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Design of Curved Slot and Parasitic Patch Ultra-Wide Bandwidth Antenna for C and X-Band Applications

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***Abstract*---The demand for wireless wideband communications is rapidly increasing due to the need to support more users and to provide more information at higher data rates. Recently, Ultra-Wideband (UWB) technology has been used in reliable communication for transmitting data within a short range of frequencies. The objective of the project is to design, simulate, fabricate, and analyze a compact size ultra-wideband microstrip patch antenna designed at a frequency of 8.6 GHz. To provide ultra-wide bandwidth, the antenna is designed using eight parasitic patches and a curved patch with a curved slot, and the ground is made partial. With the help of the parasitic patch, wide bandwidth characteristics can be achieved. FR4 (Flame-Retardant4) is used as the substrate. The simulation was performed in ANSYS HFSS software. The designed antenna can cover both C-band (4 to 8 GHz) and X-band (8 to 12 GHz) applications.**

Index terms -– Parasitic patch, Ultra Wide Bandwidth, Return loss, Radiation pattern, Gain, HFSS

I. INTRODUCTION

Ultra-Wideband (UWB) is an ultra-low power technology that transmits a high amount of data over a short distance. The term "wideband" means that the bandwidth significantly exceeds the coherence bandwidth of the channel. It uses no fixed frequency and can transmit data over wide range of frequencies. UWB corresponds to a wide bandwidth atleast greater than 500 MHz (or) the fractional bandwidth should be greater than 20 percent of critical frequency (f_C). The UWB standard is IEEE 802.15.4a and the data rate is about 1 Gbps. Data transmission using UWB is safe and secure. The main characteristics of UWB are high precision, high transmission speed, and reliability. The UWB is much better when compared to wi-fi, bluetooth, and optical communication due to its reliability, cost efficiency, scalability, and safety. UWB is used in short range wireless applications, target sensor data collection, home automation, automobile detection systems, tracking applications, precision locating, medical ranging, real time location systems**[1].**

An antenna is an electrical device which transmits and receives signals. It converts electrical power into radio waves, and vice versa. There are many types of antenna; one such is a microstrip patch antenna which consists of a radiating patch(es) on one side and has a ground plane on another side. The patch acts as a resonant cavity (short-circuit at top and bottom, and open-circuit at the sides). If the antenna is excited at a resonant frequency, a strong field will set up inside the cavity and a strong current on the bottom surface of the patch which results in significant radiation. Some advantages of using microstrip patch antenna are it has light weight; ease of installation and low cost **[2].** The microstrip patch antenna can be used in low profile applications, space craft applications, etc. In mobile, small, low cost, low profile antennas are used. Atleast one antenna will be present in mobile phones. These antennas will be used for Bluetooth and GPS and also for 4G LTE cellular communications. LTE (Long Term Evolution) is a 4G mobile communication standard helps to download our data at a faster rate. Now-a-days, 5G applications are also available. The parasitic patches can be used to obtain better bandwidth characteristics overcoming the disadvantages of microstrip patch antenna **[3].** Complex patches are used to make the radiation most efficient. Elliptical shaped patches can be introduced to make the design simple and this can be optimized to get a wider bandwidth **[4].**

II. PROPOSED METHOD

The bandwidth is one of the important parameters which are to be considered in antenna design. But, a microstrip patch antenna provides a narrow bandwidth which is a major drawback. To improve the bandwidth of antenna we can,

- Increase the substrate height
- Use low dielectric constant
- Creating slots on the patch
- Complex design patterns

In this project, the bandwidth is increased using partial ground, changing the position of the feed line, using a curved slot on the patch, and using parasitic patches.

A. Equations for designing an antenna

A microstrip patch antenna along with its dimensions is shown in Fig.1.

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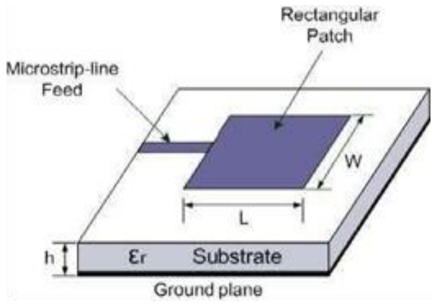


Fig.1 Microstrip patch antenna

The steps involved in designing an antenna include five steps. They are shown below.

