Compact Antenna For Future Short Range Communication Among Automobiles

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Abstract:Intelligent transportation system is being made possible by properly selecting reliable antennas. It enhances driver safety and traffic efficiency if the selected antenna properly operates at 5.9 GHz band. Dedicated Short Range Communication Systems (DSRC) guarantees high data rate in the Vehicle to Vehicle (V2V) communications. Proper antenna selection acquaints high system performance. Directional antennas are demanded for vehicular communication to support different wireless operating environments. This work deals with the design of low profile hexagonal shaped microstrip antennas suited for Vehicular communication. Shorting pins and two sets of v shaped slots are provided to achieve broadband performance. The proposed antenna is designed using ANSYS HFSS software and its performance measures such as return loss, and radiation pattern are analyzed. The subsequent section reveals the design formulae and steps in HFSS (High Frequency Structure Simulator) for the proposed antenna.

Index Terms:Hexagonal shaped, Low Profile, Short Range, Shorting pins, return loss, Omni directional, Patch, Vehicular.

1 INTRODUCTION

Antenna is a transducer which converts radio frequency (RF) fields into alternating current and vice versa. For sending or receiving radio transmissions in free space, both transmitting and receiving antennas are used. Antennas play crucial role in the operation of all radio equipment. Antennas are said to be resonant devices which offers a better output with proper impedance matching. For effective power radiation from the antenna, the impedance of the antenna must match with the free space impedance. The signal will be transmitted or received at particular operating frequency over the band of frequencies. Bandwidth is defined as range of frequencies between upper and lower cutoff frequency. Directional antennas radiates greater power in unique directions which gains better performance in desired direction, thus reducing interference from undesirable sources. Modern communication technologies have witnessed antennas for automotive communication. At present, antennas on automobiles have Global System for Mobile communication (GSM), Bluetooth, Satellite Radio, Remote Keyless Entry Service (RKES) and Tyre-Pressure Monitoring System (TPMS), Digital Audio Broadcasting (DAB), Satellite In-vehicle TV, Satellite Digital Audio Radio Service (SDARS), short range and long range radar system for adaptive cruise control, parking assistance, collision detection and avoidance[1]. Thus automobiles with these features offer passenger comfort and safety. Systems in which vehicles and roadside units are acting as communicating nodes, providing information, such as safety warnings and traffic information are called Vehicular communication systems. These devices are devoted for short range communication. They are efficient in avoiding accidents and congestion during heavy traffic. It allows automobiles to talk to each other as shown in Figure 1. Intelligent Transportation Systems (ITS) are feasible using Vehicle to Vehicle (V2V) communication. Selecting Reliable antennas for effective V2V communication is a key factor. The automotive industry requires a low-cost high-performance antenna that can be mounted on the roof of a vehicle with compact size and low profile. The frequency band for Wireless Access in vehicle environments (WAVE) and dedicated short range communication (DSRC) is 5.85 GHz~5.925 GHz where V2V Communication takes place [2].

