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Performance of Groundplane Shaping in Four-Element Dualband MIMO Antenna

Subuh Pramono*[1], Tommi Hariyadi[2], Budi Basuki Subagio[3]
[1,3]Department of Electrical Engineering, Politeknik Negeri Semarang, Semarang, Indonesia
[2]Department of Electrical Engineering, Universitas Pendidikan Indonesia, Bandung, Indonesia
*Corresponding author, e-mail: subuhpramono@gmail.com

Abstract

This work presents performance of groundplane shaping and its effect in four element dualband multiple input multiple output (MIMO) antenna. This proposed four element dualband MIMO antenna consists of four bowtie dipole antenna which operates at 1800 MHz (low frequency) and 2300 MHz (high frequency). This proposed four element dualband MIMO antenna occupies a 270 x 210 x 100 mm^3 of FR 4 substrate. We use four types of groundplane pattern i.e. full groundplane, cornered spatial groundplane, crossed middle groundplane, and spiral groundplane. These various grounplane patterns influence the performance of main parameters of dualband MIMO antenna. Cornered spatial groundplane pattern yields a largest bandwidth (VSWR ≤ 2) 282 MHz or 15.24% of center frequency at low frequency. Full groundplane pattern creates 135.2 MHz at high frequency. In addition, cornered spatial groundplane pattern also generates a lowest VSWR that is valued 1.21 at both low frequency and high frequency. The S parameters, basically both cornered spatial and full groundplane pattern produce a better return loss than two others. All four groundplane patterns deliver equally a mutual coupling parameter.The last, this proposed four element dualband MIMO with various groundplane patterns gives a good farfield properties i.e. gain, radiation pattern, H-E field.

Keywords: *groundplane, MIMO antenna, dualband, mutual coupling, S parameter, bandwidth*

1. Introduction

In recent years, telecommunication technology is moving toward into high speed data rate communication. Particularly, cellular telecommunication now is 4th generation which is 300 Mps uplink dan 75 Mbps downlink data rate. Many techniques have been developed on digital communication that addressed to support high speed data rate. One of important technique is antenna system. The antenna system has been deeply developed. Recently, receiver and transmitter use multiple antennas, it is well known as multiple input multiple output (MIMO) antenna system. The MIMO antenna system has an advantage in term of spatial multiplexing and spatial diversity. Spatial diversity provides stronger link robustness by increased signal to noise ratio. Spatial multiplexing effectively increases a link capacity [1]. A wider bandwidth is absolutely needed in recent celluler telecommunication technology. Various techniques were explored to enhance the bandwidth, such as using feed optimization, ground plane slits and shaping [2], bevels, different thickness of dielectric substrate [3], slots on the patch. This research uses microstrip patch which is compact, light, and simple structure. Creating a high isolation between closely placed antenna elements is a major challenge of microstrip MIMO antenna design [4, 5]. On the previous work [6] that the finite groundplane affects the performance of resonant frequency, input resistance, and directivity of antenna. In [7], it investigated the effects of shaped groundplane on impedance and bandwidth parameters. This proposed MIMO antenna system consists of four antenna elements. Single antenna element is constructed by bowtie dipole antenna with an integrated balun that is dualband 1800 MHz and 2300 MHz. Bowtie dipole antenna with integrated balun have been proven that can to provide a wider bandwidth [8]. This MIMO antenna operates dualband frequencies 1800 MHz and 2300 MHz which are cellular communication application.

This research investigates impact of various patterns of groundplane shaping in four element dualband MIMO antennas. In this proposed four element dualband MIMO antenna, we use four patterns of groundplane shaping i.e. full groundplane, cornered spatial groundplane,

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crossed middle groundplane, and spriral groundplane. Specifically, we focus on the effects of various patterns of groundplane shaping on main antenna parameters i.e. VSWR, bandwidth, gain, mutual coupling, and radiation pattern. This dualband MIMO antenna operates with center frequency 1850 MHz and 2350 MHz. This work comprises four sections, section I is introduction. Section II detail explains three subjects which are single element of bow tie dipole antenna design, four element dualband MIMO antenna design, various patterns of groundplane shaping. Section III discusses and analyses numerically simulated results of antenna parameters. Section IV is conclusion.

