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Investigation of Effect of Design Materials on the Performance of an Antenna

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Abstract - *In many applications that demand a high data rate, there is a need for efficient system design. In view of this different techniques and designs are proposed to increase system efficiency to provide this throughput demand. One such approach is to design an antenna that provides the best performance in terms of directivity, bandwidth, gain for a given application. The performance of the antenna mainly depends on the design materials of the antenna. This project has been carried out to analyze the performance of an antenna by simulating the antenna designs with different substrates, conducting materials, patch and substrate thickness, metamaterial use and slots in the patch. The simulation of an antenna has been done at 2.4GHZ frequency by using the HFSS tool. From the simulation results, it can be observed that the antenna with the substrate having less dielectric constant gives better performance but the substrate having high dielectric constant offers a compact antenna. Slots in the patch help to improve the gain, directivity and multiband.*

Key Words: Rectangular microstrip patch antenna, Antenna parameters, Design materials, Metamaterials, Slots.

1. INTRODUCTION

The antenna acts as a transformer between conducted waves and electromagnetic waves propagating freely in space. There are many types of antennas such as wire, aperture, reflectors, lens, microstrip and array antennas depending on shape, size, and performance. The antenna is selected based on the application and the antenna's performance. The performance of an antenna is measured in terms of antenna parameters such as frequency, bandwidth, gain, directivity, VSWR, return loss, insertion loss, efficiency, etc. Antenna parameters mainly depend on the design materials used for antenna manufacturing. So the selection of design materials is very important to design a flexible and efficient antenna.

2. PROBLEM STATEMENT

The antenna can be designed using the different substrates, which gives different results with the same shape and size. Some substrate gives more gain but fails in some cases like cost, size, frequency range, efficiency, etc. or some may give the best efficiency but it can be expensive. Some conducting materials give the best performance and some may not. Depending on the properties of materials selected and the design, the antenna performance will change. Hence in this project, an attempt to investigate how the antenna performance changes with respect to materials and design has been investigated. Further with different substrates and designs, performance has been studied. Do not add any kind of pagination anywhere in the paper.

3. LITERATURE REVIEW

Many researchers have worked on the design materials of antennas to evaluate the antenna performance. Substrates such as leather,silk, and nylon are used for smart clothing in the range of 3.3-3.7GHz [1]. Similar work has been proposed by considering different dielectric substrates such as foam, benzocyclobutane, duroid, roger 4350, Duroid 6010, and Epoxy FR_4 to enhance the efficiency of the antenna [2]. A fork-shaped microstrip antenna was designed using different substrates, and the satisfactory value of VSWR and return loss was achieved for bakelite substrate [3].

The rectangular microstrip antenna has been designed and observed the performance of the antenna by varying the substrate heights [4], Patch thickness [5] and different conducting materials such as copper, aluminum, brass, stainless steel[6], graphin[7] and a thin film of yttrium barium copper oxide (YBCO) superconductor [8]. The performance of an antenna can be improved by introducing the slots in the patch [9] and also by using the metamaterial structures [10].

From the literature survey, it is investigated that the FR4-Epoxy gives the best performance and it is cheap, so it is best suitable for the 5G sub-6GHz band (f < 6GHz). For the 5G high-frequency band (f > 24GHz) RT Duroid5880 is the best suitable substrate, which gives better performance. Increasing the substrate height increases the bandwidth but reduces the gain and directivity. An increase in the patch thickness helps to increase the gain and directivity. The conducting material also causes a difference in the results. The conducting material with good conductivity gives more gain. So in most cases, copper is used as conducting material. Another way to improve the gain, bandwidth, and multiband is to use the metamaterials and slots in the patch.

Based on the investigations, in this study microstrip patch antenna is designed with Bakelite, benzocyclobutane, RT Duroid 5880, and Taconic as substrate and Copper, aluminum, brass, and bronze are used as conducting material. This work has been carried out to analyze the Based on the investigations, in this study microstrip patch antenna is designed with Bakelite, benzocyclobutane, RT

Duroid 5880, and Taconic as substrate and Copper, aluminum, brass, and bronze are used as conducting material. This work has been carried out to analyze.

4. MICROSTRIP PATCH DESIGN EQUATIONS

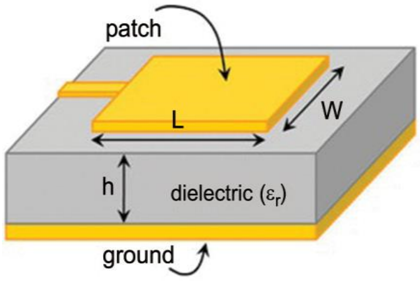


Fig -1: Basic structure of rectangular microstrip patch antenna

The basic structure of the rectangular microstrip patch antenna is shown in Fig.1. The dimensions of a rectangular microstrip antenna can be calculated by using the given formulae. The calculation needs three parameters such as operating frequency (f_0), substrate height (h) and dielectric constant of the substrate (Ɛr).

