Design and Simulation of MIMO Antenna for Road Side Unit Used inVehicular Communications

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*Abstract***The main contribution of this work is to create and develop for compact multiple-input multiple-output (MIMO) antennas based on a circular ring monopole antenna. Based on CRMA, four-element MIMO antenna systems are designed with two layers and simulation for 5.9 GHz vehicular communications. The MIMO antenna systems use orthogonally configured 2x2 CRMA with dual-fed printed on one side of the substrate to achieve good isolation. Design simulation is carried out with the aid of Attar FEKO (2017) Solver. Based on experimental results, the two MIMO antenna systems have an impedance bandwidth of exactly reach between 5.85 to 5.925 GHz, good isolation of less than 15dB.The proposed antenna can achieve VSWR<2 at operating frequency for double layer antenna, with stable and omni-directional radiation pattern. The gain is good and has a peak value of 5.85 dBi. A low envelope correlation coefficient of better than0.02 across the frequency band of (5.85–5.925GHz), which are suitable 2x2 MIMO antenna design for roadside unit vehicular communication.**

Key*words* – Circular Ring Monopole Antenna, Vehicular Communications,AttairFEKO, 2x2MIMO Antenna Design

I. Introduction

Myanmar has the second highest death toll of road accidents in Southeast Asia, according to the Myanmar There are several aspects that add to those increase such as the absence of proper road facilities and the human error factor. In recent years, the idea of exchanging information between moving vehicles and roadside unit infrastructure has attracted significant attention as a tool for reducing accident fatalities and facilitating traffic flow. One of the determinations to reduce the amount of road accident is done by installing the smart transportation system. Vehicular communication network is required for smart transportation system[1].Several research groups have investigated roadside unit (RSU) antenna influence antenna influence on the system performance. Vehicularcommunication between infrastructure and vehicles is based on roadside units with a dedicated short range communication (DSRC) and mostly omnidirectional data link. In Europe, DSRC operates at 5.9GHz, using 75MHz band [5.85 5.925GHz] with 7 channels 10MHz each [2]. MIMO antenna is the most suitable design for roadside unit antenna to get radio accept link simultaneously.Micro strip patch antennas have been of sign for a long time due to their low profile, low cost, easy printability, and fabrication, as well as the capability of being embedded within other devices. However, there are many disadvantages, such as low gain and narrow bandwidth [3, 4]. The gain of an antenna refers to the ratio of its radiation power in a specific direction to its power in the isotropic direction [5]. Many researchers are working to enhance the gain of the patch antennas using different designs, ideas, and materials [6–13].At the same time, due to the new technologies, most designers tend to reduce the size and increase the efficiency of the devices

In this paper, a new dual feed circular patch 2x2 MIMOis designed and simulated. By tuning and optimization, the desired characteristics are achieved for roadside unit antenna.

The rest of the paper is organized based on the different sections. Section II considered the design of MIMO element Section III mentions the software implementation and analysis for reference antenna based on the background theory of that antenna design. Section IV gives the performance of proposed MIMO antenna design. Finally, section V summarizes andconcludes the study.

II. Design Consideration

Primarily, the system requirement that is to choose a suitable material and geometry of the patch for the antenna has been worked to complete by using the design equations.of the reference antenna design. And then, 2x2 MIMO antenna is designed by using diversity method.

A. *Substrate Material Consideration*

Circular ring monopole antennas consist of very thin metallic strip (patch) placed on ground plane where the thickness of the metallic strip is restricted by t<< λ_0 and the height is restricted by 0.0003 <<h<<0.05. The micro strip patch is designed so that its radiation pattern maximum is normal to the patch. For a rectangular substrate, the L of the element is usually λ_0 /3<L< λ_0 /2. There are numerous substrates that can be used for the design of micro strip antennas and their dielectric constants are usually in the range of 2.2 << ε_r << 12. Then, antenna efficiency is calculated by using Tabu Search Algorithm as following:

$$\eta = 1 - 3.66 F^{1.83} G^{1.06} \varepsilon_r^{-1.32} - 2.4 F^{2.48} G^{0.5} \varepsilon_r^{-3.12} \quad (1)$$

Where, $F = (\varepsilon_r - 1)$ and $G = h/\lambda_0$

Fig 1 illustrates that the increasing value of relative dielectric constant, the radiation efficiency of the micro strip antenna is decreased. And also, the higher the dielectric constant, the less radiation efficiency is occurred. Thus it needs to choose the dielectric material having a dielectric constant less than 5.