Step 1-Width Calculation (W):

The width of the microstrip patch antenna is given by,

$$\mathbf{W} = \frac{c}{2f_0\sqrt{\frac{(\varepsilon_r+1)}{2}}}$$

where, r – Dielectric constant of the substrate
h – Height of the dielectric
W – Width of the patch

Step 2-Effective dielectric constant (ε_{reff}):

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

Step 3-Effective length (L_{eff}):

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

where, c – Speed of light (3 x 10 ^{8} m/s)
f – Resonant frequency

Step 4-Calculation of change in length (ΔL):

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

Step 5-Length Calculation (L):

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

B. Modelling and Design

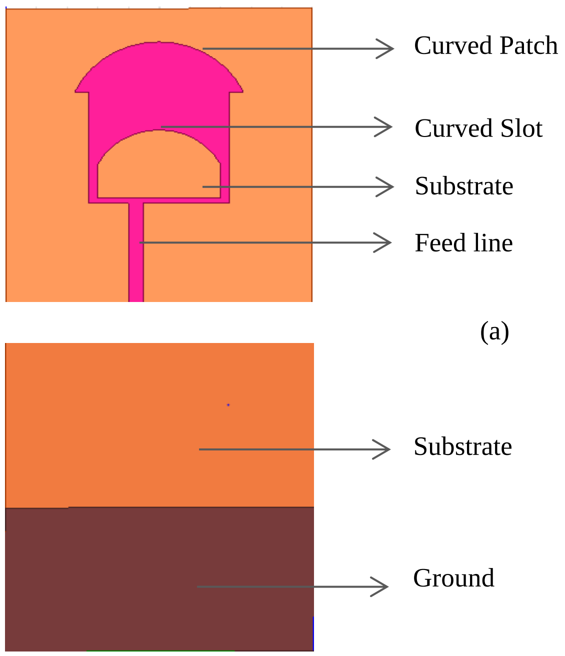
From the design formulae, the length and width of the patch is calculated and further the antenna is designed in the software by making some changes in the ground plane, feed line and also the shape of the patch and the slot in order to obtain increased bandwidth characteristics. Table.1 describes the measurements for the designed antenna.

Table.1 Antenna measurements

Substrate Material	**FR4 (Flame Retardant 4)**
Substrate Height	**1.6mm**
Substrate Dimension	**55 mm x 50 mm x 1.6mm**
Length of the feed line	**20mm**
Width of the feed line	**2.5mm**
Dielectric constant	**4.4**
Operating frequency	**8.6GHz**
Length of patch	**7.63mm**
Width of patch	**10.62mm**

In this project, three types of antenna design are introduced to obtain wide-band. The schematic model design of the top view (a) and bottom view (b) for these three proposed antenna are shown in Fig.2, Fig.3, and Fig.4.

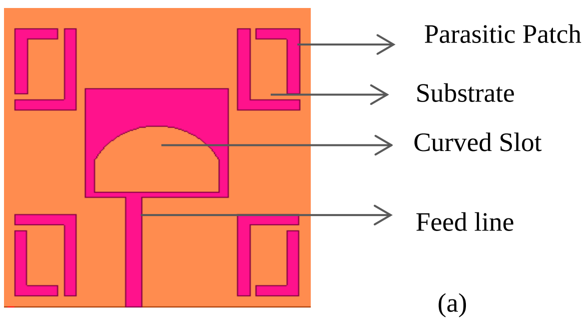
- *Proposed Model I(Curved Patch with curved slot)*



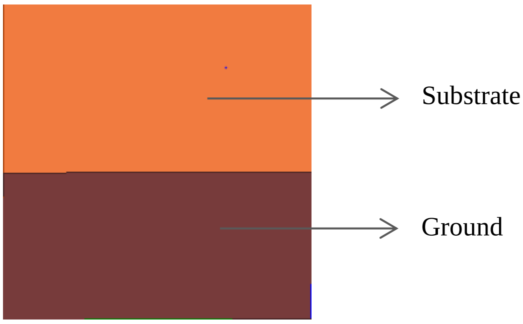
(b)