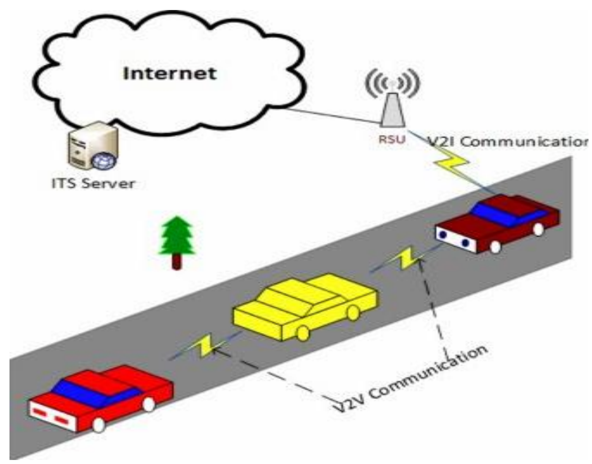


***Figure 1**. Intelligent Transportation system*

Real-world vehicle-to-infrastructure measurements in an IEEE 802.11p-based vehicular ad hoc network were made with directional and Omni directional antennas. Directional antennas with high gain offer better performance improvement [3]. Electronically steerable directional antennas mounted on a car communicating with stationary access points on road side. In addition the interference caused to other users is reduced and a higher spatial reuse can be achieved resulting in a higher capacity. Here the experiment deals with antenna directivity with respect to the duration of the connection to an access point [4]. Some researchers have done work on vehicular antennas for intelligent transportation. Two square printed monopole antennas that are installed on the vehicle have been designed by Varum et al [5]. Bras et al. designed printed loop antenna with periodical capacitive loading [6]. Alonso et al. describes that most of the present conventional vehicular safety equipments such as shadow or edge feature detectors and side view cameras have performance limitations in the presence of mist, fog and bad weather. Hence antennas play its vital role [7]. Varaiya et al. discuss about assisted collision avoidance and providing roadway condition information to vehicles [8]. Microstrip antennas are simple and compatible with printed circuit technology. They are easily conformable. Hexagonal patch antenna provides improved performance as compared to other shapes. Better impedance matching and bandwidth can also be obtained by placing shorting pins and etching V shaped slots along with hexagonal patch antenna. Gautam et al. designed a compact square microstrip antenna with four slits and a pair of truncated corner for circular polarization which shows good radiation characteristics [9]. Ray et al. designed compact hexagonal microstrip antennas. The work aimed to keep the field distribution same so that the resonance frequency remains unaltered while achieving a compact footprint [10]. Some work uses an antenna synthesis methodology for the design of Car-to-Car (C2C) Communication antennas. The synthesis allows the optimization of antenna radiation patterns based on vehicle-specific limitations [11]. Antenna array concept is used to improve the better gain of different antennas by nullify the side lobes. This paper explains about a 3x3 Rectangular microstrip patch antenna Arrays using HFSS 14.0 with measurement parameters such as gain and return loss [12]. This work deals with the design of Hexagonal microstrip antenna operating at the frequency of 5.9 GHz that suits for vehicular communication. Shorting pins and two sets of V shaped slots are utilized to achieve broad bandwidth and better operating frequency. The proposed antenna is designed using ANSYS HFSS (High frequency Electromagnetic Field Simulation) software.

2 KEY PROPERTIES OF ANTENNA

2.1 Bandwidth:
The bandwidth of an antenna refers to "the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard". Impedance Bandwidth assists to find Voltage Standing Wave Ratio and Return loss

2.2 Radiation Pattern:
It refers to directional dependence of strength of radio waves. It deals with distribution of radiated energy into space, as a function of direction. In radiation pattern, major and minor radiation areas are analyzed to compute radiation efficiency of the antenna. The maximum radiated energy exists in major lobe while some part of radiation is distributed side wards referred as side lobes. Back lobe exists exactly opposite to main lobe. Omni-directional pattern which has doughnut shape in three-dimensional view is preferred for vehicular communication.

2.3 Impedance Matching:
Impedance discontinuities in this transmission line will cause a reflection and stop effective transmission down the line. For this reason the input impedance of an antenna is critical to achieving proper matching to the transmitting device to which it is attached. Most transmission lines have an impedance of 50Ω, while the impedance of an antenna changes with frequency. Maximum power transfer from the excitation source to the antenna occurs only if the antenna is matched.

2.4 Reflection Coefficient:
The reflection coefficient measures the amplitude of the reflected wave versus the amplitude of the incident wave

$$\tau = \frac{Z_L - Z_S}{Z_L + Z_S} \quad \text{----- (1)}$$

Where, Z_L refers to the load impedance Z_s refers to the source impedance

2.5 Voltage Standing Wave Ratio:
The VSWR (Voltage Standing Wave Ratio) measurement describes the voltage standing wave pattern as shown in Figure 2 present in the transmission line due to the phase addition and subtraction of the incident and reflected waves.

$$VSWR = \frac{1 + \tau}{1 - \tau} \quad \text{---- (2)}$$

2.6 Input Return Loss:
An antenna's Return Loss indicates the proportion of radio waves arriving at the antenna input that are rejected as a ratio against those that are accepted. It is specified in decibels (dB). The return loss and radiation pattern of the designed antenna had been analyzed to achieve desired characteristics of the antenna.