Fig 2 shows that radiation efficiency is the lowest at around 5..9 GHz operating frequencies for various substrate materials. Thus after observing these figures it can be concluded that the relative dielectric constant of the dielectricmaterial should be less than 3. The operating (resonant) frequency of the micro strip antenna should be less than 10GHz. In the research work, FR4 substrate (the lowest radiation efficiency) is chosen as the condition of local market.

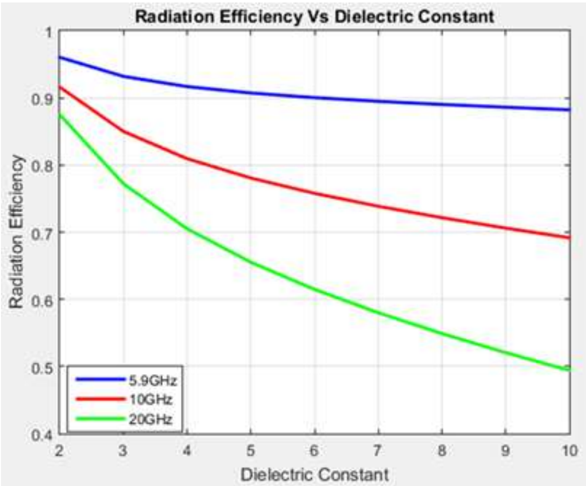


Fig 1 Radiation Efficiency Vs. Dielectric Constant at Different Frequencies

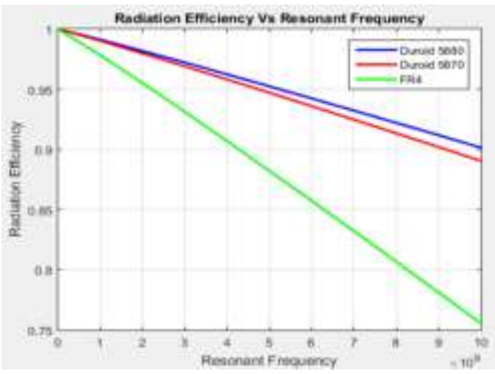


Fig 2 Radiation Efficiency Vs. Resonsnt Frequency at Different Materials

B. Micro strip Patch Shape Selection

Micro strip patch antenna element shape varies from square, rectangular, circular, elliptical, triangular to tin strip dipole. Rectangular patch and nearly square patch is the most widely used since it is very easy to perform analysis using transmission line and cavity models. In our design configuration, circular patch being considered to get coverage area.

C. Dimension Calculation of Basic Antenna Element

After finalizing the substrate, feeding mechanism and the next step to design and optimize in the first stage a single micro strip patch element. In our design configuration, circular patch is being considered for reference element of MIMO antenna. Then, the basic antenna element employed in the proposed 2x2 MIMO system for RSU.The patch size and efficiency should be adjusted to achieve optimum designed parameters using the following equations. Firstly, the width of the micro strip lin e is given by

$$W = \frac{c}{2Fo\sqrt{\frac{\varepsilon r + 1}{2}}} \qquad (2)$$

Effective Dielectric Constant is introduced to account for fringing field, it can be calculated

$$\varepsilon re = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2}\left[1 + \frac{12h}{w}\right]^{-0.5} \qquad (3)$$

