A Different Shaped Radiating Element Wide Band Multi-Band Massive MIMO Antenna for 5G/WLAN applications with Enhanced Correlation Coefficient

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Abstract. In this paper, a different shaped 8-element multiband multiple input multiple output (MIMO) massive antenna is investigated for 5G and various applications. It can be operated on various wireless communication application such as WLAN (5.15GHz to 5.30GHz and 5.73GHz to 5.85GHz) and 5G band & C-band (4 to 8GHz) for satellite communication with wideband. The 8-element Massive MIMO antenna is designed for 6GHz. This antenna is working on multiband with wideband bandwidth. The defected ground structure (DGS) systems are used for enhancement of return loss, isolation, total active reflection coefficients (TARC), correlation coefficients (CC) and envelope correlation coefficients (ECC). The rectangular shaped DGS is used in the ground plane for improvement of various parameter of antenna. This antenna provides return loss (RL) and isolation is less than -10dB.

Keywords. MIMO, DGS, TARC, CC.

1. Introduction

In recent years, wireless technology is rapidly developed with increasing tremendously of its users. Therefore, there is high demands of data rate and reliability to handle the growth of users. MIMO antenna system has bring the attention of researchers for the data rate, capacity of channel and reliability. For good communication, there is a requirement of higher bandwidth. Therefore, it is required to design the antenna which operates on wideband bandwidth. The MIMO technology is mostly useful for upcoming 5G mobile systems, as well various application of wireless system. Meanwhile, the today’s wireless systems has required the more antennas, which operates on multiple frequencies. But, more antenna on single substrate which increases the isolation. Hence, that effects on the radiation, efficiency and overall performance of antenna. So, for improvement of performance of the antenna, the isolation is required to improve. Therefore, enhancement of isolation, CC and ECC values of MIMO antenna are critical task. The different techniques are used for improvement of isolation of MIMO antenna. The decoupling method is used for enhancement of isolation [1-3]. In [4-7], a different shaped DGS is used on the ground to change the characteristics of the microstrip line to reduce isolation between the radiating elements. In [8], electromagnetics bandgap (EBG) was designed for improvement of isolation. The mutual coupling is enhanced using the metamaterial [9] and the neutralization line [10-11]. The isolation is reduced using the parasitic elements between the radiating element [12-13] and the using the traditional methods [14].

To summarize previous paper, in this paper the multi-band wideband massive MIMO antenna that consists of different shaped radiating element is designed for various application. The different shaped 8-element Massive MIMO antenna are investigated for mm-wave. The DGS is used for improvement.
of isolation between the radiating elements. The rectangular shaped DGS is used on the ground plane. This antennas are operated multiband, hence covers the different application in single antenna. Also, this antennas are operated on wideband bandwidth. These antennas works at multi-band with less than -10dB RL and -10dB isolation with wideband operation.

2. Antenna design procedure

The transmission line model (TLM) is used for calculation of geometric structure of radiating element and ground plane of antenna. This antenna is designed using the following formula and analysed using antenna parameter.

2.1. TLM technique

The length ($L_p$) and width ($W_p$) radiating patch are computed using the following equation 1 to equation 5,

$$\text{Width} \ (W_p) = \frac{1}{2f_0\sqrt{\mu_0\varepsilon_0}} \sqrt{\frac{2}{\varepsilon_{or}+1}}$$  \hspace{1cm} (1)

$$L_v = \frac{4.12}{10} h \left[ \left(\frac{\varepsilon_{eff}^{+} + \frac{3}{10}}{\varepsilon_{eff}^{-0.258}}\right) \left(\frac{\frac{W_p}{h} + 0.64}{0.8}\right) \right]$$  \hspace{1cm} (2)

$$L_{eff} = L_p + 2L_v$$  \hspace{1cm} (3)

$$f_0 = \frac{1}{2L_p\sqrt{\varepsilon_{or}\mu_0\varepsilon_0}}$$  \hspace{1cm} (4)

$$\varepsilon_{eff} = \frac{\varepsilon_{or}+1}{2} + \frac{\varepsilon_{or}-1}{2} \left[ 1 + 12 \frac{h}{W_p} \right]^{-1/2}$$  \hspace{1cm} (5)

Where, $W_p = \text{Width of Patch}$

$L_p = \text{Length of Patch}$

The length ($L_g$) and width ($W_g$) of ground plane are computed using the following equation 6 to equation 7,

$$L_g = L_p + 6h$$  \hspace{1cm} (6)

$$W_g = W_p + 6h$$  \hspace{1cm} (7)

Where,

$L_g = \text{Length of Ground}$

$W_g = \text{Width of Ground}$

The length ($L_f$) and width ($W_f$) for inset feed line (IFL) are computed using the equation 8 and 10 to excite the radiating patch of antenna.

