Middle-East Journal of Scientific Research 24 (9): 2843-2849, 2016
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2016.24.09.23874

Design and Development of Millimetre Wave Microstrip Antennas for Short Range Radar Communications

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Abstract: Two millimeter wave microstrip patch antennas suitable for operation in the ISM 5.8 and 24 GHz band are developed for short range radar communications. The design and simulations are done using Ansoft HFSS. Inset feed line is used to provide 50Ω impedance matching. Antenna gain values of around 6 dBi are obtained in addition to a very less return loss . The fabricated antenna provides a bandwidth of 120 MHz and an input impedance of ~50Ω. The phase is also found to be constant with increasing frequencies.

Key words: 5.8GHz · 24 GHz · microstrip patch antenna · Radar · Short range communications

INTRODUCTION

The 2.4GHz band is widely used in consumer devices such as WLANs, ovens, Bluetooth and local communication devices [1]. The high traffic in this band results in an increase in complexity of the receiver to reject noise and interference to maintain signal quality. Hence it is better to use an uncluttered and larger band as the 5.8GHz band and 24 GHz bands, for better management of large capacity real-time systems. Most short-range communications occur around human structures, such as vehicles and buildings. Because of their shorter wavelength, the signals at 5.8GHz and 24.125GHz can pass through the narrowest of spaces. At the same time, they maintain their ability to penetrate through almost similar materials such as waves in the 433MHz band. Therefore, when the waves at 433MHz are blocked or diffracted by obstacles, due to the signal wavelength of more than 70cm, the signal at 5.875GHz can easily pass through these obstacles of its very short wavelength of only 5.17cm. The propagation characteristics [2] of signal at 433MHz, 900MHz, 2.4GHz, 5.875GHz and 24.25 GHz in the free space are similar in situation of rain. This is important to consider in tropical climates and continental for outdoor applications. The bit error rate per bit transmitted (BER) is much lower due to a less crowded bandwidth. This is almost twice the bandwidth of 2.4GHz band. This results in more energy-efficient products with higher data rates.

The antennas developed in this paper are intended for a automotive radar system [3] with which the location and the speed of vehicles or objects around the vehicle can be detected. Current systems which use laser technology or infrared/ultrasonic are not immune to bad weather conditions, when these systems are needed the most.

Several features are offered by an automotive radar system. The collision warning system is a feature that alerts the driver during parking and on road it indicates the distance between vehicles. Automotive radar system also helps in obstacle detection in blind spots around the driver. The lane change assisting feature warns the driver of impending cars during lane changing and overtaking.

Vehicles [4] approaching from behind also have to be monitored permanently. When an obstacle is sensed within the collision radius, safety systems like tightening of the seatbelt or bringing to halt using smart brake system have to be automatically switched on to protect the passengers. These features are illustrated in Figure 1.

The paper is organized as follows: Tha antenna is designed for the required band using the design equations. The designed parameters are then optimized using the simulation tool to provide the desired results. The antennas can be integrated with the feeding network on the same substrate, resulting in structures that are compact and very useful in real-time applications.