Fig.2 Proposed antenna design Model-1

- *Proposed Model II (Parasitic patch with curved slot)*



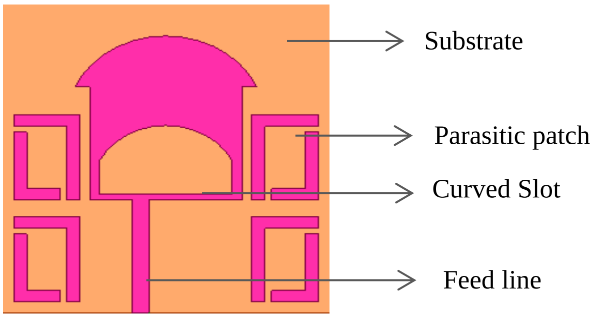
(a)



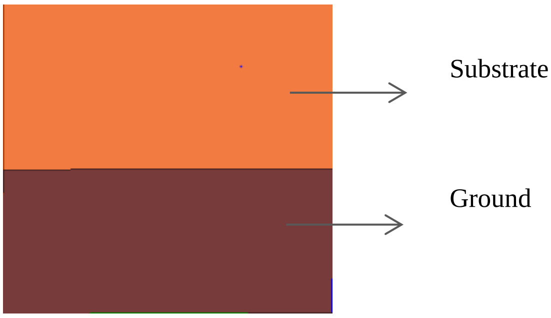
(b)

Fig.3 Proposed antenna design Model-2

- *Proposed Model III (Parasitic patch and curved patch with curved slot)*



(a)



(b)

Fig.4 Proposed antenna design Model-3

III. SOFTWARE AND HARDWARE REQUIREMENTS

Generally to design an antenna, we need software. In this project, the antenna is designed and simulated using the HFSS software. After designing the antenna, fabrication process is done. Later on the fabricated antenna is tested by a test system. Here, Vector Network Analyser (VNA) is used for testing the antenna.

ANSYS HFSS (High Frequency Structure Simulator) is simulation software for designing and simulating high-frequency electronic products. The optimization tool available with HFSS is very useful for antenna engineers to optimize the antenna parameters very accurately. For boundary schemes, Radiation and Perfect-E boundaries are widely used for this design. In this project, HFSS is used to design an antenna which should satisfy increased bandwidth suitable for many applications.

The steps involved in designing the antenna and simulation procedure is mentioned in the following flowchart (Fig.5).

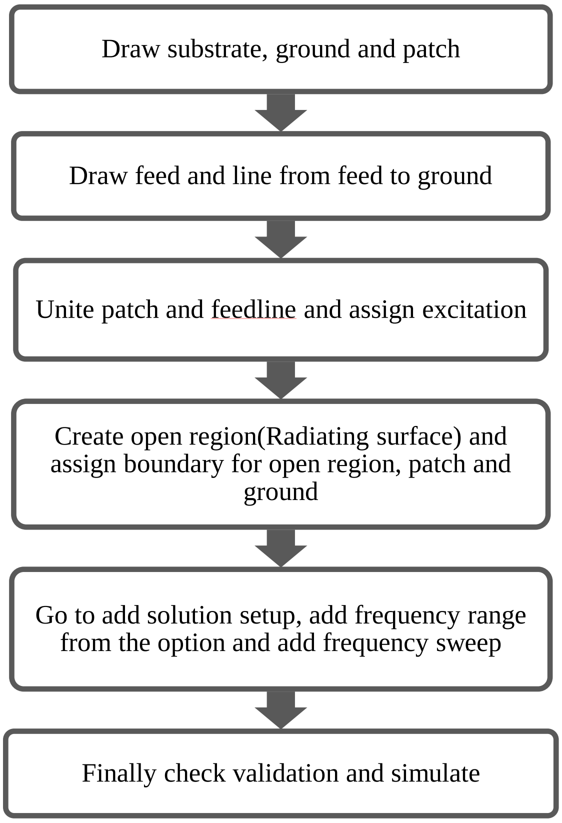


Fig.5 Steps involved in designing an antenna

IV. RESULTS AND DISCUSSION

A. *Bandwidth Calculation:*

The bandwidth can be calculated as the difference between the higher cut-off frequency (f_H) and lower cut-off frequency(f_L). It is given by,

