

A Study on V-Shaped Microstrip Patch MIMO Antenna

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Abstract

A study on the V-shaped microstrip patch antenna for multiple-input multiple-output (MIMO) communication system based on the antenna orientation is performed. First the microstrip patch antenna operating at 2.45 GHz is calculated and simulated. Next, multiple elements of antennas for MIMO system is simulated and discussed. V-shaped with 45 degree slanted inward and outward is studied. The antenna properties are analyzed and compact antenna design is determined based on the simulation results. The results show the gap between antennas can be optimized to 1 mm while maintaining low mutual coupling. The gain of the MIMO antenna is 8.42 dBi. The simulated return losses, together with the radiation patterns, are presented and discussed.

Keywords: MIMO antenna, V-shaped Patch antenna, Microstrip

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1. Introduction

Wireless radio communication relies on the antenna electromagnetic properties to transmit wireless signal. The antenna with good performance determines the maximum data transfer rate. MIMO antenna configuration has a higher data transfer as compared to the single-input single-output (SISO) antenna. The single element antenna configuration typically has a wider antenna radiation pattern while the multiple element antenna has a more directional pattern. The directive pattern of an antenna is resulted from the displacement manipulation of the individual element within the array antenna or varying the gap between the antennas. The corresponding techniques enable the radiation of the transmitting antenna to be more focused toward the receiving counterpart, which subsequently achieves greater distance coverage.

However the main advantage of the MIMO antenna is the robustness against the channel fading and interferences. The MIMO antenna allows for a faster data rate through spatial multiplexing [6]. The additional antenna does not increase the data speed as the additional antennas only increases the diversity order and provides dependent communication channels [2]. Single antenna link capacity increases linearly with the signal-to-noise ratio (SNR) at low SNR, and increases logarithmically with SNR at high SNR [3]. This creates a capacity limitation for the single antenna [4]. Using multiple antennas with lower capacity allowing the total transmit power to be divided among the multiple spatial paths (or modes), which subsequently driving the link capacity closer to the linear regime for each mode, thus increasing the aggregate spectral efficiency.

The theory is supported by the Shannon's Law, which indicates that the link capacity can grow linearly with the number of antennas used [5]. Mutual coupling is a phenomenon in which the electromagnetic of the antenna interacts with each other in the array. This reduces the antenna performance in MIMO system. The spacing creates the magnetic walls that protect each individual antenna's radiation from interfering with the neighbouring antenna in the MIMO system [6-7]. The other factor that contributes to the mutual coupling is the geometry of array and antenna element, position of antenna element in the array and the frequency used by the antenna [8]. The mutual coupling can also be reduced by decreasing the antenna substrate thickness [9-10].

For point-to-point communication, the suitable mutual coupling S_{21} must be lower than -20 dB. By manipulating the antenna polarization, the parametric study for the antenna spacing is conducted. The return loss of the antenna is the power reflected back from the antenna, which expressed in terms of S_{11} (S_{ii} , $i = 1, 2, 3...$). The antenna with significant return loss occurs when the antenna input voltage is not properly match with the antenna voltage. As a result, the voltage in the transmission line is doubled by the voltage standing wave [1]. The over voltage supplied causes the received signal to be partially deflected. Thus, the received power by the antenna is lower than the actual power that should be reached by the receiver.

In this paper, the effect of the polarization in the V-shaped microstrip patch antenna in compact MIMO antenna is discussed. The antenna S-parameter mutual coupling (S_{21}), antenna return loss (S_{11}), antenna gain and antenna radiation pattern are analyzed based on the parametric study. The V-shaped patch antenna is introduced in order to achieve low mutual coupling between antennas. Parametric study has been done by varying the gap between antennas. The optimum results are used to design a MIMO antenna array.

2. Antenna Analysis

In order to understand on the MIMO antenna array design, parametric study on the mutual coupling between the two single patch antennas is investigated. The transmission coefficient which represents the mutual coupling performance is discussed. The mutual coupling is the effect that exists due to the electromagnetic interference between the adjacent antenna elements. For the antenna polarization, the antenna is slanted at 45 degree inward or outward from one another.