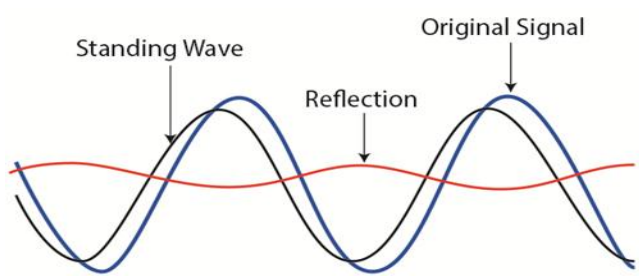


Figure 2. *Standing Wave Pattern of Electromagnetic wave*

3 STEPS TO DESIGN THE CHOSEN ANTENNA USING ANSYS HFSS SOFTWARE

3.1 Geometry Creation
A 3D (3 Dimensional) modeler within HFSS is used to create a structure which is considered as variable considering dimension of the geometry and property of the material used. Infinite ground plane is created by using 2D (2 Dimensional) object from the toolbar. Patch elements are formed above the substrate material which is assigned from 3D (3 Dimensional) modeler material tool box. Proper coaxial feed is then provided. Figure 3 shows the geometry structure.

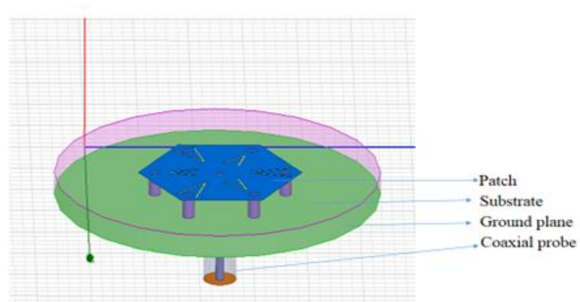
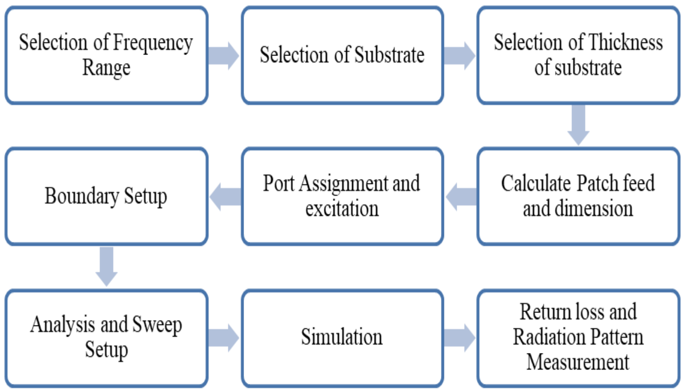


Figure 3. *Creation of Geometry of the designed Antenna*

***Figure 4**. Flow diagram of Antenna design*



3.2 Assignment of Radiation box

A radiation boundary as shown in Figure 5 can be regarded as an open model. It must be designed quarter wavelength aside the radiating surface.

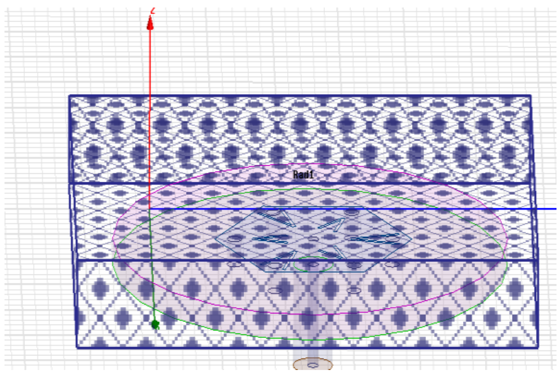


***Figure 5.** Assigning radiation boundary to the designed 3D structure*

3.3 Allot excitation

Field information, Scattering parameters, Impedance and admittance parameters are provided by proper port assignment. The designed antenna is excited using coaxial feed. A wave port can be considered as a transmission line structure with appropriate impedance and propagation constant. Figure 6 depicts the coaxial feed excitation supplied to the designed antenna.

3.4 Fast sweep using solution setup

Faster convergence to the desired solution, frequency band of interest, maximum number of adaptive steps and the desired solution over the frequency range are defined under solution setup. Change in delta-S value provides change in electric field distribution between successive passes. Fast sweep solution can be considered as highly accurate.

