Microstrip Patch Antennas for Microwave S band, C band and X band Applications

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Abstract:

Advantages of Microstrip patch antennas make them solid candidate for the field of communication in Microwave application. This paper consists of Microstrip patch antennas with complete mathematical calculations, Simulation results and the relevant antenna applications on the operating frequencies. These designed antennas have frequency ranges in Microwave S band, C band and X band. S band cover the frequencies of 2 GHz, 3 GHz and 3.5 GHz. C band cover the frequencies of 6GHz, 7GHz. X band cover the frequencies of 8GHz and 9 GHz. These antenna simulations performed by using Ansoft HFSS TM V10.0. Simulation results are presented in terms of Resonant Frequency Return Loss, VSWR, Radiation Pattern and the antenna Gain. Microstrip patch antennas have wide range of applications, however here in this paper following applications are presented. WLL, WiMAX, Satellite Communication and Marine Radar Communication (SART).

Index Terms: **SART, WiMAX, Satellite Communication, Microstrip Patch Antenna**

1. Introduction:

In high performance applications like Unmanned Aircraft, Radar Systems, Satellite Communication Systems, WLAN, WiMAX, missile, Mobile Radio and Wireless Communication Systems size, cost, weight, ease of fabrication, ease of installation offer constraints. Microstrip patch antenna can perform well in Microwave applications as particular of interest like in Satellite Communication (FSS) and Marine Radar Communication (SART).

The increasing popularity of indoor wireless LAN capable of high speed transfer rate is prompting the development of efficient antennas. Due to increased usage in residential and office areas, these systems are required to be Low Profile, Aesthetically pleasing and Low Cost as well as Highly effective and efficient. Microstrip patch antennas are well suited for wireless LAN application systems due to their Versatility, Conformability, Low Cost and Low Sensitivity to manufacturing tolerances. Recently importance has been placed upon creating patch antennas that show broadband properties and capable of high speed data transfer.

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Microstrip antennas are small structures, used in external public switched network (PSTN), to collect or radiate electromagnetic wave. Most people require an antenna that can stand up to daily abuse and still keep reception when connected to the network. 3 to 3.6 GHz is the frequency band used in the WLL technology. Wireless local loop (WLL) sometimes called radio in the loop, or fixed-radio access (FRA), uses public switched telephone Network (PSTN) to connect subscribers using radio signal instead of copper wire for all or part of the connection. In rural telephony WLL uses the 3 to 3.6 frequency band.

WiMAX (Worldwide Interoperability for Microwave Access) is a wireless digital Communications System, also known as IEEE 802.16, that is intended for wireless "Metropolitan Area Networks" (MAN). WiMAX can provide Broadband Wireless Access (BWA) up to 30 miles (50 km) for fixed stations, and 3 - 10 miles (5 - 15 km) for mobile stations. WiMAX has three allocated frequency bands called low band, middle band and high band. The low band has frequency from 2.5 GHz to 2.8 GHz, the middle band has frequency from 3.2 GHz to 3.8 GHz and the high band has frequency from 5.2GHz to 5.8 GHz. Due to the advantages of Microstrip Patch Antenna such as low weight, low profile planar configuration, low fabrication costs and capability to integrate with microwave integrated circuits technology, the Microstrip Patch Antenna is very well suited for applications such as wireless communications system, cellular phones, pagers, radar systems, and satellite communications systems, so here we use middle band frequency that is 3.5GHz resonant frequency (the main reason is that in Pakistan WiMAX operates on 3.5GHz frequency), we will design Square Microstrip Patch Antenna using probe feed technique for WiMAX application.

A wideband slotted circularly polarized patch antenna is used for 5-6 GHz WLAN Applications. Circularly polarized antennas are receiving much attension these days due to their increasing importance in commercial and defense Wireless Communication Applications. These include Low-Earth-Orbit (LEO) and Medium-Earth Orbit(MEO) Satellite Communication as well as Wireless Local Area Network(WLAN)Applications.

TheUltra-WideBand (UWB) antennas have been widely adopted in communication systems of commercial and military domains. Because of the attractive feathers,such as low cost, small size, and easy fabrication.7Ghz can be used

SART stands for “Search And Rescue Transponders” also known as “Search And Rescue radar Transponders” which used for the locating of vessels in distress or of their survival craft. A SART has a receiver that detects the signals from X-band radars (9.2 - 9.5 GHz). If the SART detects a signal it immediately transmits twelve pulses on the same frequency these pulses detected on the radar screen, by using these dots or signals location of the life boat or marine can easily detected[1], [2][3].