The width of the patch is calculated by

$$W = \frac{1}{2f}\sqrt{\frac{2}{\varepsilon_0 + 1}}$$

The effective dielectric constant is given by

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}$$

The effective length is given by

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

The extension length is given by

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

The actual length of the patch is given by

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

The length and width of the ground plane is given by

$$L_g = 6h + L$$

$$W_g = 6h + W$$

The length and width of the substrate are the same as the length and width of the ground plane.

5. METHODOLOGY: ANTENNA SIMULATION AND PERFORMANCE ANALYSIS

Simulation of an antenna is done using the HFSS tool. Antenna parameters such as gain (G), directivity (D), return loss (S11), bandwidth (BW), and VSWR are observed to analyze the antenna performance. Simulation is performed for different substrates, heights of the substrate, width of transmission line, patch thickness, conducting material, using metamaterial and introducing slots in the patch.

Here antenna is designed for 2.4GHz operating frequency and the thickness of the substrate is 1.5mm. The microstrip feed line is used as a feeding technique and inset feeding is used to perfect impedance matching. A lumped port is used to excite the antenna. Antenna design parameters for different substrates are shown in Table-1.

Table -1: Antenna dimensions for different substrates

Substrate	ε_r	Patch	Ground	Feed	Inset
RT Duroid 5880	2.2	41×49	60×60×1.5	10×5	14×1
Benzocyclobutane	2.6	38×46	60×60×1.5	12×4.5	11.7×3
Taconic TLC	3.2	34×43	52×52×1.5	10×2.5	9.5×1
Bakelite	4.8	28×36	45×45×1.5	10×3.5	9.5×2

5.1 Effect of Substrate

Table -2: Simulation results of an antenna with different substrates

Substrate	S11	G	D	BW	VSWR
RT Duroid 5880	-26.38	7.15	7.42	130	0.83
Benzocyclobutane	-20.40	7.14	7.21	110	1.66
Taconic TLC	-34.98	6.26	6.79	150	1.66
Bakelite	-28.69	5.50	6.005	130	0.63

From Table 1 and 2, it can be observed that the substrate with a less dielectric constant gives a large patch and results in more gain and directivity. Taconic having dielectric constant 3.2 gives -34.98 dB return loss, 150MHz bandwidth, and a gain of 6.26. RT Duroid having dielectric constant 2.2 gives -26.38 dB return loss, 130MHz bandwidth, which is less than the Taconic but gives better gain and directivity. From the literature survey and simulation results, it can be concluded that the substrate with less dielectric constant gives the best performance.

5.2 Effect of Substrate Thickness(h)

The antenna is designed by using the RT Duroid 5880 substrate with Ɛr=2.2 and copper as conducting material.

Table -3: Simulation of an antenna with different heights of substrate

h (in mm)	S11	G	D	BW	VSWR
1.1	-8.55	6.99	7.43	70	6.815
1.3	-15.44	7.11	7.44	80	2.96
1.5	-26.38	7.15	7.42	130	0.83

By observing Table 3, the gain, directivity, and bandwidth increase with the increase in the height. From simulation results and literature survey, it can be concluded that as the height of substrate increases, it results in less return loss, more gain, and bandwidth. But this height should be always less than 0.05 . If the height is beyond the limit, the patch stops radiating.

5.3 Effect of Width of Transmission Line (Wt)

Table -4: Simulation results of an antenna with different widths of transmission line

Wt (in mm)	S11	G	D	BW	VSWR
3	-7.55	7.14	7.41	60	7.80
4	-10.73	7.15	7.40	100	5.19
5	-26.38	7.15	7.42	130	0.83
6	-5.38	6.99	7.37		10.44

From Table 4, Gain and directivity are increased with an increase in the width of the transmission line and it achieves more bandwidth with less return power. Beyond a certain point, both are decreased, and return loss is more. Resonating frequency can be shifted by varying the width of the transmission line.

5.4 Effect of Patch Thickness (Tp)

Table -5: Simulation results of an antenna with different patch thickness

Tp (in mm)	S11	G	D	BW	VSWR
0.1	-22.12	7.21	7.45	110	1.36
0.05	-26.38	7.15	7.42	130	0.83
0.025	-23.46	7.18	7.44	120	1.16

From Table 5, the gain and directivity increase with the increase in the patch thickness but there is a decrease in bandwidth. From the literature survey and table 4.5, it can be observed that to get the best performance of an antenna, the patch thickness should be very much greater than the skin depth value of the conducting material.