$$\textbf{Bandwidth} = f_H - f_L$$

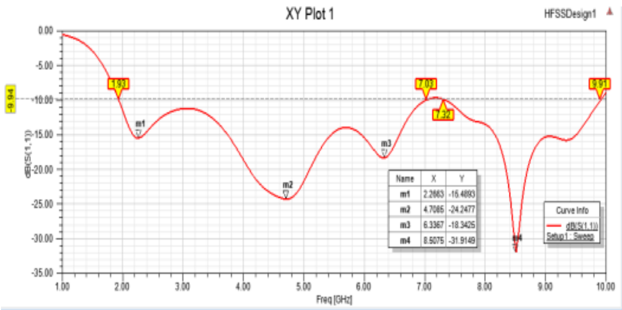


Fig.6 Return loss for the proposed antenna(Model-1)

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From the Fig.6, the bandwidth is calculated using, f_H = 7.03 GHz and f_L = 1.93 GHz and critical frequency 8.6 GHz. Thus, the bandwidth obtained is 5.1 GHz. The percentage of the bandwidth is obtained as ((5.1/8.6) x 100) i.e. 59.3 %. Hence, the fractional bandwidth for the antenna is 59.3 %.

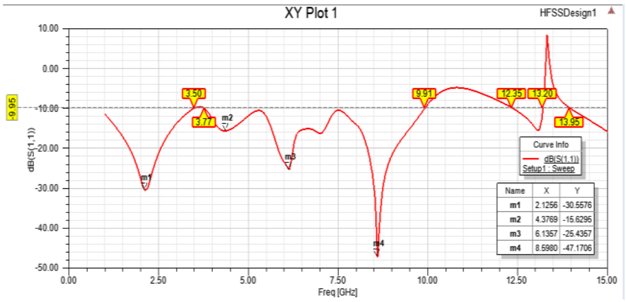

Fig.7 Return loss for the proposed antenna(Model-2)

In the Fig.7, we have f_H = 9.91 GHz, f_L = 3.77 GHz and f_C = 8.6 GHz. Thus, the bandwidth can be calculates as (9.63 – 3.67 = 6.41GHz) and the percentage of the bandwidth is obtained as ((5.96/8.6) x 100) i.e. 71.39 %. Thus, the impedance bandwidth is 71.39 %.

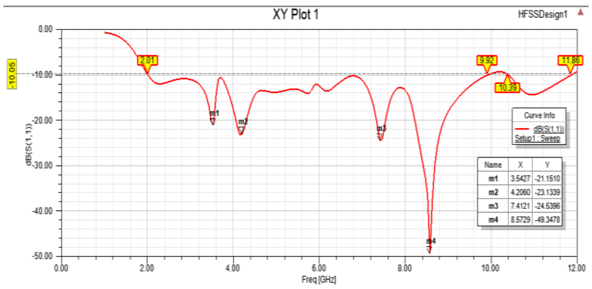

Fig.8 Return loss for the proposed antenna(Model-3)

From the Fig.8, f_H = 9.92 GHz and f_L = 2.01 GHz and f_C = 8.6 GHz. Thus, the bandwidth can be calculates as (9.63 – 2.02 = 7.91 GHz) and the percentage of the bandwidth is obtained as ((7.61/8.6) x 100) i.e. 91.97 %. Hence, the fractional bandwidth for the antenna is achieved as 91.97 %.

