Hexagonal Patch Microstrip Antenna with Parasitic Element for Vehicle Communication

Jimi Prasojo
Department of Information Technology Management
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
jimiprasojo@gmail.com

Riyanarto Sarno
Department of Informatics
Institut Teknologi Sepuluh Nopember
Surabaya, Indonesia
riyanarto@if.its.ac.id

***Abstract*—In this paper, a compact conformal antenna is proposed for vehicle to X (V2X) communication applications. The Hexagonal-shaped geometry is applied in the design to attain desired band in the vehicular communication spectrum. The proposed dimension antenna is 50mm x 50mm x 1.6 mm. By loading the hexagonal patch and annular slot with different sizes at each angle, it realizes to enhance bandwidth and increase the gain. This article explains how we found that tuning and overlapping of resonant frequency was mainly achieved by hexagonal parasitic element. The prototype antenna had been design using Ansys HFSS v.15. The simulation result shows that the antenna had resonant frequency at 5.9 GHz with return loss value of 32.95 dB. The antenna had VSWR value of 1.0189. This microstrip antenna had thickness of 1.6 mm, so it should be easy to fit up hidden in front of a vehicle for vehicular communication.**

Keywords: Hexagonal Patch, Microstrip Antenna, Vehicle Communication, Wireless Communication.

I. INTRODUCTION

The wireless communication are one of advanced technology of our time. In the present days, wireless communication becomes an essential part of various types of wireless communication devices. There are many devices, as it allows users to interact with others. Wireless communication technologies are widely used for transmission of data or information from one place to another. It should bring great convenience for the activities of people. For example, cellular communication such as GSM, LTE, and 5G can make interpersonal communication more convenient and makes people connecting faster [1]. Not only used as wireless communication, it can also be used to manage vehicles; for instance, it can support system to provide information about real time traffic on the roadway to effectively help drivers from traffic congestion and traffic accident [2].

Nowadays, the population of vehicles remains increasing, be it for public transportation and personal transportation. Each year the number of vehicles on the road has grown faster than the roadway capacity. It is not comparable with the existing road segments. Thus, the level of traffic congestion has also increased significantly in every year.

In addition, the traffic accident can also lead to traffic congestion on the road. Therefore, it takes a system that can help a driver who is able to give information about the speed, position, direction and traffic situation when driving the vehicle. For this reason, the 5.9 GHz has allocated for the dedicated short-range communication (DSRC) system. DSRC is communication technologies which help the various communications between vehicles and infrastructure [3]. DSRC uses the IEEE 802.11p wireless access for vehicle environments (WAVE) standard which modified of the IEEE 802.11 Wi-Fi standard. The bandwidth allocation for DSRC is 75 MHz from 5.85 to 5.925 GHz. It has applied for the DSRC system which includes the vehicle to vehicle (V2V) communication and the vehicle to infrastructure (V2I) communication [4].

Among many antenna technologies existing in the recent years, ones which are widely used and can be implemented on the vehicles are Monopoles Antenna, Patch Antenna, On-Glass Antenna, Glued Foil Antenna, and Fractal Antenna [5]. But, the patch antenna is more popular in the automotive industry than others. Because it is unobtrusively flat and easily implemented into the vehicles component; for example behind a bumper, fender, roof or trunk cover.

