# Design of Rectangle Microstrip Patch Array Antenna for UWB Vehicular Short Range Radar Application

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***Abstract* — Objective of this paper is to study the design of UWB antenna for short range vehicular application within 20 to 30 GHz frequency range. Initially, a study was conducted on RF requirements for short range vehicular radars, taking into considerations the positions of transmitting and receiving antennas, transmission distance, and antenna beam requirements. For this purpose, numerical calculations were carried out to determine the conditions of main lobe beamwidth to avoid destructive reflections from the ground. Based on these calculations, a microstrip patch array antenna was designed and analyzed using 3D-EM simulations. The parameters that were analyzed include the radiation pattern, side lobe angle return loss and antenna gain. Observation on the controlling parameters of the array antenna was conducted to investigate their effect on radiation pattern and side lobes. And efficiency of the design with different dimension of the design include size patch, length and width of transformer, length and width of feedline, and length and width of substrate.**

***Keywords - rectangle antenna array, microstrip patch, UWB, and short range vehicular radar.***

## 1. INTRODUCTION

Ultra wideband (UWB) is a radio frequency (RF) technology that uses significantly wide signal bandwidth compared to conventional narrowband systems. UWB technology is pioneered by Robert A. Scholtz and other researcher. Basically, for short range applications, the UWB uses a very low energy level, with high-bandwidth communications over a large portion of the spectrum. The Ultra-Wide Band usually used in non-cooperative radar imaging. Most recent application of UWB is target sensor data collection, tracking purpose, as well as precision locating. According to Federal Communications Commission (FCC), UWB uses more than 25% of fractional bandwidth, and its operating frequency is over 500 MHz [1]. A new revision of part 15 of the Commission's Rules stated that they had amended that section to give a way to the other people and researcher explores the technology of UWB [2]. UWB has also been research to be used as radar signals due to its high range resolution obtained from wide bandwidth. Upon achieve the investigation of this project will produce a new design to obtain optimum performance for the short range vehicular system.

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The communication between two vehicular can be established in full performance using the proposed antenna design that takes into account, important parameters of the communication system itself. The data can include a warning in front of the leading vehicular as well as an emergency from behind. This type of antenna also can be implemented to an ambulance, fire fighter truck and also a police patrol car to warn other driver. This type of antenna can be fit as Original Emblem Manufacture (OEM) with collaboration of the Malaysia government and manufacturer such as Proton, Honda, or Toyota. Other than that, if the communication between vehicular can be established, this will avoid or reduce the percentage of accident by sending the intention of lead vehicle to the surrounding vehicle.

Vehicular radar systems were known to be susceptible to multipath effects due to reflections from background environment and unwanted targets [3]. The main concern of this study is to design an antenna that yields a radiation pattern optimized for short range vehicular radar application, reducing the ground reflections. Conventional antenna design mostly focused on gain enhancement, while other researcher rarely discuss how to minimize the side lobe or how to make the radiation pattern become narrow at 20.9 GHz for short range vehicular application [4, 5, 6].

The objectives of this paper are as follows:

1. To study the condition of optimum transmission in short range vehicular communication application in terms of antenna placement and main lobe beamwidth parameters.
2. To design a UWB array patch antenna to obtain optimum gain, beamwidth, and side lobe level for short range vehicular communication application.

## 2. METHODOLOGY

This project will start with the estimation of minimum side lobe angle to avoid destructive ground reflections. This activity will be carried out based on numerical calculation of transmission environment and beamwidth condition. The details will be described in Section 3. The study will continue with antenna design and simulation, using 3D-EM simulation software as the analysis tools. The software that will be use is

Computer Simulation Technology (CST) software. The CST simulation is divided into several major categories but in this project, the Microwave and Radio Frequency simulation software will be used. This study will analyze the angle covered and return loss of the patch array antenna in order to design the antenna for transmission and reception condition between the transmitting and receiving antennas for short range vehicular purpose.

