Design, Fabrication and Measurement of Circular Ring Monopole Antenna for DSRC

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Abstract:- This paper presents the design, fabrication and characterization of circular ring monopole antenna (CRMA) for dedicated short range communication. Design simulation is carried out with the aid of Attar FEKO (2017) Solver The 26×20×1.6 mm antenna was fabricated using an FR4 composite material. The return loss of prototype is measured with Anritsu MS 2036C Network Analyzer. Between the measurement and simulation result is a little different but two results cover DSRC band. The return loss is about -37 dB and fractional bandwidth of 26.9 % at the selected frequency 5.9GHz. 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 realize near omnidirectional radiation pattern in the H-plane and linear polarization antenna due to the phase changing of current distribution. In this research work, circular ring monopole antenna is small in size, simple in design and fabrication but its performance is the best for DSRC applications.

Keywords:- *Circular Ring Monopole Antenna, Dedicated Short Range Communications, Attair FEKO, Anritsu MS 2036C Network Analyzer.*

I. INTRODUCTION

The purpose design of circular ring monopole antenna is to develop a novel design for the dedicated short range communications that affords a recovering piece and functionality as compared to normal monopole antenna. Vehicular communication between infrastructure and vehicles is based on 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 [1].

Micro strip antenna is applied to get wireless access for communication applications. The printed monopole antenna is needed to design to get wide band due to the quick development of wireless communications. This research work is intended to new design of single antenna which can cover DSRC applications over very large bandwidth [2] [3]. A wire monopole antenna is placed in free space look like to dipole antenna but the different of feed element is located over a ground plane. Fundamentally, the ground plane cannot be retained infinite hence its dimensions are carefully chosen which are comparable with the length of active element. Some drawback of having narrow bandwidth of wire monopole antenna can be avoided by using printed monopole antenna. Printed monopole antenna is a good applicant for high data rate wireless communication at GHz frequency, because of its wide impedance bandwidth, Omni directional radiation pattern, compacted simple structure and easiness of fabrication. In printed monopole antenna, ground plane is orthogonal to patch as well as dielectric and 50 ohm coaxial transmission line give the excitation [4].

Due to the appearances of monopole antenna, circular ring shape is chosen to get coverage area, high radio accept link and omnidirectional radiation pattern. The demand of innovative technologies, this design is tend to reduce the size, less metallic surface and raise the proficiency of the devices.

The rest of the research work is composed based on the different sections. Section II considered the design specification and formula section III mentions the software implementation and analysis for reference antenna based on the background theory of that antenna design. Section IV fabricate and measure the performance of proposed CRMA antenna design. Finally, section V summarizes and concludes the study.

II. DESIGN SPECIFICATION

The proposed design antenna fed micro strip feed line with SMA connector. The design consideration of CRMA is the following.

A. Substrate Material Consideration

Circular ring monopole antennas consist of very thin metallic patch placed the other side of ground plane. The thickness of the metallic strip is limited by t<< λ_0 and the height is restricted by 0.0003 << h<< 0.05. For a substrate, the L of the element is usually $\lambda_0/3 < L < \lambda_0/2$. There are various substrates that can be used for the micro strip antennas and their dielectric constants are typically in the range of 2.2 << ε_r << 12.Then the 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 $G = h/\lambda_0$

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Fig 1 illustrates that the growing value of relative dielectric constant, the radiation efficiency is declined. And also, the dielectric constant is higher, the radiation efficiency is lesser. So, dielectric material should be chosen a dielectric constant less than 5.

Fig 2 shows that radiation efficiency is the lowest at around 5.9 GHz working frequencies for FR4 substrate materials. In the research work, FR4 substrate (the lowest radiation efficiency) is chosen as the condition of local market although FR4 substrate may cause the lowest efficiency.