Feed line length ($L_f$) = $\frac{\lambda_g}{4}$  \hspace{1cm} (8)

Guided wave length ($\lambda_g$) = $\frac{\lambda_0}{4}$  \hspace{1cm} (9)

The width ($W_f$) of the IFL required to excite the radiating patch is given by,

$$W_f = 0.636h \times \left[ \frac{592.19}{Z_0\sqrt{\varepsilon_{or}}} - 0.7 - \ln \left(\frac{2\times377\pi}{Z_0\sqrt{\varepsilon_{or}} + 1}\right) \right] + \frac{2h}{\pi} \times \left[ \frac{(\varepsilon_{or}-1)}{2\varepsilon_{or}} \left( \frac{592.19}{Z_0\sqrt{\varepsilon_{or}} - 1} - \frac{0.6}{\varepsilon_{or}} \right) \right]$$  \hspace{1cm} (10)

Where,
Characteristics Impedance = \( Z_0 = 50\Omega \)

2.2. MIMO antenna parameter

1) \( TARC \)
   This is calculated using equation 11.
   \[
   TARC (\tau) = \sqrt{\left[(S_{11} + S_{12}e^{\theta})^2 + (S_{21} + S_{22}e^{\theta})^2\right]/2} \]  \( (11) \)
   Where:
   \( \theta = \text{Phase of the input feeding} \)
   \( S_{11} \) and \( S_{22} = \text{Reflection coefficient} \)
   \( S_{12} \) and \( S_{21} = \text{Isolation} \)

2) \( CC(\rho_{xy}) \text{ and } ECC(\rho_{ecc,xy}) \)
   These are calculated by using the equation-12 for 2-element.
   \[
   \rho_{xy}^2 = \rho_{ecc,xy} = \left[\frac{(S_{11}S_{12} + S_{21}S_{22})}{\sqrt{(1-S_{11}^2-S_{21}^2)(1-S_{22}^2-S_{12}^2)}}\right]^2 \]  \( (12) \)
   Where:
   \( \rho_{xy} = \text{CC value between the 1\textsuperscript{st} (x) and 2\textsuperscript{nd} (y) element} \)
   \( \rho_{ecc,xy} = \text{ECC value between the 1\textsuperscript{st} (x) and 2\textsuperscript{nd} (y) element} \)

3) Diversity Gain (DG)
   DG of the antenna is find out using equation 13.
   \[
   DG = 10 \sqrt{1 - (0.99ECC)^2} \]  \( (13) \)

4) Bandwidth
   Bandwidth of antenna is calculated by using equation 14.
   \[
   \%BW = \{\left(\frac{F_h - F_l}{F_0}\right) \times 100\} \]  \( (14) \)
   \[
   F_0 = \{F_l + \left(\frac{F_h - F_l}{2}\right)\} \]  \( (15) \)
   Where:
   \( BW = \text{Bandwidth} \)
   \( F_h = \text{Higher frequency} \)
   \( F_l = \text{Lower frequency} \)
   \( F_0 = \text{Center frequency} \)

3. Antenna Design and analysis

In this paper, 8-element massive MIMO antennas are designed.

3.1. Design of Different Shaped 8-radiating element massive MIMO antenna.

The 8-element Massive MIMO antenna using DGS is designed on FR4 substrate as shown in figure 1. The characteristics of FR4 substrate is shown in table-1. This antenna consists of 8-radiating element (P1 to P8), patch-1 to patch-8 is designed for 6GHz frequency (mm-wave) as shown in figure 1 and figure 2. The geometrical structure of radiating element for 6GHz frequency is as shown in figure 2 and table 1. Every radiating element is energized using the inset feed techniques having dimensions are shown in table 1. The antenna dimensions are 32.58mm \( \times \) 74mm \( \times \) 1.6mm. The rectangular shape
structure has used as DGS (G1 to G8) in ground plane as shown in figure 3 having dimensions are shown in figure 4 and table 2. The spacing between the radiating elements is less than $\frac{\lambda}{2}$ with respected to 6GHz frequency.