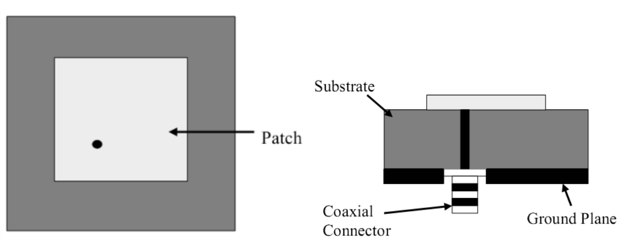
A Microstrip antenna has a dielectric substrate having a radiating patch on one side and a ground plane on the other side. The EM waves fringe off the top patch into the substrate and are radiated out into the air after reflecting off the ground plane, EM waves change their direction according to the input signal cycle. The feed of Microstrip antenna can have many configurations like Microstrip line, coaxial, aperture coupling and proximity. Of the four feeding techniques, Microstrip line and coaxial are relatively easier to fabricate. However, Microstrip line limits the bandwidth to 2 to 5% as spurious radiations increase with the increase in substrate thickness [5]. Therefore, coaxial feed is used for feeding Microstrip antenna. However, coaxial feed and antenna matching is required as antenna input differs from 50 ohm. The analysis and design of Microstrip antenna can be carried out using different techniques and models. The most popular one are transmission line, cavity and full wave [5]. The design of Microstrip antenna is carried out using transmission line model (TLM) [6] of Munson and Derneryd, as it gives good physical insight [5] and results adequate for most engineering purposes. It requires less computation [4]. However, it is difficult to model coupling using TLM.

Organization of the paper is as follows: Section-2 describes the complete design procedure and implementation of both Microstrip antennas. Results of simulations of designed model are presented in Section-3. Finally, conclusion has been shown in the end.

2. Design Procedure:

The coaxial line fed Microstrip antennas are designed at their respective resonant frequency and the resonant frequency of a rectangular Microstrip antenna has been designed for based on the width and length of the patch, given height and permittivity of the dielectric material between the conductive Microstrip and ground plane.

The design procedure of designed antennas carried out step by step [5], [7] is given below;



(a) (b)

Fig.1: (a) Top view of Microstrip patch antenna (b) Side view of Microstrip patch antenna (Coaxial Line feed)

2.1. Substrate Selectivity:

The first step is to select the appropriate substrate and thickness of substrate. Bandwidth and radiation efficiency increase with substrate thickness, and radiation efficiency of the Microstrip patch antenna mainly depends on the dielectric constant or permitivity of the substrate. Because permittivity of the substrate effects the transmission efficiency. [8]

In this paper, the substrate that used in the designing process is FR4 Epoxy Glass, that have relative permitivity of 4.4 and the substrate height will be 1.6mm. To manage the bandwidth of the antenna substrate height can be varied depending upon situation and the requirements of the antenna bandwidth.

Practical values can be calculated by using standard formulas.

2.2. Width of Patch:

Width of patch can be calculated by using following equation

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

Here c = $3\text{x}10^{11}$ mm/s

For 2 GHz

Width of the Patch having substrate FR4 Epoxy Glass with relative permitivity of $\epsilon_r = 4.4$ at resonant frequency of 2 GHz is,

W = 4.74 cm

For 3 GHz

Width of the Patch having substrate FR4 Epoxy Glass with relative permitivity of $\epsilon_r = 4.4$ at resonant frequency of 3 GHz is,

as patch is square so length and width will remains equal, and can be calculated by using this formula.

$$W = L = \lambda_o / 2$$

W = L = 2.38 cm

For 3.5 GHz

Width of the Patch having substrate FR4 Epoxy Glass with relative permitivity of $\epsilon_r = 4.4$ at resonant frequency 3.5 GHz is, as patch is square so length and width will remains equal, and can be calculated by using this formula.

$$W = L = \lambda_o / 2$$

W = L = 2.04 cm

For 6 GHz

Width of the Patch having substrate FR4 Epoxy Glass with relative permitivity of $\epsilon_r = 4.4$ at resonant frequency of 6 GHz is,

as patch is square so length and width will remains equal, and can be calculated by using this formula.

$$W = L = \lambda_0 / 2$$

W = L = 1.2 cm

For 7 GHz

Width of the Patch having substrate FR4 Epoxy Glass with relative permitivity of $\epsilon_r = 4.4$ at resonant frequency of 7 GHz is,

as patch is square so length and width will remains equal, and can be calculated by using this formula.

$$W = L = \lambda_0 / 2$$

W = L = 1.022 cm

For 8 GHz

Width of the Patch having substrate FR4 Epoxy Glass with relative permitivity of $\epsilon_r = 4.4$ at resonant frequency of 8 GHz is,

W = 8.47 mm

But as patch is square so length and width will remains equal, and can be calculated by using this formula.