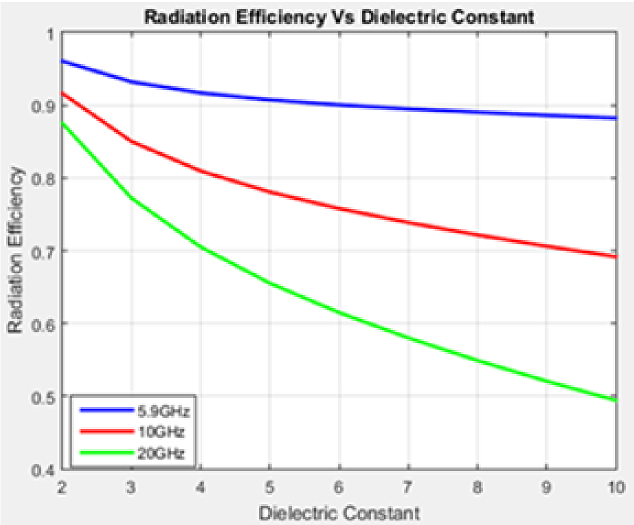


Fig. 1:- Radiation efficiency vs. dielectric constant at different frequencies

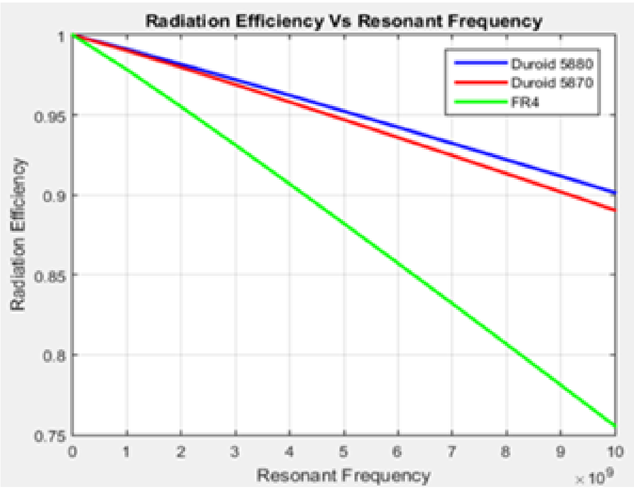


Fig. 2:- Radiation efficiency vs. resonant frequency at different materials

B. Micro Strip Patch Shape Collection

Micro strip patch shape varies from square, rectangular, circular, elliptical, triangular to tin strip dipole. A circular ring patch was chosen as the monopole radiation element to get coverage dedicated short range communications. The antenna is fed by a micro strip feed line, which connected to the coaxial cable through a standard 50 SMA connector for measurement.

C. Dimension Calculation Of Circular Monopole Antenna

The initial Length (L) and width (W) of the patch has been calculated using the following formula [3].

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

Where

c= free space velocity of light

ε_r= dielectric constant of the substrate

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

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

And then the effective length of the substrate can be calculated

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

Increase in patch length

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

Due to the effect of fringing fields, the resonant length of patch is not equal to the physical length. So, the actual length of patch (L)

$$L = \frac{c}{2 * f_r * \sqrt{\varepsilon_r}} \quad (6)$$

Physical length is given as:

$$L = Leff - 2\Delta L \quad (7)$$

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

$$Lg = L + 6h \quad (8)$$

$$wg = w + 6h \quad (9)$$

The impedance matching can be found the following;

$$ZA(\Delta x = 0) = 90\frac{\varepsilon r^2}{\varepsilon r-1}\left[\frac{L}{W}\right]^2 \Omega \quad (10)$$

Since the dimension of circular loop radius is given by [4].

$$fr = \frac{Xmn}{2\pi ae\sqrt{\varepsilon r}}c \tag{11}$$

The value of dominant mode TM11 is X_{mn} =1 .8411, f_r is the resonance frequency of the patch, c is the velocity of light in free space and εr is the relative permittivity of the substrate.

The effective radius of the circular patch and given by

$$ae = a\left[1 - \frac{2h}{\pi a \varepsilon r}\left(\ln\frac{\pi}{2h} + 1.7726\right)\right]^{\frac{1}{2}} \tag{12}$$

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

$$B = \frac{377\pi}{2Zo\sqrt{\varepsilon r}} \tag{13}$$

$$\frac{Wm}{h} = \left\{\begin{matrix} \frac{8e^{A}}{e^{2A}-2}; \frac{Wm}{h} \prec 2\ for A \geq 1.52 \\ \frac{\pi}{2}\left\{B - 1 - \ln(2B-1) + \frac{\varepsilon r - 1}{2\varepsilon r}\left\{\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon r}\right\}\right\} \end{matrix}\right\}$$
(14)

$$Wf = \frac{Wm}{h} \tag{15}$$

From above equation, the mentions of optimization values are shown in table 1.

Design Specifications	Value	Design Parameters	Length in mm
εr	4.4	W_f	2
tan∂	0.016	a, t	7.5, 2
Thickness(h)	1.6	Wg, Lg	20, 11
Operating Frequency f	5.9GHz	W, L	20, 26

Table 1:- The Dimensions of the Designed Antenna

The design calculations of antenna such as radius of circular monopole, length of feed gap and width of ground plane are affected on the performance of antenna. So, the optimized design of these parameters is going to change to get DSRC band. The main aim of this research work is to achieve optimum design of DSRC band as below.

