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# 4 × 1 Array Antenna with Staging Transmission Line for Vehicle **5G** Application

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Abstract. This project implemented the role of 5G technologies for vehicle application. 5G connectivity will give added value to a vehicle, to be able to connect to the networks and also talk to each other without any interference in very low latency. Implementing such kind of this technology will leverage disruptive new applications that will allow to improve driving efficiency and enhance road safety. With the increasing demand for mobile traffic and the delay and security of VANET based on IEEE 802.11p, the key technology of the fifth-generation mobile communication (5G) is combined with the functional characteristics of vehicle networking. And analyzes the application of D2D technology, cognitive radio to improve vehicle communication delay, flexibility, spectrum utilization efficiency and 5G technology in automatic driving. Finally, the potential application of 5G vehicular network is pointed out. This project used microstrip antenna because it has several advantages that did not feature on conventional microwave antenna such as light weight, low volume and thin profile configurations, which can be made conformal. The fabrication process might not cost the budget and mass production is also possible in a period. This research work is focusing on design, simulate, fabricate and analyze a 5G wireless antenna that operates at 26 GHz to 28 GHz by using Rogers RT/Duroid 5880, where this range of frequencies is one of the standard frequencies of the 5G communication. The development of wireless device prototype is also focused in this project as it will be install on a vehicle to enable 5G. This project consist of three major parts which are calculation, simulation and hardware design. Computer Simulation Technology (CST) microwave studio software used to simulate the designed antenna, it prompt the optimization of the antenna designed to achieved desired result before proceed with fabrication. The comparison between theoretical result and practical result was made to analyze margin error and trace the probable cause of the error. The measure of the antenna performance (basic antenna parameter) between array antenna and single patch antenna also studied in this project to conclude the most compatible antenna for vehicle application. 40 GHz Vector Network Analyzer (VNA) had been used to measure the fabricated antenna.

#### 1. Introduction

Today latest technology 5G, The Fifth-Generation wireless system is the following significant period of mobile telecommunication standards past 4G. A technology that pushes us toward systems that associate various kinds of devices working at faster speeds, instead of networks design for mobile devices alone. Among the features included in 5G are high throughput, reduced latency, improved spectrum efficiency, high connection density and better mobility support. It bolsters intelligent interactive media, Web, voice,

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video, and other broadband services. So, as to help expanded throughput prerequisites of 5G, new spectrum has been doled out to 5G in mmWave bands. Additionally, 5G utilize massive Multiple Input Multiple Output (MIMO) to essentially expand network limit. The development of the Internet of Things (IoT) and the ascent popular for access to video and services over wireless broadband are the main factors for the advancement of 5G wireless communication standard, it is now being led by companies such as Intel, Samsung, Ericsson, Nokia, BT, AT&T, Verizon, and Qualcomm [1].

Recent technology 4G LTE have very high end to end latency, limited availability, limited access, unreliable and insecure for vehicular communication, considering all the challenges to obtain stringent delay requirement in case of high cellular traffic road. With a new 5G technology, all of those problems can be solved. Nevertheless, to perform high speed data exchange come sort of new obstacles, while 4G occupied the frequency range 600 MHz to 6 GHz, the frequency spectrum got very crowded nowadays that lead to slower data transfer, 5G technology on the other hand capable of operate at frequency range from 30 GHz to 300 GHz, it mean more bandwidth for everyone, operating at this frequency range make data transfer more faster than before because of its mmWave, the con of this high frequency is to proper work with this level of frequency band required the elimination of cable and connectors for making even calibrated measurement on the subsystem and the integrated system and so making calibrated measurements over the air is feasible [2].

Previous research suggested wireless connectivity for vehicle, which is Dedicated Short Range Communication, or DSRC for short. It is an efficient communication system in term of price that provide features like 3600 view of similarly equipped vehicles that present their communication range. The system is a combination between DSRC and GPS. This system does not provide navigation system, internet access, notification, and other advance technology in communications [3].

Since this technology will be apply to a moving object like vehicle, we need to assure that the speed of data transfer and receive are much faster than the movement of a vehicle, because the demand of this 5G ready vehicle is mostly for safety purpose. When we are driving the car automatically alert us from another car that come from our blind spot. This is one of the examples why we should have better connectivity while driving.

The project scope is the development of 5G connectivity in a vehicle with low latency and sustain minimum level of loss possible. The process included routers systems prototype for V2V communication, 5G supported antenna design by using CST Studio Suite® 2019, antenna fabrication and measurement by using Keysight<sup>TM</sup> equipment provided in laboratory. The 5G antenna designed with respect to vehicle-to-vehicle (V2V) applications and also the focal point of this antenna design is the working performance under all type of weather in Malaysia's climate such as rainy, moist, dusty and dried. The antenna will be designed by using CST Studio at frequency 26 GHz to 28 GHz. Before designing the antenna by using the CST, the dielectric permittivity and thickness of the antenna must be first measured. A new antenna design will be simulate and optimize before the fabrication process. Finally, the fabrication can be proceed based on the value retrieved from the simulation process. Complete antenna module will be tested it performance in term of its parameter by using Vector Network Analyzer (VNA). Afterward, the connection between router and antenna module will be made by using coaxial cable. The router is the device that will enable 5G connectivity to a vehicle. All the results will be recorded for report purpose.