3.5 Solving and processing the results

The designed model can now be analyzed. Model geometry, solution frequency, and available computer resources are the factors which decide the analysis time. Then the S-parameters are examined and plotted for the designed model.

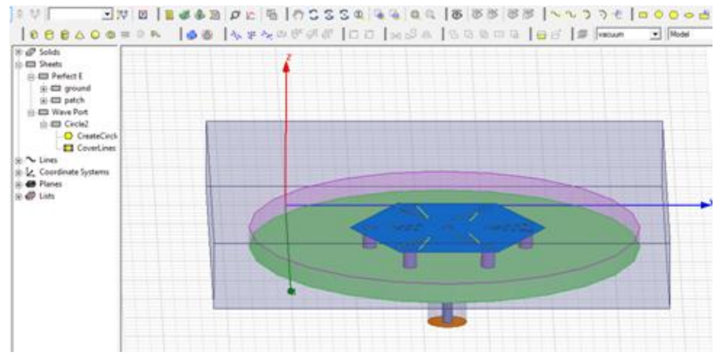


***Figure 6**. Coaxial feed assignment to the designed 3D structure*

4 ANTENNA DESIGN SPECIFICATIONS

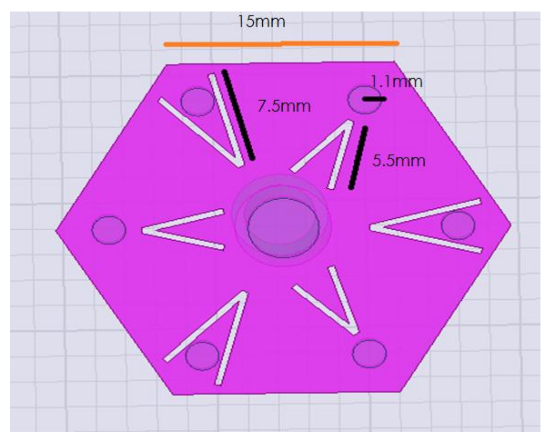


***Figure 7**. Design of Proposed Antenna*

4.1 Design Formulae

Resonant frequency

$$f_r = (1.8411 * c)/(2\pi a_e \sqrt{\varepsilon_r}) \quad \text{---- (4)}$$

Where,

c – velocity of light in free space

ε_r – relative permittivity of the substrate

a_e – radius of circular patch

Side length of the designed Patch

$$s^2 = (2 * \pi a_e^2)/(3\sqrt{3}) \quad \text{---- (5)}$$

Where,

S – side length of hexagon

a_e – radius of circular patch

Length of the Coaxial Probe

$$L_c = 6 * \text{substrate height} \quad \text{---- (6)}$$

***Table 1**. Antenna Design Specifications*

Specifications	Design Values
Operating frequency	5.9 GHz
Patch length	15 mm
Width	0.45 mm
Substrate material & height	FR4 and 3 mm
Loss Tangent	0.02
Dielectric Constant	4.4
Big V shape length	7.5 mm
Small V shape length	5.5 mm
Shorting pin radius	1.1 mm

5 EXPERIMENTAL WORK AND RESULT ANALYSIS

5.1 Hexagonal Patch

A dedicated short range communication (DSRC) can be achieved by designing a hexagonal patch as shown in Figure 8 operating at required frequency range of 5.9GHz. The length of designed patch is 15 mm. FR4 substrate with εr=4.4 and h=3mm are utilized. Coaxial feed provides excitation. Table 1 describes the design specifications of the proposed antenna operating at 5.9 GHz. Figure 8 illustrates the designed hexagonal patch antenna. Hexagonal patch offers wide bandwidth and less orientation bias. Hexagonal patch is constructed from circular or square patch

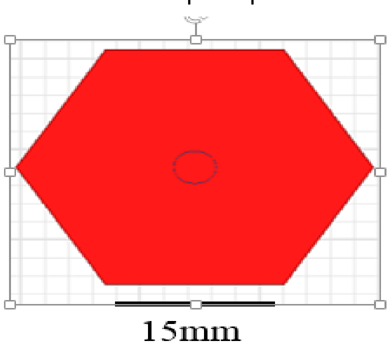


***Figure 8**. Hexagonal patch*

Return loss measurement with hexagonal patch

Loss of power due to reflection of signal from its discontinuity in transmission line is measured as return loss. The discontinuity may be due to mismatch with the terminating load. It is expressed in decibels (dB). It is notated by S_{11}(Input return loss). The designed hexagonal patch should be simulated by ANSYS HFSS. The return loss of 12.9458dB can be found at 10.9 GHz. It can also be referred from Figure 9.