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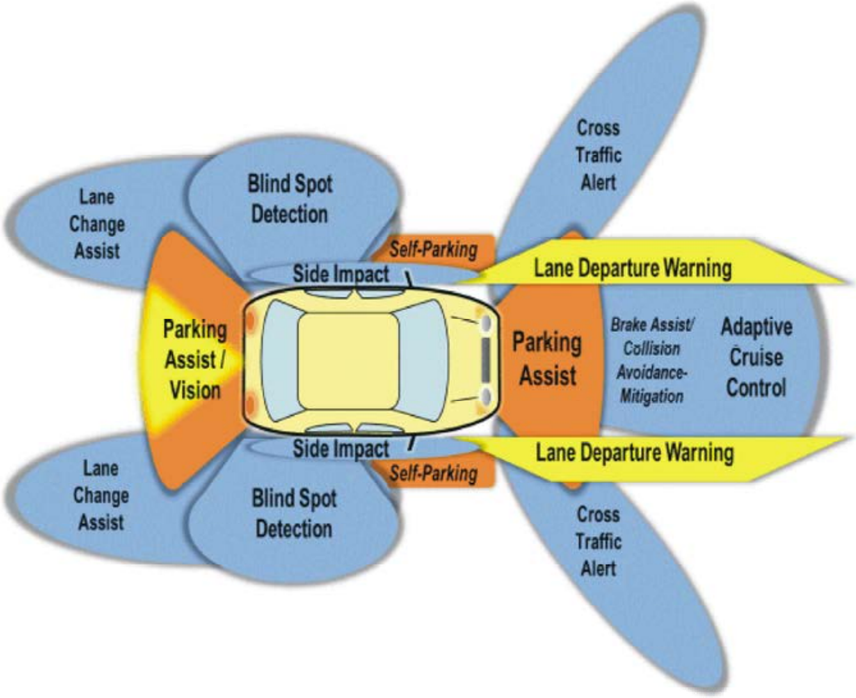


Fig. 1: Sophisticated features offered by a short range automotive radar system

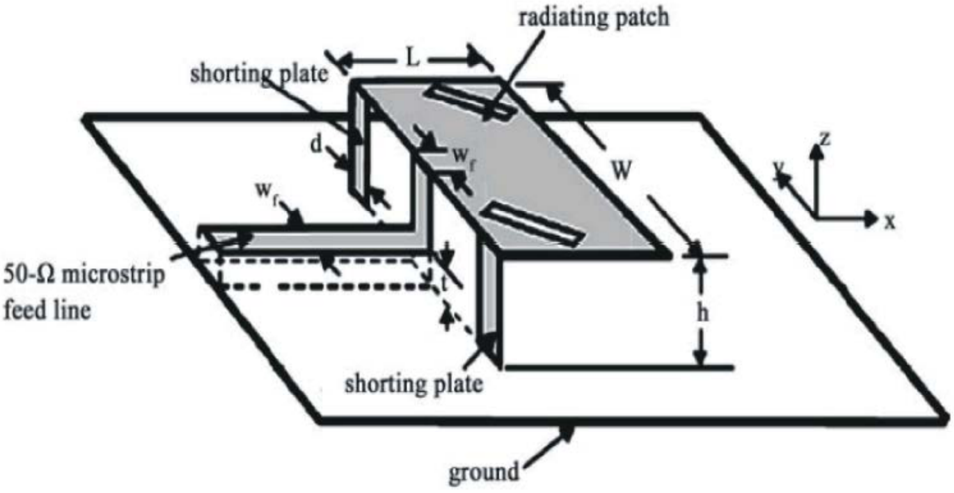


Fig. 2: Design of a Microstrip patch geometry

Both antennas are simulated in RT/Duroid 5880 substrate material in order to achieve good resonance. The antennas are then fabricated and their real time measurements are compared.

Microstrip Antenna Design Analysis: Figure 2 shows the physical layout of a rectangular microstrip antenna[5] with microstrip line feed system. A microstrip antenna generally contains ground plane, dielectric substrate and a patch with a feed system.

The antenna dimensions are calculated using the available design equations (2.1) to (2.9). The two main critical design parameters namely the dielectric constant (ε_r) and height (h) of the substrate are carefully chosen according to the availability.