2. Multiple Input Multiple Output (MIMO) Antenna

This MIMO antenna comprised four antennas element. A single antenna element on this proposed four element dualband MIMO antenna is designed using by bowtie dipole antenna with an integrated balun.

2.1. Bowtie Dipole Antenna

In this research, single bowtie dipole antenna comprises bowtie dipole, arm dipole, matching impedance, balun, and feeder. The size of the bowtie dipole antenna, impedance characteristic and equivalent dielectric constant can be estimated by these below formulas [9]:

$$Z_t = 120 \ln \cot \frac{\theta}{4} \quad (1)$$

$$L = \frac{\lambda}{2} \times \frac{1}{\sqrt{\varepsilon_f}} \quad (2)$$

$$\varepsilon_f = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 10\frac{d}{w}\right)^{-0.55} \quad (3)$$

L is length of bowtie dipole antenna. Z_t is characteristic impedance of the bowtie dipole antenna. θ is bowtie dipole antenna angle. W is width of bowtie dipole antenna. ε_f is equivalent dielectric constant. ε_r is dielectric constant of substrate, d is thickness of the substrate. The arm dipole and bowtie dipole are vertically placed to groundplane. Complete geometrical design of single bowtie dipole antenna is depicted at Figure 1. Furthermore, Table 1 describes a precisely size of single bowtie dipole antenna.

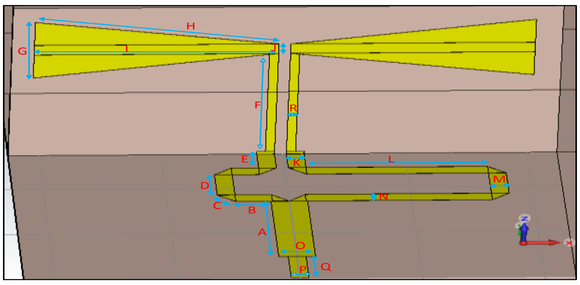


Figure 1. Single Bowtie Dipole Antena Design

Table 1. Single Bowtie Dipole Antenna Parameters

Parameter	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
Value (mm)	24.5	6	4.1	9	7	30	16.9	40.6	40	2.9	2.9	30.5	2.9	2.9	5.5	2.9	9.5	1.5

2.2. Four Element Multiple Input Multiple Output (MIMO) Dualband Antenna

Complete geometrical design of four element dualband MIMO antenna is shown at Figure 2. This proposed antenna occupies a 270 x 210 mm^2 of FR 4 substrate ($\varepsilon_\gamma = 4.4$, $\tan\delta = 0.02$, thinkness 1.6 mm). Four antennas element are arranged into two block confrontly

(Table 2). It works at dualband frequencies with center frequency 1850 MHz and 2350 MHz. This four element dualband MIMO antenna generates four S parameters. The S parameters are described as below matrix [10].

$$S_{4x4} = \begin{pmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{pmatrix} \quad (4)$$

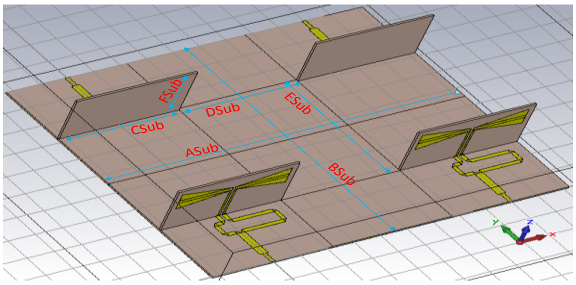


Figure 2. Geometrical of Four Element MIMO Dualband Antenna Design

Table 2. Four element MIMO Dualband Antenna Parameters

Parameter	Asub	Bsub	Csub	Dsub	Esub	Fsub
Value (mm)	270	210	90	90	110	50

2.3. Groundplane Shaping

A ground plane is an electrically conductive surface. Groundplane is placed at the bottom side of this proposed antenna. This research uses four patterns of groundplane shaping i.e. full groundplane, cornered spatial groundplane, crossed middle grounplane and spiral groundplane which are detail described at Figure 3.