5.2 Hexagonal Patch with Shorting Pins

Shorting pins can be used to tune the antenna to the required resonant frequency. It can reduce the size of the patch antenna. They are effective in widening the bandwidths of both the quarter wave patch and the regular patch.

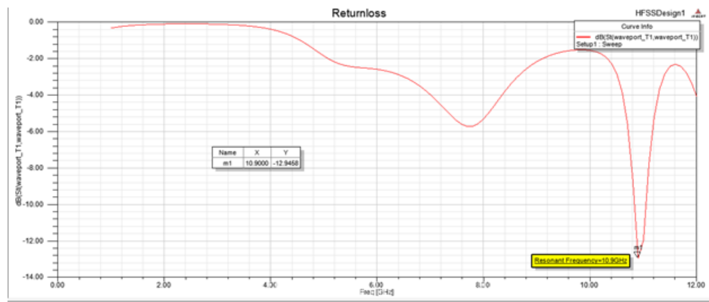


***Figure 9**. Return loss of designed hexagonal patch*

It is used to achieve better impedance matching and low cross polarization. As these paired pins simultaneously move away from the center towards the radiating edges of patch, the resonant input impedance of the patch antenna is increasingly reduced. Six shorting pins are placed on the six angles of the regular hexagon patch to realize conductive connecting between the patch and ground. It is equivalent to introduce parallel inductance between the patch and ground .Adjusting the size and location of shorting pins can effectively decrease input impedance and obtain wide impedance bandwidth. Shorting pins provide conductive connection between designed patch and ground plane. From tool bar, cylinder with radius of 1.1 mm must be chosen as shown in Figure 10 and copper can be assigned as material. Six shorting pins are used in the designed antenna.

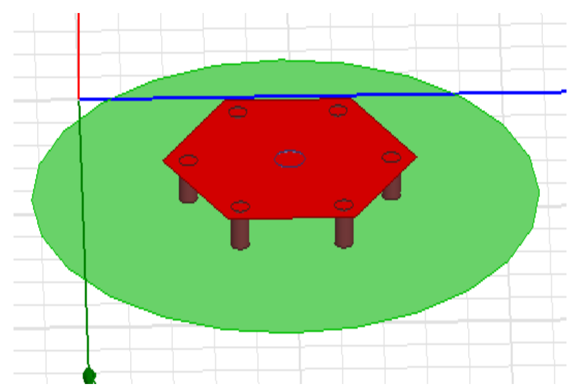


***Figure 10**. Shorting pins between patch and ground*

Return loss and Radiation pattern measurement with Shorting pins between patch and ground plane

Shorting Pins are imparted on the hexagonal patch to provide broad bandwidth. By adding six shorting pins at desired locations, the return loss of -15.6293 dB can be obtained at 5.8 GHz. The designed antenna offers a bandwidth of 481 MHz which can be seen from Figure 11. A radiation pattern defines the variation of the power radiated by an antenna as a function of the direction away from the antenna. It can be useful for visualizing at which directions the antenna radiates. Omni directional radiation pattern can be observed at horizontal plane in Figure 12.

5.3 V shaped slots on proposed design

Microstrip patch antennas are widely implemented in many applications, especially in wireless communication system applications. It has attractive features such as low profile, light weight, conformal shaping, low cost, simplicity of manufacture and easy integration to circuits. However, the major drawback is its narrow bandwidth and gain. Loading slots on the conducting element of the patch antenna reduced