**Table 1. Dimensions of Massive MIMO antenna**

| Parameter                     | Value of Parameter |
|-------------------------------|--------------------|
| Frequency                     | 6 GHz              |
| Dielectric Constant ($\varepsilon_0r$) | 4.4                |
| Height of Substrate           | 1.6mm              |
| Patch Width                   | $W_p = 15.21\text{mm}$ |
| Length of patch               | $L_p = 11.34\text{mm}$ |
| Width ($W_f$) of inset feed line | $M = 2.942\text{mm}$ |
| Length ($L_f$) of inset line  | $N = 6.387\text{mm}$ |
| Length “K”                    | $K = 12.69\text{mm}$ |

**Figure 1.** Different Shaped 8-element Massive MIMO antenna

**Figure 2.** Top side of antenna geometry
After analysis of antenna using HFSS software, the analysis of RL and isolation are obtained as shown in following figures. This antenna is operated on multiband for the 5.0GHz, 5.5GHz, 6.0GHz, 6.1GHz, 6.3GHz, 6.4GHz, 6.7GHz and 6.9GHz frequencies.
This antenna is consists of 8 different shaped radiating element and all 8 different shape are placed on the substrate. Which forms the 8-element Massive MIMO antenna. This antenna is operated on multiband with wideband application. The parameter RL and isolation is enhanced using DGS structure. Also, the all resonating band are operated on wide band (Bandwidth is in between 1% to 20%) with respect to 6GHz frequency.

The RL $S_{11}$, $S_{22}$, $S_{33}$, $S_{44}$, $S_{55}$, $S_{66}$, $S_{77}$ and $S_{88}$ and relative isolation is as shown in following figure 5 to figure 12 with in the table 3 to table 10 respectively (m1 and m2 are show points on graph of RL and isolation). The bandwidth (% bandwidth) of antenna is calculated using the equation 14 and equation 15.

![Figure 5. RL ($S_{11}$) and related isolation](image)

**Table 3. The results of radiating patch-1**

| Parameter | Operating Frequency (in GHz) | Values |
|-----------|------------------------------|--------|
| $S_{11}$ (m2) | 5 | -16.62 dB |
| $S_{12}$, $S_{13}$, $S_{14}$, $S_{15}$ (m1), $S_{16}$, $S_{17}$ and $S_{18}$ Bandwidth | | Less than -13.02 dB 132MHz (2.19%) |

![Figure 6. RL ($S_{22}$) and related isolation](image)
### Table 4. The results of radiating patch-2

| Parameter | Operating Frequency (in GHz) | Values |
|-----------|-----------------------------|--------|
| $S_{22}$ (m2)          |                            | -16.96 dB |
| $S_{21}$, $S_{23}$, $S_{24}$, $S_{25}$, $S_{26}$, $S_{27}$ (m1) and $S_{28}$ | 6.1 | Less than -12.64 dB |
| Bandwidth            |                            | 294MHz (4.9%) |

### Table 5. The results of radiating patch-3

| Parameter | Operating Frequency (in GHz) | Values |
|-----------|-----------------------------|--------|
| $S_{33}$ (m2)          |                            | -11.41 dB |
| $S_{31}$, $S_{32}$ (m1), $S_{34}$, $S_{35}$, $S_{36}$, $S_{37}$ and $S_{38}$ | 5.5 | Less than -10.55 dB |
| Bandwidth            |                            | 152MHz (2.53%) |

![Figure 7. RL ($S_{33}$) and related isolation](image7)

![Figure 8. RL ($S_{44}$) and related isolation](image8)
Table 6. The results of radiating patch-4

| Parameter | Operating Frequency (in GHz) | Values |
|-----------|-----------------------------|--------|
| $S_{44}$ (m1) | 6.3 GHz | -14.16 dB |
| $S_{41}$, $S_{42}$, $S_{43}$, $S_{45}$, $S_{46}$, $S_{47}$ and $S_{48}$ (m2) | 6.3 GHz | Less than -11.58 dB |
| Bandwidth | | 98 MHz (1.63%) |

Figure 9. RL ($S_{55}$) and related isolation

Table 7. The results of radiating patch-5

| Parameter | Operating Frequency (in GHz) | Values |
|-----------|-----------------------------|--------|
| $S_{55}$ (m1) | 6.4 GHz | -17.27 dB |
| $S_{51}$, $S_{52}$, $S_{53}$, $S_{54}$, $S_{56}$, $S_{57}$ and $S_{58}$ (m2) | 6.4 GHz | Less than -10.89 dB |
| Bandwidth | | 242 MHz (4.04%) |

