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Development of Circular Monopole Antenna for Intelligent Transportation System

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Abstract: Circular monopole antenna design is very attractive research area in smart city area. There have been many research works in that area for getting the better performance and higher accuracy. The paper presents the development of circular monopole antenna for intelligent transportation system based on the idea of vehicular communication network. In this work, the design of antenna parameters are very important to make the novel design of proposed antenna system with specific frequency range. At first, the radiation efficiency with respect to height, dielectric constant and Resonant Frequency of the substrate for designing the antenna system. And then, the effective permittivity versus width and length of the proposed antenna system. The design with stripline circular monopole antenna and coplanar waveguide circular monopole antenna have been developed with the help of FEKO software and MATLAB codes. The return loss with SL-CMA and CPWCMA by using the reflection coefficient and smith chart analysis. And the radiation pattern based on E-plane and H-plane and far-field with 3D plot have been analyzed by using simulation tools. The simulation results confirmed the designed monopole antenna has been received the better performance for intelligent transportation system applications. Based on the simulation results, the proposed antenna design would be utilized for Intelligent Transportation System with specific frequency.

Keywords: Circular Monopole Antenna, Intelligent Transportation System, FEKO, MATLAB, Simulation Results

1. Introduction

Transportation is very important in modern human lives, which makes Intelligent Transportation Systems (ITS) very crucial in any highly urbanized city in the world. Problems such as congestion are causing substantial loss of time and money, heavy environmental pollution, high fuel consumption, and traffic accidents, and, hence, deployments in ITS are in great demand. Vehicle positioning is an enabling technology in ITS. Projects such as vehicle navigation, route planning, fleet management or any location sensitive information service depends on positioning. The individual communication between infrastructure and vehicles is based on roadside unit with a short range and mostly bidirectional data link. In Europe, a microwave frequency of 5.8 GHz is recommended for initial traffic applications [1]. Two or four channels, respectively with 5 MHz bandwidth each and a maximum EIRP (Equivalent isotropic ally _Radiated Power) of 3 dB are available. The communication zones for downlink and uplink can be shaped with especially developed antennas on the road side, such as planar micro strip antenna with suitable amplitude and phase weightings. Antenna is an essential part of each remote correspondence framework which gives a way to transmitting and accepting electromagnetic waves from one specialized gadget to other. Contemporary advancements in wireless correspondence have expanded the interest for multiband antenna working with variable frequencies with adequate data transfer capacity.

Currently, circular polarization has gained much devotion due to the large number of applications in wireless communication. This is due to the circumstance that a circularly polarized antenna does not require orientation of electric field vector at the receiving and transmitting ends. A single patch antenna can be made to radiate circularly polarized field if two orthogonal patch modes are concurrently excited with equal amplitude and with ±90 degree phase difference with the sign determining the sense of rotation [2]. The circular monopole antenna is chosen as it is capable of generating circular polarization and can be designed by using variation of static energy below a circular patch. A frequency selective surface (FSS) is proposed with dimensions smaller than that of a conventional FSS structure. Further, a comparison of the performance of the proposed FSS with a conventional FSS is done in terms of their effect on return loss, bandwidth and gain. The simulated and measured results are in good agreement.

In this paper, a circular monopole antenna is proposed and investigated. The geometric antenna dimensions are maintained to obtain a bandwidth of 10 MHz and acceptable radiation pattern properties. In addition to these, the antenna can cover intelligent transportation system application. A strip line and CPW-fed antenna not only performs better with respect to bandwidth and radiation pattern, but also is easily manufactured, which has increased its importance. Recently, there are rapid developments in wireless communications, in order to satisfy the IEEE ITS standards in the 5 GHz band [3].

This paper presents a design of antenna operating at 5GHz and covering (4–6) GHz band, with compact sizes, good isolations, and simple fabrication. In this work, the hexagonal geometry is adopted as a radiating element todesign the MIMO antenna systems since it has smaller size and can be designed by using variation ofstatic energy below the square or circular monopole antennas [1].

In [4], the comparison between the Rectangular Patch Antenna and Modified Rectangular PatchAntenna has been done for 5G application. The results have been found out to be in the desired range offrequency 28 GHz. The Maximum Resonant frequency, VSWR and Gain for without modified is 27.35GHz, 27.46GHz and -2.0 dB and for modified antenna 27.16GHz Maximum Resonant frequency, 27.46GHz for VSWR and -1.20 dB for Gain. In this project, he Modified Rectangular Patch antenna gives the better result than the rectangular patch antenna.

In another design [5], the design of the E-shape Micro strip antenna, using HFSS software and finite element method (FEM) respectively. Firstly, the Return Loss (-16.59dB), Bandwidth (80MHz) and VSWR (1.34) at Operating Frequency 2.40 GHz for the E-shaped Micro strip Antenna with Slots using HESS Software. On the other Hand, Measured Return Loss (-19.59dB), Bandwidth (100MHz) and VSWR (1.22) at Operating Frequency2.40GHz with Network Analyzer [7-21].

Based on the related works, this paper presents a circular monopole antenna design approach for designing compact antenna. The design initially begins with a conventional reference antenna, stripline-fed circularmonopole antenna (CMA), then the desired CPW-fed CMA is designed with miniaturized size of 50%compared with the stripline-fed CMA counterpart. Two full-wave commercially software packages areused in this wok. The first one is a FEKKO, and the second one is MATLAB.

The rest of the paper is organized as follows. Section 2 describes the fundamental concept for design of proposed antenna. Section 3 mentions the implementation of proposed antenna design with the help of FEKO. Section 4 concludes the simulation results for the proposed antenna system.