$$W = L = \lambda_0 / 2$$

W = L = 8.9 mm

For 9 GHz

Width of the Patch of a Microstrip patch antenna having substrate FR4 Epoxy Glass with relative permittivity $\epsilon_r = 4.4$ at resonant frequency f = 9 GHz is,

W = 7.53 mm

But as patch is square so length and width will remains equal, and can be calculated by using this formula.

$$W = L = \lambda_0 / 2$$

W = L = 7.9 mm

2.3. Effective Dielectric Constant:

The effective dielectric constant can be calculated by using this equation,

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[1 + 12\frac{h}{w}\right]^{-0.5}$$

For 2 GHz

Patch antenna using substrate FR4 Epoxy Glass

For $\epsilon_r = 4.4$, W=4.74 cm and h = 0.0032 m,

$\varepsilon_{eff} =$ **3.9**

For 3 GHz

Patch antenna using substrate FR4 Epoxy Glass

For $\epsilon_r = 4.4$, W=2.38 cm and h = 0.0032 m,

$\varepsilon_{eff} =$ **3.75**

For 3.5 GHz

Patch antenna using substrate FR4 Epoxy Glass

For $\epsilon_r = 4.4$, W=2.04 cm and h = 0.0032 m,

$\varepsilon_{eff} =$ **3.70**

For 6 GHz

Effective relative permitivity of patch having substrate FR4 Epoxy Glass of relative permitivity $\epsilon_r = 4.4$, height of substrate h = 0.16 cm and width of patch W = 1.2 cm at resonant frequency **f = 6 GHz** is,

$$\epsilon_{eff} = 3.7543$$

For 7 GHz

Effective relative permitivity of patch having substrate FR4 Epoxy Glass of relative permitivity $\epsilon_r = 4.4$, height of substrate h = 0.16 cm and width of patch W = 1.022 cm at resonant frequency **f = 7 GHz** is,

$$\epsilon_{reff} = 3.702$$

For 8 GHz

Effective relative permitivity of patch having substrate FR4 Epoxy Glass of relative permitivity $\epsilon_r = 4.4$, height of substrate h = 1.6 mm and width of patch W = 7.9 mm at resonant frequency **f = 8 GHz** is,

$$\epsilon_{eff} = 3.6579$$

For 9 GHz

Effective relative permitivity of patch having substrate FR4 Epoxy Glass of relative permitivity $\epsilon_r = 4.4$, height of substrate h = 1.6 mm and width of patch W = 7.6 mm at resonant frequency f = 9 GHz is,

$$\epsilon_{reff} = 3.6195$$

2.4. Length Extension of Patch:

Length extension of the patch can be calculated by using this equation,

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

For 2 GHz

Length extension of patch at frequency 2 GHz with $€_{reff=}$ 2.54, width W = 4.74 cm and height h = 0.0032 m is,

ΔL = 0.72 cm

For 3 GHz

Length extension of patch at frequency 3 GHz with $€_{eff=}$ 2.2, width W = 2.38 cm and height h = 0.0032 m is,

ΔL = 0.07 cm

For 3.5 GHz

Length extension of patch at frequency 3.5 GHz with $€_{eff=}$ 2.2, width W = 2.04 cm and height h = 0.0032 m is,

ΔL = 0.06 cm

For 6 GHz

Length extension of patch at frequency 6 GHz with $€_{eff=}$ 3.7543, width W = 1.2 cm and height h = 0.16 cm is,

ΔL = 0.069971 cm

For 7 GHz

Length extension of patch at frequency 7 GHz with $€_{eff=}$ 3.702, width W = 1.022 cm and height h = 0.16 cm is,

ΔL = 0.701 cm

For 8 GHz

Length extension of patch at frequency 8 GHz with $€_{eff=}$ 4.18, width W = 7.9 mm and height h = 1.6 mm is,

ΔL = 0.7029 mm

For 9 GHz

Length extension of patch at frequency 9 GHz with $€_{eff=}$ 4.18, width W = 7.6 mm and height h = 1.6 mm is,

ΔL = 0.6971 mm

2.5. Actual Length of Patch:

Actual length of patch can be calculated by using this equation,

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

For 2 GHz

Patch antenna using substrate FR4 Epoxy

For L_{eff} = 3.8 cm and

ΔL = 0.072cm

L_{actual} = 3.7 cm

For 2.5 GHz

Patch antenna using substrate Rogers RT/Duroid 5880 (tm)

For L_{eff} = 4.2008 cm and ΔL = 0.166cm

L_{actual} = 3.86 cm

For 3 GHz

Patch antenna using substrate FR4 Epoxy

For L_{eff} = 4.2008 cm and ΔL = 0.07cm

L_{actual} = 2.44 cm

For 3.5 GHz

Patch antenna using substrate FR4 Epoxy

For L_{eff} = 4.2008 cm and ΔL = 0.07cm

L_{actual} = 2.09 cm

For 6 GHz

Actual Length of Patch antenna using substrate FR4 Epoxy Glass having relative permitivity $€_r$ = 4.4, L_{eff} = 1.2903 cm and ΔL = 0.039971 cm is,