(a) Full groundplane (b) Cornered spatial groundplane (c) Crossed middle groundplane (d) Spiral groundplane

Figure 3. Four Patterns of Groundplane Shaping

Full groundplane pattern, its all groundplane area is covered by conductive surface, enables entire groundplane area that distributes a current surface. It is depicted at Figure 3(a). Cornered spatial groundplane pattern only provides four squared small conductive surfaces at each corner of groundplane. This cornered spatial grounplane pattern is shown at Figure 3(b). These four squared small condutive surfaces are precisely placed opposite of the bowtie dipole antennas. Crossed middle groundplane pattern shows that groundplane area is still mostly covered by conductive surface excepted of four squared small opposite areas of bowtie dipole antennas. It is illustrated at Figure 3(c). The last, spiral groundplane pattern is to partition off groundplane into two spiral areas that are figured at Figure 3(d).

3. Results and Analysis

In this section, we will provide a discussion and analysis of groundplane shaping effects in four element dualband MIMO antenna performance. The groundplane shapings affect the antenna parameters i.e. bandwidth, mutual coupling, VSWR, gain and radiation pattern. The proposed four element dualband MIMO antenna was designed using the CST studio suite.

3.1. Voltage Standing Wave Ratio (VSWR) & Bandwidth

Based on Figure 4 and Table 3 shows that simulation VSWR results in various groundplane shaping is in range of 1.21 until 13.16 both at low frequency (1800 MHz) and high frequency (2300 MHz). The lowest VSWR is obtained from cornered spatial groundplane pattern at low frecuency (1800 MHz). Meanwhile, the highest VSWR is produced from spiral groundplane pattern at low frecuency (1800 MHz). It means that the reflected voltage is only 9.5 % of forwarded voltage at the lowest VSWR. In case of the highest VSWR, almost 85.8 % of forwarded voltage is reflected. Furthermore, cornered spatial groundplane pattern generates a widest bandwidth (VSWR < 2) 282 MHz at low frequency (1800 MHz). It is 15.2 % of center frequency. Meanwhile, full groundplane pattern yields a largest bandwidth (VSWR <2) 135.2 MHz at high frequency (2300 MHz) which is 5,7 % of center frequency. Whereas, both crossed middle groundplane pattern and spiral groundplane pattern can not meet the bandwidth VSWR< 2. The simulation VSWR and bandwidth (VSWR <2) results are detail depicted at Figure 4 and Table 3-4.

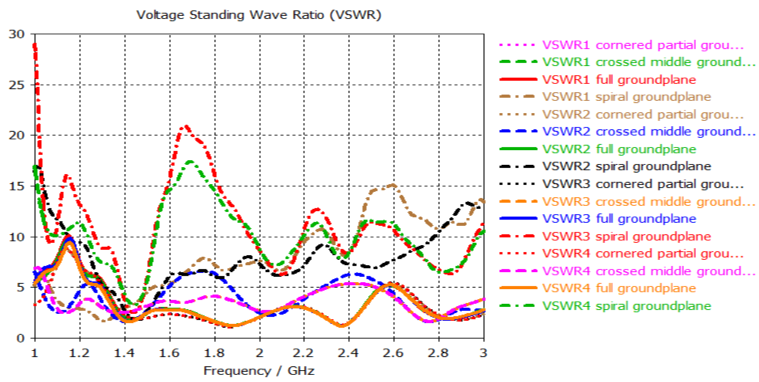


Figure 4. VSWR profile

Table 3. VSWR at Low Frequency (1800 MHz) and High Frequency (2300 MHz)