Most of vehicle antenna are designed for low frequency application; for example, frequency and amplitude modulation on radio broadcasting at 30-300 MHz, GSM spectrum frequency at 800-900 MHz, GPS at 1.23 – 1.57 GHz, and Bluetooth transmission, often known to be connected to radio on the vehicle has frequency at 2.45 GHz [6]. There were very few research projects on vehicular communication antenna which are operated on the high frequency at 5 GHz. Some papers have been reported in the literature that proposes antenna designs for the DSRC system to vehicle communication [7]. The various antenna had proposed in previous work that achieved DSRC system frequency for vehicular communication. In [8], antenna had presented for DSRC system at resonant frequency from 5.8 – 5.95 GHz. It combines rectangular patch antenna design with broadsides radiator. By modifying the width of feed line antenna can control the position of resonant frequency. In [1], the hexagonal microstrip antenna for vehicle communication has resonant frequency at 4.74 – 6.79 GHz. The hexagonal microstrip antenna had designed by inserting short pins and etching V shape slot with various sizes at each angle of the hexagonal patch. The result of V shape slot achieved wide impedance bandwidth and good impedance matching. In [9], the researcher proposed to design antenna used by hexagonal geometry microstrip combined with Koch fractal geometry. The result shows that the insert cut feeding on the proposed antenna has better performance than without insert cut feeding. The proposed antenna has multiband frequency at 3.36 GHz, 5.61 GHz, 8.58 GHz, and 9.48 GHz. The radiation pattern of the antenna showed a good result. It showed multidirectional radiation had achieved compatible for multiband application. In [10], the researcher opts for hexagonal patch because it has improved performance over rectangular and circular patch. The proposed antenna has resonant frequency for S-band spectrum at 2.4 – 3.0 GHz by selected dimension of hexagonal shape.

In this study, a microstrip antenna is used because it has a small volume, low profile, compact design, light weight, compatible integration with other devices, and good concealment. It also has a wide application prospect in the field of the vehicular antenna [11]. The low profile and low cost can eliminate the disadvantage of the existing vehicular communication antenna [12]. Loading the shorting pin and checking the hexagonal slots of the antenna can produce wide bandwidth and achieve good impedance matching. Moreover, Omni-directional radiation patterns can be obtained. The proposed antenna are small in size and can be simply checked which is suitable for V2V communication. This paper uses conventional survey method [13-15] to optimize iteration design antenna. The iterations are used in designing antenna in order to better parameter value.

A. Dedicated Short Range Communication

DSRC (Dedicated Short-Range Communications) is a wireless communication technology developed to support communication between vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). V2V communication is used when vehicles need to exchange information wirelessly with other vehicles in order for the operative to work properly such as their location, heading, and speed, whereas V2I communication is used when vehicle need to exchange information wirelessly with smart road infrastructures such as traffic signals, lane road marking, and other smart roadside units. DSRC technology uses radio frequency spectrum on 5.90 GHz. It is effective to operate over short to medium range communication services for support operation in V2I and V2V communication. IEEE 802.11p is DSRC standard has mentioned that this technology support transmission distance up to 1000 meters. DSRC can provide data rates from 6 – 27 Mbps where support vehicles move at speed up to 140 km/h. Besides, DSRC has high reliability and low latency, so it is a secure transmission and support interoperability to receive a slight disruption, even in the extreme weather condition, due to the short span that stretches. This makes it ideal for communication to and from fast-moving vehicles.

A dedicated spectrum of 75MHz in the 5.9 GHz band is allocated for Intelligent Transportations Systems (ITS), specifically for DSRC technology [16]. The DSRC services are connecting the vehicle communications system to help and protect the safety of the road users. It can save lives of the road users from dangerous condition on the road by warning system. Moreover, the frequency band of 5.90 GHz has standard operation to control traffic signals, such as transmit signal priority for the emergency vehicle, to avoid intersection collision, toll collection, electronic parking payment, and other transit services.

Fig.1 shows the topology of DSRC vehicle communication. The Equipment of the DSRC system are On Board Unit (OBU) and Road Side Unit (RSU). Antenna as transceiver equipment must be placed on the OBU and RSU. The OBU equipment is fitted up on the vehicle and the RSU equipment is fitted up on the infrastructure component. OBU consists of the transceiver radio, GPS, and other applications to connect OBU with other vehicles and infrastructures. Meanwhile, RSU consists of the transceiver radio and other applications and interfaces that connect with the V2I communication network.