And then the Effective Length of the substrate can be calculated

$$Leff = 0.5\frac{0.508}{\sqrt{4.4}} \qquad (4)$$

And then, the length extension of the substrate is

$$\Delta L = 0.412\left(\frac{\varepsilon re + 0.3}{\varepsilon re - 0.3}\right)\frac{\left[\frac{w}{t} + 0.264\right]h}{\left[\frac{w}{t} + 0.8\right]} \qquad (5)$$

$$L = Leff - 2\Delta L \qquad (6)$$

The actual ground plane dimension of the antenna can be calculated;

$$Lg = L + 6h \qquad (7)$$

$$wg = w + 6h \qquad (8)$$

The impedance matching of the antenna design can be found the following;

$$ZA(\Delta x = 0) = 90\frac{\varepsilon r^2}{\varepsilon r - 1}\left[\frac{L}{W}\right]^2 \Omega \qquad (9)$$

Since the dimension of the patch is treated a circular loop, the actual radius of the patch is given by [15].

$$fr = \frac{Xmn}{2\pi ae\sqrt{\varepsilon r}}c \qquad (10)$$

where fr is the resonance frequency of the patch, Xmn =1 .8411 for the dominant mode TM11, c the velocity of light in free space, εr the relative permittivity of the substrate and ae the effective radius of the circular patch and given by

$$ae = a\left[1 - \frac{2h}{\pi a \varepsilon r}\left(\ln\frac{\pi}{2h} + 1.7726\right)\right]^{\frac{1}{2}} \quad (11)$$

'a' is the actual radius of the circular patch antenna and microstrip feeding techniques can be calculated the following.

$$B = \frac{377\pi}{2Zo\sqrt{\varepsilon r}} \quad (12)$$

$$\frac{Wm}{h} = \begin{cases} \dfrac{8e^{A}}{e^{2A}-2}; \dfrac{Wm}{h} \prec 2\, for A \geq 1.52 \\ \dfrac{\pi}{2}\left\{B - 1 - \ln(2B-1) + \dfrac{\varepsilon r - 1}{2\varepsilon r}\left\{\ln(B-1) + 0.39 - \dfrac{0.61}{\varepsilon r}\right\}\right\} \end{cases} \quad (13)$$

$$Wf = \frac{Wm}{h} \quad (14)$$

$$A = \frac{Zo}{60}\sqrt{\frac{\varepsilon r + 1}{2}} + \frac{\varepsilon r - 1}{\varepsilon r + 1}\left(0.23 + \frac{0.11}{\varepsilon r}\right) \quad (15)$$

III. Reference Element Design and Simulation

For this system, above designed equations are used to calculate antenna parameters such as patch width and length. Circular ring monopole antenna was used reference element of the MIMO antenna design that covered the frequency (5.85 GHz – 5.925 GHz).

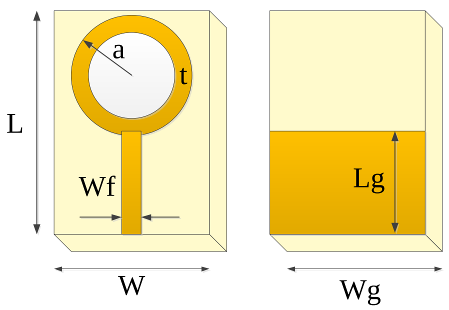


Fig 3 Top and bottom view of reference element

From above equations design antenna parameters are shown in the following table.

Table 1. The dimensions of the designed antenna

Design Parameters	Length in mm	Design Parameters	Length in mm
W	20	a	7.5
L	26	t	2
Wf	2	Wg, Lg	20, 11

The circular ring monopole antenna is designed and simulated by FEKO software[17] and antenna parameters are analyzed and discussed in the following sections. The return loss for the circular ring monopole antenna can be obtained from Fig 4. For an antenna to radiate effectively, the return loss value should be less than -10 dB. From figure, the return loss is about -37 dB at the selected frequency. The antenna provides input impedance bandwidth of 1.59 GHz (4.7 to 6.36 GHz) which fully covers 5.875 to 5.925 DSRC bands. It can be expressed as a fractional bandwidth of 26.9 % at the selected frequency.

