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Metamaterial structures of MIMO Antenna for Dual Band Automotive Radar Applications

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ABSTRACT

To design, a novel 2 × 2 multiple-input multiple-output (MIMO) antenna array with four patch elements is designed. The proposed antenna is the first dual band ,operating at two prominent working frequency:24(24.28-25.111) GHz and 77 GHz of automotive radars. This structure is composed of two antenna modules colocated on a single substrate, whereas each module is made up of a corporate fed planar array of two elements. This attractive feature enables us to utilize the antenna in two different ways; either both modules serve as the transmitting / receiving antenna of a monostatic radar or one module serves as a transmitter and the other one as the receiver of a bistatic radar. Most of the existing autonomous radar applications operating at 24 GHz .Hence, our design is very attractive as it operates with the required performance in the bands with another added feature of the MIMO structure. The placement of antenna elements is also optimized in terms of inter- and intra-element separation of greater than λ/2 so as to ensure high diversity gain of 9.6 dBi. In addition to the above-mentioned benefits, this design also addresses mutual coupling reduction that is a common problem in MIMO structures by using complementary split ring resonator (CSRR) structures.

Keywords: MIMO, CSRR, Gain, Directivity, Gain, labyrinth structure

1. Introduction:

The revolution in the automobile industry is supported on a large scale by the developments in electronics, artificial intelligence, communication, and radar technology. All these technologies are highly in the mandate for the upgrade of automotive cars/vehicles into a higher level. Thus, the highly automated vehicles (HAV) that incorporate various customer needs such as safety, flexibility to handle, moneysaving, and luxury are in huge demand in the market. The above services can easily be provided by the innovation and implementation of suitable technologies in autonomous systems. Recently, there is an enormous growth in the automation industry using advanced driver assistance systems (ADAS). ADAS includes the most important automatic emergency braking system (AEBS) and adaptive cruise control (ACC) that falls in the coverage range of up to 150 m. On the other hand, long-range radar (LRR) used in these systems is operated at the low-frequency range of 24GHz (24–24.25 GHz). %ese automotive cars are additionally supported by techniques such as blind spot detection (BSD) and cross-traffic alert (CTA) whose maximum range is 30m and hence are being supported by short-range radars (SRR). For short-range radar applications, the 2 GHz NB of bandwidth 250MHz is suitable for simple cases such as BSD, and ultrawide band (UWB) of bandwidth up to 5 GHz is needed for high-range resolutions. Due to spectrum regulations developed by the European Telecommunications Standards Institute (ETSI) and the Federal Communications Commission (FCC), the 24GHz band will be phased out soon.

Multiple-Input Multiple-Output (MIMO) antennas have two or more antennas in a single physical package. The antennas are housed inside a single antenna enclosure, so from the outside it looks like a single antenna. By utilizing multiple antennas, data throughput, speed and range are increased compared to a single antenna using the same radio transmit power. MIMO antennas improve link reliability and experience less fading than a single antenna system. By transmitting multiple data streams at the same time, wireless capacity is increased thereby making MIMO antenna more reliable for 5G communication.

MIMO technology uses multipath to improve wireless performance. MIMO technology takes a single data stream and breaks it down into several separate data streams and sends it out over multiple antennas.

□The resource requirements and hardware complexity is higher compare to single antenna antenna based system. Each antenna requires individual RF units for radio signal processing. Moreover advanced DSP chip is needed to run advanced mathematical signal processing algorithms.

□The hardware resources increase power requirements. Battery gets drain faster due to processing of complex and computationally intensive signal processing algorithms. This reduces battery lifetime of MIMO based devices .□MIMO based systems cost higher compare to single antenna based system due to increased hardware and advanced software requirements.

2. Related works

Chirag Arora et al.[1] proposed a microstrip fed patch antenna array, loaded with metamaterialsuperstrate. An unloaded antenna array resonates at IEEE 802.16a 5.8GHz Wi-MAX band with gain of 4.3 dBi and bandwidth of 425 MHz. However, when the same array is loaded with a metamaterial superstrate, composed of a pair of Split Ring Resonators (SRR), there is simultaneous gain and bandwidth improvement to 8 dBi and 680MHz, respectively, which corresponds to gain improvement by 86% and bandwidth enhancement of 60%. The fabrication of this proposed antenna array is done, and its simulated and measured results are compared. Equivalent circuit model of this composite structure has been developed and analyzed. The electrical dimension of the patch is $0.23\lambda \times 0.3\lambda$.