The Fig.6, Fig.7, and Fig.8 show the return loss plot for the desired proposed antenna for the Model-1, Model-2, and Model-3 respectively

B. Radiation Pattern:

The radiation pattern of microstrip patch antenna is broad. It has a low radiated power and bandwidth is narrow. It has lesser directivity. Fig.9 shows the desired radiation pattern for the proposed antenna for Model-1 design. Here, at 2.26 GHz, the radiation pattern is wider when compared to other frequencies. Fig.10 shows the pattern for the Model-2 design where, it is wider at 8.59 GHz. The radiation pattern for Model-3 design shows a wider range at 8.57 GHz and it is shown in Fig.11

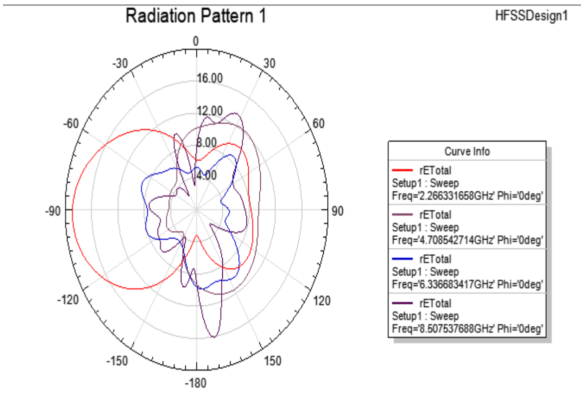

Fig.9 Radiation pattern for the proposed antenna (Model-1)

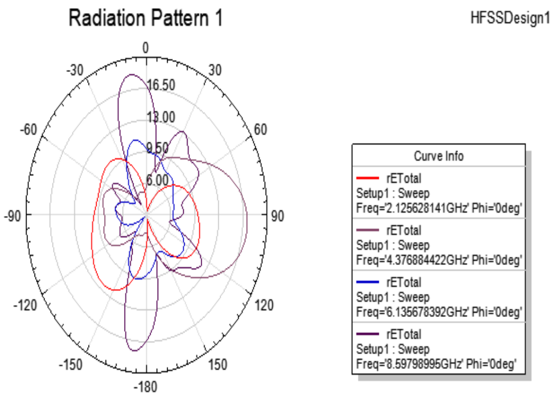

Fig.10 Radiation pattern for the proposed antenna(Model-2)

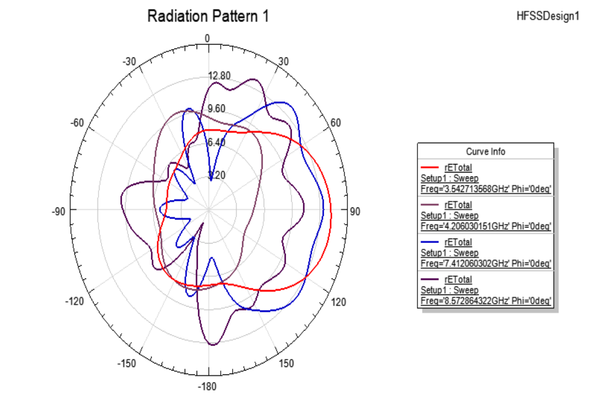

Fig.11 Radiation pattern for the proposed antenna(Model-3)

C. VSWR:

VSWR stands for Voltage Standing Wave Ratio. It is related to the reflection coefficient of an antenna, which describes how much power is reflected from the antenna. In terms of VSWR, a good antenna should satisfy the condition (1 < VSWR < 2). The VSWR for the proposed antenna for Model-1 design is shown in Fig.12, Model-2 design in Fig.13, and Fig.14 shows the VSWR plot for the Model-3 design.