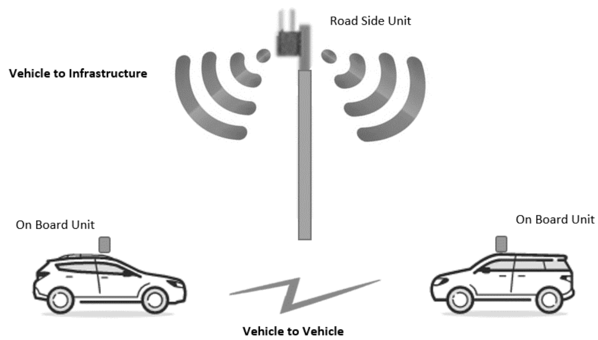


Fig.1 Topology of DSRC Vehicle Communication

RSU functions to broadcast data to OBU or exchange data with OBU on the communications zone. The DSRC technology has been standardized to be implemented and thoroughly tested for V2X applications for more than a decade. The products are ready and large for DSRC ecosystem providers a full suite of interoperable solutions [16]. OBU is placed on the roof of vehicle because it is the high above ground and unobstructed. It provides omnidirectional for good reception of wireless system. The aim of DSRC is to allow communication system that it can work properly on Non Line Of Sight (LOS) condition, since no other sensor is able to. It is optimized for high mobility even in the presence of obstructions and handling fast changing environment at speeds as high as 500 km/h. It has been shown that a range over 1 km is routinely achievable. DSRC can ensure a common interoperable safety standard for vehicles, regardless of size, to help avoid crashes, optimize traffic flow, and reduce congestion.

B. Hexagonal Microstrip Antenna

Microstrip antenna has various shapes for antenna design, such as rectangular, triangular, circle, pentagonal, hexagonal, and other shape geometry [17]. Each shape has difference characteristic for microstrip antenna. The hexagonal antenna was first proposed by [22]. Hexagonal microstrip antenna is capable for linear polarization operation that has been reported in [10.18]. The calculation size of hexagonal patch antenna is made by considering frequency response. The proposed antenna can be considered as hexagonal shape. The hexagonal shape had chosen because of the regular hexagon has the most compact geometry which having more area coverage than other basic geometrical shapes, such as triangular, rectangular and circular [19]. In [20], the simple hexagon geometry on the microstrip patch antenna shows good performance to reach high gain and wide bandwidth. Moreover, the hexagonal slot also increases bandwidth of the antenna and achieve dual band frequency [21]. The structure of hexagon patch antenna had printed by copper on the upper side of the substrate and transmission line on ground plane which printed below the substrate.

The purpose of this study is to determine whether the hexagonal patch antenna design can be implemented in vehicular communication. The antenna should work properly on resonant frequency at 5.9 GHz with high gain and proportional bandwidth. Also, the DSRC does not require wide bandwidth to minimize interference. In this paper, an analysis of the hexagonal patch microstrip antenna with parasitic element for vehicle communication is presented and discussed. The second section of the paper describes the design structure of proposed antenna. The development and simulation result analysis of the iteration parameters antenna are included in section 3. The impact analysis of parameters antenna on frequency response of the antenna has been investigated in section 4. Section 5 is the final section to conclude the experiment of the proposed work.

II. ANTENNA DESIGN

In this section, we determine the proposed antenna parameters such as material of substrate, thickness of substrate, relative permittivity of substrate, and resonant frequency of the antenna. The simulation design antenna used low cost substrate material FR4 epoxy because it has good mechanical properties and fairly small thickness. The thickness of substrate material is 1.6 mm. FR4 epoxy has relative permittivity (εr) value of 4.4 and loss tan value of 0.02. The resonant frequency (fr) of the proposed antenna is 5.90 GHz.

The antenna design used hexagonal geometrical shape of which equation is to calculate the radius of patch (Rp). The radius of patch is radian length of the hexagonal patch as shown in Fig. 2. The equation (1) and (2) was perform to obtain the Rp value of 24.0 mm.