2. Design of Antenna Parameters

For designing circular monopole antenna element, two of CMAs are presented. One is based on SL-fed and called SL CMA, and the other is based on CPW-fed and called CPW CMA. They closely related to each other, and the size and parameter dimension values of them are equal.

2.1. Frequency Selection

Initially, SL CMA is designed to be resonated at the fundamental resonance frequency which is approximately given by

$$fr = \frac{Xmn}{2\pi ae\sqrt{\varepsilon r}}c \tag{1}$$

Where;
fr = the resonance frequency of the patch,
X_{mn} = 1.8411 for the dominant mode TM_{11},
C = the velocity of light in free space,
ε_r = the relative permittivity of the substrate and
a_e= the effective radius of the circular patch

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

Where;
h = the height of the substrate

2.2. Height of the Substrate

Height of the dielectric constant should be used

$$0.0003\lambda o \le h \le 0.05\lambda o$$

So h = 1.6mm choose for the substrate, height of the substrate is related with radiation efficiency from equation of Tabu Search Algorithm as following

$$\eta = 1-3.66F^{1.83}G^{1.06}\varepsilon r^{-1.32} - 2.4F^{2.48}G^{0.5}\varepsilon r^{-3.12} \tag{3}$$

Where;

$$F= (\varepsilon r\text{-}1) \text{ and } G=h/\lambda o$$

The lower the value of the height of the substrate as well as its dielectric constant, the higher radiation efficiency can be achieved. To achieve the higher radiation efficiency, the height of the substrate should be less than 1.6mm.

Design of micro strip antennas and their dielectric constant

$$2.2 \le \varepsilon r \le 12 \tag{4}$$

Generally, substrate materials can be separated into three categories according to the dielectric constant

a) $1 \le \varepsilon r \le 2$ (air, polystyrene foam, dielectric honeycomb)
b) $2.0 \le \varepsilon r \le 4.0$ (fiberglass reinforced telfon)

c) $4.0 \le \varepsilon r \le 10$ (ceramic, quartz or alumina)

Antenna efficiency is calculated by using above Tabu Search Algorithm and MATLAB simulation result are following