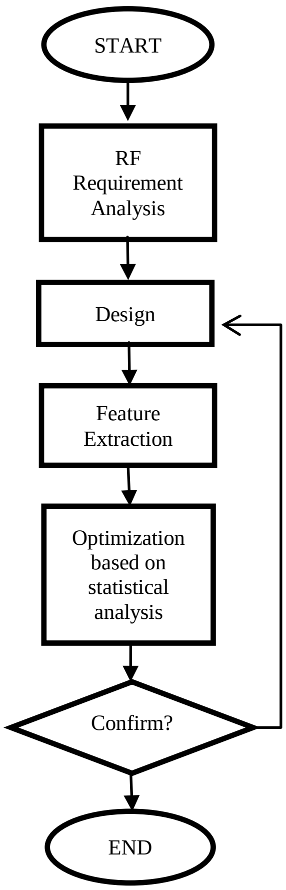


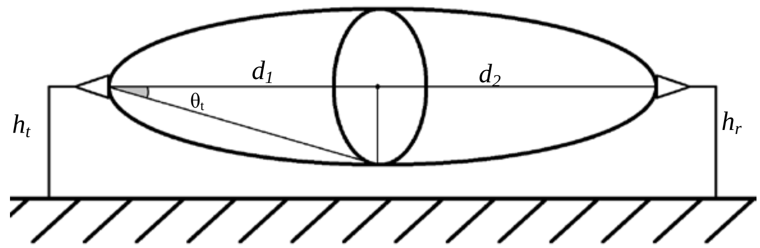

**Figure 1:** Flow Chart

Figure 1 shows the flowchart of this project. This project will start from the study of theoretical calculation include the calculation of possible angle covered, and calculation of height of transmitting and receiving antenna. The next step is applying the measurement into simulation design. Extract and analyze the result produce from the CST. The design might be need some optimization to get the desired output. The analysis will be concluding from the final result.

### 2.1. UWB Short Range Vehicular Radar Requirement Estimations

The UWB can be used in a vehicular system. By using UWB, the driver between two cars can be communicating with each other and the system also can detect other object surrounding the car include the blind spot which is the system will monitor the car in 360º [4]. The numerical simulation of intereference effects from UWB radar signals on the performance of a digital orthogonal frequency transmission system was evaluated in [7]. The position of antenna for short range vehicular radar system is also important. It is because the position will affect the angle of the transmitting and receiving antenna. The position of antenna for short range vehicular radar system has been study by S. Kaul, K. Ramachandran, P. Shankar and Co [5] by using operating frequency of 5 GHz. The car effect geometry also gives an impact to the vehicular network communication. The effect of car geometry is divided into two parts of that study which is effect of car geometry on antenna pattern and effect of car geometry on communication link.

**Figure 2:** Concentric ellipse of transmission.




In order to eliminate the destructive wave from the ground that could reduce the receiving power, transmitting and receiving antennas heights are placed at 1.2 meters from the ground are sufficient for the system. Figure 2 is the illustration of the concentric ellipse of transmission of the antenna. Total distance from transmitting and receiving antenna is 30 meters which $d_1$ and $d_2$ are both 15 meters while $h_t$ and $h_r$ are both 1.2 meters. The radius concentric ellipse of transmission by angle ($\theta_t$) covered for 30 meters distance can be calculated by using basic formula below;

$$Tan\ \theta_t = \frac{Leg\ B}{Leg\ A} \qquad (1)$$

$$\theta_t = tan^{-1}\frac{Leg\ B}{Leg\ A} \qquad (2)$$

Where Leg A and Leg B is the distance of transmitting antenna to the center of transmission path, and the radius of the concentric ellipse respectively.

By using 15 meters for Leg A and 1.2 meters same as assumed antenna height as Leg B, angel θ can be calculate; $\theta_f = tan^{-1}(\frac{1.2}{15})$. Thus the value of $\theta_f = 4.57°$ as shown in Figure 3. This 4.55° is the maximum permissible angle for that antenna, otherwise the beamwidth will bounce to the ground causing ground reflections, that condition will reduce the receiving power.