Rifaqat Hussain et al.[2] proposed an antenna which is integrated with ultra-wideband (UWB) sensing antenna in order to achieve a compact, novel multi-mode, multi-band frequency reconfigurable multiple-input–multiple-output (MIMO) antenna system. The developed model can be used as a complete antenna platform for the cognitive radio application. The antenna system is built as a single unit Board area with dimensions of 65 x 120 mm2. The proposed detection antenna is used to cover a wide frequency range Band of 710 to 3600MHz. Frequency reconfigurable dual-element MIMO antennas are integrated into P-type. Unique N-type (PIN) diode for frequency agility. Various selection modes are used for MIMO antenna systems Reconfigurable to support various wireless system standards. The proposed MIMO antenna configuration is used to cover different frequency bands from 755 to 3450MHz. A complete system consisting of reconfigurable multi-band MIMO antennas and UWB acquisition antennas for cognitive radio applications is proposed in a compact form factor

K. Roshna et al.[3] proposed a portable UWB MIMO systems in order to achieve a compact ultra-wideband (UWB) multiple-input multiple output (MIMO) antenna, with high isolation. Two coplanar strapline feed the cascade radiation and the elements are joined back to back. The prototype is Substrate with a dielectric constant of 4.4 and overall dimensions of 25 mm x 30 mm x 1.6 mm. This antenna configuration using insulating metal. The strip placed between the two radiating elements guarantees high insulation. The entire UWB band. The proposed antenna has a good VSWR of 2: 1 Impedance bandwidth covering the entire UWB band (3.1 to 10.6 GHz) High isolation over 20dB, peak gain of 5.2dBi, peak efficiency Guaranteed value of 90% envelope correlation coefficient (ECC) ≤ 0.1641.

Prem P. Singh and Sudhir K. Sharma [4] proposed a compact and hexagon-shaped microstrip patch antenna operating in three bands is described in this paper. Multiband functionality of the antenna is achieved by adding two inclined strips and cutting modi¯ed slots on the radiating patch. The antenna consists of a hexagonal patch and partial ground plane, has the total dimensions of 15x17x:6mm3, and operates over three frequencies 5.40 GHz, 6.76 GHz, and 8.82 GHz for WLAN, TV satellite broadcasting, WiMAX (5250-5850 MHz), IEEE 802.11a (5.47-5.725 GHz), 5G Unlicensed band (5.2-5.7 GHz), weather monitoring, and radar applications. This antenna has the novelty that it can also be used as a reconfigurable antenna, and the notched bands can be controlled.

Sreenath Reddy et al.[5] proposed a four port MIMO antenna for Midband 5G applications. In this paper, a multifunctional reconfigurable filter that can work in three operating modes has been presented. The three operating modes are: Allpass filter, tunable band pass filter, and tunable band reject filter. The developed filter has been integrated with an ultra-wideband antenna that results in a reconfigurable filtenna. Such four filtennas are arranged on a single substrate, and sufficient isolation is maintained between them by using reflectors to form a four port multiple input multiple output (MIMO) filtenna that can work for midband 5G cognitive radio (CR) applications. By controlling the operating modes of the filter, the final developed structure gives sensing and communicating antennas for spectrum interweave and spectrum underlay CRs. Simulated results have been validated by carrying out the measurement. MIMO performance. The proposed antenna was evaluated by measuring the envelope correlation coefficient and found to be suitable for practice application.

Praveen Kumar Rao et al.[6] proposed the design of a 4×1 MIMO antenna that can be used for 5G Cellular applications. The proposed antenna design consists of four T-shaped MIMO structure radiating patches on the top layer of the substrate. To improve the bandwidth and return loss characteristics, defected ground structure (DGS) is incorporated on the bottom plane along with parasitic element on both sides of patches. A single element antenna is with the size of 12mm×12mm×0.8mm and a complete antenna is with the size of 12mm×50.7mm×0.8mm. The proposed antenna design is found to resonate at many adjacent frequencies, rendering a large bandwidth which makes it suitable for 5G applications. The simulated and measurement results show a wide bandwidth of 28 GHz – 44 GHz with a peak gain of 10.1 dB.