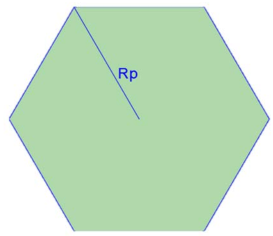


Fig.2 Basic Hexagonal Antenna [9]

$$Rp = \frac{F}{\{ 1+ \frac{2h}{\pi F\, \varepsilon r}[\ln\left(\frac{\pi F}{2h}\right)+1.7726]\, \}^{\frac{1}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$F = \frac{8.791\, x\, 10^{9}}{fr\, \sqrt{\varepsilon r}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

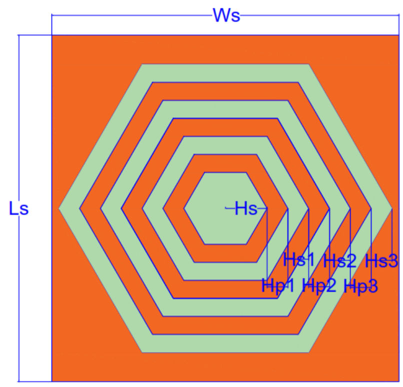
The thickness (h) and relative permittivity (εr) of the substrate has highly influence the width of feed line. The equation (3) and (4) are follows to reach the width of the feed line as can be seen at [10].

$$W_f = \frac{2h}{\pi}\left(B - 1 - \ln(2B-1) + \frac{\varepsilon r - 1}{2\varepsilon r}\right)\left(\ln(B-1) + 0{,}39 - \frac{0{,}61}{\varepsilon r}\right) \ldots (3)$$

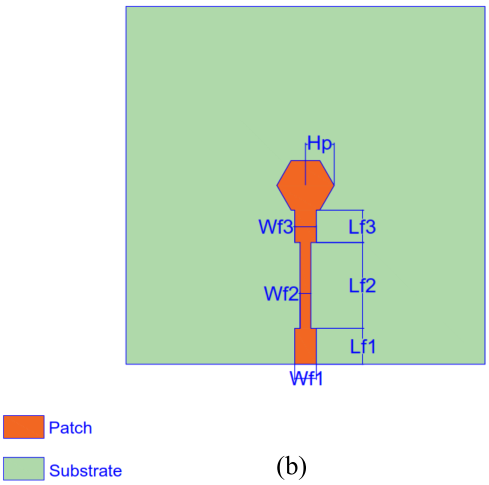
$$B = \frac{377\,\pi}{2\, Z_0 \sqrt{\varepsilon r}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

A. Parameters Microstrip Hexagonal Antenna

Fig. 3 illustrates the design structure of the hexagonal patch antenna with parasitic slots. The hexagonal shaped patch is positioned on the center of the antenna. Then, the parasitic hexagonal slot element is put on the antenna. It can enhance bandwidth and gain of the antenna. Detail dimension of the antenna is presented in table 1. It shows the dimensions of the hexagonal patch and slot on the top layer substrate and feed line with hexagonal shape dimension on the bottom layer substrate. The changes in the dimension antenna can present the different parameter results as well. By choosing the proper choice of mode excitation beneath the patch this can be achieved.



(a)



(b)

Fig.3. Design of Hexagonal Microstrip Antenna: (a) Top Layer (b) Bottom Layer

Tabel I. Structural parameters and dimension antenna

Parameters	Dimensions in mm	Parameters	Dimensions in mm
Ws	50	Hp3	3
Ls	50	Hs3	3
Hs	6	Wf1	3
Hp	4	Lf1	5
Hp1	3	Wf2	1.5
Hs1	3	Lf2	12
Hp2	3	Wf3	3
Hs2	3	Lf3	4.53

The thickness of the conducting copper patch layer is taken 0.035 mm. In this case, the copper patch layer function as resonator. We used iteration methodology of simulation antenna design on the patch and slot to optimize the parameter results. The proposed antenna was simulated using the Ansys HFSS software computation.

III. ANALYSIS SIMULATION RESULT

In this section, we analyze the hexagonal patch microstrip antenna using slot parasitic elements on the patch method and the parameter results of the iteration design on the proposed antenna. The selection of dielectric material performs a major role in the design of a microstrip antenna [8].