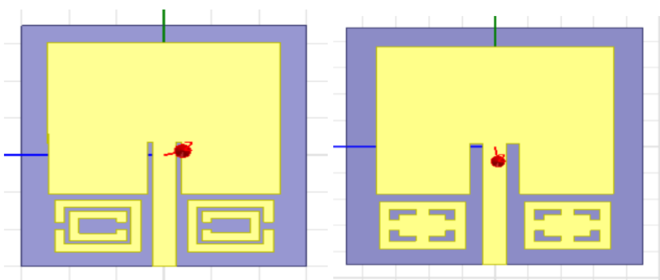
5.5 Effect of Conducting Material

Table -6: Simulation results of an antenna with different substrates and conducting materials

Substrate	Conducting material	S11	G	D	BW
RT Duroid 5880	Copper	-26.38	7.15	7.42	130
	Aluminium	-26.92	7.11	7.42	130
	Brass	-27.68	6.98	7.41	130
	Bronze	-27.32	6.9	7.42	130
Benzocyclobutane	Copper	-20.40	7.14	7.21	110
	Aluminium	-20.59	7.10	7.21	110
	Brass	-20.87	6.96	7.21	110
	Bronze	-20.81	6.88	7.21	110
Taconic TLC	Copper	-34.98	6.26	6.79	150
	Aluminium	-49.50	6.20	6.77	170
	Brass	-39.44	6.11	6.78	150
	Bronze	-27.32	6.04	6.78	140
Bakelite	Copper	-28.69	5.50	6.005	130
	Aluminium	-27.32	5.46	6.005	130
	Brass	-24.12	5.33	6.005	130
	Bronze	-22.68	5.25	6.005	120

From the Table 6, it can be observed that the different conducting material gives different effect on the various substrates. Copper gives less return loss with Bakelite, Aluminium gives less return loss with Taconic and gives a bandwidth of 170MHz. Brass gives less return loss with RT duroid and benzocyclobutane. But copper gives more gain than others. So from simulation results and literature survey, it can be concluded that the material with good conductivity is most preferable.

5.6 Effect of Metamaterial



(a) (b)

Fig -2: Antenna design with (a) metamaterial1 (b) metamaterial2

1. Metamaterial structure1:

Table -7: Simulation results of an antenna with metamaterial structure1

Substrate	S11	G	D	BW	VSWR
Bakelite	-31.43	5.48	5.99	150	0.46
Benzocyclo butane	-24.12	7.10	7.19	130	1.08
RT Duroid 5880	-26.35	7.17	7.42	130	0.83
Taconic TLC	-45.90	6.26	6.80	170	0.08

From Table 7, Taconic gives the best performance among the other substrates using the metamaterial. Using this metamaterial decreases the return loss and increase the bandwidth, gain and directivity of an antenna with RT Duroid and Bakelite substrate but there is a slight decrease in the gain and directivity of an antenna with Taconic and Benzocyclobutane.

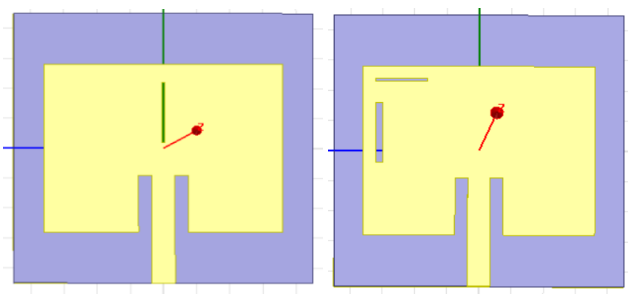
2. Metamaterial Structure2:

Table -8: Simulation results of an antenna with metamaterial structure2

Substrate	S11	G	D	BW	VSWR
Bakelite	-29.14	5.55	6.04	130	0.606
Benzocyclo butane	-23.88	7.12	7.21	120	1.11
RT Duroid 5880	-36.85	7.11	7.38	150	0.24
Taconic TLC	-36.27	6.32	6.83	150	0.26

From Table 8, RT Duroid with metamaterial structure2 gives less return loss and more bandwidth. By comparing the Table 2 and Table 8, the use of this metamaterial decreases the return loss and increases the gain, directivity and bandwidth. From the literature survey and the simulation results, metamaterials will help to decrease the return loss and increase the gain, directivity and bandwidth.

5.7 Effect of Slots



(a) (b)

Fig -3: Antenna design with (a) single slot (b) two slots

1. Single Slot Etched in Patch:

Table -9: Simulation results of an antenna with single slot in patch

Substrate	S11	G	D	BW	VSWR
Bakelite	-31.43	5.48	5.99	150	0.46
Benzocyclo butane	-24.12	7.10	7.19	130	1.08
RT Duroid 5880	-26.35	7.17	7.42	130	0.83
Taconic TLC	-45.90	6.26	6.80	170	0.08

From Table 9, it can be observed that the slot etched in a patch gives better results. As compared to table 4.2, the gain and directivity are increased with this design. By placing the slots in the patch, the antenna with Taconic substrate gives a little amount of return loss and more bandwidth but in case of gain and directivity, RT duroid gives the best performance.