Figure 10. RL ($S_{66}$) and related isolation
Table 8. The results of radiating patch-6

| Parameter          | Operating Frequency (in GHz) | Values                      |
|--------------------|------------------------------|-----------------------------|
| $S_{66}$ (m1)      |                              | -10.31 dB                  |
| $S_{61}$, $S_{62}$ (m2), $S_{63}$, $S_{64}$, $S_{65}$, $S_{67}$ and $S_{68}$ | 6.9                         | Less than -13.49 dB          |
| Bandwidth          |                              | 43 MHz (0.72%)              |

Figure 11. RL ($S_{77}$) and related isolation

Table 9. The results of radiating patch-7

| Parameter          | Operating Frequency (in GHz) | Values                      |
|--------------------|------------------------------|-----------------------------|
| $S_{77}$ (m2)      |                              | -16.52 dB                  |
| $S_{71}$, $S_{72}$, $S_{73}$, $S_{74}$, $S_{75}$, $S_{76}$ (m1) and $S_{78}$ | 6.0 GHz                     | Less than -13.18 dB          |
| Bandwidth          |                              | 311 MHz (5.19%)             |

Figure 12. RL ($S_{88}$) and related isolation
Table 10. The results of radiating patch-8

| Parameter | Operating Frequency (in GHz) | Values |
|-----------|-------------------------------|--------|
| $S_{B1}$, $S_{B2}$, $S_{B3}$, $S_{B4}$, $S_{B5}$, $S_{B6}$ and $S_{B7}$ | 6.7 GHz | -27.11 dB |
| Bandwidth | | Less than -10.95 dB |
| | | 358 MHz (5.96%) |

The VSWR of radiating patch is as shown in figure 13 and table 11. The gain ($G_A$) and directivity ($D_A$) of antenna is as shown in figure 14 and values shown in table 12. The radiation pattern of antenna is as shown in figure 15. The antenna parameters are as shown in table 13 which is calculated using equation 11 to equation 15.

![Image of VSWR graph](image-url)

Figure 13. VSWR

Table 11. VSWR

| Parameter | Frequency (GHz) | Values (dB) | Absolute Values |
|-----------|-----------------|-------------|-----------------|
| Patch-1 $VSWR$ (m1) | 5.0 | 2.58 | 1.81 |
| Patch-2 $VSWR$ (m2) | 6.1 | 2.51 | 1.78 |
| Patch-3 $VSWR$ (m3) | 5.5 | 4.7 | 2.95 |
| Patch-4 $VSWR$ (m4) | 6.3 | 3.4 | 2.18 |
| Patch-5 $VSWR$ (m5) | 6.4 | 2.39 | 1.73 |
| Patch-6 $VSWR$ (m6) | 6.9 | 5.2 | 3.31 |
| Patch-7 $VSWR$ (m7) | 6.0 | 2.61 | 1.82 |
| Patch-8 $VSWR$ (m8) | 6.7 | 0.67 | 1.16 |
Figure 14. Gain $G_A$ and Directivity $D_A$

Table 12. Gain ($G_A$) and Directivity ($D_A$) of antenna

| Parameter | Values in dB |
|-----------|--------------|
| Gain      | 2.11         |
| Directivity | 4.40       |

Figure 15. Radiation Pattern

Table 13. Parameter of MIMO antenna

| Parameter | Values                  |
|-----------|-------------------------|
| TARC      | Less than 0.159 (less than -7.98dB) |
| CC        | Less than 0.12          |
| ECC       | Less than 0.0148        |
| DG        | Close to 10dB           |

4. Conclusion

The 8-different shaped element massive MIMO antenna is investigated for millimetre wave. The analysis of antenna shows that, it is operated on multi-band for 5.0GHz, 5.5GHz, 6.0GHz, 6.1GHz, 6.3GHz, 6.4GHz, 6.7GHz and 6.9GHz frequencies. This antenna is operated on wideband bandwidth. The analysis of antenna shows that less than -10dB RL and less than -10dB isolation with 2.11 dB gain, 4.40 dB directivity and bandwidth is in between 43MHz to 358MHz. The absolute VSWR values are in between
The analysis of antenna shows less than 0.12CC and less than 0.0148 ECC. The diversity gain of antenna is close to 10dB and less than -7.98 dB TARC. This antenna is used for the WLAN (5.15GHz to 5.30GHz and 5.73GHz to 5.85GHz) and 5G band & C-band (4 to 8GHz) for satellite communication.

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