L_{actual} = 1.15 cm

For 7 GHz

Actual Length of Patch antenna using substrate FR4 Epoxy Glass having relative permitivity $€_r$ = 4.4, L_{eff} = 1.114 cm and ΔL = 0.07 cm is,

L_{actual} = 0.976 cm

For 8 GHz

Actual Length of Patch antenna using substrate FR4 Epoxy Glass having relative permitivity $€_r$ = 4.4, L_{eff} = 6.9 mm and ΔL = 1.66 mm is,

L_{actual} = 7.5 mm

For 9 GHz

Actual Length of Patch antenna using substrate FR4 Epoxy Glass having relative permitivity $€_r$ = 4.4, L_{eff} = 6.9 mm and ΔL = 1.66 mm is,

L_{actual} = 6.5 mm

2.6. Ground Plane Dimensions:

The transmission line model even though is applicable to infinite ground planes only but for practical considerations, a finite ground plane is used. However, size of ground plane should be greater than the patch dimensions by approximately six times the substrate thickness all around the periphery so that results are similar to the one using infinite ground plane. The ground plane dimensions Length and Width can be calculated by using following equations,

$$L_g = 6h + L$$

$$W_g = 6h + W$$

It can also be calculated using another formula as,

Lg=40h+L

Wg=40h+W

For 2 GHz

Patch antenna using substrate

Lg =4.3cm

Wg =5.5cm

For 3 GHz

Patch antenna using substrate

Lg = 3.2cm

Wg =4cm

For3.5 GHz

Patch antenna using substrate..

Lg = 2.8cm

Wg =3.5cm

For 6 GHz

Length and Width of antenna having substrate FR4 Epoxy Glass is,

Lg=40h+L = **7.7cm**

Wg=40h+W = **7.95cm**

For 7 GHz

Length and Width of antenna having substrate FR4 Epoxy Glass is,

Lg=40h+L = **7.376cm**

Wg=40h+W = **7.704cm**

For 8 GHz

Length and Width of antenna having substrate FR4 Epoxy Glass is,

$$L_g = 6h + L = \textbf{71.5 mm}$$

$$W_g = 6h + W = \textbf{75.4 mm}$$

For 9 GHz

Length and Width of antenna having substrate FR4 Epoxy Glass is,

$$L_g = 6h + L = \textbf{70.5 mm}$$

$$W_g = 6h + W = \textbf{74.1mm}$$

2.7. Coaxial Feed Point Location:

The inner conductor of the coax is connected to the radiation patch and the outer conductor to ground plane. The feed point should be near one of the two radiating edges [9].Parametric sweep method is applied to determine the feed point exactly.

Table 2.7.0 Feed Point Location

Antenna	Feed Point Location
2 GHz	**5.4, 4.9,0 (cm)**
3 GHz	**4.1, 4. 3,0 (cm)**
3.5 GHz	**4.71, 4.19,0 (cm)**
6 GHz	**3.8, 3.7,0 (cm)**
7 GHz	**3.79, 3.66,0 (cm)**
8 GHz	**36, 35.8,0 (mm)**
9 GHz	**35.8,35.8,0 (mm)**

Table 2.7.1 For 8 Ghz patch antenna:

Element	Calculated (mm)	Practically Used(mm)
W (Width of Patch)	W = 7.9 mm	W = 8.9 mm
L (Length of Patch)	L = 7.9 mm	L = 7.5 mm
Wg (Width of Ground)	Wg = 75.4 mm	Wg = 75.4 m
L (Length of Ground)	Lg = 71.5 mm	Lg = 71.5 mm

Table 2.7.5 For 2 GHz patch antenna:

Element	Calculated (cm)	Practically Used(cm)
W (Width of Patch)	W = 4.74	W = 3.48
L (Length of Patch)	L = 3.38	L = 3.48
Wg (Width of Ground)	Wg = 5.5	Wg = 10.9
L (Length of Ground)	Lg =4.3	Lg = 9.8

Table 2.7.6 For 3 GHz patch antenna:

Element	Calculated (cm)	Practically Used(cm)
W (Width of Patch)	W = 2.38	W = 3.1
L (Length of Patch)	L = 2.38	L = 3.5
Wg (Width of Ground)	Wg = 4	Wg = 9.4
L (Length of Ground)	Lg = 3.2	Lg = 8.5

Table 2.7.7 For 3.5 GHz patch antenna:

Element	Calculated (cm)	Practically Used(cm)
W (Width of Patch)	W = 2.04	W = 3.3
L (Length of Patch)	L = 2.04	L = 3.5
Wg (Width of Ground)	Wg = 3.5	Wg = 9
L (Length of Ground)	Lg = 2.8	Lg = 8.5