Full groundplane			Cornered spatial groundplane			Crossed middle groundplane			Spiral groundplane		
F(MHz)	Ant	VSWR	F(MHz)	Ant	VSWR	F (MHz)	Ant	VSWR	F(MHz)	Ant	VSWR
1800	1	1.42	1800	1	1.21	1800	1	5.71	1800	1	6.27
1800	2	1.42	1800	2	1.21	1800	2	5.71	1800	2	5.94
1800	3	1.42	1800	3	1.21	1800	3	3.93	1800	3	14
1800	4	1.42	1800	4	1.21	1800	4	3.93	1800	4	13.16
2300	1	1.33	2300	1	1.41	2300	1	5.6	2300	1	9.6
2300	2	1.33	2300	2	1.41	2300	2	5.6	2300	2	8.24
2300	3	1.33	2300	3	1.41	2300	3	5.17	2300	3	10
2300	4	1.33	2300	4	1.41	2300	4	5.17	2300	4	8.52

Table 4. Bandwidth VSWR ≤ 2

Full groundplane			Cornered spatial groundplane			Crossed middle groundplane			Spiral groundplane		
F(MHz)	Ant	BW(MHz)	F(MHz)	Ant	BW(MHz)	F(MHz)	Ant	BW(MHz)	F(MHz)	Ant	BW (MHz)
1800	1	235.5	1800	1	282	1800	1	0	1800	1	0
1800	2	235.5	1800	2	282	1800	2	0	1800	2	0
1800	3	235.5	1800	3	282	1800	3	0	1800	3	0
1800	4	235.5	1800	4	282	1800	4	0	1800	4	0
2300	1	135.2	2300	1	122	2300	1	0	2300	1	0
2300	2	135.2	2300	2	122	2300	2	0	2300	2	0
2300	3	135.2	2300	3	122	2300	3	0	2300	3	0
2300	4	135.2	2300	4	122	2300	4	0	2300	4	0

3.2. S Parameter

This proposed four element dualband MIMO antenna creates four port S parameters. The S parameters include a return loss (S11,S22,S33,S44) and a mutual coupling (S12,S13,S14,S21,S23,S24,S31,S32,S34,S41,S42,S43). Based on Figure 5, we can see the return loss results that cornered spatial groundplane pattern produces the best return loss in range of -22 dB until -26 dB at low frequency (1800 Mhz). At the high frequency (2300 MHz), full grounplane pattern yields the best return loss in range of -17 dB until -20 dB. Both crossed middle groundplane pattern and spiral groundplane pattern generates a worse return loss in range of -2 dB until -5 dB. Figure 6 shows the simulation results of mutual coupling. Basically, all various groundplane patterns, both low frequency and high frequency, creates equally mutual coupling results in range of -10.168 dB until -52.111 dB (Table 5). With all obtained values of mutual coupling are relative high that means four element antennas in this proposed dualband MIMO antenna design are independently existence. Decreasing of groundplane can reduce the fringing effect on the edge.

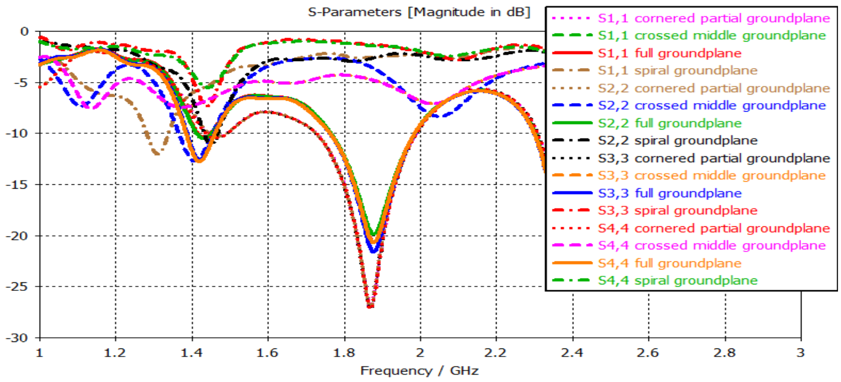


Figure 5. Return Loss Curves (S11, S22, S33, S44)