Noelia Ortiz et al.[7], proposed a simple and successful dual band patch linear polarized rectangular antenna design. The dual band antenna is designed etching a complementary rectangular split-ring resonator in the patch of a conventional rectangular patch antenna. Furthermore, a parametric study shows the influence of the location of the CSRR particle on the radiation characteristics of the dual band antenna. Going further, a miniaturization of the conventional rectangular patch antenna and an enhancement of the complementary split-ring resonator resonance gain versus the location of the CSRR on the patch are achieved. The dual band antenna design has been made feasible due to the quasistatic resonance property of the complementary split ring resonators. The simulated results are compared with measured data and good agreement is reported.

Zicheng Niu et al.[8] proposed a closely coupled dual-band multiple-input–multiple-output (MIMO) patch antenna which resonates at 3.7 and 4.1 GHz. MIMO antenna two mirror symmetric single-feed patch antennas in close proximity to each other placed at about $0.034\ \lambda 0$ (where $\lambda 0$ is the wavelength at 3.7 GHz). Decoupling structure consists of modified ones. They are array antenna decoupling surface (MADS) and H-shaped defect. The basic structure of the lower band and upper band, respectively. Insulation is determined by simulation and measurement over 30 dB in both frequency bands, significant improvement over the original antenna array. Under MADS operation, the measured gain increases as follows: 2.2 and 0.8 dB at resonant frequencies of 3.7 and 4.1 GHz. The measurement result of the proposed decoupling structure is very suitable for tightly spaced dual bands MIMO antenna.

3. Proposed design

3.1 Design of MIMO with basic shapes

Two designs are designed and tested in this paper. Proposed design with labyrinth procedure starts with the design of a rectangular patch antenna with the dimension of 4.9mm× 5.1mm. Designs are as follows :

Width of patch antenna

$$W = \frac{1}{2*f_r*\sqrt{\mu_0\varepsilon_o}}\sqrt{\frac{2}{\varepsilon_r+1}}$$

For the resonant frequency at 24 GHz:

$$W = \frac{V_o}{2*f_r}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{3*10^8}{2*24*10^9}\sqrt{\frac{2}{2*2+1}}$$

$= 4.941 * 10^{-3}$

Effective dielectric constant of the patch

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+12*\frac{h}{w}\right)^{\frac{-1}{2}}$$

$$= \frac{2*2+1}{2} + \frac{2*2-1}{2}\left(1+12*\frac{0.5}{4.9}\right)^{\frac{-1}{2}}$$

$= 2.002$

$1 < \varepsilon_{reff} < \varepsilon_r$

Extended incremental length of the patch ΔL is

$$\Delta L = h*0.412\left[\frac{(\varepsilon_{reff}+0.3)(\frac{\omega f}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{\omega f}{h}+0.8)}\right]$$

$$= 0.5*0.412\left[\frac{(2.002+0.3)(\frac{4.9}{0.5}+0.264)}{(2.002-0.258)(\frac{4.9}{0.5}+0.8)}\right]$$

$= 2.51 * 10^{-9}$

Actual length of the patch

$$\text{Length} = \frac{\lambda}{2} - 2\Delta L$$

$$= \frac{\frac{L}{f}}{2} - 2\Delta L$$

$$= \frac{\frac{3*10^8}{24*10^9}}{2} = 2 * (2.51 * 10^{-4})$$

$= 5.748 * 10^{-3}$ meter

$L_{effective} = L + 2\Delta L = 6.25$ mm

(or) $= \frac{\lambda}{2} = 6.25$ mm

After designing a single structure with this patch specifications,2x2 MIMO structure is implemented. The substrate used in our design is Rogers RT/duroid 5880 with thickness of h = 0.5 mm, relative permittivity of $\varepsilon_r = 2.2$, and loss tangent of $\tan\delta = 0.0009$. This material is selected since it has a low dielectric constant and low dielectric loss, making them well suited for high frequency/broadband applications.

In the first structure, two concentric rings were inducted as shown in Figure 1 that resonate with the antenna under dual modes. The proposed design values are tabulated in Table 1.