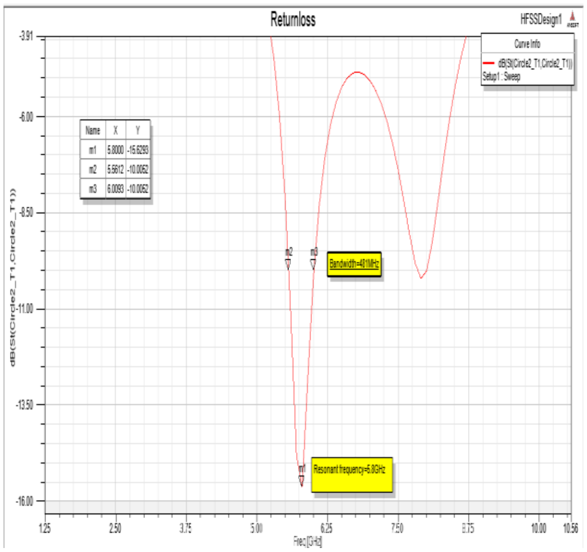


Figure 11.*Return loss of designed hexagonal patch with Shorting pins*

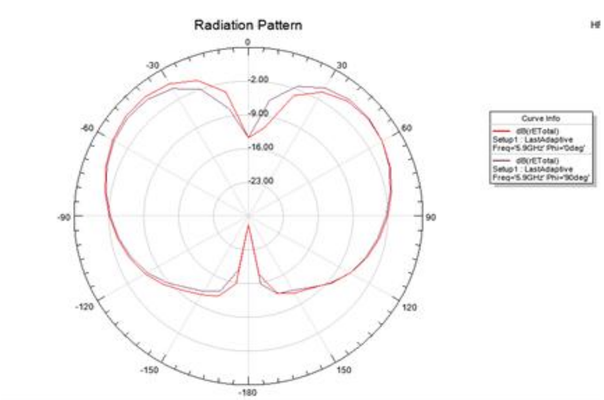


Figure 12. *Radiation Pattern of designed hexagonal patch with Shorting pins*

the antenna size with improvement in bandwidth and gain can be obtained. In this antenna two types of v shape slots are used. One is small V- shape slots and another one is big V shape slots. Two sets of V-shape slots with different size are etched on the regular hexagon patch, which is equivalent to introduce the capacitive reactance and inductive reactance. Selecting the appropriate positions and lengths of two sets of V-shape slots, makes the antenna get a better impedance matching. It also gives larger impedance bandwidth. As length of the big V shape slots increased, the resonance point of the antenna moves to the right and bandwidth is increased wider slightly. When length of the small V shape slots increases the resonance point of the antenna moves to the left and bandwidth becomes narrow. So, by adjusting the length of the v shape slots we can achieve required bandwidth. Big and small V slots are used in the design. Big V shaped slots are designed closer to shorting pins. The design length of big V slots is 7.5 mm. Resonance points of antenna moves to right if the length of big V slots is increased. Figure 13 describes big V slots closer to shorting pins. Small V shaped slots are designed far away from shorting pins. The design length of small V slots is 5.5 mm. Resonance points of antenna moves to left if the length of big V slots is increased. Figure 13 shows small V shaped slots.

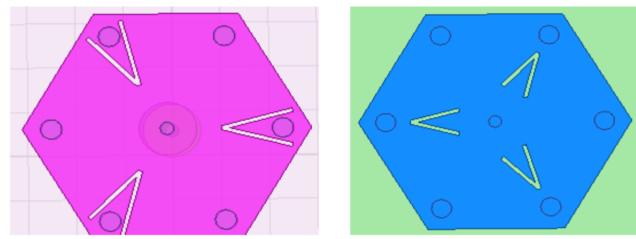


Figure 13. *Big V slot and Small V slots*

The designed hexagonal patch antenna with shorting pins and v shaped slots is shown in Figure 14.