Patch width [6] of microstrip antenna is calculated using the below equation (2.1).

$$W = \frac{C_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{2.1}$$

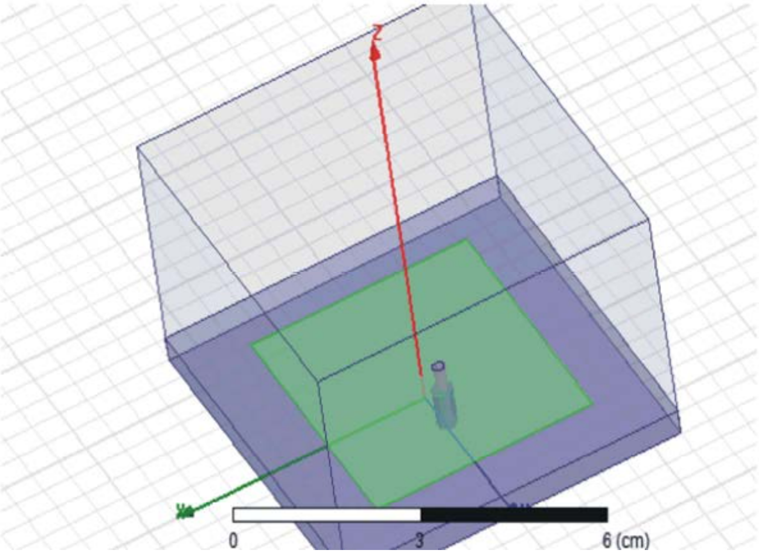


Fig. 3: Design and Simulation of 5.8GHz (above) and 24 GHz (below) microstrip patch with inset feed line

where C_0 is the velocity of light in free space; $\varepsilon_r = 2.2$; $f_r = 5.875/24.125$GHz

Effective dielectric constant [7] is given by the equation (2.2).

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1\backslash 2} \qquad (2.2)$$

where h is the height of the substrate. Usually the height is much lesser than the wavelength of signal and W/h >1.. The increase in patch length, ΔL that occurs due to fringing effects and is calculated using equation 2.3.

$$\Delta L = 0.412h\left[\frac{\varepsilon reff + 0.3}{\varepsilon reff - 0.258}\right]\left[\frac{\frac{W}{h} + 0.264}{\frac{w}{h} + 0.813}\right] \qquad (2.3)$$

Finally, the length of the patch is calculated using equation (2.4).

$$L = \frac{C_0}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L \qquad (2.4)$$

Simulation of 24 Ghz Microstrip Patch: The calculated values obtained from the design equations are used to simulate in Ansoft HFSS. Changes in the values of the dielectric constant resulted in the change of the centre frequency. The height is fixed at 0.787mm based on the limit available in market. If the substrate width is decreased, input impedance increases and when the length is decreased, resonant frequency shifts.

The probe feed method resulted in a return loss of -10.15 dB and the response was found to be very poor. Parasitic coupling increases the return loss and hence a fractional bandwidth of 4.4 % is obtained. Inset feed produces good bandwidth, gain and directivity. The height of the substrate is to be kept at more than 0.05λ to obtain better bandwidth.

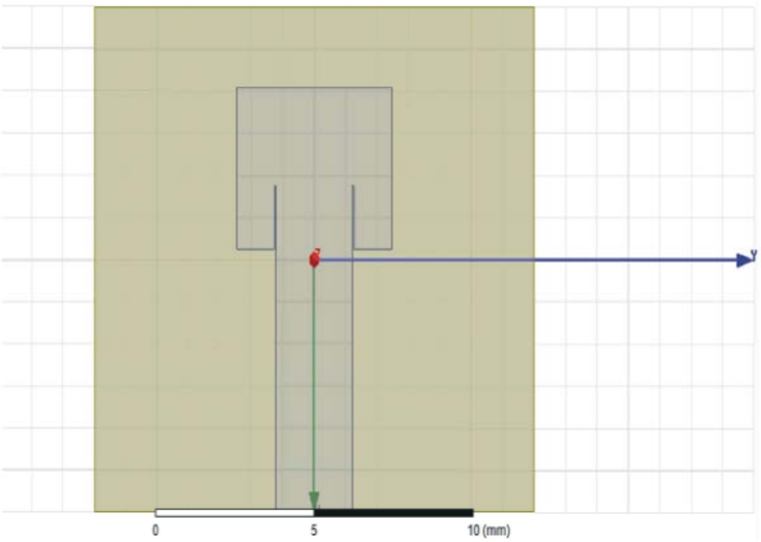
RT/Duroid 5880 substrate with dielectric constant of 2.2, height 0.787 and tanδ of 0.0009 is used. Copper material is chosen for patch and ground plane design. The thickness of the copper patch is taken as 70 microns. The simulated top design is shown in Figure 3.