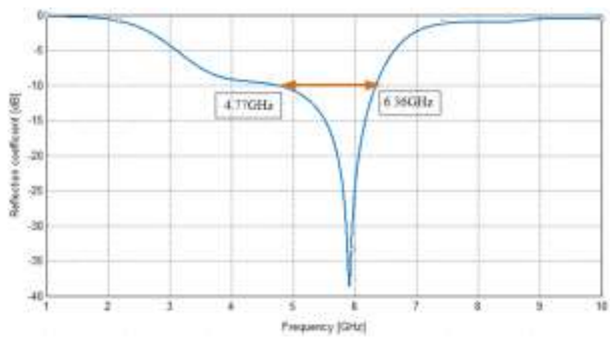
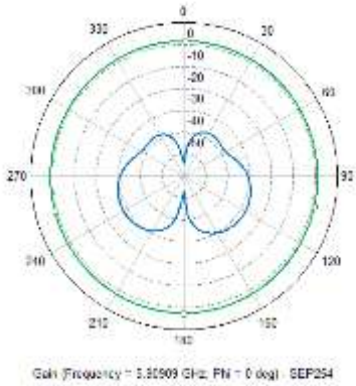
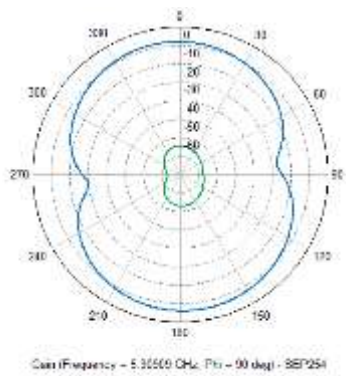


Fig 4.Return loss of an antenna

Radiations pattern can be drawn in polar plot also as shown in the Fig 5. The simulated radiation patterns of proposed antenna in the E-plane (xz-plane) and H-plane (yz-plane) for frequencies 5.9 GHz. The patterns in the xz-plane are quite omnidirectional as expected. In the yz-plane, the radiation patterns remain roughly a dumbbell shape like a small dipole leading to bidirectional patterns. So, this antenna is called omni-directional radiation pattern.



(a)



(b)

Fig 5 Radiation pattern (a) xz-plane (b) yz-plane

The surface current distribution of the reference element system is shown in Fig 6. The current distribution is the same in all phase. So, this type of antenna is linear polarization.

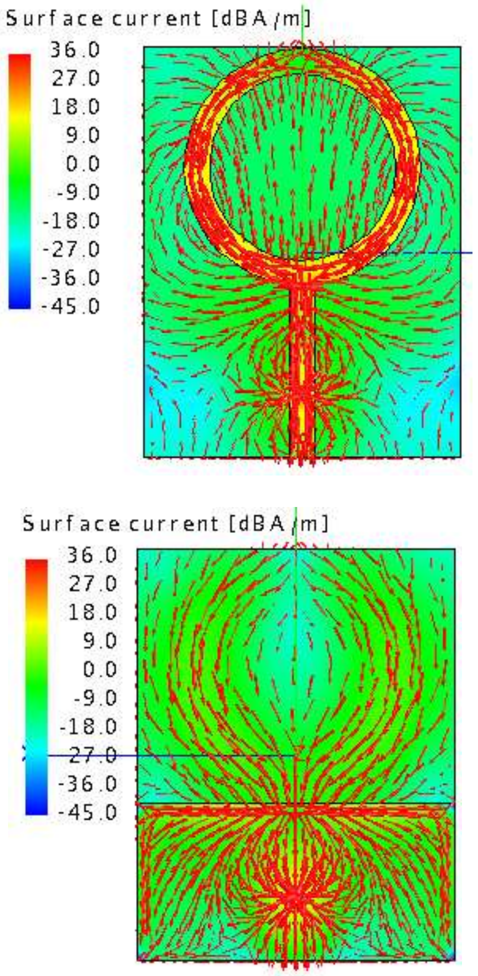


Fig 6 Current Distribution of Top and Bottom View

The gain is the ratio of the output power for an antenna to the total input power to the antenna. The input power to the antenna is the total power including, radiated power and the overall losses power. So, the gain can be represented as follows:

$$G = \frac{P_{out}(OutputPowerofAntenna)}{P_{total}(InputPowerofAntenna)} \quad (16)$$