A. Analysis Simulation Result

The hexagonal patch has been integrated with microstrip feed line on the bottom layer with optimization characteristic size. The dimension of the feed line are Hp=4 mm, Wf1 = 3 mm, Wf2 = 1.5 mm, Wf3 = 3 mm, Lf1 = 5 mm, Lf2 = 12 mm, and Lf3 = 4.53 mm. By optimizing the characteristic size of the feed line design, a better reflectance can be achieved. It gives suppress out of band harmonics. Fig.4 shows the simulation results of the illustrate structure of the hexagonal patch antenna. We optimized the characteristic dimension of the hexagonal parasitic width of patch and slot antenna. The value of iteration 1 are Hp1 = Hp2 = Hp3 = 3mm and Hs1 = Hs2 = Hs3 = 3mm. The value of iteration 2 are Hp1 = Hp2 = Hp3 = 2mm and Hs1 = Hs2 = Hs3 = 3mm. The value of iteration 3 are Hp1 = Hp2 = Hp3 = 3mm and Hs1 = Hs2 = Hs3 = 2mm. The value of iteration 4 are Hp1 = Hp2 = Hp3 = 4mm and Hs1 = Hs2 = Hs3 = 2mm. The alteration value of Hp1, Hp2, and Hp3 parameters can achieved some harmonic band resonant frequency for return loss (S11) < -10 dB. Each iteration has different position of resonant frequencies. So, the iteration of which has resonant frequency at 5.9 GHz must be chosen.

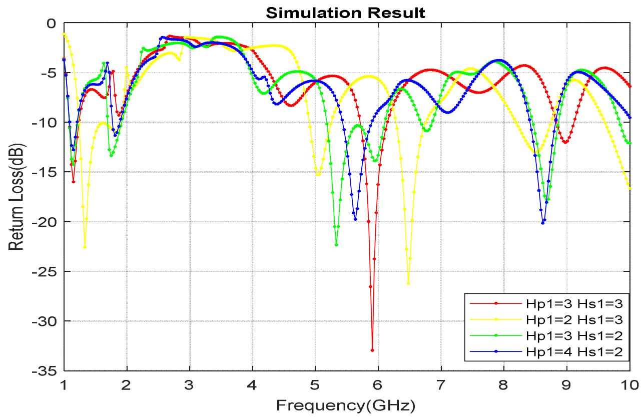


Fig.4.Return loss simulation result for alteration value of parasitic width

The simulation alteration value in term of the width of feed line parameters antenna is used to achieve suppress out band harmonic. The value of iteration 1 is Wf2 = 1.5 mm, iteration 2 is Wf2 = 2 mm, and iteration 3 Wf2 = 3 mm. Fig. 5. Shows the return loss simulation result for the iteration values. By reducing size of the Wf2 value, the impedance matching at frequency band of 5.9 GHz is improved.

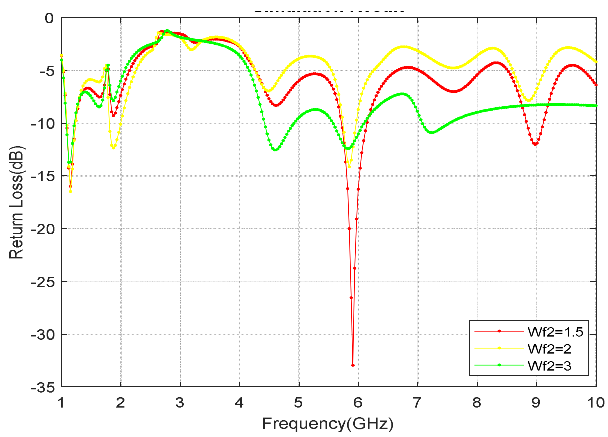


Fig.5.Return loss simulation result for alteration value of feed line width

IV. RESULT AND DISCUSSION

In this section, we choose the best iteration of the antenna parameters to analyze the simulation result. The proposed antenna has been simulated to concern the value of return loss, bandwidth, gain, VSWR, and radiation pattern at different size parameters. The proposed antenna was analyzed using the hexagonal parasitic element of patch and design type of feeding transmission line. The simulation result has a return loss value < -10 dB at frequency band from 5.70 – 6.10 GHz. It means the bandwidth value is 400 MHz. The return loss of the simulation result at frequency of 5.9 GHz is -32.95 dB. It indicates that the antenna performs good reflectance. Fig.6 shows the return loss simulation result of the antenna design as shown in Fig 3.