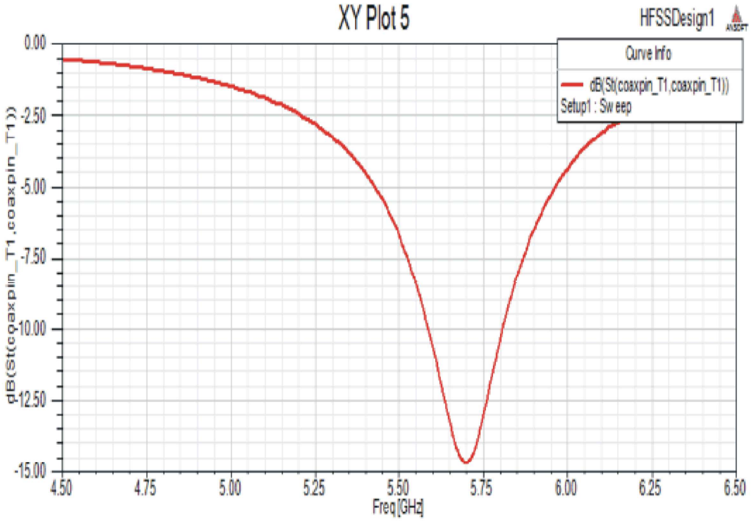
EXPERIMENTAL RESULTS

The design was simulated in Ansoft HFSS software and the design specifications of the antennas are listed below in Table 1. The physical dimensions of the design are critical during fabrication since a slight change in the dimensions results in the total shift of the centre frequency of antennas.

The antennas are characterized by parameters namely the return loss, gain and bandwidth. Since a gain of 6 dB is required for short range communications, the design was optimized to provide a 6 dB gain.

The rectangular plot shown in Figure 4 shows that the return loss, $S_{11\ dB}$ is minimum at 24.17 GHz which is very near to the resonant frequency.





(a)

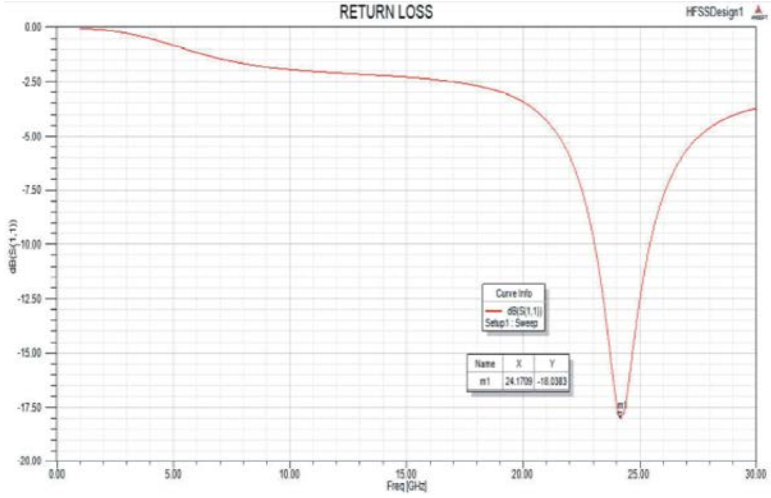


Fig. 4: S_{11} Parameter for (a)5.725GHz and (b)24.25GHz band

Table 1: Antenna Simulation Results

S.No	Parameters	5.725-5.875GHz Band	24-24.25 GHz
1	Simulated Resonant Frequency	5.875GHz	24.2 GHz
2	Patch Length	16.3mm	3.82 mm
3	Substrate height	1.5mm	0.787 mm
4	Dielectric Constant of Substrate	2.2	2.2
5	Min. Return Loss	-14.5 dB	-22.1 dB
6	Bandwidth	200 MHz	1.2 GHz
7	Total gain	5.84 dBi	5.95 dBi
8	Half Power Beamwidth	52 degrees	46 degrees
9	Fractional Bandwidth	5%	5%
10	Directivity	4.87	4.94
11	Line Impedance	50Ω	50Ω