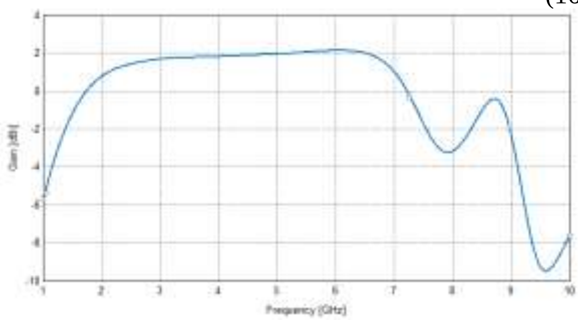


Fig 7 Simulated result of gain for CRMA

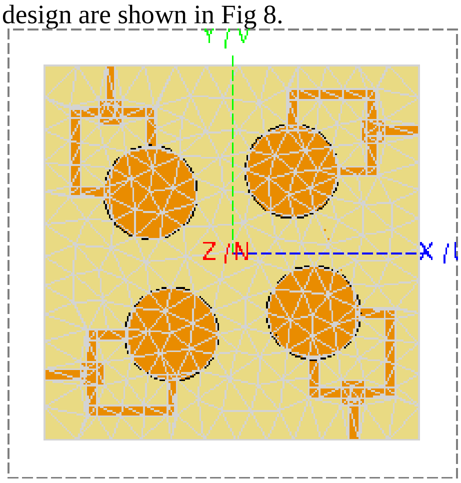
The gain result of CRMA 2dBi at operating frequency 5.9GHz is shown in Fig 7. If the reference element is sufficient characteristics for MIMO antenna design, reference element is redesigned with dual feed line. And then the size of reference element is reduced by lowering their sizes from 26×20mm2 to 13×10mm2.After that, the four element are orthogonally symmetrically placed with an an interval lof90◦ on the substrate area of 26x26mm2. The shortcomings of one layer can be overcome by using multilayered micro strip antennas[10]. Proper combination of the substrate and super substrate thickness over and under the patch[13]

IV. PROPOSED MIMO ANTENNA DESIGN AND SIMULATION

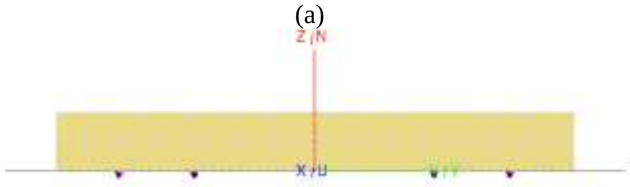
The proposed dual-layer microstrip patch antenna design was developed by taking the design of the reference antenna, and then changing the dual feed lines with full ground plane is used.In order to make the patch antenna operate at the desired characteristics, a tuning and optimization technique is introduced.

Fig 7 illustrates the dimensions of the proposed antenna. The overall dimensions are 26mm × 26 mm. The substrate is FR-4, with a permittivity of 4.4 and loss tangent of 0.025, coated with annealed copper of 0.035 mm thickness at both sides. A second FR-4 layer, which is coated with annealed copper of 0.035 mm thickness at both sides, is placed at a distance of 0.04 from the first FR-4 layer. The second FR-4 layer acts as a reflector to redirect the propagation density from the back lobe to the main lobe. Hence, for the same radiation efficiency, increasing the directivity,, means increasing the gain, , as follows [15]:

The lower patch has a same size with the upper patch shape with different Two layer of proposed 2x2 MIMO antenna design are shown in Fig 8.



(a)



(b)

Fig.8.Two layer MIMO antenna (a) top view (b) side view

The simulated reflection coefficient of (S11, S22, S33, S44) of the proposed antenna is depicted in Fig 9. The graph shows the maximum return loss of -24.85 dB at the resonant frequency 5.9 GHz. The graph also depicts that below -10dB the antenna attained the bandwidth of 0.075GHz (1.27%).