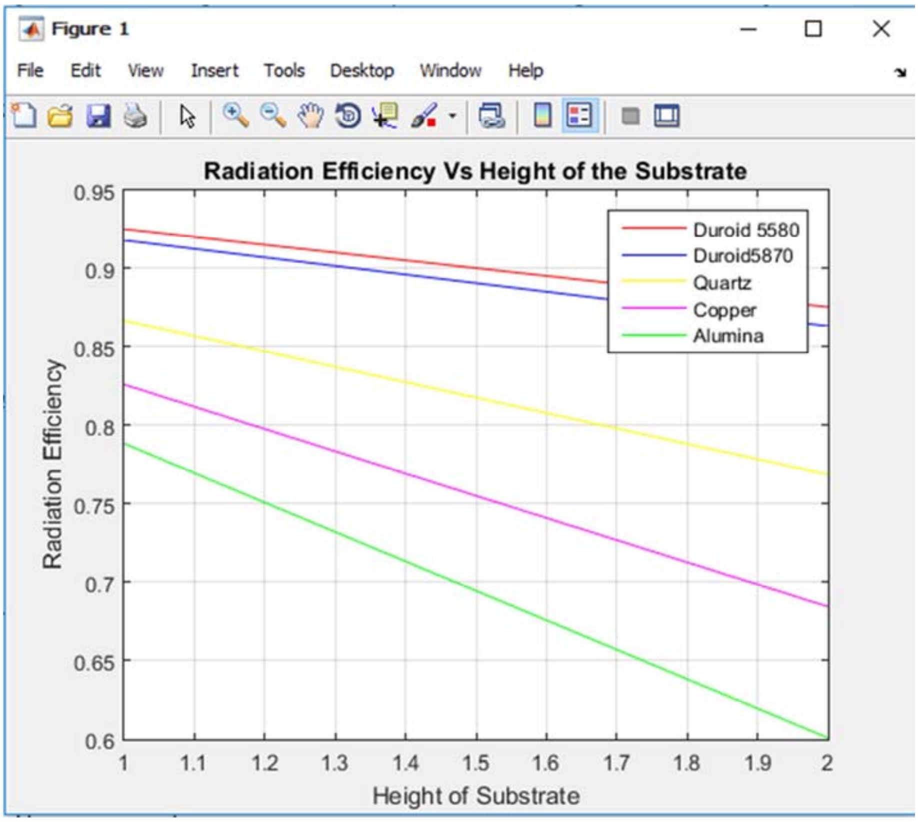

Figure 1. *Radiation Efficiency Vs. Height of Substrate at Different Materials.*

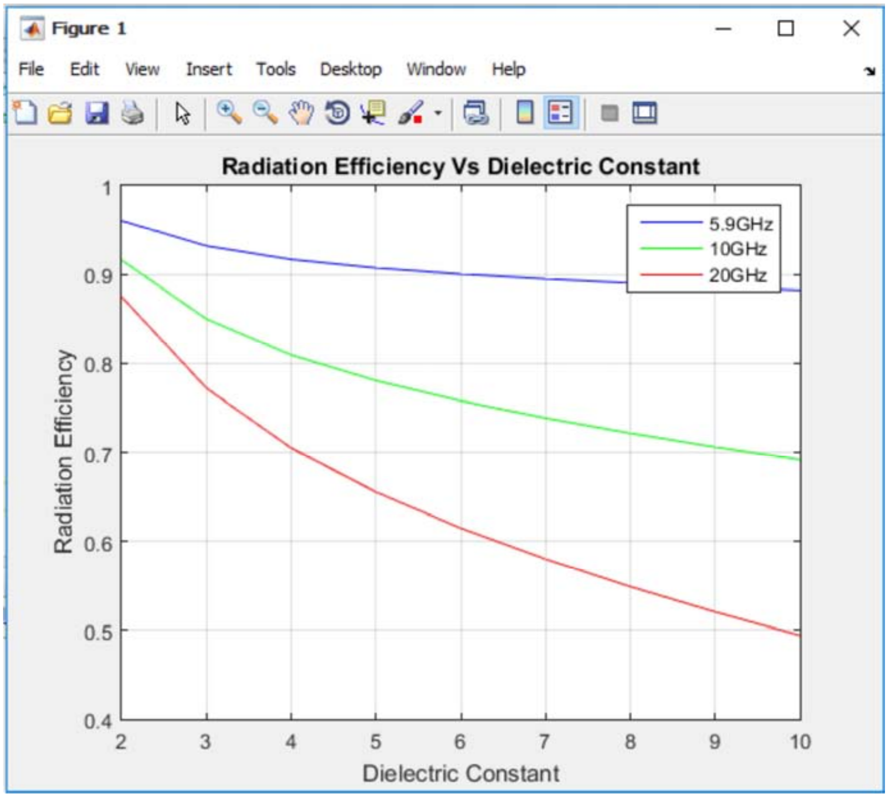

Figure 2. *Radiation Efficiency Vs. Dielectric Constant at Different Frequencies.*