Table 2: Test Measurement Results.

Parameters	5.725-5.875GHz Band	24-24.25 GHz
Return Loss	-38.79 dB	-20 dB
Bandwidth	120 MHz	100 MHz
VSWR	1.023	1
-10 dB Impedance bandwidth	0.5 %	0.5 %
Line impedance	49.12 Ω	50 Ω

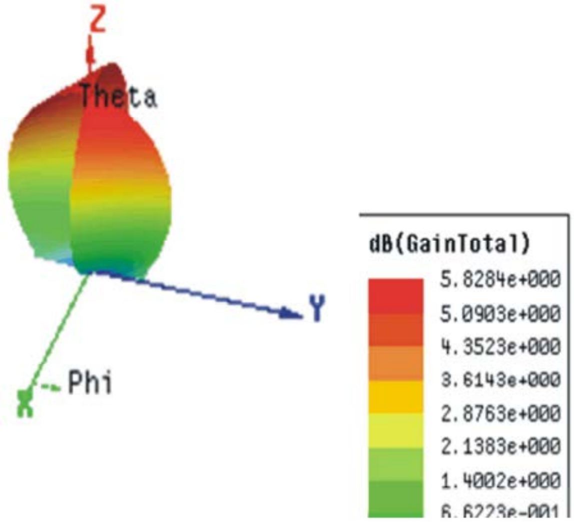
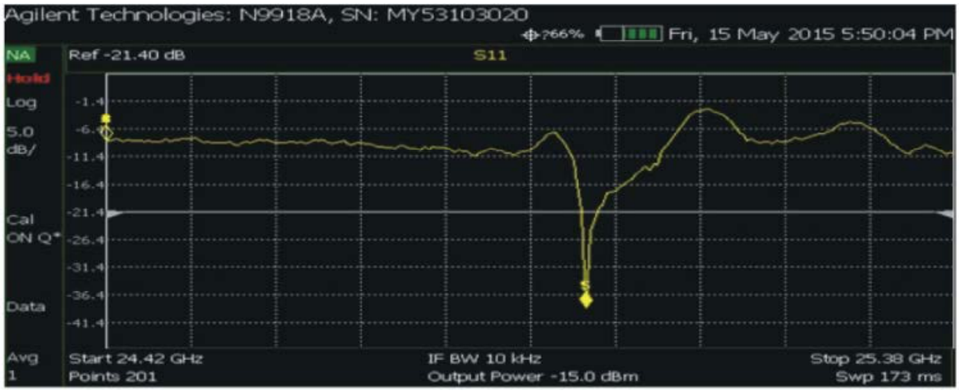