III. DESIGN AND SIMULATION

The circular ring monopole antenna design is shown in Fig 3.The specifications and parametric values are described in table 1.The circular ring monopole antenna is designed and simulated by FEKO simulator software [5] and the performances of the CRMA such as current distributions, return loss, radiation patterns, and gain are discussed in the following sections.

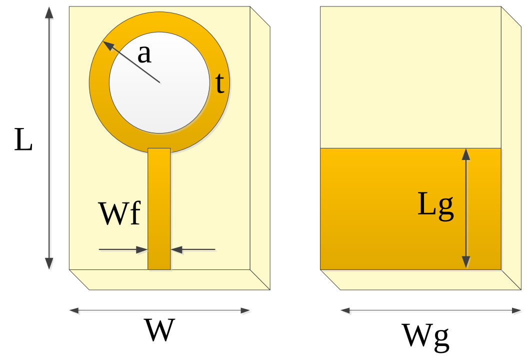


Fig. 3:- Geometry of the monopole structure design

A. *Return Loss and Fractional Bandwidth*

For antennas, the characteristic impedance must match between the antenna and the transmission line as closely as possible to avoid energy losses of reflected waves. The two variables of the reflection coefficient, S11, and the voltage standing wave ratio (VSWR) are mostly measured to determine proper impedance matching. The reflection coefficient is the amplitude of the wave transmitted to a port over the amplitude of the wave reflected back to the port from the system. Effective antennas have low reflection coefficients because they transmit supplied electromagnetic waves into free space rather than reflecting them back toward the source. For an antenna to radiate effectively, the return loss value should be less than -10 dB [4]. From figure, the return loss is about -37 dB at the selected frequency. The return loss for the circular ring monopole antenna can be obtained from Fig 4.

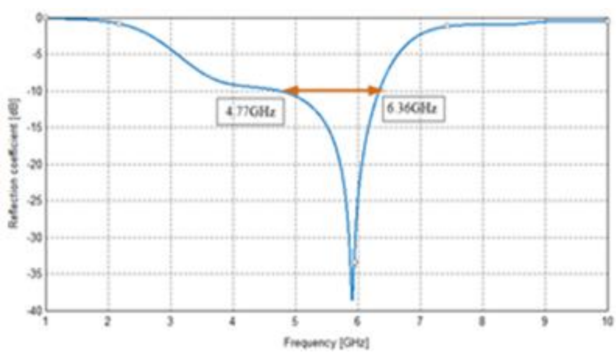


Fig. 4:- Return loss of an antenna

The antenna bandwidth is generally calculated as the frequency range at the magnitude of S11 is below -10dBs [3].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.

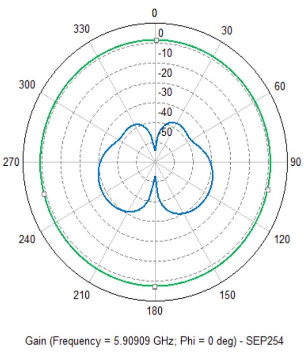
Percentage is referring to a quantity more commonly called fractional bandwidth (FBW).

$$FBW = \frac{BW}{f_c} \qquad (16)$$

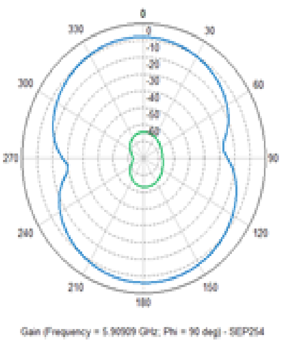
The FBW varies between 0% and 200%. The FBW of 20% or more than 20% is called wideband antennas. Ultra-wideband antennas are greater than 50% of FBW [4].

B. Radiation Pattern

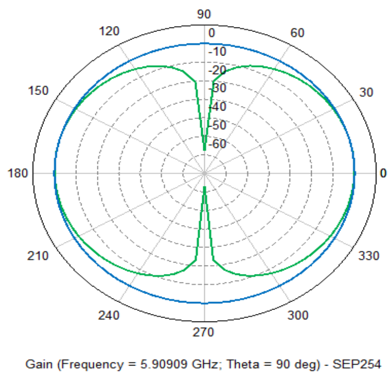
The radiation property of the antenna is defined as radiation pattern [4]. The polar plot of radiations pattern is shown in Fig 5. The simulated radiation patterns of proposed antenna in the xz-plane, yz-plane and xy-plane theta 90 for frequencies 5.9 GHz. The patterns in the xz-plane and xy-plane are quite Omnidirectional as expected. In the yz-plane, the radiation patterns remain roughly a eight shape like bidirectional radiation patterns. So, this type of antenna is called Omni-directional radiation pattern.