Table 2.7.3 For 6 GHz patch antenna:

Element	Calculated (cm)	Practically Used(cm)
W (Width of Patch)	W = 1.2 cm	W = 1.15 cm
L (Length of Patch)	L = 1.2 cm	L = 1.15 cm
Wg (Width of Ground)	Wg = 7.6 cm	Wg = 8 mm
L (Length of Ground)	Lg = 7. 6 cm	Lg = 8 cm

Table 2.7.4 For 7 GHz patch antenna:

Element	Calculated (cm)	Practically Used(cm)
W (Width of Patch)	W = 1.022 cm	W = 0.98 cm
L (Length of Patch)	L = 1.022 cm	L = 0.98 cm
Wg (Width of Ground)	Wg = 7.6 cm	Wg = 8 mm
L (Length of Ground)	Lg = 7. 376 cm	Lg = 7.376 cm

Table 2.7.2 For 9 GHz patch antenna:

Element	Calculated (mm)	Practically Used(mm)
W (Width of Patch)	W = 7.6 mm	W = 7.9 mm
L (Length of Patch)	L = 7.6 mm	L = 6.5 mm
Wg (Width of Ground)	Wg = 74.1 mm	Wg = 74.1 mm
L (Length of Ground)	Lg = 70. 5 mm	Lg = 70. 5 mm

3. Simulation and Results:

Simulation of the coaxial fed Microstrip antenna is carried out in Ansoft HFSS TM V 10.0. Analysis of radiation pattern and gain show that the coaxial fed Microstrip antennas have achieved the desired specifications successfully.

3.1. Simulation Results for 8 GHz:

A patch antenna model with L = W = 4.70 cm and a feed point at ~2.36 cm along the patch diagonal yielded a resonant frequency of 8 GHz, as well as an excellent resonant return loss. VSWR is less than 2.0.