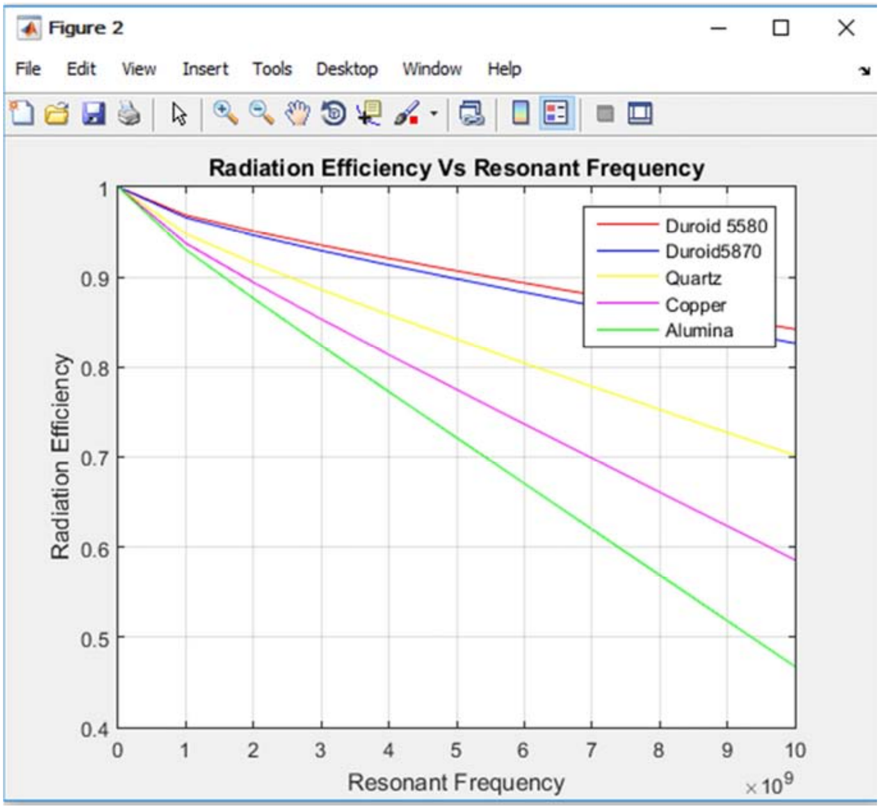

Figure 3. *Radiation Efficiency Vs. Resonant Frequency at Different Materials.*

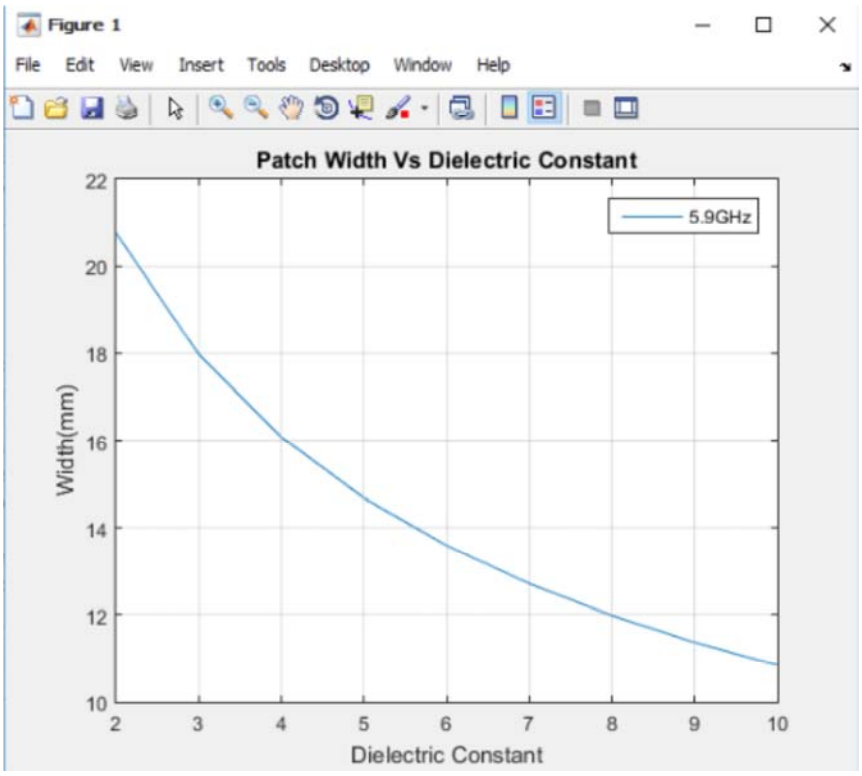

Figure 4. *Effect of* εr *on Width of the Microstrip Patch.*

The higher dielectric constant, the less radiation efficiency is occurred. Thus 5.9GHz needs to choose the dielectric material having a dielectric constant less than 5. The radiation efficiency is the lowest at around 10GHz operating frequencies for various substrate materials. Thus, the operating frequency should be less than 10GHz. The centered frequency 5.9GHz, which is allowable spectrum (5.875-5.905GHz) is chosen for research.

2.3. Effect of ε_r on Width & Length of a Micro Strip Patch

Copper substrate are available with ε_r ranging from 2 to 4. Higher ε_r yields a smaller patch size at the expense of bandwidth and gain. The patch size and efficiency should be adjust to achieve optimum designed parameters using the following equations;

$$W = \frac{c}{2Fo\sqrt{\frac{\varepsilon r+1}{2}}} \quad (5)$$

$$\text{Length } L = Leff - 2\Delta L \quad (6)$$

$$\Delta L = 0.412\left(\frac{\varepsilon re+0.3}{\varepsilon re-0.3}\right)\frac{\left[\frac{w}{t}+0.264\right]h}{\left[\frac{w}{t}+0.8\right]} \quad (7)$$