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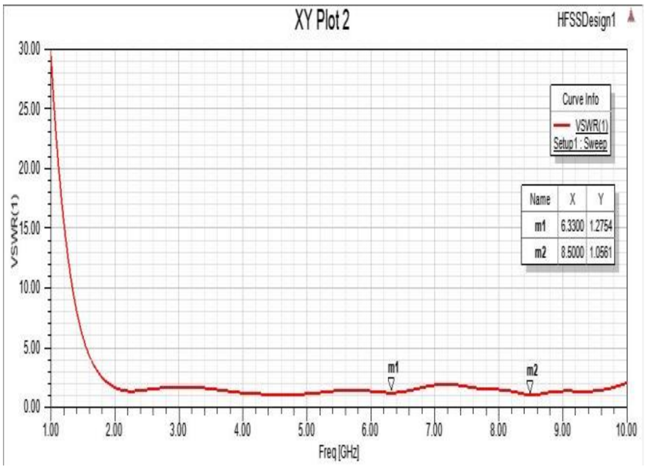

Fig.12 VSWR for the proposed antenna(Model-1)

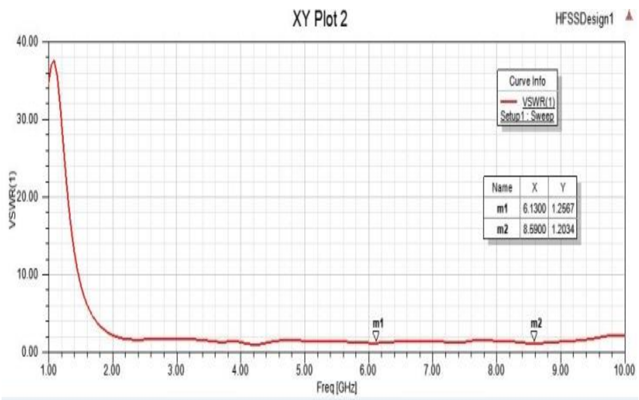

Fig.13 VSWR for the proposed antenna(Model-2)

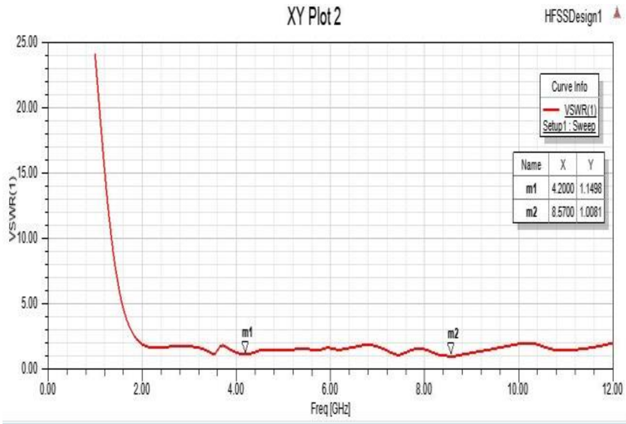

Fig.14 VSWR for the proposed antenna(Model-3)

D. Gain:

The gain can be defined as the ratio of maximum power received from the given antenna to the maximum power received from the reference antenna. From the gain obtained, it is clear that the power radiated by an antenna is concentrated at one direction and minimum at other directions.

The antenna parameters for the three proposed model are obtained as shown in Fig.14, Fig.15 and Fig.16 respectively. For the proposed antenna (Model 3), the bandwidth is found to be 7.91 GHz. It offers a wide impedance bandwidth of 91.97% (covering from 2.01 to 9.92 GHz at VSWR≤ 2), symmetric radiation pattern, and a high gain of 6.8 dB at 7.4 GHz(C-band) and 4.58 dB at 8.6 GHz(X-band). The Model-2 proposed antenna provides a bandwidth 6.41 GHz and a gain of 5.67dB at 8.6GHz.

Antenna Parameters:

Quantity	Freq	Value	Freq	Value	Freq	Value	Freq	Value
Max U	2.26633...	473.73 mW/sr	4.70854...	205.5 mW/sr	6.33668...	354.29 mW/sr	8.50753...	510.08 mW/sr
Peak Directivity		3.9918		2.6978		4.8577		6.5289
Peak Gain		6.1262		2.5922		4.5184		6.4141
Peak Realized Gain		5.9532		2.5824		4.4522		6.41
Radiated Power		1.4913 W		957.25 mW		916.53 mW		981.78 mW
Accepted Power		971.75 mW		996.24 mW		985.35 mW		999.36 mW
Incident Power		1 W		1 W		1 W		1 W
Radiation Efficiency		1.5347		0.96086		0.93015		0.98242
Front to Back Ratio		5.3037		10.661		33.029		4.0228
Decay Factor		0		0		0		0