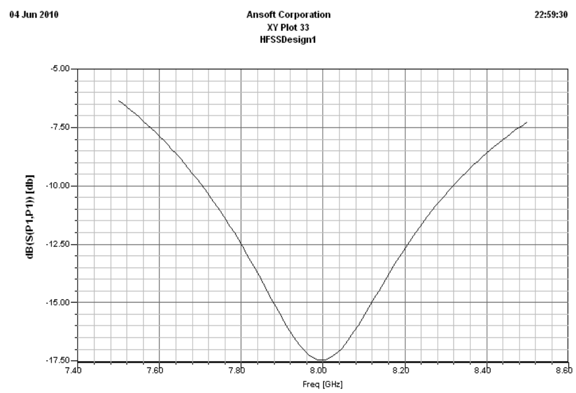


Fig.1: S11 response

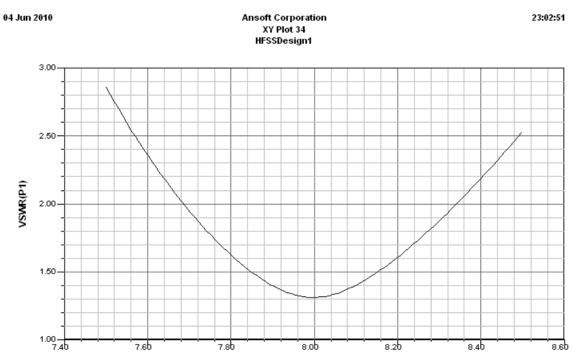


Fig.2: VSWR

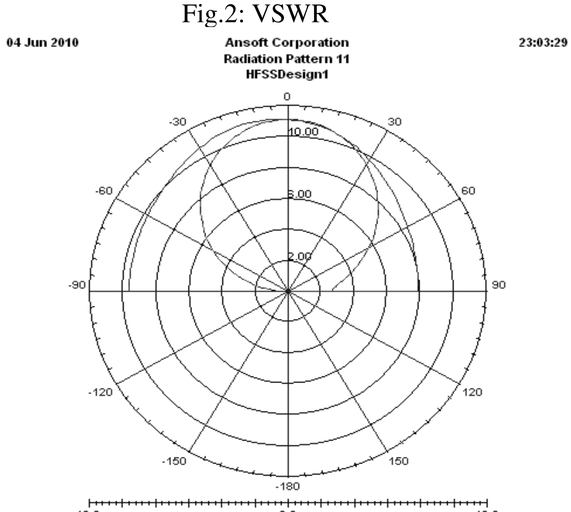


Fig.4: Radiation Pattern

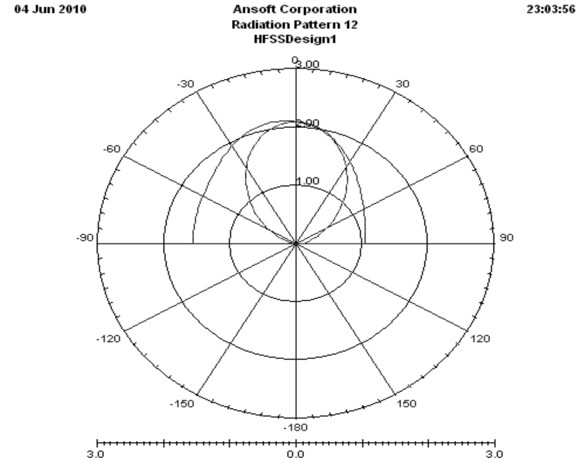


Fig.4: Antenna Gain

3.2. Simulation Results for 9 GHz:

A patch antenna model with L = W = 4.70 cm and a feed point at ~2.36 cm along the patch diagonal yielded a resonant frequency of 8 GHz, as well as an excellent resonant return loss. VSWR is less than 2.0.

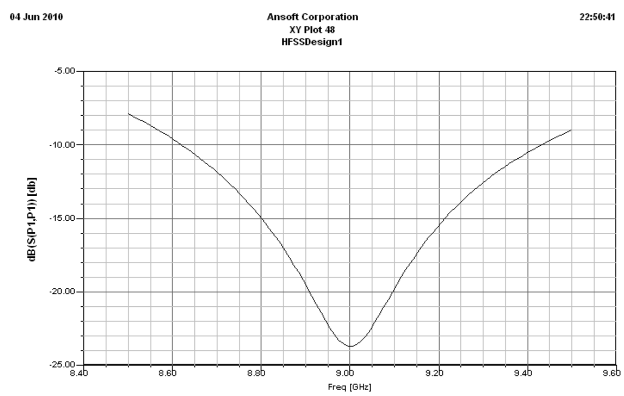


Fig.5: S11 response

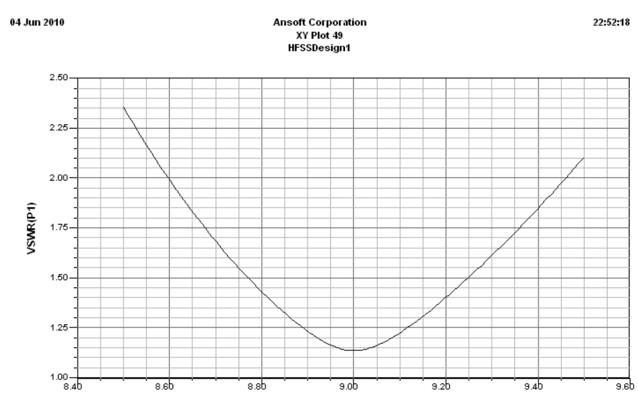


Fig.6: VSWR

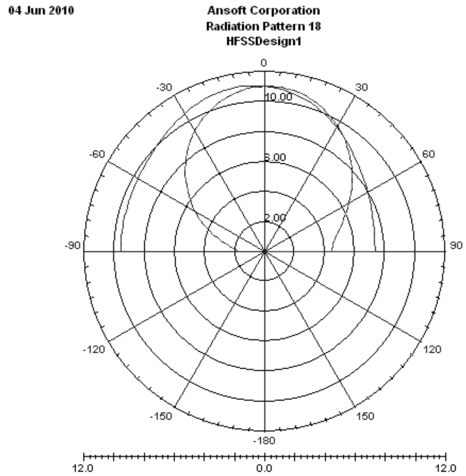


Fig.7: Radiation Pattern

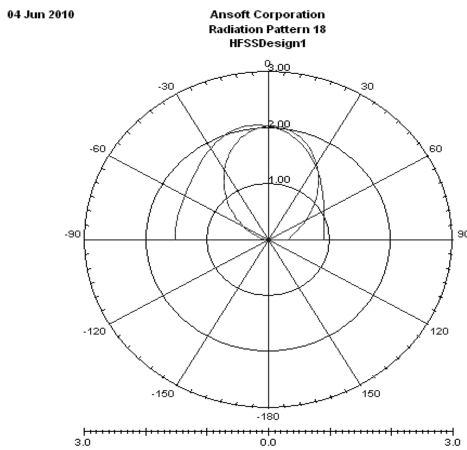


Fig.8: Antenna Gain

3.3. Simulation Results for 6 GHz:

A patch antenna model with L = W = 1.2. cm and and a

feed point of (3.8, 3.7 ,0)cm along the patch diagonal yielded a resonant frequency of 6 GHz, as well as an excellent resonant return loss. VSWR is less than 2.0

Fig.9:S11 Response for HFSS Simulation of Microstrip

Patch antenna.