$$Leff = 0.5\frac{\lambda}{\sqrt{\varepsilon r}} \quad (8)$$

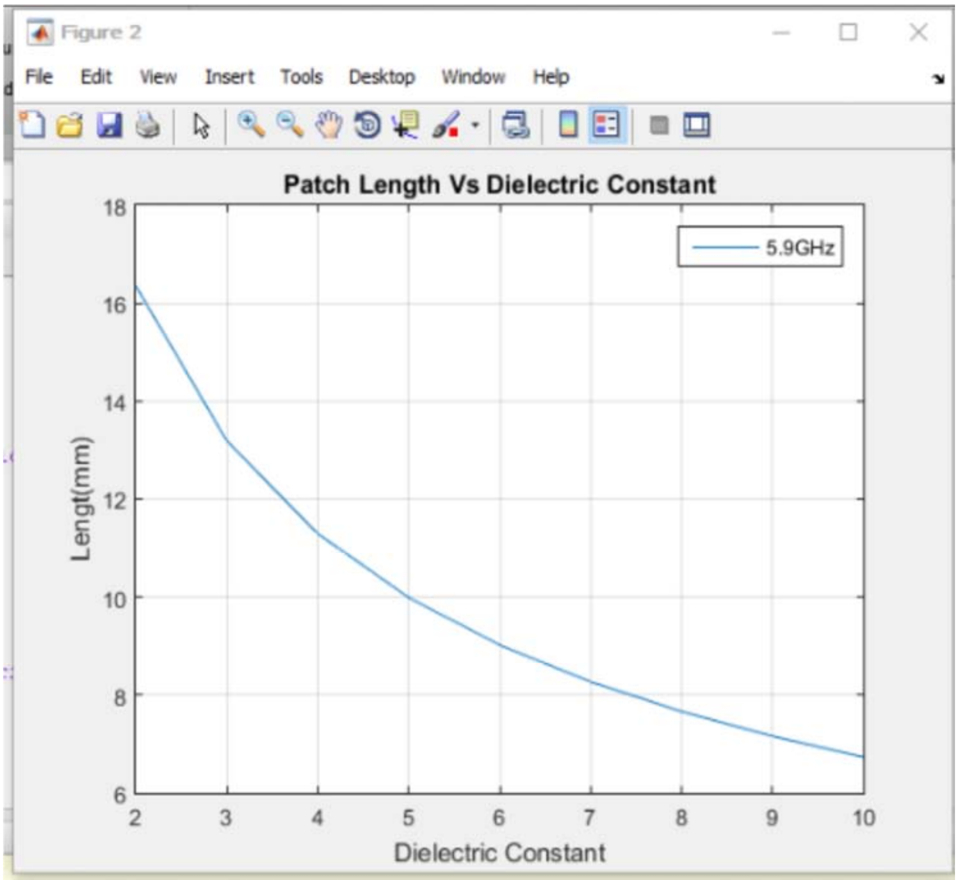

Figure 5. *Path Length Vs Dielectric Constant.*

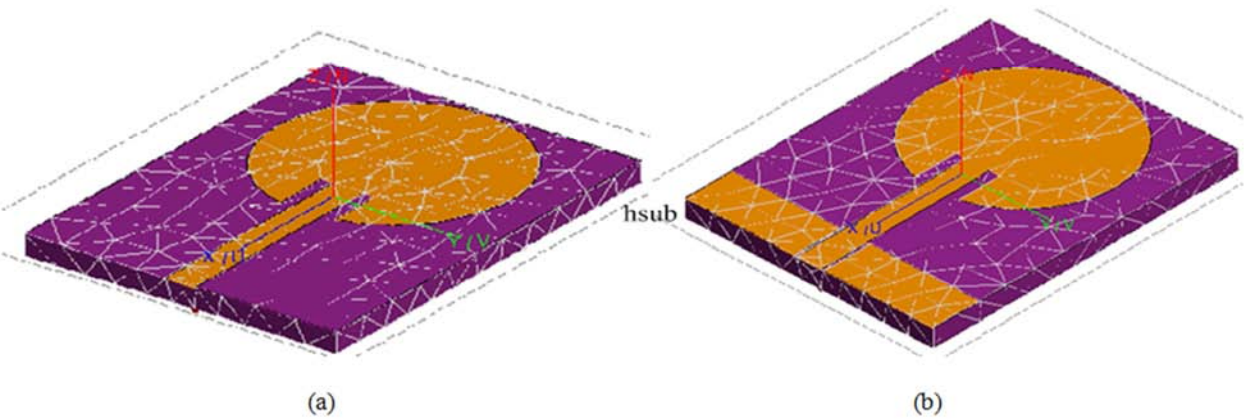

Figure 6. *Proposed Circular Antenna Element (a) strip line (SL)-fed circular monopole antenna element SL-CMA (b) Coplanar Waveguide (CPW) –fed circular monopole antenna element CPW-CMA (Lsub = 20mm, Wsub = 25mm, hsub = 1.6mm, Wf = 1.9mm, a = 7.5mm, yg = 4mm, g = 0.2mm, εr = 4.4).*