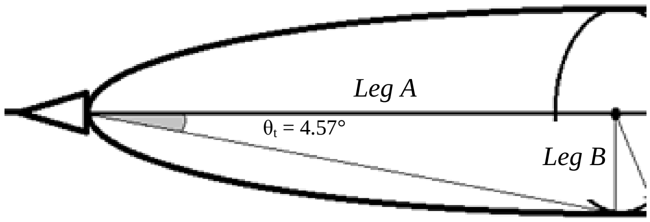



**Figure 3:** Maximum Permissible Angle

## 3. ANTENNA DESIGN

A microstrip antenna is known as patch antenna is a variety of radio antenna. This antenna is basically consisting of radiating patch which it is radiate on only one side of the substrate while the other side of antenna has a ground plane. This type of antenna can be mounting in a flat plane, which is desirable in automotive applications due to space constraints. The original type of microstrip antenna describe by Howell in 1972 [8] two metal sheets is combined together form a resonant part of microstrip transmission line with a length of approximately one-half wavelength of the radio waves.

Rectangular microstrip antenna is one of the designs that can be applied in microstrip antenna. The shape of this patch is rectangle as well as the substrate of the antenna. The width and length of patch can be determined by calculation [9-11]. The dielectric constant ($\varepsilon_r$) is substrate material and the thicknesses ($h$) are known before start the project. To estimate the physical length ($L_p$) and physical width ($W_p$) of the patch for the desired resonant frequency ($f_o$). The physical width of the patch can be determined by using formula [12];

$$W_p = \frac{\lambda o}{2\sqrt{\frac{\varepsilon_r+1}{2}}}; \quad (3)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right] \quad (4)$$

where $\lambda_0 = c/f_o$ is the free-space wavelength

While to determine the physical length of the patch can be calculate by using formula;

$$L_P = L_e - 2\Delta L; \quad (5)$$

$$\Delta L = 0.412h\left[\frac{\varepsilon_{eff}+0.3}{\varepsilon_{eff}-0.258}\right]\left[\frac{\frac{W}{h}+0.264}{\frac{W}{h}+0.813}\right]; \quad (6)$$

$$L_e = \frac{\lambda_0}{2\sqrt{\varepsilon_{eff}}} \quad (7)$$

When the patches are combined together on the same substrate, it will produce an antenna array. It is often called a phased array which it is a set of two or more antenna patches. When the antenna is combined together on a same side on the substrate, the signal of each antenna patch is processed or combined in order to increase the performance compared the single antenna. The result of phased array can be used to increase overall gain. Other than that, antenna array should steer the array, hence that antenna array will be sensitive in a particular direction and also to determine the direction of receiving signal [13].

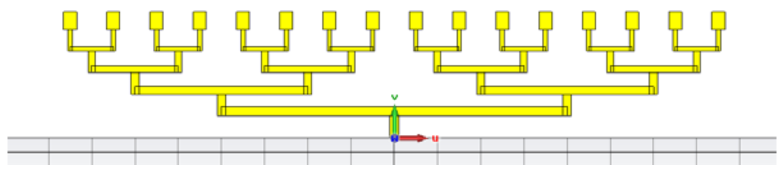


**Figure 4:** Antenna design

Figure 4 shows the design of 16 rectangle microstrip patch array antenna. Usually the patch design for Ultra Wide Band antenna is small. In our study, after few optimizations to get an optimum result, the size of patch is 3mm x 4 mm while the width of feedline is 2.275 mm to get best outcome for feedline impedance value of 50 Ohm. By using this size of feedline, the result of impedance value is 49.99 Ohm as shown in Table 1. From the observation, the Line impedance is disproportionate with the width of feed line. Bigger width size of feedline, the smaller result of line impedance.

**Table 1: Line Impedance**

| Feedline Width (mm) | Line Impedance (Ohm) |
|---|---|
| 2.180 | 51.30 |
| 2.200 | 51.02 |
| 2.275 | 49.99 |
| 2.280 | 49.92 |
| 2.300 | 49.66 |
| 2.400 | 48.36 |

## 4. RESULT

The parameters that will be analyzed in this study include the radiation pattern and return loss. Observation on the controlling parameters of the array antenna is conducted to investigate the effect of radiation pattern, And efficiency of the design with different dimension of the design include size patch, length and width of transformer, length and width of feedline, and length and width of substrate.