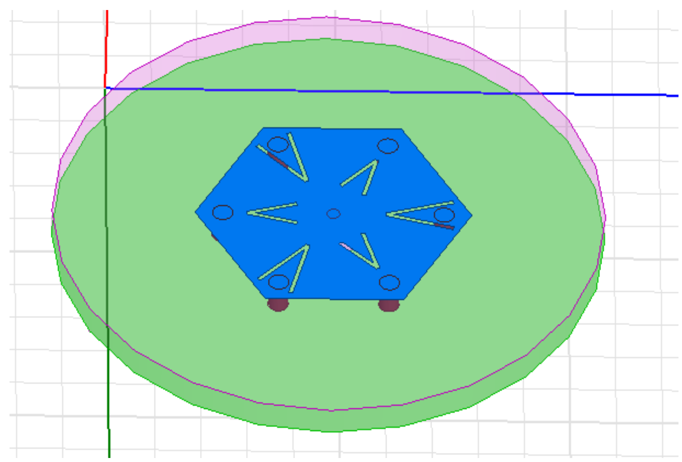


Figure 14. *Complete design of Antenna*

Return loss measurement and Radiation pattern measurement admitting V shaped slots in overall design

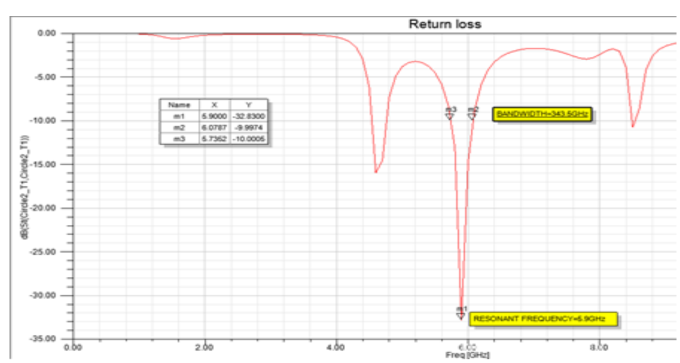


Figure 15. *Return loss measurement with V shaped slots on overall design*

V shaped slots provide easy impedance matching, broad bandwidth, and good radiation efficiency. Figure 15 indicates return loss obtained with V shaped slots. The return loss of 32.8300dB seems to be obtained at desired frequency of 5.9 GHz with the bandwidth of 343 MHz. By using V shaped slots, good improvement in return loss of -32.8300 dB can be observed at desired operating frequency. Figure 16 describes the radiation pattern obtained by incorporating V shaped slots with hexagonal patch having shorting pins. The radiation pattern is the locus of points same electric field. It shows the best angle of emission. It achieves antenna gain by concentrating more of the radiation into a main lobe directed at the horizon at the expense of radiation in other directions

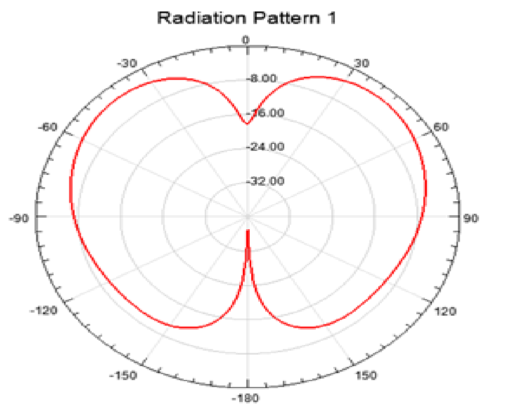


Figure 16. *Radiation Pattern with V shaped slots*

6 CONCLUSION AND FUTURE WORK

Intelligent Transport System requires integration of many types of antennas on automobile. As a consequence of this trend, analysis of low cost prediction of antenna characteristics is increasingly needed. Communication between vehicles is needed for avoiding accidents and congestion during heavy traffic. Hence this work considers design of low profile antenna for short range communication. Hexagonal microstrip antenna with shorting pins and two sets of v shaped slots offers good impedance matching, wide bandwidth and Omni directional radiation pattern. The required resonant frequency of 5.9 GHz is achieved by adjusting position and length of v shaped slots. It dwells among 5.85GHz~5.925GHz which is assigned for dedicated short range communication (DSRC). The return loss of -12.9458 dB can be found at 10.9 GHz with hexagonal patch antenna. By using six shorting pins at desired locations, the return loss of 15.6293 dB can be obtained at 5.8 GHz. Then further two sets of V shaped slots are added to achieve return loss of -32.8300 dB at 5.9 GHz with the bandwidth of 343 MHz. Thus the designed antenna ensures proper vehicular communication. Further this low cost, low profile and simple antenna can be easily mounted on a roof top of vehicles. The future work is focused on designing array of hexagonal patch antenna that could offer better gain and antenna efficiency.

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