3. FEKO© Simulated S11 Curves of Circular Patch Antennas

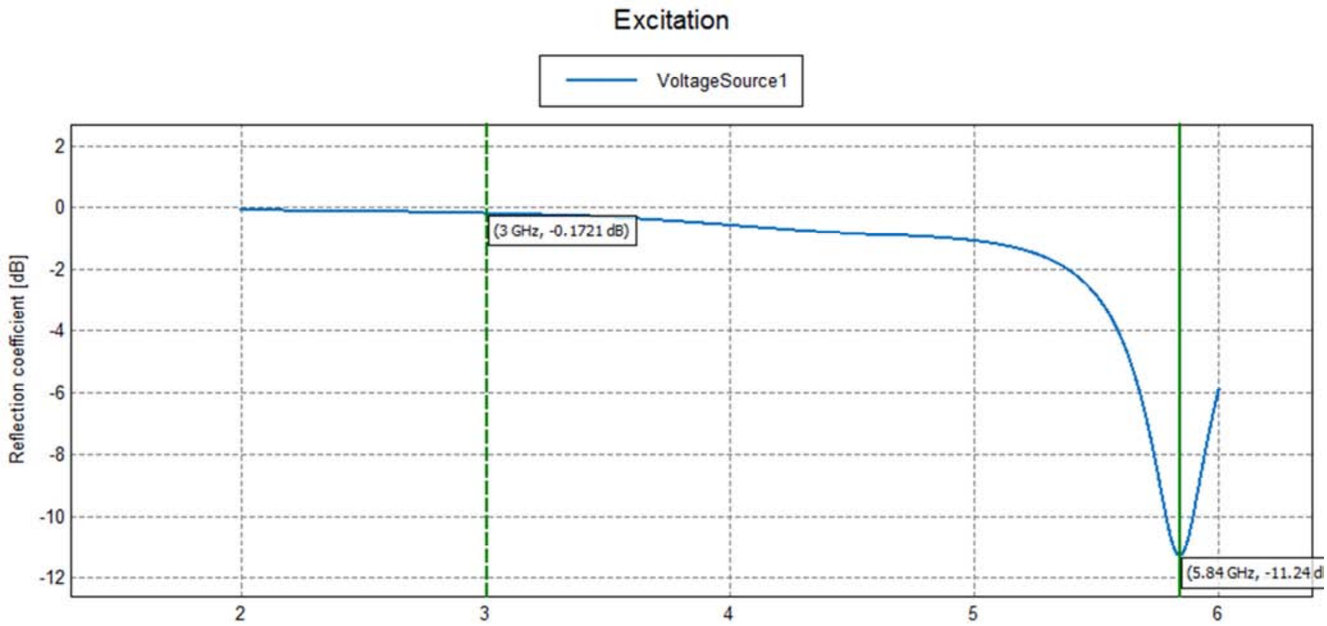

Figure 7. *Return Loss forSL-CMA.*

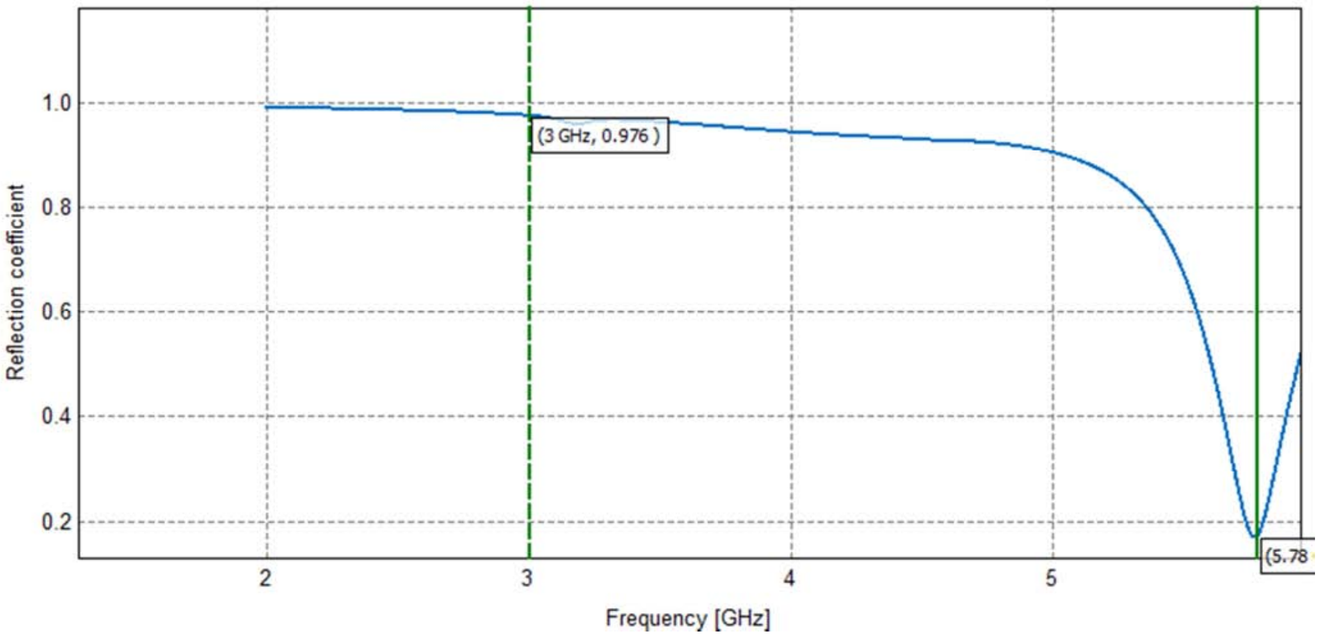

Figure 8. *Return Loss for CPW-CMA.*

The graph show the maximum return loss is -11.5dB & 15.5dB. The bandwidth percent of the antenna at the standard value -10 dB is 1.8% & 2.9%. The measured and simulated S11 curves by FEKKO for the single-element antenna are shown in Figure7 and 8. As can be noticed from this figure, the antenna resonates at 5GHz, so the aim of design procedure has been satisfied. The FEKKO −10-dB simulated impedance bandwidth covers frequency from 5.78GHz (5.689 GHz) to 5.91GHz (5.858 GHz). It is seen that there is a good agreement between the two simulations with a small variation between them. The differences between the measured and simulated results, but follow the same pattern of simulated results, may come from the manufacture error and the uncertainty in relative dielectric constant and thickness of the substrate.

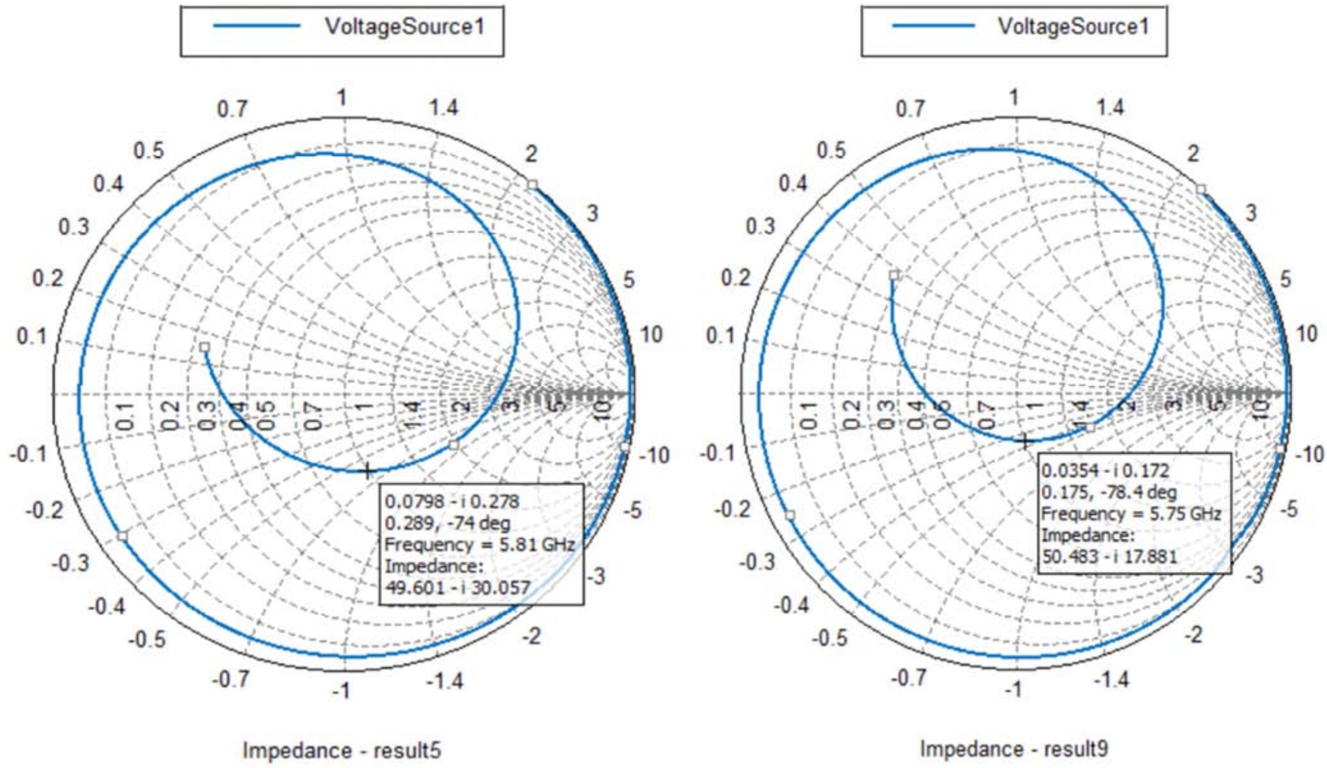

Figure 9. *Return Loss on Smith Chart for SL-CMA and CPW-CMA.*

The results shown on the Smith Chart indicatethat the optimum source impedance has to be presented toeach diode moving counter-clockwise with an increase infrequency, and closer to the center of the Smith Chart with anincrease in input power. The return loss of the patch on Smith chart for various frequency range S11 parameter value on the axis is Mag=0.289, phase=-74deg & Mag 0.175, -78.4deg. These values can be converted to the circular plot return loss value 11dB & 15dB.