### 4.1. Radiation Pattern

Radiation pattern or known as antenna/far-field pattern is the directional in term of angular dependence of the strength of radio waves from transmitter and the receiver. For this study, it is required to design an antenna that can produce a narrow radiation pattern. It is because to eliminate an unwanted signal and to avoid the signal bounce to the ground that might be reduced the receiving power. There are several method and point to compare between rectangular patch antenna and circular patch antenna. In this study, the comparison between these two types of antenna is in term of Half Power Beam Width (HPBW) [14] in E-Plane (EHPBW) and H-Plane (HHPBW). By using the same frequency (6 GHz) and same dielectric constant (εr=1.5) the result for circular patch is better than rectangular patch in term of EHPBW and the HHPBW for rectangular patch is 72° while the circular patch is 74°. Thus the rectangular patch cover the less area compare to circular patch.

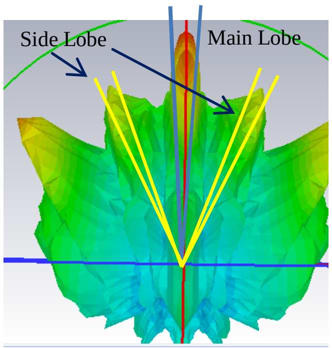



**Figure 5:** Radiation Pattern 3D

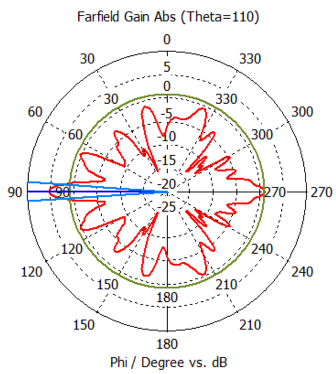



**Figure 6:** Polar

Figure 5 shows the radiation pattern for rectangle microstrip patch array antenna at 20.9 GHz for UWB short range vehicular radar application in 3D. While Figure 6 shows the radiation pattern in polar mode. In this mode, there are divided into three axis's which is X-axis that present constant phi, Y-axis and Z-axis that present constant theta. The far-field can be cut (cross sectional area) at particular angle. For this study, we use the angle of 110° at constant theta axis to get the most narrow radiation pattern to meet the requirement of narrow radiation pattern.

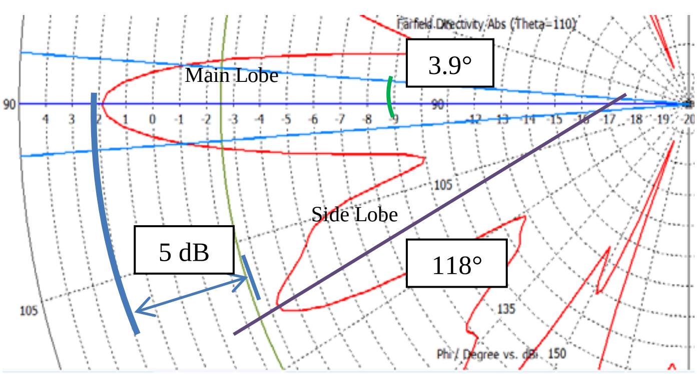



**Figure 7:** Polar View

From the polar view in Figure 7, the main lobe for this radiation pattern is equal to 7.8° while the side lobe to main lobe angle is 118° - 3.9° (main lobe divide by two) – 90° (wave direction) = 24.1º. The different between main lobe and side lobe is 5 dB. Thus according to the previous calculation for radius of concentric ellipse of transmission, for 3.9° covered give us the new value of Leg B in radius to be 1.022 meters by using equation (1).