In the MIMO design, the placement of the antenna from each other affects the antenna mutual coupling. To minimize the mutual coupling effect, the antenna spacing need to be calculated before the feeder network can be inserted. The calculation is done based on the following formula in equation 1.0 where the coupling between two antennas is c_{tr} , P_L is the power delivered to the load of the un-excited antenna and P_D is the power delivered (or radiated) by the excited antenna. From the return loss, the antenna S-parameter of S_{21} can be calculated using the formula in equation 2.0 where S_{11} is the antenna return loss.

$$c_{tr} = \frac{P_L}{P_D} \quad (1)$$

$$|S_{21}| = (1 - |S_{11}|^2) c_{tr} \quad (2)$$

As the S_{21} value cannot be determined accurately using the mathematical formula, parametric study method is used to analyze the effect of the antenna distance and the antenna mutual coupling. The Microstrip patch antenna is chosen for the antenna design as it offers directional pattern, low profile and cost effective. FR4 with permittivity of 4.5, thickness of 1.6 mm and tangential loss of 0.0019 is chosen for the antenna substrate. The antenna width is represented by $a = 38$ mm and the length is represented by $b = 30$ mm. Antenna inset feed is represented by $c = 11$ mm with a width of 1 mm. The inset feed of the antenna is varied accordingly for proper input matching. The antenna matching is represented by return loss value. The antenna gap is represented by d with its value being study parameterically. The antenna parametric study was done by varying the antenna gap, d to study the antenna mutual coupling effects.

Computer Simulation Technology (CST) software is used to simulate the antenna design. In the parametric study analysis, single element antenna is designed and simulated with an operating frequency of 2.45 GHz. Two single patch antennas is placed side by side with 45 degree slanted outward as shown in Figure 1. The results of parametric study is tabulated in Table 1 based on varying the gap, d between the antenna elements.

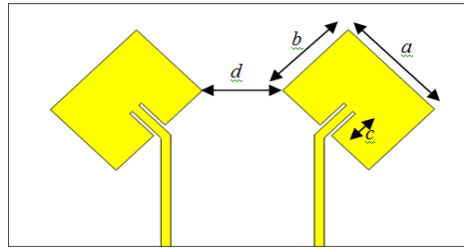


Figure 1. Single element antenna with polarization effect

Table 1. Parametric study of antenna separation, d and antenna properties

| Antenna Separation(mm), d | 5 | 10 | 15 | 20 | 25 |
|--|-------|-------|-------|-------|-------|
| Antenna Reflection Coefficient (-dB) | 21.13 | 20.56 | 20.34 | 20.07 | 19.85 |
| Antenna Transmission coefficient (-dB) | 32.23 | 33.67 | 35.75 | 37.93 | 39.91 |

Table 1 shows the positive result where the mutual coupling (transmission coefficient) between antennas is greater than 20 dB at the shortest gap, $d = 5$ mm. The simulation of separation distance is extended in decreasing order from 4 mm to 1 mm. The result is tabulated in Table 2. Results shows that at 1 mm gap, the mutual coupling between antennas is kept low below -20 dB.

Table 2. Parametric study of antenna separation, d and antenna properties

| Antenna Separation (mm), d | 1 | 2 | 3 | 4 | 5 |
|--|-------|-------|-------|-------|-------|
| Antenna Reflection Coefficient (-dB) | 20.61 | 21.23 | 20.66 | 20.64 | 21.13 |
| Antenna Transmission coefficient (-dB) | 43.67 | 37.27 | 33.87 | 32.76 | 32.23 |

The simulation is continued by further studying the use of the two single patch antennas with 45 degree slanted inward as shown in Figure 2. The simulation result is recorded in Table 3. From Table 3, the mutual coupling is kept below -20 dB with good reflection coefficient. The simulation of separation distance is extended in decreasing order from 4 mm to 1 mm. The results are tabulated in Table 4. As can be observed, the mutual coupling is kept below -20 dB down to 1 mm separation between antennas.

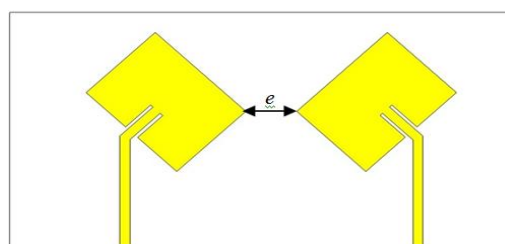


Figure 2. Single element antenna with polarization effect

Table 3. Parametric study of antenna separation, e and antenna properties

| Antenna Separation (mm), e | 5 | 10 | 15 | 20 | 25 |
|--|-------|-------|-------|-------|-------|
| Antenna Reflection Coefficient (-dB) | 20.76 | 20.91 | 20.96 | 20.94 | 20.86 |
| Antenna Transmission coefficient (-dB) | 21.79 | 22.68 | 23.43 | 24.02 | 24.55 |