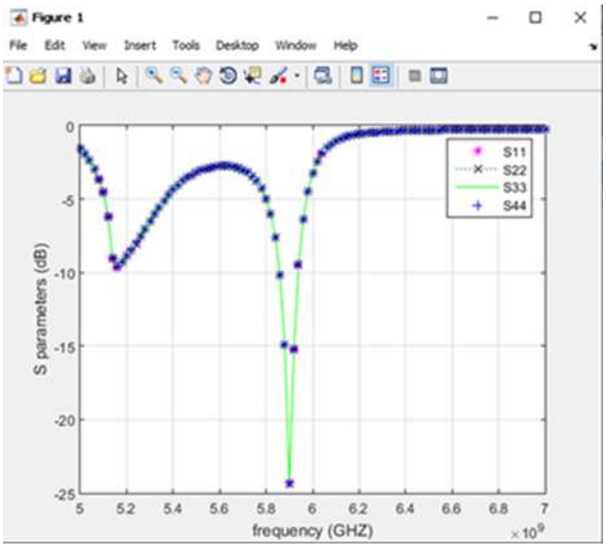


Fig.9. Reflection coefficient result of 2x2 MIMO

. Fig. 10 shows the isolation characteristics of each antenna element. Mutual coupling is found -15 and −42 dB at 5.9GHz.

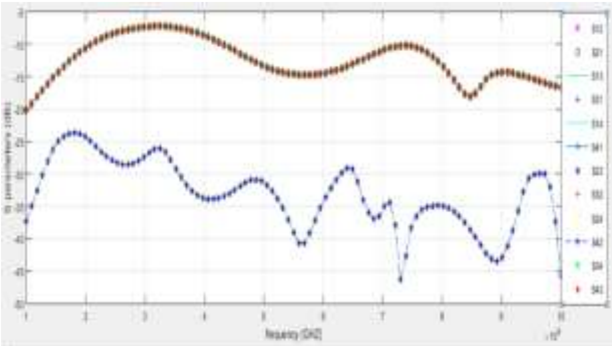


Fig.10. Transmission coefficient result of 2x2 MIMO

Impedance bandwidth indicates the bandwidth for which the antenna is sufficiently matched to its input transmission line such that 10% or less of the incident signal is lost due to reflections. Impedance bandwidth measurements include the characterization of the VSWR and return loss throughout the band of interest. The smaller the VSWR is, the better the antenna is matched to the transmission line .The minimum VSWR is 1.0, no power is reflected from the antenna, which is ideal. Fig 11 shows the result of VSWR reach nearly 1.5.

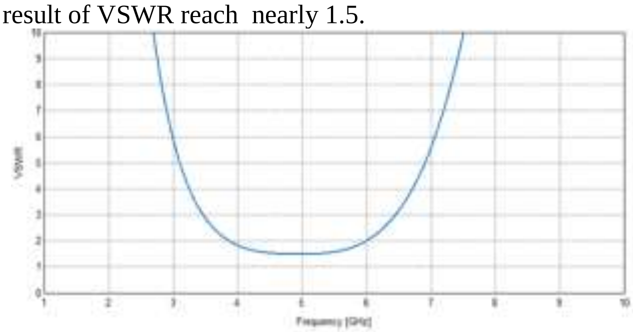


Fig 11 VSWR of two layer 2x2 MIMO

Impedance matching to minimize reflections is achieved by making the load impedance equal to the source impedance. In RF systems, a common value for source and load impedance is 50 ohms. Fig 12 shows 50 ohm impedance matching of two layer MIMO design.

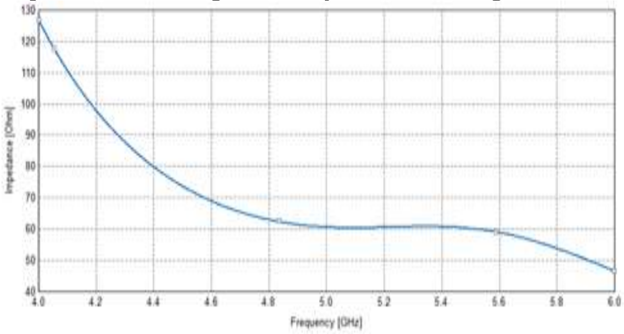
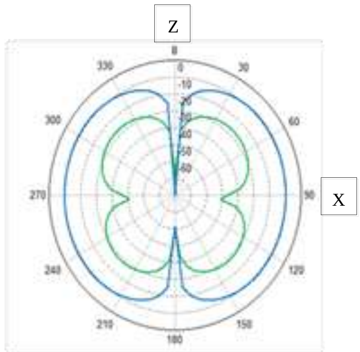
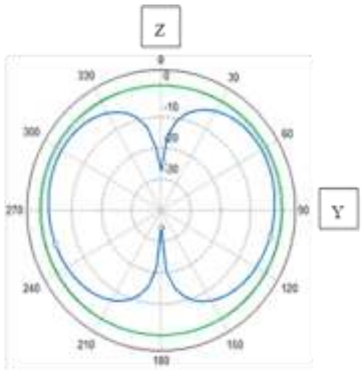