#### 2. Antenna Design

This project methodology can be divided into two stage which are the designing and measurement stage. For the designing stage, it involved the calculation of parameters for the antenna and then proceeds with the antenna designing and simulation by using CST software. On the other hand, the measurement stage includes the fabrication and measurement step by using VNA provided by the laboratory. In the common design plan strategy of the Microstrip antenna, the ideal resonant frequency, thickness and dielectric constant of the substrate are known or chosen at first. In this structure of microstrip patch antenna, Rogers RT 5880 dielectric material ( $\varepsilon_r = 2.2$ ) with dielectric loss tangent of 0.0009 is chosen as the substrate with 0.5 mm thickness. At that point, a patch antenna that works at the predetermined resonance frequency  $f_0 =$ 

28 GHz can be design by utilizing transmission line model equation. Microstrip Line Feed technique has been used and this inset feed technique applied to make connection between conductor patch and feedline[4]. For designing of a microstrip patch antenna, the resonant frequency and a dielectric material and permittivity for which antenna is to be structured has been calculated as below.

Parameter	Description	Value
F	Frequency 26 – 28	
С	Free-space velocity of light	3x10 <sup>8</sup> m/s
٤ <sub>r</sub>	Relative permittivity of substrate 2.2	
н	Height of dielectric 0.5 mm	
т	Conductor thickness	0.035 mm

Width (W):

The width of the patch is calculated by using the following equation.

$$W = \frac{0}{2f_r} \frac{1}{2f_r} \frac{1}{1}$$
$$W = \frac{3 \times 10^8 \, m/s}{2(28 \, GHz)} \sqrt{\frac{2}{2.2 + 1}} = 4.23 \, mm$$

In the design technique of a microstrip patch antenna, the effective refractive record estimation of a patch is a significant parameter. The radiation released by the air and some by the substrate from the patch to the ground (called as fringing)[5]. Bath air and substrates have different dielectric estimates, so we find the calculation of viable dielectric constant along these lines to account for this. With the following equations, the value of the persuasive dielectric constant (creff) is determined:

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

$$\varepsilon_{reff} = \frac{1}{2} + \frac{2.2}{2} \left[1 + 12\frac{0.5 \ mm}{4.23 \ mm}\right]^{-\frac{1}{2}} = 1.4147$$

The size of the antenna is amplified by interval of  $(\Delta L)$  because of fringing. The calculations of length  $(\Delta L)$  of the patch using the following equation:

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

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$$h^{\Delta L} = 0.412 \left( \frac{(1.4147 + 0.3)^{4.23 \ mm}_{\underline{0.5 \ mm}} + 0.264)}{(1.4147 - 0.258) \left( \frac{4.23 \ mm}{0.5 \ mm} + 0.8 \right)} \right)$$

#### $\Delta L=0.2877\;mm$

The equation to measure length (L) of the patch is shown, required value of constant Co equal to 3x108,  $\Delta L$ , frequency resonant fr, and  $\varepsilon$ reff:

$$L = \frac{C_0}{-2f_r \sqrt{\varepsilon_{reff}}} - 2\Delta L$$





Figure 1. (a) Antenna Design Based on Calculation (b) Optimized Design

The antenna has been evolving into 4-Element (2x2 Array) in order to achieve better return loss and to have higher gain. The feed parameter is still using the same value except for the feed for the 2-Elements and another 2- Elements. It is because they use the separation between the element more than once. The following formula has been used to generate the value of feed between 2-Elements.

$$\frac{W1}{h} = \frac{8C^{A}}{e^{2A} - 2} for \frac{W1}{h} < 2$$

$$\frac{2}{\pi} [B - 1 - (2B - 1) + \frac{\varepsilon_{e}}{r} \{(B + 1) + 0.39 - \frac{0.61}{\varepsilon_{r}}\}] fr \frac{W1}{h} > 2$$

$$A = \frac{Z_{0}}{60} \frac{\sqrt{\varepsilon_{r} + 1}}{\sqrt{2}} + \frac{\varepsilon_{r} - 1}{\varepsilon_{r} + 1} \{0.23 + \frac{0.11}{\varepsilon_{r}}\}$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$$

Table 2. Design of Feedline for 4-Element Array Antenna				
Design of feed	Width of feed (mm)	Length of feed (mm)		
50 Ohm	1.5406	1.9581		
70 Ohm	0.8995	1.9873		
100 Ohm	0.44812	2.0201		



Figure 2. Array Design Based on Calculation



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Figure 3. (a) 1<sup>st</sup> iteration of array antenna (b) 2<sup>nd</sup> iteration of antenna (c) 3<sup>rd</sup> iteration of array antenna

To evaluate the distance between each patch the  $\lambda/4$  technique had been used, this technique also known as the quarter-wave transformer[6]. It was used to match the real load of impedance to a different source of impedance, and frequently used in antenna design. The technique applied in designing antenna for this project for the antenna to have broader bandwidth by extended the design into multi-section designs.

