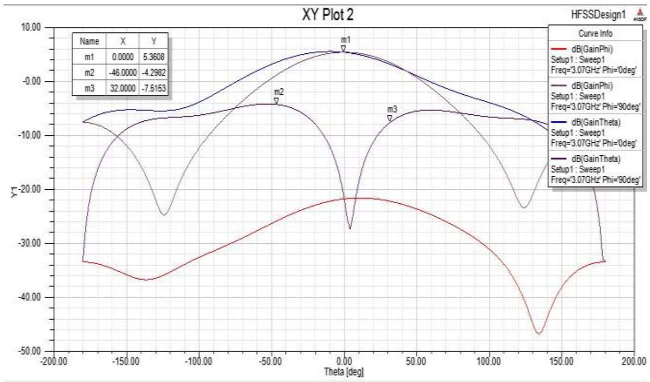

Fig. 15. Gain of Polythene MPA

TABLE X
PERFORMANCE COMPARISON OF QUARTZ REFERENCE AND PROPOSED RMPA

Sl no	Parameter	Reference RMPA	Proposed RMPA
1	Resonance Frequency	3.76GHz	3.74GHz
2	S11	-28.55dB	-30.5dB
3	Bandwidth	70MHz	107MHz
4	Gain	4.5dB	5.6dB
5	Input impedance	50 ohms	50 Ohms
6	Radiation pattern	Hemisphere	Hemisphere
7.	Patch Resistance	218 ohms	217 ohms
7	VSWR	1.1	1.05

The comparison of Quartz reference and proposed RMPA with multiple substrate, multilayer are shown in Table No. 10 From comparison, it is found resonance frequency is more in proposed RMPA and bandwidth is also more. The bandwidth is enhanced by 67.14% The gain is enhanced from 4.5 to 5.6dB. There is 24.4% enhancement in gain. The directivity and Radiation pattern are comparable with improvement of 1dB. The total resistance of patch and input resistance are also comparable. The VSWR of reference RMPA is around 1.5 and is acceptable. The VSWR of Proposed RMPA is 1.05 is and it is perfect matching of antenna with transmission line. From comparison the bandwidth and gain are enhanced by 67.14% and 22.4% in proposed antenna and has better performance enhancement.

TABLE XI
PERFORMANCE COMPARISON OF POLYTHENE REFERENCE AND PROPOSED RMPA

Sl no	Parameter	Reference RMPA	Proposed RMPA
1	Resonance Frequency	3.75GHz	3.75GHz
2	S11	-28.6dB	-26.5dB
3	Bandwidth	70MHz	112MHz
4	Gain	5.36dB	6.4dB
5	Input impedance	50 ohms	50 Ohms
6	Radiation pattern	Hemisphere	Hemisphere
7	VSWR	1.5	1.2

The comparison of Polythene reference and proposed RMPA are shown in Table No. 11. From comparison, it is found resonance frequency proposed RMPA and bandwidth is same . The bandwidth is enhanced by 74.3% The gain is enhanced from 5.36 to 6.4dB. There is 19.4% enhancement in gain. The directivity and Radiation pattern are comparable with improvement of 1dB. The total resistance of patch and input resistance are also comparable. The VSWR of reference RMPA is around 1.9 and is acceptable. The VSWR of Proposed RMPA is 1.2 is and it is very good matching of antenna with transmission line. From comparison the bandwidth and gain are enhanced by 74.3%, 19.4% in proposed antenna and has better performance enhancement