Fig.12. Impedance matching curve of two layer MIMO

The radiation pattern of XZ-plane, YZ-plane and XY plane are shown in Fig 13. According the radiation pattern of three plane, this antenna type is omnidirectional radiation pattern.



(a)



(b)

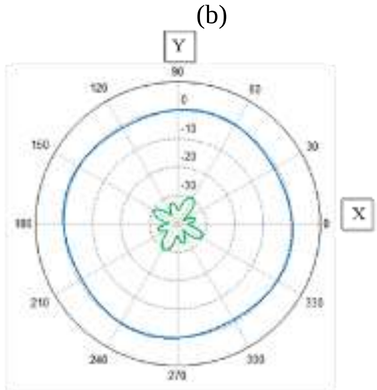


Fig.13. Radiation Pattern of (a) XZ-plane (b) YZ-Plane (c) XY-Plane

Omnidirectional radiation pattern can also show in 3D far field radiation patter n shown in Fig 14.

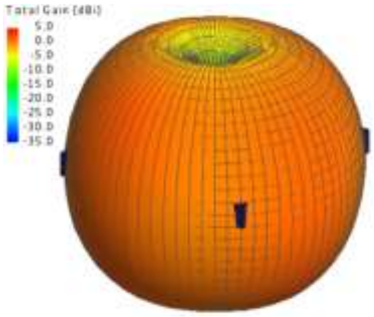


Fig.14Simulated 3-D far-field radiation pattern for the proposed MIMO antenna system

The variation of antenna gain across the ITS band within 5.85 dBi is shown in Fig 15.

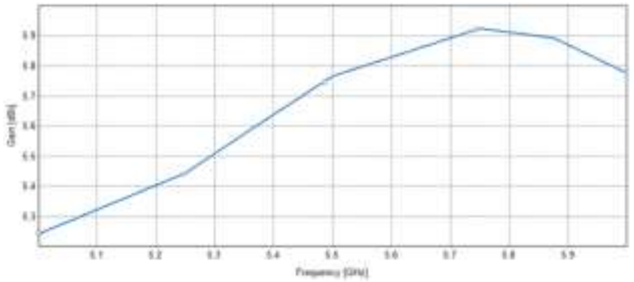
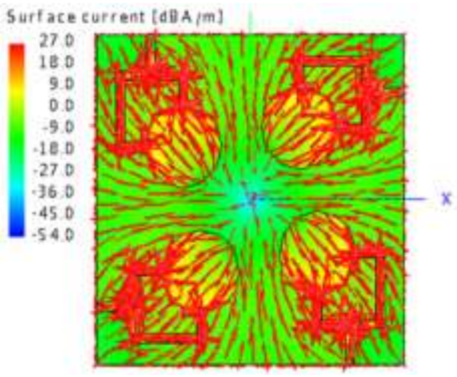
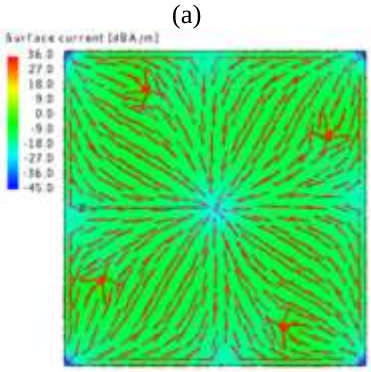


Fig.15. Simulated Antenna Gain for Two Layer MIMO Antenna

Current is mainly distributed along the circular patch is shown in Fig 16.