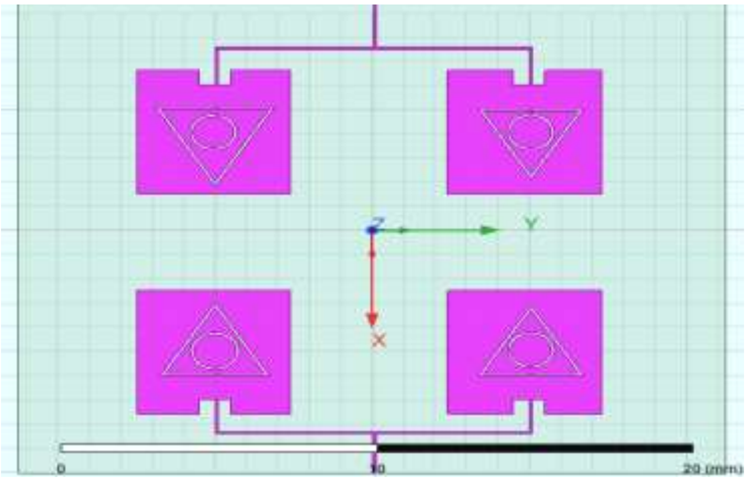


Figure 1: Proposed Labyrinth structure with different shapes

Table 1: Dimensions of proposed design

Parameters	Dimensions (mm)
Ground width (Wg)	22.5
Ground length (Lg)	20.6
Substrate width (W)	22.5
Substrate length (L)	20.6
Substrate height (h)	0.5
Patch width (Wp)	4.9
Patch length (Lp)	5.1
Length of feed line (Lf)	2
Width of inset feed (Winf)	0.1
Length of inset feed (Linf)	0.78

Next structure is designed with circular CSRR structure as shown in Figure 2.

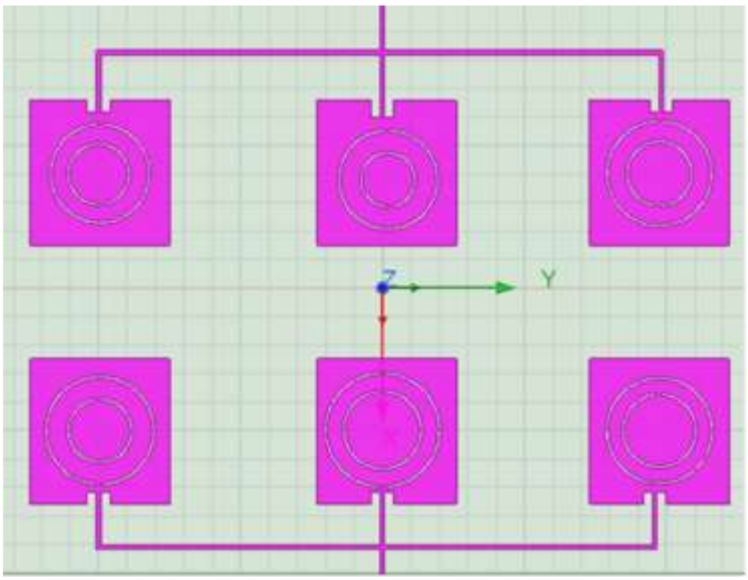
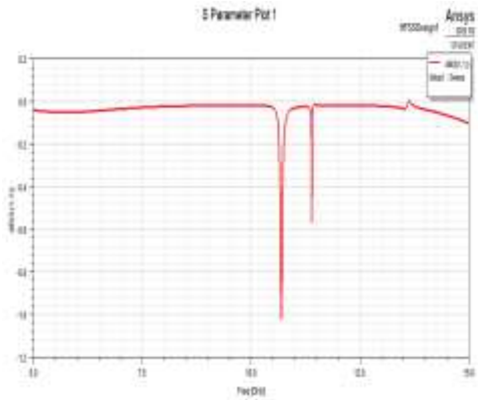
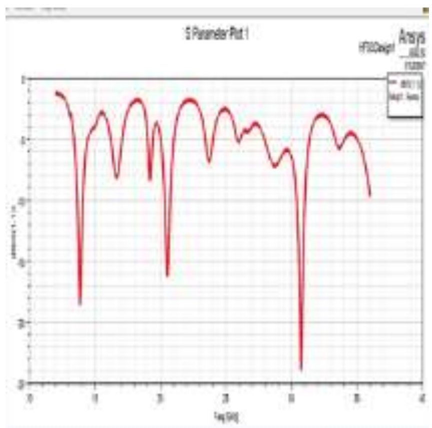
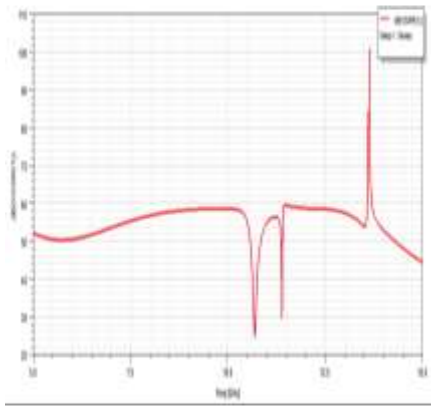
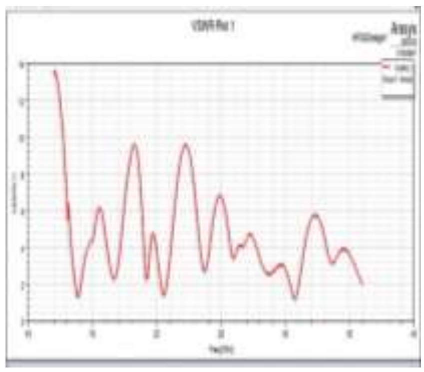
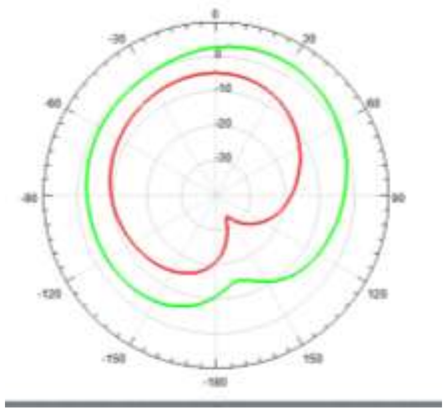
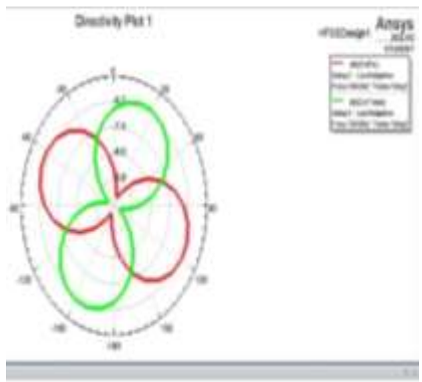
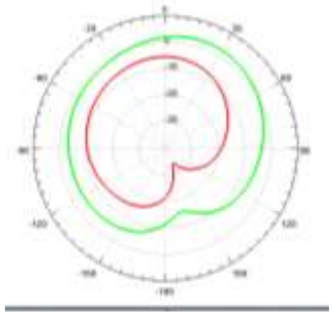
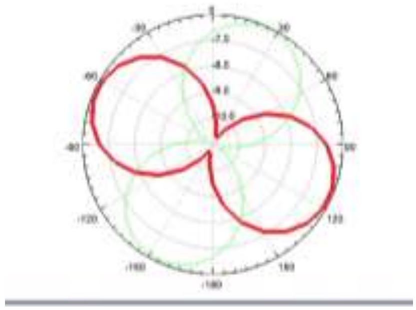