Table 4. Parametric study of antenna separation, e and antenna properties

| Antenna Separation (mm), e | 1 | 2 | 3 | 4 | 5 |
|--|-------|-------|-------|-------|-------|
| Antenna Reflection Coefficient (-dB) | 20.77 | 20.72 | 20.72 | 20.73 | 20.76 |
| Antenna Transmission coefficient (-dB) | 22.23 | 21.64 | 21.55 | 21.63 | 21.79 |

From the parametric study above, the antenna slanted 45 degree outward has better performance than the antenna with 45 degree slanted inward. The orientation of the antennas with V-shape polarization allow the antenna arrays to avoid electromagnetic interaction between each one another which reduces the mutual coupling effect. Based on this parametric study, the design serves as the basis for the MIMO antenna array design.

3. Antenna Design & Analysis

Figure 3 shows the dimension of the proposed V-shaped MIMO antenna array. At 1 mm gap, g the overall antenna size is 120 mm \times 133 mm. The transmission line of the antenna is marked by $h = 60.8$ mm, $l = 38$ mm and $j = 21$ mm. The separation between antennas are, $f = 1.5$ mm and $g = 1$ mm, respectively. The antenna dimension is based on the antenna operating frequency and the desired bandwidth. The antenna length is corresponding to the wavelength of the operating frequency. The width of the antenna affects the antenna operational bandwidth. The antenna inset feed controls the antenna impedance in order to match with the input impedance of the SMA port.

The antenna transmission line is designed by matching the antenna array impedance without changing the size of the antenna element. The position of the antenna element is optimized in such way that the radiating electromagnetic wave that may cancel out the antenna array wave is avoided.

The antennas are placed at 45 degree slanted orientation as the 45 degree angle gives low mutual coupling between antennas. In a normal position (0 degree) with 1 mm gap between antennas, the antennas will produce high mutual coupling which affect the performance of the antenna.

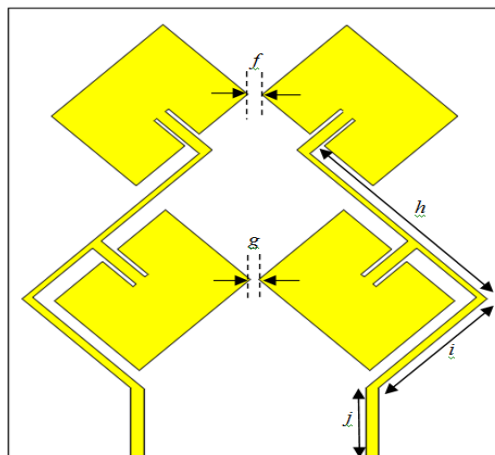


Figure 3. MIMO antenna design

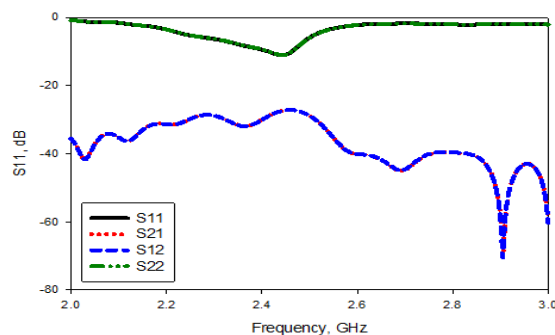


Figure 4. Antenna S parameter

Figure 4 shows the antennas reflection coefficient and the transmission coefficient. The antenna shows a peak value at 2.45 GHz in which the antenna reflection coefficient is -12 dB and the antenna transmission coefficient is 27dB. The antennas is properly matched as the graph shows that the forward reflection coefficient and reverse reflection coefficient is almost identical. The bandwidth of the antennas is 50 MHz from 2.41 GHz to 2.46 GHz.

The antenna radiation pattern can be presented in three dimensional (3D) or in polar plot coordinates. Figure 5 shows the 3D radiation pattern while Figure 6 shows the polar plot radiation pattern at 2.45 GHz. The figure shows that the MIMO antenna array is directional with 8.42 dBi gain. The antenna is highly suitable for point-to-point wireless communication at 2.45 GHz band. The wave is more focus at the main front lobe with a front to back ratio of 14 dB. The antenna array is able to produce a narrow radiation pattern and high gain due to the arrangement of the antenna array and low mutual coupling between antenna elements. The 3-dB beamwidth of the antenna in H-plane and E-plane is 99.6 degree and 54 degree, respectively. Furthermore, the designed antenna is linear polarized.