(a)



(b)

Fig.16. (a) Top and (b) Bottom View of Current Distribution

The Envelope Correlation Coefficient (ECC) is an important parameter to evaluate the diversity performance in MIMO antenna system that tells about how much the antenna elements are correlated to each other. The S-parameters have been used to compute ECC, derivation of which has been explained in [16]. For the ECC (ρe,ij) calculations between ith and jth element of the proposed design, the following formula has been used:

It can be observed from the Fig. 10 (a) that the ECC between each pair of antenna element is well below the acceptable limit of 0.5 in the entire application frequency range.

$$\rho_e(1,2,4)=\frac{\left|S_{11}^{*}S_{12}+S_{21}^{*}S_{22}+S_{13}^{*}S_{32}+S_{14}^{*}S_{42}\right|^{2}}{\left(1-|S_{11}|^{2}-|S_{21}|^{2}-|S_{31}|^{2}-|S_{41}|^{2}\right)\left(1-|S_{12}|^{2}|S_{22}|^{2}-|S_{32}|^{2}-|S_{42}|^{2}\right)} \quad (17)$$

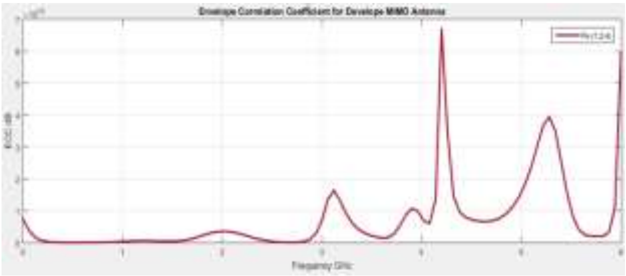


Fig.17 Port 1,2,4ECC for Two Layer MIMO

And then port 1,3,4

$$\rho_e(1,3,4)=\frac{\left|S_{11}^{*}S_{13}+S_{21}^{*}S_{23}+S_{13}^{*}S_{33}+S_{14}^{*}S_{43}\right|^{2}}{\left(1-|S_{11}|^{2}-|S_{21}|^{2}-|S_{31}|^{2}-|S_{41}|^{2}\right)\left(1-|S_{13}|^{2}|S_{23}|^{2}-|S_{33}|^{2}-|S_{43}|^{2}\right)} \quad (18)$$

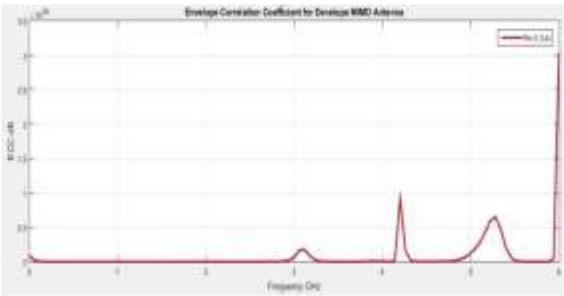


Fig.18 .Port 1,3,4ECC for Two Layer MIMO

Fig 17 and 18 shows An ECC value is nearly 0. The value of 0 represents they are highly isolated [14].So, two layer 2x2 MIMO antenna design is no correlation and good isolation.

V. Conclusion

Design evolution of a novel compact roadside unit MIMO antenna system has been proposed and investigated Circular ring monopole antenna design is exactly reached the dedicated short range band .Reference antenna element has a compact size by reducing 50% smaller than circular ring monopole antenna.2x2 MIMO antenna is arranged by using diversity method. Two layers are redesign to get MIMO performance.The graph sho the maximum return loss of -24.85 dB at the resonant frequency 5.9 GHz MIMO antenna systems have good omnidirectional radiation characteristics and wide enough bandwidth of 75MHz (5.85 to 5.925GHz). From the current distribution result, this type of antenna is linear polarization. Besides, these antennas show good isolation less than 24 dB and low envelope correlation coefficient better than0.002dB across the operating frequency band

Therefore, the proposed antenna can be used for roadside unit antenna in vehicular communication network.

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