(a)



(b)



(c)

Fig. 5:- Radiation pattern (a) xz (b) yz (c)xy-plane

C. Current Distribution

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

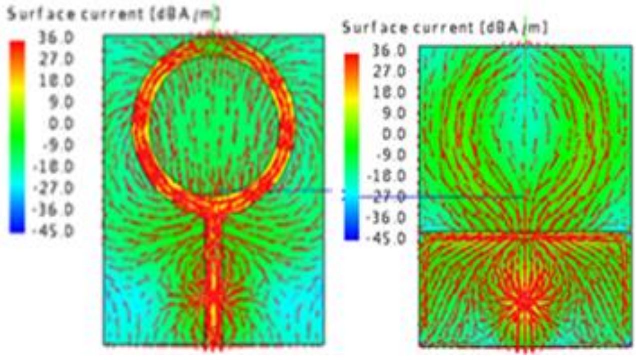


Fig. 6:- Top and bottom view of current distribution

D. Gain

If the power established by the antenna were radiated isotropically, the radiation intensity in a particular direction that would be obtained. Antenna gain is correlated to the antenna types and substrate materials. FR4 is losses material therefore high frequency range cannot get large gain from FR4. In Fig 7 the proposed antenna gain depicted nearly 2 dBi at operating frequency 5.9 GHz.

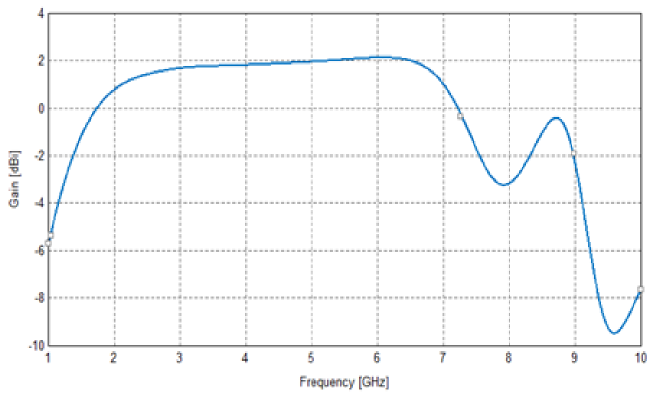


Fig.7:- Simulated result of gain for CRMA

IV. ANTENNA FABRICATION AND MEASUREMENTS

As usual the printed monopole antennas are fabricated after doing a lot of simulations. Firstly, the proposed design antenna was drawn by using Design View Easy –Cad Drawing software or Corel Draw or Dip Trace PCB Software. In this work, Dip Trace software is used to draw fabricated design shown in Fig 8.

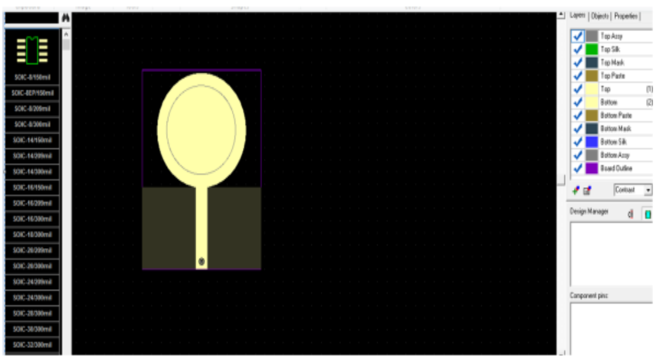


Fig. 8:- Dip Trace PCB drawing of CRMA

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A. Fabrication with LPKF

The proposed cad drawing design was fabricated with MITS Design Pro CAM-Lab or LPKF (Laser & Electronics) milling machine.

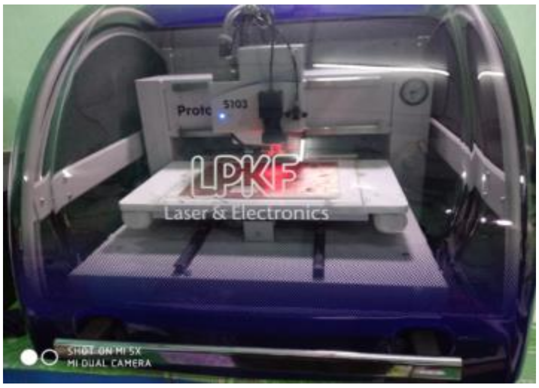

Fig. 9:- Fabricate with Laser & Electronics

The main goals of CRMA antenna were to fabricate use of cost effective materials in the design. According to the local market condition, FR4 material was chosen for the process of milling. Fig 9 shown fabricated condition with LPLF milling machine.