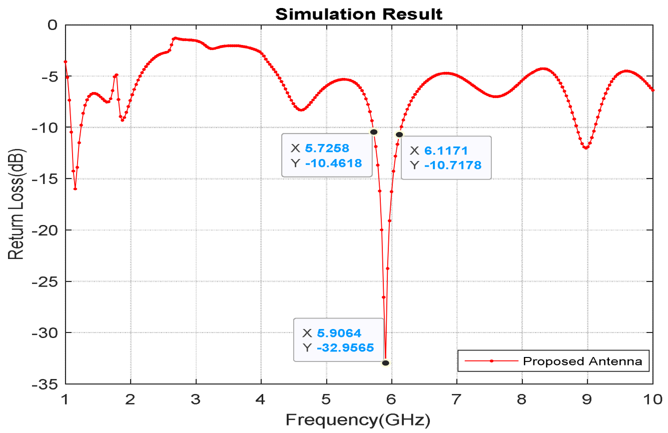


Fig.6. Return loss result.

The VSWR value should be < 2 for the frequency band because it is the optimum value for the antenna to work more effectively. Fig.7 shows the VSWR simulation result of the proposed antenna. It achieves 1.0189 at frequency band of 5.9 GHz. It means that the proposed antenna has good power reflector. It is also observed that the parasitic element on the patch of the antenna has great effect on the performance of the proposed antenna.

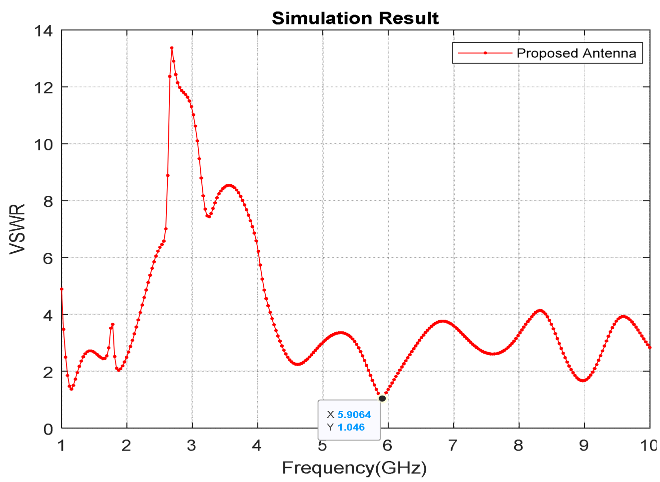


Fig.7.The VSWR result.

The radiation characteristic of the proposed antenna has been simulated to analyze the performance. There is gain and radiation pattern. The simulation result of gain can be seen at Fig.8. It achieves 7.6549 dB at 5.90 GHz. It indicates that the hexagonal parasitic element has reached high gain on the parameter antenna results. Fig.8 presents the simulated result of gain on 3D far field radiation pattern for resonant frequency at 5.90 GHz. From the 3D diagram, it is shown that the red color has strong gain antenna performance. The gain antenna exists only on the upper layer which serves as irradiation because the copper on the bottom layer has been coated for feeding transmission line.