2. Two slots Etched in patch:

Table -10: Simulation results of an antenna with two slots in patch

Substrate	S11	G	D	BW	VSWR
Bakelite	-19.06	5.47	6.03	110	1.94
Benzocyclo butane	-25.51	7.08	7.20	130	0.92
RT Duroid 5880	-27.02	7.19	7.45	130	0.77
Taconic TLC	-17.56	6.21	6.79	90	2.31

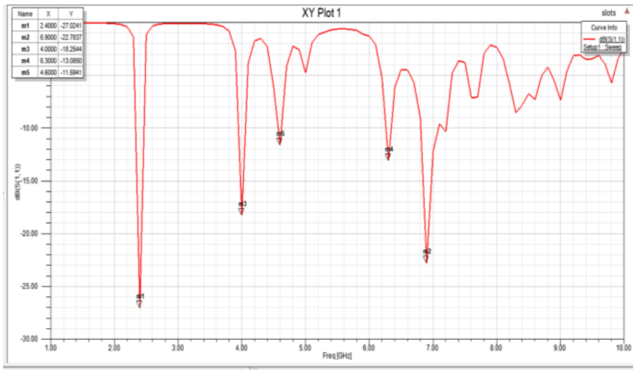
From Table 10, benzocyclobutane and RT Duroid gives more gain and directivity with less return loss. From the literature survey and simulation results, it can be observed that the slots help to increase the gain, directivity, and multiband but cause a small increase in the return loss. Return loss less than -20dB is most preferred. So the antenna design with RT Duroid 5880 substrate and copper as a conducting material gives better performance at 2.4GHz and some more frequencies.

6. RESULTS AND DISCUSSIONS

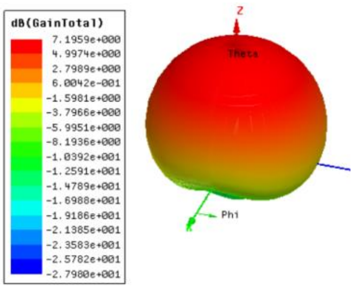
Simulation results of an antenna are made by changing the antenna design materials such as patch designs, substrate thickness, patch thickness, transmission line width, conducting materials, and metamaterials. From the results, it can be concluded that the antenna with low dielectric constant offers more gain, directivity, bandwidth, and less return loss but the size of the patch is larger than the antenna with the substrate having more dielectric constant. The substrate with high thickness provides the best performance and thickness should be less than 0.05 . The next design parameter to be considered is the patch thickness, which must be greater than the skin depth value of conducting material.

High conductivity material is well suited for antenna design to achieve less return loss with more gain. Aluminum can be used as conducting material to achieve very less return loss and high bandwidth. Gain and directivity of the antenna are improved by introducing the slots in the patch and multiband can also be achieved. Metamaterials are more suitable for improving the antenna performance, mainly in improving the multiband and bandwidth enhancement.

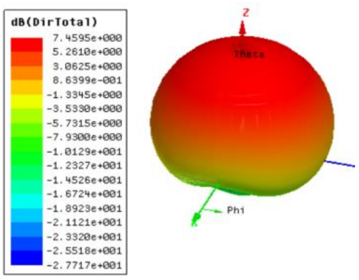
In simulated antennas, the antenna with double slots in the patch provides the best performance. It uses RT Duroid 5880 as substrate, copper as conducting material, and provides -27.02dB return loss with 130MHz Bandwidth at 2.4GHz resonating frequency. The gain of this design is 7.19dB and directivity is 7.45dB. The advantage of this design is that it offers multiband at 4GHz, 4.6GHz, 6GHz, and 6.3GHz frequencies, as shown in Fig.4. This antenna can be used in WLAN applications.



(a) Return loss



(b) Gain



(c) Directivity

Fig -4: Simulation results of an antenna with the double slots etched in patch

7. CONCLUSION AND FUTURE SCOPE

From the results of investigation and simulation, it can be concluded that the antenna with copper as a conducting material and substrate having less dielectric constant is more suitable to achieve more gain, directivity with less return loss. Antenna performance can be improved by using metamaterials and slots. The antenna with double slots etched in the patch helps to improve the gain and directivity with less return loss at 2.4GHz and achieves the multiband.

Antenna with metamaterial helps to achieve high bandwidth with very less return loss but gain is decreased. The future scope is to work on the antenna with metamaterial to increase the gain and directivity and also to enhance the bandwidth of an antenna with double slots etched in the patch.

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