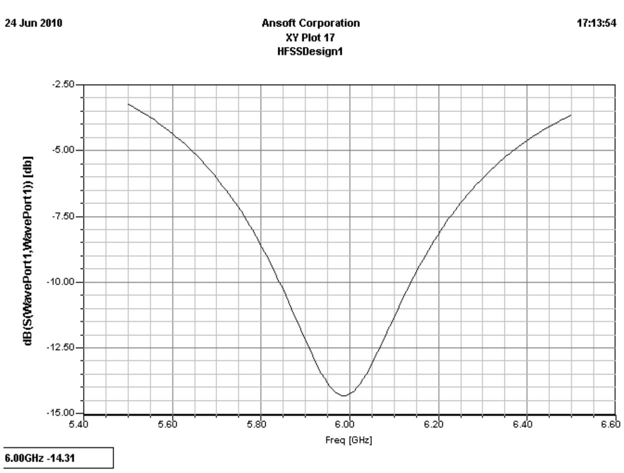


Fig. 9: S11 response

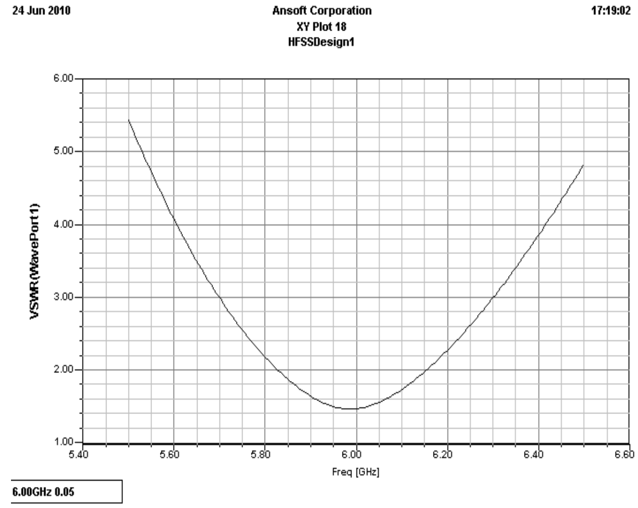


Fig.10: VSWR

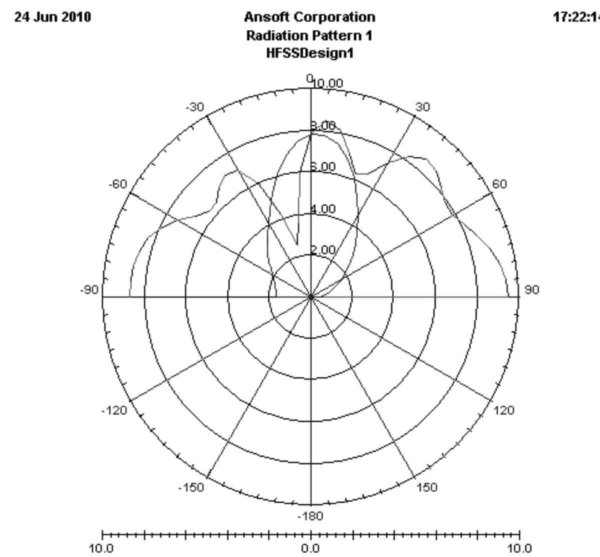


Fig.11: Radiation Pattern

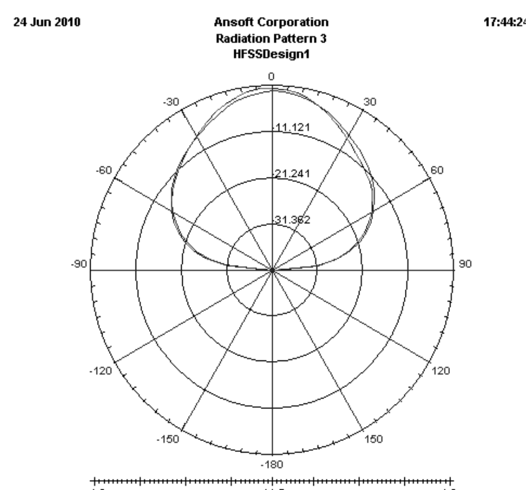


Fig.12: Antenna Gain

3.4. Simulation Results for 7 GHz:

A patch antenna model with L = W = 1.022. cm and a feed point of (3.79, 3.66, 0) cm along the patch diagonal yielded a resonant frequency of 6 GHz, as well as an excellent resonant return loss. VSWR is less than 2.0