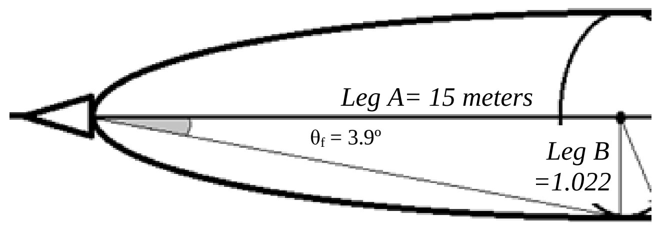



**Figure 8:** Obtained Leg B value from the designed antenna.

Illustration in Figure 8 shows obtained main lobe beamwidth and radius of concentric ellipse of transmission (Leg B). The antenna height is 1.2 meters, hence to avoiding the miss directive wave to the ground that could reduce the receiving power. It will not affect the receiving power. 24.1º is the angle from the side lobe to main lobe is much larger that is radiate out of the concentric ellipse of transmission. Since the side lobe gain is 5 dB lower, this side lobe effects can be ignored.

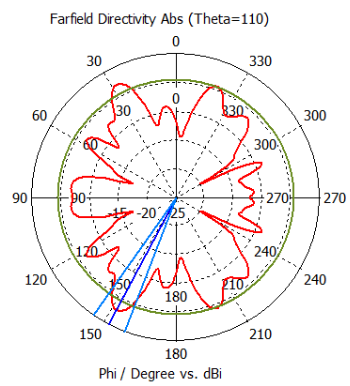



**Figure 9:** 8 Patch

The polar view shown on Figure 9 above is the result of radiation pattern for rectangle microstrip 8 patch arrays. The pattern is similar to rectangle microstrip 16 patch arrays. With the addition of arrays, we can improve the main lobe power to push further in order to get the narrower radiation pattern. For the 8 patch arrays we can clearly see that the main lobe is not enough power to point the direction in 90º of direction. The main lobe angle is 30.8º, the radius of Leg B will become larger (8.94 meters). Thus with this angle, the beamwidth will bounce to the ground. The side lobe is larger and further than 16 patch arrays. The angle from side lobe to main lobe is 23º. The best design of this short range radar application is 16 patch compared to 8 patch. This is aligned with theoretical principle where the larger number of array will produce the narrower beamwidth. [15]

### 4.2. Radius of Concentric Ellipse of Transmission With Varying Distance

Moving vehicle will varying the distance from transmitting and receiving antenna. With this circumstance, the radius (LegB) of angle covered also affected.

**Table 2: Radius of Leg B**

| Total Distance (mtrs) | $d_1 = d_2$ (mtrs) | Radius (Leg B) (mtrs) |
|---|---|---|
| 30 | 15.0 | 1.022 |
| 25 | 12.5 | 0.852 |
| 20 | 10.0 | 0.682 |
| 15 | 7.5 | 0.511 |
| 10 | 5.0 | 0.341 |
| 5 | 2.5 | 0.170 |
| 1 | 0.5 | 0.068 |

Table 2 above shows the variation of radius (Leg B) in meters from the center of antenna to the ground calculated based on the main lobe beamwidth of the designed antenna.. Height of antenna, $h_t$ and $h_r$ are both fix at 1.2 meters from the ground, while the radius (Leg B) of angle covered will change. Nearest the distance between transmitting antenna and receiving antenna will produce the smaller radius. This result indicate that from 0 to 30 meters of target distance, the effect to ground reflection can be ignored, showing the usability of the designed antenna for short range vehicular radar application.

### 4.3. Return Loss

S-Parameters are entitling the relative between input and output ports in the system. For this study, we are focusing on $S_{11}$ which is represent that how many power reflected from that antenna. It is known as reflection coefficient, return loss, or sometime written as gamma, Γ. For example if there is 0dB, means that there are none power reflected from that antenna. If the graph of $S_{11}$ is equal to 15 dB for the slope, this indicates that if 3 dB of power is delivered to the antenna, -12 dB is the reflected power. The remainder of the power was "accepted by" or delivered to the antenna.