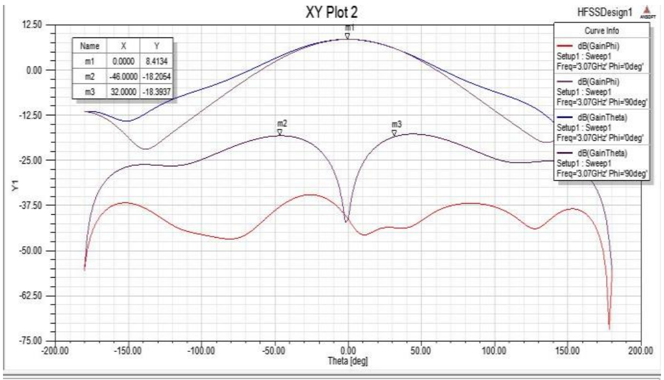

Fig. 16. Gain of RT Duroid MPA

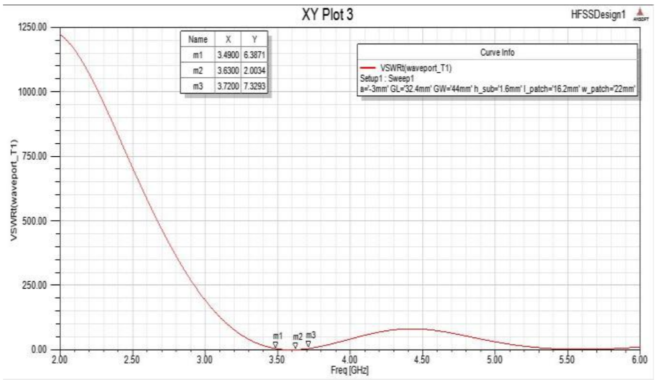

Fig. 17. VSWR of Glass MPA

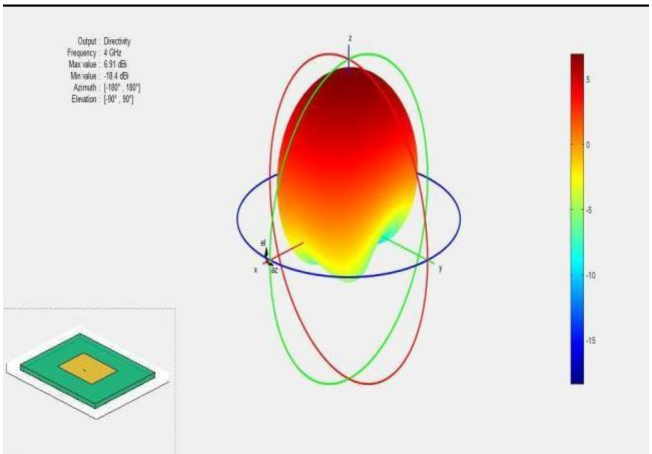

Fig. 18. Matlab simulation of Reference MPA

TABLE XII
PERFORMANCE COMPARISON OF RT DUROID REFERENCE AND PROPOSED RMPA

Sl no	Parameter	Reference RMPA	Proposed RMPA
1	Resonance Frequency	3.4GHz	3.6GHz
2	S11	-23.6dB	-29.7dB
3	Bandwidth	100MHz	205MHz
4	Gain	4.6dB	8.4dB
5	Input impedance	50 ohms	50 Ohms
6	Radiation pattern	Hemisphere	Hemisphere
7	VSWR	1.5	1.1

. The comparison of RT- Duroid and proposed RMPA are shown in Table No. 12. From comparison, it is found resonance frequency same in proposed RMPA and bandwidth is more. The bandwidth is enhanced by 105% The gain is enhanced from 4.6 to 8.4dB. There is 82.61% enhancement in gain. The directivity and Radiation pattern are comparable with improvement of 1.3dB. The total resistance of patch and input resistance are also comparable. The VSWR of reference RMPA is around 1.5 and is acceptable.The VSWR of Proposed RMPA is 1.1 is and it is perfect matching of antenna with transmission line. From comparison the bandwidth and gain are enhanced by 105% and 82.6% in proposed antenna and has better performance enhancement

V. CONCLUSION AND FUTURE WORK.

Rectangular microstrip patch antenna(RMPA) is designed with 1.6mm of different substrates and with dimensional change techniques . The performances are compared. Bandwidth, gain and other parameters different dielectric materials of reference. antenna and proposed antenna are compared. Bandwidth of Silicon reference lowest value of 30 MHz, but % enhancement is max and is 150%. The Max. value of Bandwidth is found in FR-4 material, then in RT-Duroid material. The gain value enhancement is maximum with RT duroid and lowest with Polytene material. When more bandwidth moderate gain are required FR-4 di-electric is preferred and both moderate bandwidth and high gain required RT duroid is preferred. Hence there is a bandwidth and gain enhancement of with proposed antenna. There is also improvement in directivity and VSWR performance. Hence proposed antenna performance of is enhanced, without affecting performance of other parameters. The Future work RMPA performance enhancement can be extended for various shapes of microstrip patch with other types of feed methods and different shapes of slots.

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