Fig. 5: 3-D Radiation pattern of the simulated 5.8 GHz microstrip patch

Fig. 6: Fabricated patch antennas with feed points


Agilent Technologies: N9918A, SN: MY53103020

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Ref -21.40 dB

S11

Start 24.42 GHz

Points 201

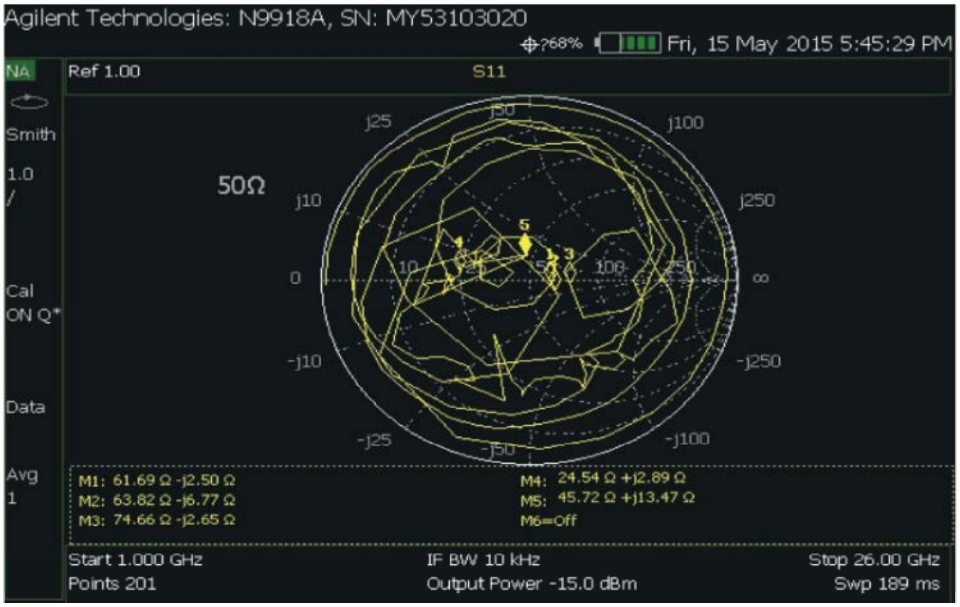
IF BW 10 kHz

Output Power -15.0 dBm

Stop 25.38 GHz

Swp 173 ms

Fig. 7: Measured S_{11}parameter of the patch using Vector Network Analyzer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Ref 1.00

S11

M1: 61.69 Ω -j2.50 Ω

M2: 63.82 Ω -j6.77 Ω

M3: 74.66 Ω -j2.65 Ω

M4: 24.54 Ω +j2.89 Ω

M5: 45.72 Ω +j13.47 Ω

M6=Off

Start 1.000 GHz

Points 201

IF BW 10 kHz

Output Power -15.0 dBm

Stop 26.00 GHz

Swp 189 ms

Fig. 8: Measured input impedance

The bandwidth of 2.3 GHz can be obtained from the plot. The frequency band providing less than -10 dB return loss is taken as the bandwidth of the antennas. Radiation pattern and gain pattern obtained and shown in Figures 5 and the patch antenna is shown in Figure 6 respectively.

The antennas are fed through inset feedline. Circular polarization (CP) is achieved through this design. The detailed results obtained through simulation are listed in Table 1. Return loss is measured using Agilent Vector Network Analyzer (VNA) N9918A.The VNA supplies -15 dBm output power to the fabricated patch.

The Vector Network Analyzer measurements show a minimum return loss, S_{11} at 24.96 GHz with -38.79 dB and -20dB for 5.8GHz band. A frequency sweep from 1GHz to 26 GHz has been applied and return loss has been measured for the patch as shown in Figure 7 and the measured impedance is shown in Figure 8. The measured results are tabulated below in Table 2.

The 6dB gain obtained by both the antennas proves that there are suitable for short range communications. Both 5.8 GHz and 24 GHz band suffer from high attenuation during rainy conditions. So it is important that these antennas are well covered in a semi-transparent cover to safeguard from environmental effects while using outdoor. They also suffer from absorption inside buildings hence repeaters can be provided for short range indoor communications.

CONCLUSION

Two antennas, one in 5.875 GHz and another in 24 GHz ISM bands are designed, simulated in HFSS, fabricated and tested. The antennas were designed mainly for short distance communications, like vehicular communication. The simulated parameters and the measured parameters are compared. The fabricated antennas provides a gain of 5.9dBi for an input impedance of ~50Ω and VSWR of 1.023. The results show that these bands can be used to replace the more congested 2.4GHz band.

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