Simulation result of Far Field Radiation Directivity are as follow:

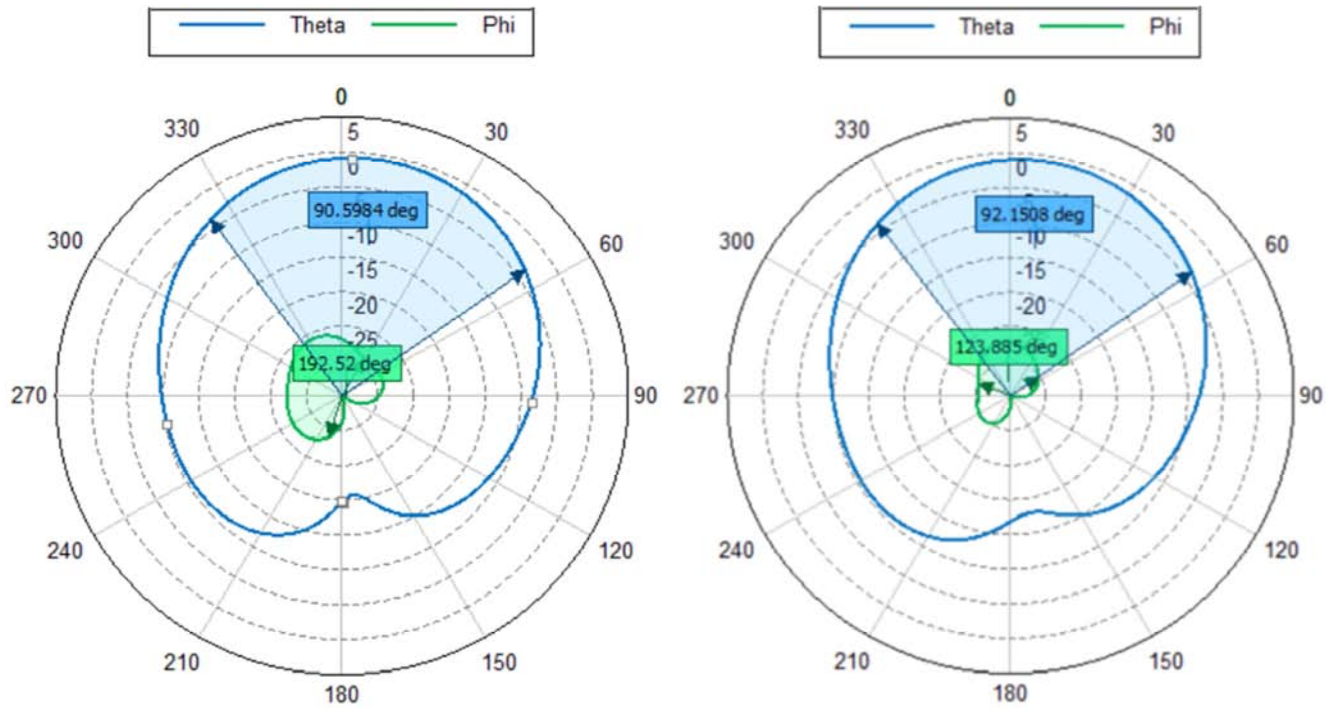

Figure 10. *Radiation Pattern of Phi=0 deg E-Plane.*

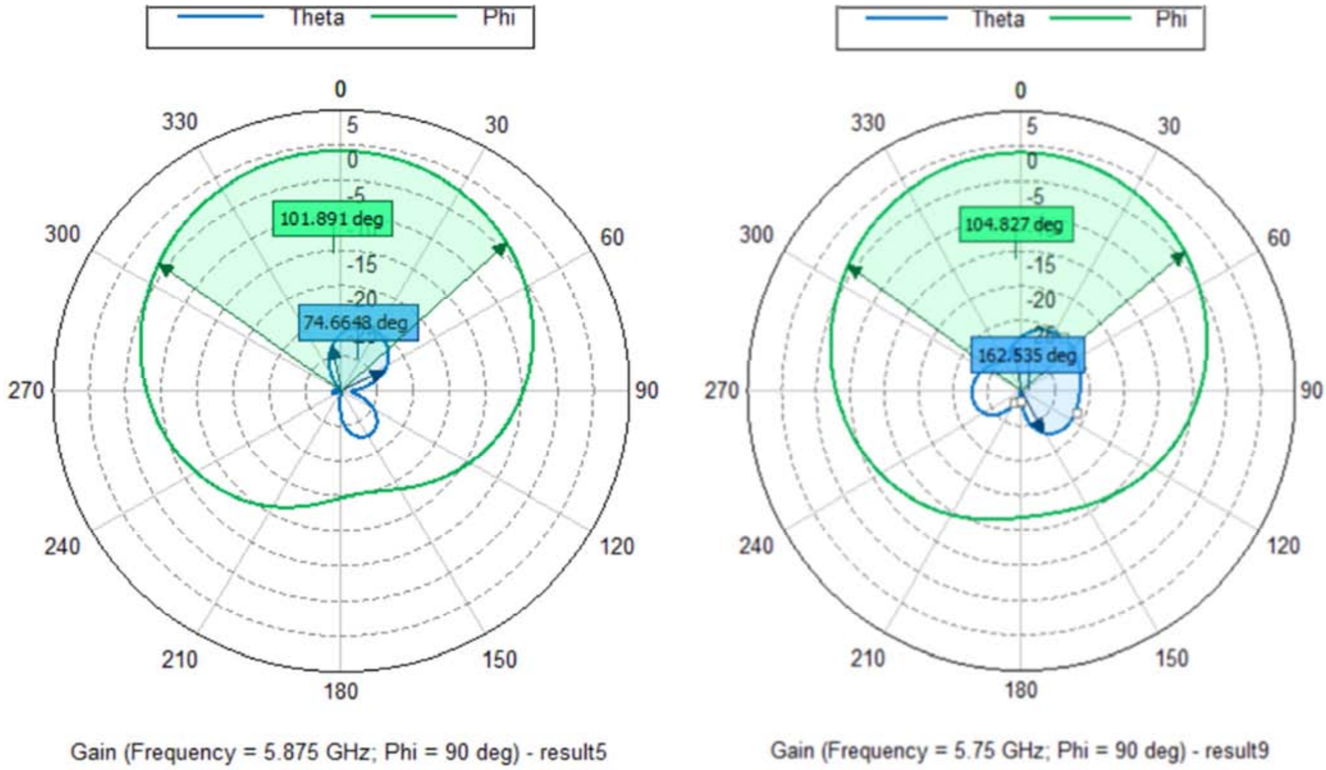

Figure 11. *Radiation Pattern Phi=90deg H-Plane.*

Figure 10 and 11 respectively shows the simulated radiation pattern at Φ=0˚ and Φ=90˚ for the proposed antenna system at the resonant frequency Fr= 5.85 GHz and 5.771GHz. From the polar figure, the designed antenna system produce circular radiation pattern. It is noted that temain beam angle is about broadside angle.

Simulation Result for 3D Far field Pattern are shown in Figure 12.

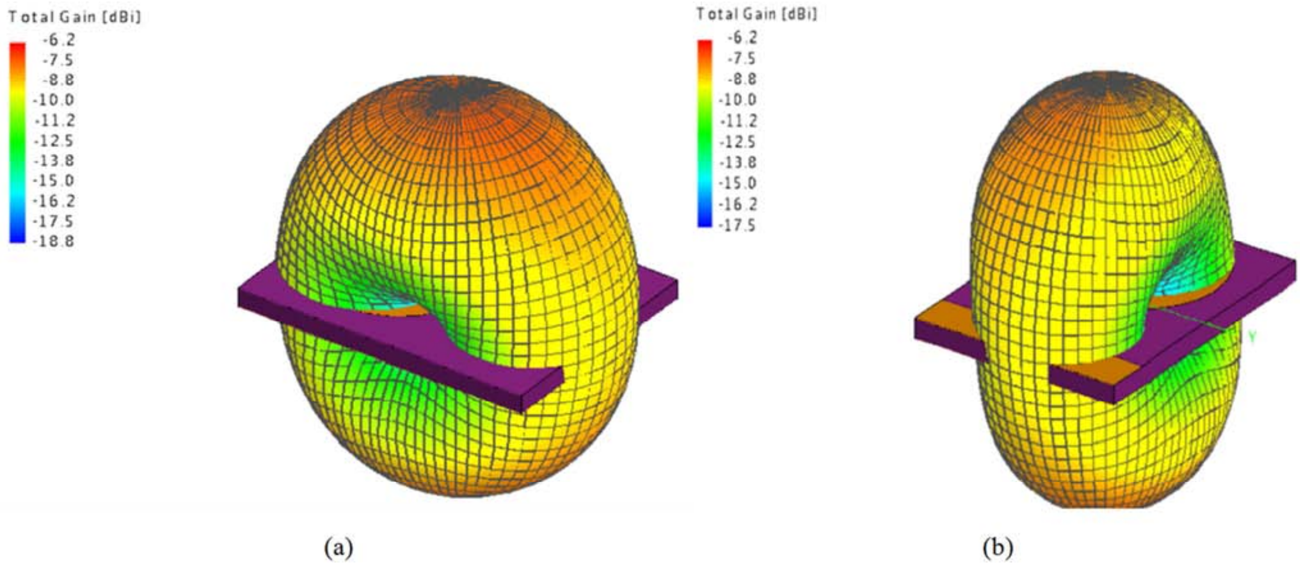

Figure 12. *Far-field Radiation Pattern (a) SLCMA, (b) CPWCMA.*

4. Conclusion

The simulation results for analysis of circular monopole antenna have been highlighted to apply for the Intelligent Transportation System with the help of FEKO and MATLAB in this paper. The proportion between radiation patterns with height of the substrate is always inversed. We found that the resonant frequency for designing the antenna varies the radiation efficiency inversely. We can find the value of permittivity are also inversely proportion to the width and height of the antenna but the adjustment could be done based on the resonant frequency. Based on the return loss analyses, we could easily find that SL-CMA could meet with the ITS standard band whereas CPWCMA could not encounter with the ITS standard band. We can evaluate the magnitude and phase from the return loss based on the Smith Chart analysis and the results have been engaged with the proposed system. The circular radiation pattern and far-filed considerations for two methods say the same values for the system. Therefore, the proposed antenna system for specific applications promises the performance of antenna design.

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