Fig.15 Antenna parameters for the proposed antenna(Model-1)

Antenna Parameters:

Quantity	Freq	Value	Freq	Value	Freq	Value	Freq	Value
Max U	2.12562...	254.99 mW/sr	4.37688...	459.31 mW/sr	6.13567...	199.94 mW/sr	8.59798...	451.76 mW/sr
Peak Directivity		2.2024		5.9788		3.0487		6.7403
Peak Gain		3.2072		5.9344		2.5198		5.6772
Peak Realized Gain		3.2044		5.772		2.5126		5.6771
Radiated Power		1.4549 W		965.42 mW		824.14 mW		842.27 mW
Accepted Power		999.12 mW		972.64 mW		997.14 mW		999.98 mW
Incident Power		1 W		1 W		1 W		1 W
Radiation Efficiency		1.4562		0.99257		0.8265		0.84228
Front to Back Ratio		6.3308		7.759		4.0084		1.5187
Decay Factor		0		0		0		0

Fig.15 Antenna parameters for the proposed antenna(Model-2)

Antenna Parameters:

Quantity	Freq	Value	Freq	Value	Freq	Value	Freq	Value
Max U	3.54271...	400.85 mW/sr	4.20603...	238.61 mW/sr	7.41206...	539.4 mW/sr	8.57286...	364.9 mW/sr
Peak Directivity		5.5498		3.2177		7.8611		5.6927
Peak Gain		5.0762		3.0132		6.8023		4.5856
Peak Realized Gain		5.0373		2.9986		6.7784		4.5856
Radiated Power		907.65 mW		931.91 mW		862.27 mW		805.51 mW
Accepted Power		992.33 mW		995.14 mW		996.48 mW		999.99 mW
Incident Power		1 W		1 W		1 W		1 W
Radiation Efficiency		0.91466		0.93646		0.86532		0.80552
Front to Back Ratio		11.467		3.1453		38.76		22.77
Decay Factor		0		0		0		0

Fig.16 Antenna parameters for the proposed antenna(Model-3)

Table.2 Bandwidth comparison table

	Bandwidth (F_H - F_L)	**Fractional Bandwidth (Bandwidth / F_C) x 100**
Proposed Model 1	**5.1 GHz**	**59.3 %**
Proposed Model 2	**6.41 GHz**	**71.39 %**
Proposed Model 3	**7.61 GHz**	**91.97 %**

Table 2 shows the bandwidth obtained by the proposed antenna for the three different models.

V. CONCLUSION

The proposed microstrip patch antenna is thus designed by using a curved slot and parasitic patches to obtain wide bandwidth characteristics. Additionally, the position of the feed line is also changed and the ground is made partial. The microstrip patch antenna is designed using ANSYS HFSS software and the simulated results are obtained. The return loss curve was plotted radiation pattern and the antenna parameters were obtained. From the simulated results, the proposed Model-3 antenna provides better bandwidth characteristics than other antennas. This antenna offers a wide impedance bandwidth of 91.97% (covering from 2.02 to 9.92 GHz at VSWR≤ 2), symmetric radiation pattern, and provides a gain of 4.58 dB at 8.6 GHz. These three proposed antenna are at good assent with other works. Since it covers C-band and partially X-band, it can be used in C-band applications and some X-band applications.

VI. FUTURE SCOPE

For further bandwidth enhancement, the design should be optimized to provide an ultra-wide bandwidth i.e. the return loss plot should be obtained as a horizontal straight line satisfying the ultra-wide range. The microstrip patch antenna can be designed using **parasitic patch(es), partial ground, slot(s), and DGS(Defective Ground Structure)**. Parasitic patch and partial ground can help to improve the bandwidth. So with the help of such design we can get better wide bandwidth characteristics and can cover both C-band (4 to 8 GHz) and X-band (8 to 12 GHz) applications.

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