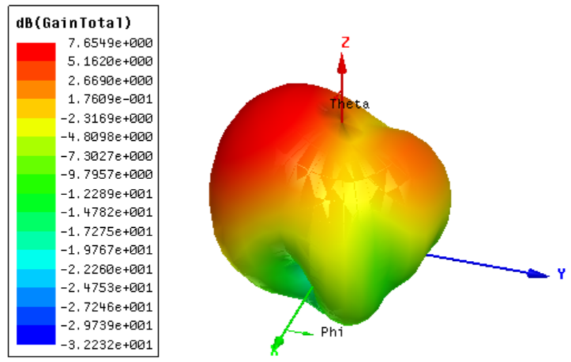


Fig.8. Gain result at 5.9 GHz

Fig.9 shows the simulated 2D far field radiation pattern for resonant frequency at 5.90 GHz. The 2D radiation pattern are calculated for phi = 0° and phi = 90°. The simulated antenna has reached directional radiation pattern, so it performs good transmission power in a particular direction. Moreover, the gain and radiation pattern diagram has similar meaning. The bright red color in Fig.8 means the greater gain in that direction. The simulation result shows gain on 3D diagram while radiation pattern on 2D diagram.

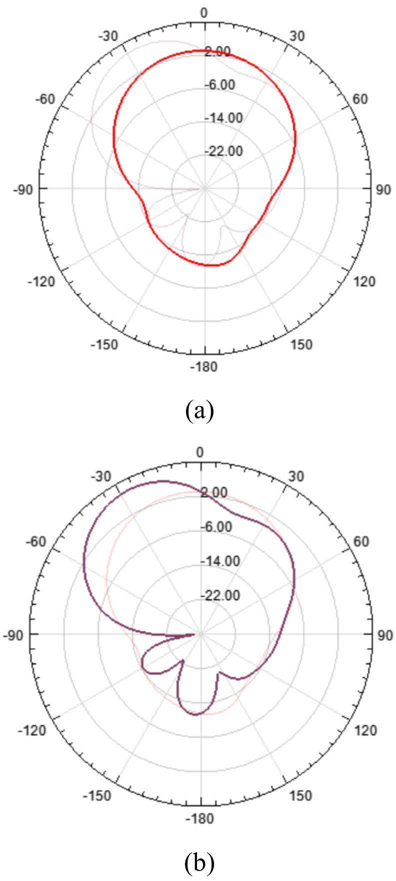


Fig.9. Radiation pattern result at 5.9 GHz. (a) phi=0° (b) phi=90°

A. Comparative Results

This study improves the other previous work on the hexagonal microstrip antenna design. Table II shows the various result of the antenna parameters. Antenna [1,2,9] used FR4 material substrate while antenna [7] use Neltec NX9320. Antenna [1,2,7,9] had different designs separately by combining hexagonal patch with V shape slot, combining hexagonal patch with modified rectangular slot, modified hexagonal geometry to be hexagonal Sierpinski fractal, and combining hexagonal patch with Koch curves on the side length of hexagonal geometry.

Tabel II. Comparative with previous work

Antenna	Parameters			
	Dimension (*l x w x h*) (*mm*)	**Frequency (GHz)**	**Bandwidth (MHz)**	**Gain (dB)**
This Study	50 x 50 x 1.6	5.9	400	7.65
Antenna [1]	circular Ø 30 x 3	5.9	2060	4.2
Antenna [2]	36 x 30 x 1.6	8.8	11.85	4.0
Antenna [7]	75x75x0.76	1.57; 3.71; 5.9	16.8; 77; 154	5.8; 8.6; 9.02
Antenna [9]	45 x 45 x 1.6	3.34; 5.56; 8.58; 9.37	135; 117; 180; 130	4.6; 2.17; 7.54; 11.70

V. CONCLUSION

The hexagonal patch microstrip antenna was proposed to work at resonant frequency of 5.9 GHz in S_{11} (-32 dB) for wireless communication system. The frequency of the purposed antenna covers for vehicle communication system. The proposed antenna has good return loss with suppressed band harmonic and high gain. The VSWR value is 1.0189 at a resonant frequency of 5.9 GHz. The propose antenna has enhanced bandwidth up to 400 MHz. The Antenna also improve gain value at 7.6549 dBi. The wide bandwidth frequency response characteristic of this antenna is achieved by selecting proper dimension of the hexagonal parasitic element. The gain value achieved by iterating the dimension of the feed line on the bottom layer. Moreover, the proposed antenna has improvement gain for spectrum frequency of vehicular communication by using parasitic element on hexagonal patch antenna.

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