Figure 2 : Proposed CSRR structure with MIMO

4. Results

The return loss of the two antenna structures are shown in the table below. The return loss of CSRR structure is found to be -24.7 dB at the frequency of 30.9 GHz. Antenna gain is the ability of the antenna to radiate more or less in any direction compared to a theoretical antenna. Radiation E pattern is obtained by plotting gain plot at degree 0.the radiation E-pattern BW is 88.83 degree. The gain obtained is 4.2 dB.The Voltage Standing Wave Ratio is the measure of loss at the feeder because of mismatch. It normally ranges between 0 to infinite. For practical antennas the value should be less than 2 then the antenna is said to be matched. The VSWR obtained by our proposed structure at the frequency of 30.9 GHz is 0.159 dB. It oscillates back and forth. It is shown in the Table 1 below.

S. No	Labyrinth Structure 1	CSRR structure
Ruturn loss		
VSWR		
Directivity		

Gain		

5. Conclusion

The proposed 2 × 2 MIMO antenna consists of four identical patch elements that are loaded with a novel CSRR structure. The CSRR structure helps in resonating the antenna under two prominent frequencies of autonomous radar 24 GHz and 77 GHz with a wide operating bandwidth of 700 MHz and 4 GHz, respectively. The two element corporate feed patch array in each transmit/receive unit of the MIMO structure resulted in high gains of 11.3 dBi and 11.8 dBi at the above two operating frequencies, respectively. The optimized inter- and intra element spacing of patch elements on the collocated substrate resulted in very high isolation of more than −44.26 dB makes this colocated array design a perfect candidate for automotive MIMO radar. Another important parameter, VSWR also achieved optimum values of 1.02 and 1.1 at the dual modes of 24 GHz and 77 GHz, respectively.

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