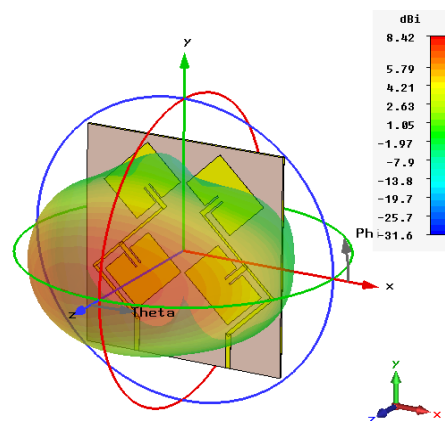


Figure 5. 3D Antenna radiation Pattern of the proposed antenna at 2.45 GHz

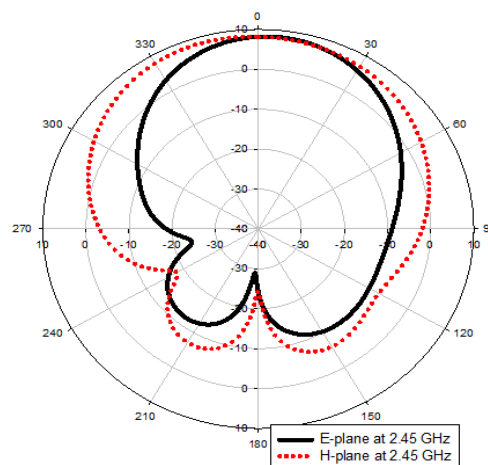


Figure 6. Radiation pattern of the proposed antenna at 2.45 GHz

Figure 7(a) shows the antenna current distribution of the antenna Port 1 while Figure 7(b) shows the antenna current distribution of Port 2. The antenna is connected using open end wire. The current looping of the both end was out of phase. The V-shaped of the antenna allows the antenna to reduce its mutual coupling as the actual resonant is polarized to be parallel with each other.

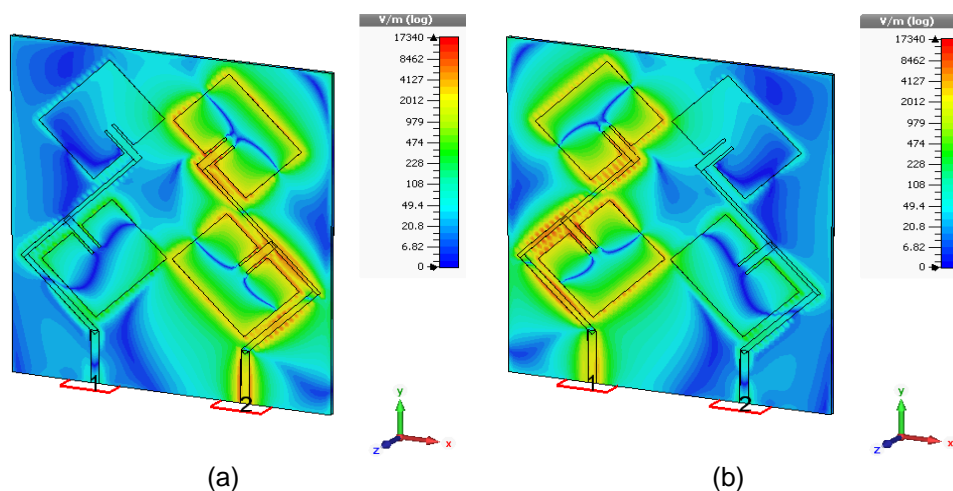


Figure 7. Current distribution of the proposed antenna at 2.45 GHz

4. Conclusion

Antenna orientation allows the antenna array to lower the mutual coupling effect as the antenna polarization effect taking place. The orientation (V-shape) manipulates the antenna polarization from affecting one antenna element to another. The separation distance can be greatly reduced to 1 mm. Any separation distance lower than 1mm, the antenna may not be able to be manufactured precisely as the patch antenna will be fabricated using the PCB etching technique. For the MIMO configuration, the multiple antennas can be placed closely to each other taking the full advantage of the space available with an operating frequency of 2.45 GHz. The orientation lowers the antenna gap between the antennas without sacrificing the antenna performance. The MIMO antenna placed in such position providing more directive radiation pattern while maintaining its compact sizes. The radiation pattern of the antenna is directional in pattern and the gain of the antenna is 8.42 dBi. The MIMO array antenna is suitable for point to point wireless communication system.

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