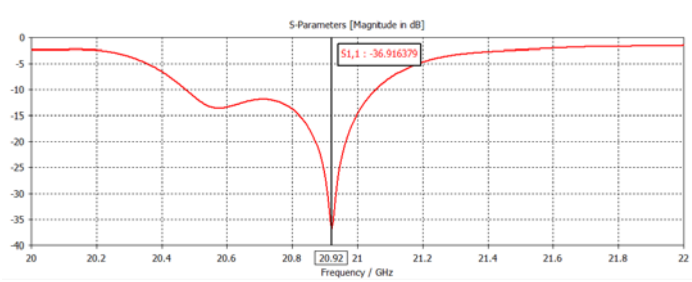



**Figure 10:** $S_{11}$

Figure 10 shows the result of $S_{11}$ of the designed rectangle microstrip patch array antenna at 20.9 GHz for UWB short range vehicular radar application. At frequency of 20.92 GHz, the slope of $S_{11}$ is -36.9164 dB. In the $S_{11}$ graph, the frequency of area that below -10 dB is 0.592 GHz, it is more than 500 MHz which is satisfying the criteria of Ultra Wide Band frequency as shown in Figure 11.

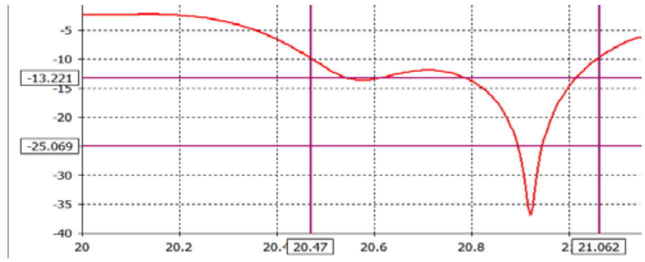



**Figure 11:** $S_{11}$ Slope

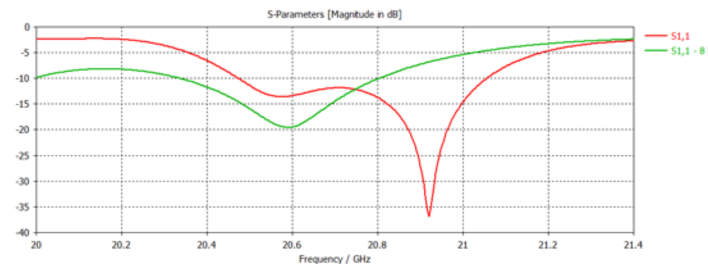



**Figure 12:** $S_{11}$ Comparison

The different between graphs for rectangle microstrip 8 patch arrays and rectangle microstrip 16 patch arrays can be observe in Figure 12. The red color curve is represent rectangle microstrip 16 patch arrays, while the green color curve is represent rectangle microstrip 8 patch arrays. From the observation, we can see the huge different between that two arrays. For 8 patch arrays, the slope is only -20 dB while for 16 patch arrays, the slope is almost -40 dB which is better compare to 8 patch arrays. The bandwidth for 16 patch arrays is larger than 8 patch arrays. 427 MHz is the bandwidth of 8 patch arrays. It is not meet the minimum requirement of Ultra Wide Band criteria. The different between those two designs in term of bandwidth is 165 MHz.

### 4.4. Antenna Gain

Usually, the single patch antenna can produce a maximum directive gain around 6 to 9 dB. An array patch antenna is designed to improve the gain of the antenna. More arrays added, more gain will be produce. In this study, by using 16 patches, the gain produced is 14.59 dB.

## 5. CONCLUSION

This paper presented the design of array microstrip patch antenna for UWB short range vehicular radar applications. The angle of this main lobe is within the angle limit which was estimated in preliminary calculations considering antenna height and transmission distance. Thus it can eliminate the destructive wave from the ground that could reduce the receiving power. The side lobe of this design was 5 dB lower than the main lobe, reducing the effects of destructive ground reflections. The return loss of this study is clearly proved on $S_{11}$ parameter that the minimum bandwidth of Ultra Wide Band criteria is achieved. The bandwidth is 592 MHz which is satisfying the UWB requirement.

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