On Fig. 3(c), since the transformation from single element to array antenna affected the operating frequency, the L-bend technique had been used in order to manage this issue, it work by sliding the position of feedline at patch end until the desired frequency obtained, while remain position of the other end which connect to the port[7]. The transformation supposed to increase gain of the antenna. Hence, by altering the position of feedline from middle of 100 Ohm transmission line helped to obtained back operating frequency within desired range. The distance between each patch also had been changed on second iteration from the value of wavelength, which is 10.95 mm to 50 mm horizontally and 41.5 mm vertically, this process has improved the value of return loss and gain.

### 3. Result and Discussion

The designed antenna has undergoes staging process by increasing the size of slot and several dimension from the origin value obtained from calculation for the purpose of optimization. The simulation was done every 0.025 mm for staging and every 0.5 mm for a slot. The result for optimization can be observed from Fig. 1(b) and Fig. 4. From the result obtained, it can be certain that the design from Fig. 1(b) shows the best and accurate result simulation as it has fulfilled the criteria of best performance in simulation of the antenna.



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**Figure 8.** Return loss for array antenna (3<sup>rd</sup> iteration)

Based on Fig. 4, the return loss for the single patch is -37.308 dB at 28 GHz is higher compared to array on Fig. 8 that achieved value of return loss -27.822 dB at 27.4 GHz. Both of the antenna achieved return loss below -10 dB at their operating frequency, that was an ideal return loss for an antenna because at -10dB it represents 90% of total power received at load and another 10% is reflected back to source[8].

From the simulation results obtained, the bandwidth for single patch as shown in Fig. 4 is 450 MHz, while the bandwidth for array antenna shown in Fig. 8 is 604 MHz. By increasing the number of antenna element from single to multiple patches, it has increased the bandwidth of an antenna. A significant result had been achieved for array antenna, this characteristic is crucial in the making of 5G antenna.



Theta / Degree vs. dBi Figure 9. The Directivity of Single Element Antenna

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Theta / Degree vs. dBi Figure 10. The Directivity of Array Antenna

From the simulation result shown in Fig. 10, the 4-Element design gives a higher result compared to single patch antenna. The main lobe magnitude or directivity in this 4-element patch antenna is 11 dBi with its angular width (3 dB) 17.0 degree. The Main lobe direction is at 66.0 degree, this means that the antenna is best working at that position. Gain for single element antenna obtained 5.726 dBi. From the result shown in Fig. 9 the angular width (3 dB) is 49.3 degree with its main lobe magnitude is 2.07 dBi. The array antenna is considered directive as its 10.08 dBi gain radiated in a particular way. Hence this antenna could be putting at various positions on the vehicle, for example, on the windscreen and back window of the vehicle.



Figure 11. The Radiation Efficiency of Single Element Antenna

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Fig. 11 shows the radiation efficiency of single element antenna, the antenna radiated effectively at frequency 28 GHz, it can be observed that 85% of total power radiated by an antenna to the net power accepted. Fig. 12 shows the radiation efficiency of Array antenna, the antenna radiated effectively at frequency 27.4 GHz, it can be observed that 82% of total power radiated by an antenna to the net power accepted.

3D VIEW	RADIATION PATTERN	
	Single Patch Antenna	Array Antenna
Side	Z Theta Phi x	Theta Ppi x

Table 3. The Radiation Pattern of Antennas Designed



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Tuble 4. The Summary of America Simulation Result				
ANTENNA PARAMETER	SIMULATION RESULT			
	SINGLE PATCH	ARRAY ANTENNA		
	ANTENNA			
Frequency (GHz)	28.000	27.410		
Directivity (dBi)	2.070	11.000		
Gain (dBi)	5.726	10.080		
Radiation Efficiency (%)	85	82		
Return Loss (dB)	-37.308	-27.822		
Bandwidth (MHz)	450	604		

Table 4. The Summary of Antenna Simulation Result

#### 4. Conclusion

The antenna designed had been operating at 5G frequency, based on the characteristic that has been achieved during simulation, both single patch and array antenna feature mmWave frequency, 28 GHz for single patch antenna and 27.4 GHz for array antenna. However, the array antenna had been chose to applied on a vehicle, considering it have very high gain and larger bandwidth compared to single patch antenna. By referring to the simulation result, even though the return loss of the single patch antenna is much better than array antenna, the antenna has not been selected as it not compatible to be used for a 5G vehicle, because of its gain is lower to be used on open space condition, considering a vehicle is adynamic object that travel farther from everywhere, especially the base station, it need a very high gain to reach them. The bandwidth of the array antenna also one of the selection factors, in order to reduced system complexity, this wideband antenna is suitable to cover mobile and wireless services.

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