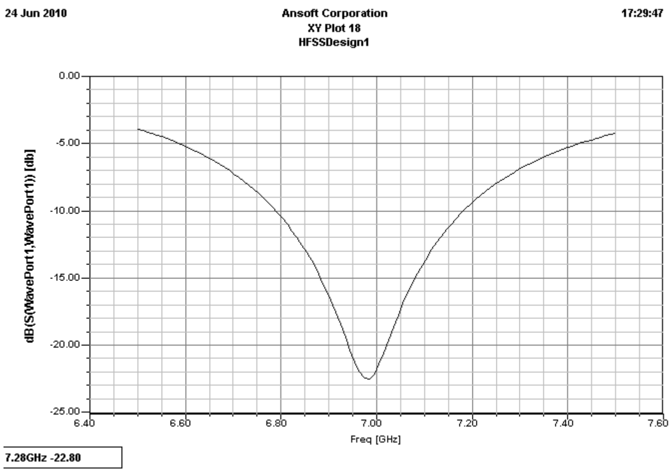


Fig.13: S11 response

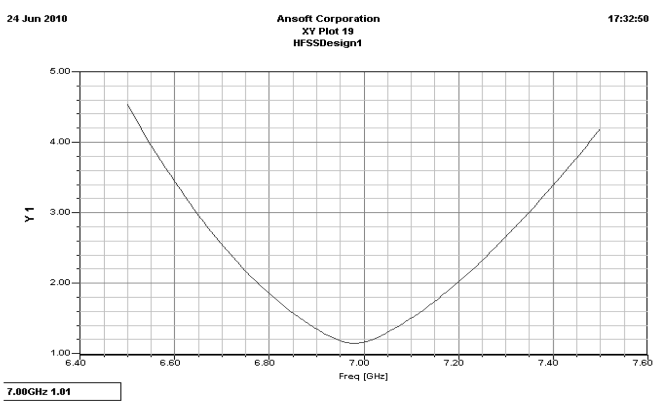


Fig.14: VSWR

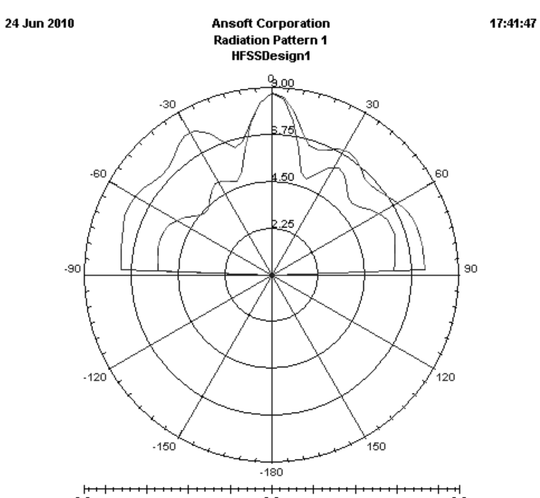


Fig.15: Radiation Pattern

For 2 GHz patch antenna

The simulation result of 2 GHz Patch antenna is shown below.

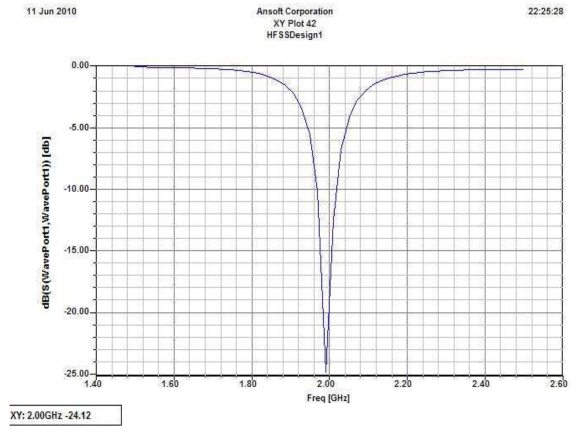


Fig16. S_{11} response

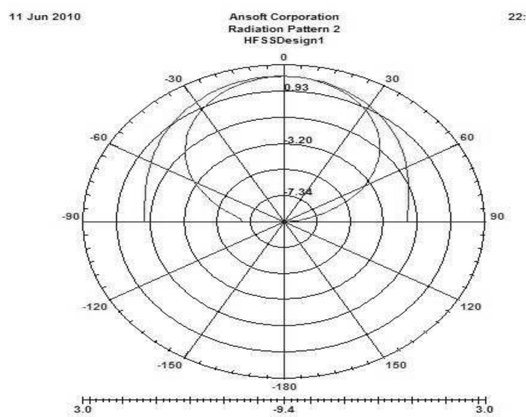


Fig 17: Radiation Pattern

Conclusion-

These antennas used for several applications specially 3 GHz to 3.6GHz for wireless local loop, 3.5 GHz for WIMAX, 5GHz to 6GHz for WLAN, 7 GHz for Ultra-Wide Band Communication, 8 GHz for transmission and 9.2-9.5 GHz for reception of SART (Search and Rescue Transponders) for signals coming from X-band radars.

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