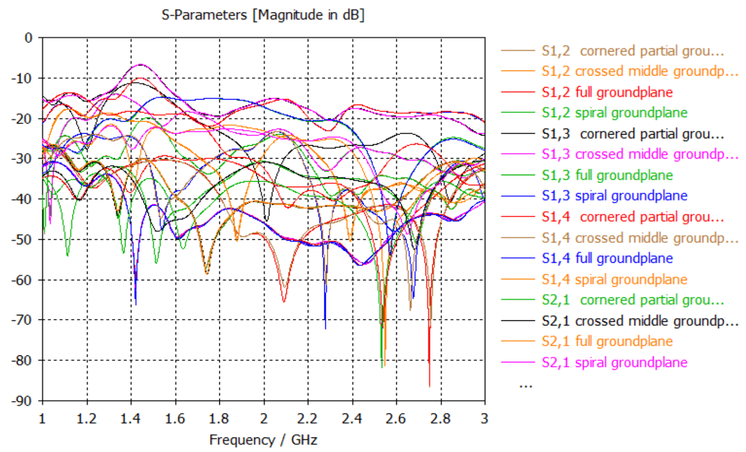


Figure 6. Mutual Coupling Curves (S12,S13,S14,S21,S23,S24,S31,S32,S34,S41,S42,S43)

Table 5. Mutual Coupling at Low Frequency and High Frequency in all Various Groundplane Patterns

Full groundplane		Cornered spatial groundplane	
F (MHz)	Mutual coupling (dB)	F (MHz)	Mutual coupling (dB)
1850	-21.715 - -44.481	1850	-15.386 - -47.21
2350	-24.669 - -52.111	2350	- 21.293 - -41.148
Crossed middle groundplane		Spiral groundplane	
F (MHz)	Mutual coupling (dB)	F (MHz)	Mutual coupling (dB)
1850	-24.669 - -45.649	1850	-19.043 - -40.023
2350	-27.207 - -45.368	2350	-10.168 - -38.616

3.3. Radiation Pattern, Gain & H-E Field

Figure 7, Figure 8 and Table 6 explains a simulation result of farfield properties which is including 2D (two dimensional) magnetic field (H) – electrical field (E), 3D (three dimensional) radiation pattern, and antenna gain, respectively. All farfield properties of four element dualband MIMO antenna are simulated with all various groundplane patterns at both low frequency and high frequency. Based on Figure 8 and Table 6, shows that both full groundplane pattern and cornered partial groundplane pattern yield a better gain than spiral groundplane pattern and crossed middle groundplane pattern.

Full groundplane pattern and cornered partial groundplane pattern gives a gaining in range of 6.59 dBi until 8.45 dBi. Meanwhile, spiral groundplane pattern and crossed middle groundplane pattern creates a lower gaining than two previous patterns.It is lower valued in range of 4.66 dBi until 7.18 dBi.

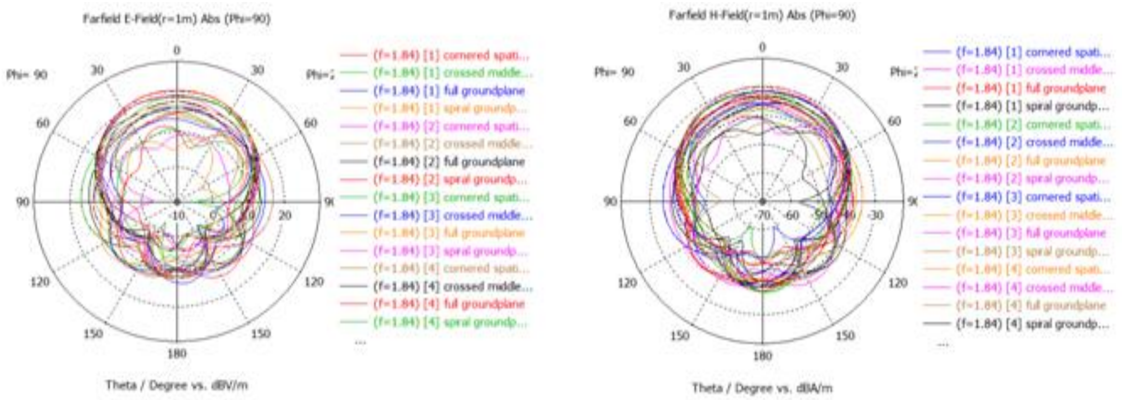
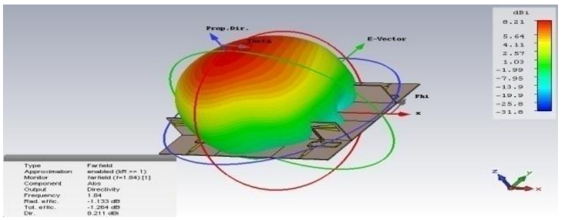
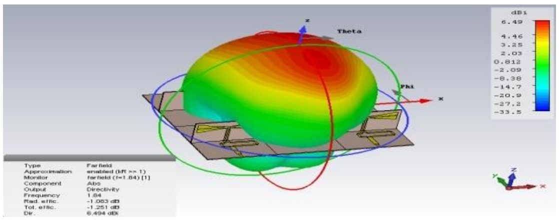