Fig. 10:- Top and bottom view of prototype CRMA

After the CRMA antenna board had milled, the SMA connectors had to be attached to the feed points on the antenna structure. The interface to which the antenna can be connected to external measurement equipment for characterization is called SMA connector. SMA connector is soldered straight to the feed point as shown in Fig 10.

B. Measurement Setup

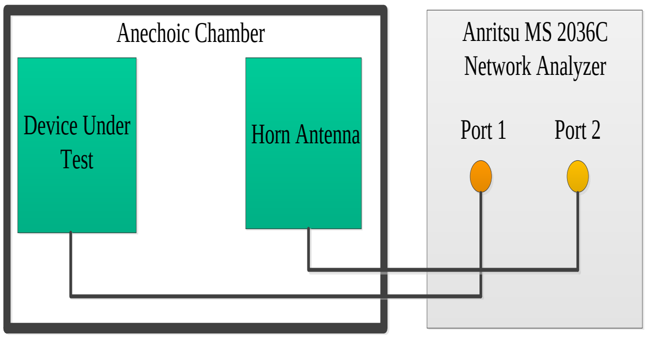

Fig. 11:- Block diagram of measurement setup in an anechoic chamber

The prototype of CRMA is set up with network analyzer. Block diagram of measurement setup is shown in Fig 11. This network analyzer measures the allowance of signals from 1 MHz to 6GHz. A network analyzer must be calibrated to provide highly accurate measurements. The calibration technique of short, open, load and thru (SOLT) was used on the network analyzer prior to the CRMA antenna characterization. One port of the network analyzer is connected to the low gain of the horn antenna and other port is connected CRMA in the measurement system.

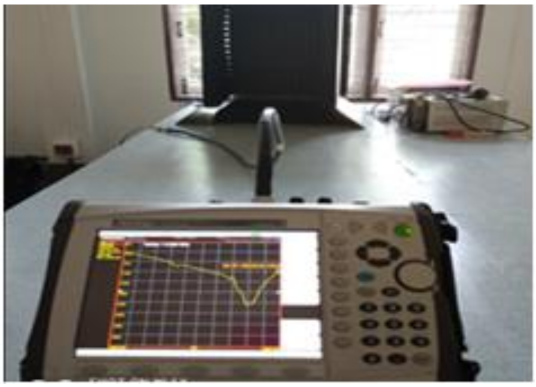

Fig. 12:- Measurement of reflection coefficients

When antenna measurements are involved, further steps must be taken to ensure the measurements are accurate which includes placing the antenna within an anechoic chamber. It is a room designed to absolutely absorb reflections of electromagnetic waves or sound these were made in free space.

Setup of the measurement device and measured the reflection coefficients of antenna as shown in Fig 12.

C. Comparison between Simulations and Measurement

According to the Anritsu MS 2036C network analyzer range, software result showed frequency range from 1 to 10GHz but the comparison result showed frequency range from 0 to 6GHz. The resonance frequencies can be appeared larger than simulation result in measurement work shown in Fig 13. This condition can be caused by calibration errors, or also in the manufacturing process.

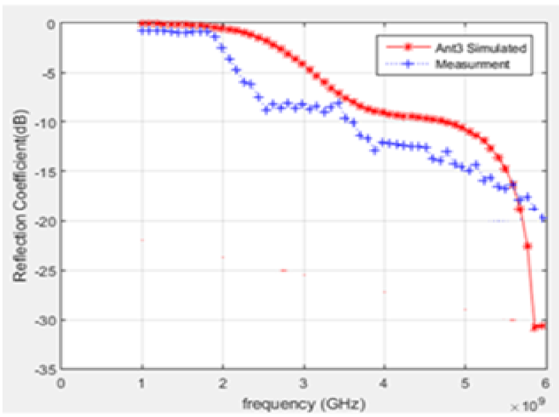

Fig. 13:- Comparison between measurement and simulation result

V. CONCLUSION

In this paper, circular ring monopole antenna which is basically a printed micro strip antenna with partial ground plane for dedicated short range communication has been simulated and measured. The circular ring monopole antenna is simulated on FEKO simulator. From the simulation results, this antenna type is linear and omnidirectional radiation pattern. If the software is sufficient for antenna characteristics, the proposed antenna design is fabricated with LPKF (Laser& Electronics) milling machine. After that, this prototype is measured by using SMA connector, Network Analyzer, An-echoic chamber, horn antenna and calibration kit. Both simulation and measurement produce a bandwidth of 75MHz (5.85 to 5.925GHz) covering dedicated short range communication.

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