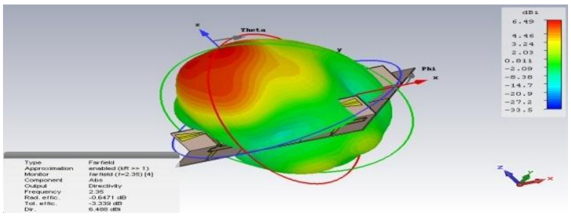
Figure 7. 2D of Magnetic Field (H) and Electrical Field (E)



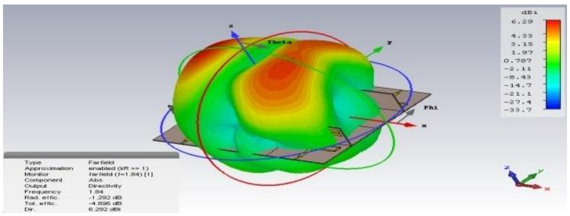
Antenna 1 1800 MHz full groundplane



Antenna 1 1800 MHz cornered spatial groundplane



Antenna 1 1800 MHz crossed middle groundplane



Antenna 1 1800 MHz spiral groundplane

Figure 8. 3D Radiation Pattern

Table 6. Dualband MIMO Antenna Gain with Various of Groundplane Pattern

Full groundplane			Cornered spatial groundplane			Crossed middle groundplane			Spiral groundplane		
F (MHz)	Ant	Gain (dBi)	F (MHz)	Ant	Gain (dBi)	F (MHz)	Ant	Gain (dBi)	F (MHz)	Ant	Gain (dBi)
1800	1	8.21	1800	1	6.49	1800	1	5.2	1800	1	6.29
1800	2	8.21	1800	2	6.49	1800	2	5.2	1800	2	4.66
1800	3	8.21	1800	3	6.54	1800	3	4.86	1800	3	5.85
1800	4	8.2	1800	4	6.53	1800	4	4.86	1800	4	6.17
2300	1	8.14	2300	1	6.59	2300	1	5.83	2300	1	7.33
2300	2	8.14	2300	2	6.59	2300	2	5.83	2300	2	6.88
2300	3	8.45	2300	3	6.56	2300	3	6.49	2300	3	7.93
2300	4	8.44	2300	4	6.56	2300	4	6.49	2300	4	7.18

4. Conclusion

In this work provides a design of four element MIMO duallband antenna. A single antenna element is constructed by bowtie dipole antenna. This proposed four element MIMO dualband antenna occupies a 270 x 210 x 100 mm^3 of FR 4 substrate. Various groundplane patterns give effect on main parameters of proposed MIMO dualband antenna. Cornered spatial groundplane pattern yields widest bandwidth, 282 MHz or 15.24 % of center frequency, at low frequency (1800 MHz) while full groundplane pattern creates a 135.2 MHz bandwidth at high frequency (2300 MHz).In addition, cornered spatial groundplane pattern also generates a lowest VSWR, it is 1.21, both low frequency and high frequency. Second, cornered spatial and full groundplane pattern also produces a better return loss than both spiral and crossed middle groundplane pattern.Third,all various groundplane patterns give a equally value of mutual coupling. This proposed four element MIMO dualband antenna with four groundplane patterns also generates good farfield properties i.e. gain, radiation pattern, H-E field.

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