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Design and Performance Analysis of Coaxial Probe-fed Rectangular Microstrip Patch Antenna (RMPA) for IEEE 802.11p Standard

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ABSTRACT: *In this paper a rectangular microstrip patch antenna (RMPA) has been designed with coaxial feeding for 5.9GHz resonant frequency. This frequency spectrum is known as Wave Access in Vehicular Environment (WAVE) or IEEE 802.11p. Performance of the RMPA has been analysed by the simulation tool CST Microwave Studio v.2012. Several performance parameters such as return loss, bandwidth, Voltage Standing Wave Ratio (VSWR), directivity, gain and radiation efficiency have been obtained by simulation. This antenna has shown desirable results after a few optimization of design specifications. Designed RMPA resonates at 5.93 GHz and bandwidth has been found as 0.1417 GHz which has fractional bandwidth of 2.39% and that covers IEEE 802.11p band. Directivity and gain obtained at resonant frequency are 5.52 dBi and -0.174 dB respectively. The proposed RMPA radiation efficiency was found as 26.93% and VSWR as 1.05. As an overall evaluation, this antenna's performance was found to beat a satisfactory level.*

KEYWORDS: RMPA, WAVE, IEEE 802.11p, CST MWS.

Introduction

In the fields of technology and information systems, wireless technology plays an important role in daily life. Nowadays, almost everybody is using smart phones, tablets or Wi-Fi enabled devices. One of the major components of these wireless devices is the antenna. Invention of smaller antennas is necessary to make wireless technology user friendly. The antenna should small enough to fit into a mobile phone or tablet casing. Moreover, radiation from the antenna can be harmful for humans as well as for the environment (Maria Blettner, Gabriele Berg 2000). Excessive radiation exposure is related to various diseases, so researchers are continuously innovating to design more compact and less harmful antennas (Maria Blettner, Gabriele Berg 2000).

Various types of antenna exist for wireless communication, such as the planar inverted-F antenna, horn antenna, helical antenna, patch antenna (Saunders & n-zavala, 2007, pp. 73-85). The patch antenna has become popular due to its low profile, low cost, low weight, compact size etc. (Singh & Tripathi, 2011). Many shapes (rectangular, circular, triangular) have been developed for patch antennas (Balanis, 2007). For these antennas,several feeding techniques are used (microstrip line feed, probe feed, aperture-coupled feed and proximity-coupled feed) (Balanis, 2007, pp. 813-814). All of them have specific advantages.

There are various wireless transmission protocols such as WiMAX, Wibree, Bluetooth, WLAN etc. (Mitra, 2009, pp. 19-21).WLAN is also called the IEEE 802.11 standard. It uses ISM band (5.25 GHz to 5.825 GHz) (Mitra, 2009, pp. 19-21). IEEE 802.11p is a protocol by which a moving vehicle can establish connection with another vehicle on the road (Eichler, 2007). It is an amendment of the WLAN standard. IEEE 802.11p standard uses the 5.9GHz band, which operates within frequency range of 5.85GHz to 5.925GHz (Eichler, 2007). According to (Eichler, 2007) this standard was previously known as Dedicated Short Range Communication (DSRC), and it might be popular in the near future.

In this paper, based on the amendment of WLAN, a rectangular microstrip patch antenna with coaxial probe feeding technique has been designed, and the performance of the RMPA has been analysed.

Antenna Design

For designing the antenna, a resonance frequency and substrate material have been selected. Then, by using associated formulas, antenna dimensions have been calculated in MATLAB. A code has been developed for this purpose.The proposed RMPA has been designed on a Fiber Reinforced (FR-4) glossy substrate, which has relative permitivity of 4.3 and loss tangent of 0.025. For an antenna patch, this becomes the perfect electric conductor (PEC) material. The ground plane also has been made of the PEC. The associated formulas are given below.

The width of the patch can be calculated by equation (1) (Majumder, April, 2013; Balanis, 2007, pp. 727-730)

$$W = \frac{c}{2f_0\sqrt{(\epsilon_r + 1)/2}} \quad \dots\dots\dots (1)$$

The effective relative permitivity of the substrate material has been calculated by equation (2) given at (Balanis, 2007, pp. 727-730; Majumder, April, 2013; Pozar, 2012, pp. 147-150).

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\left(\frac{h}{w}\right)\right]^{-1/2} \dots\dots\dots (2)$$

Extended length of the patch can be calculated by equation (3), which is taken from (Majumder, April, 2013; Balanis, 2007, pp. 727-730).

$$\Delta L = \frac{0.412h\left(\left(\epsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)\right)}{\left(\epsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \dots\dots\dots (3)$$

According to (Majumder, April, 2013; Balanis, 2007, pp. 727-730)the actual length of the patch can be given as follows,

$$L = \frac{\lambda_o}{2} - 2\Delta L \dots\dots\dots (4)$$

Feeding position of the coaxial cable can be obtained by using following equations give at (Majumder, April, 2013).

$$X_f = \frac{L}{2\sqrt{\epsilon_{reff}}} \dots\dots\dots (5)$$

$$Y_f = \frac{W}{2} \dots\dots\dots (6)$$

From (Majumder, April, 2013) ground dimension of the RMPA also found as,

$$L_g = 6h + L \dots\dots\dots (7)$$

$$W_g = 6h + W \dots\dots\dots (8)$$

The proposed RMPA is shown in Figure 1(a) and 1(b). A pin of thePEC is connected through the substrate with the patch; and the coaxial port is made of a dielectric material, teflon, which has been shown in Figure 1(b). The patch, substrate, width and length of the RMPA are shown in Figure 1(a). Figure 1(b) shows the coaxial feed, which is connected with the ground plane. The probe has been inserted inside the substrate.

Figure 1a: Perspective view of RMPA

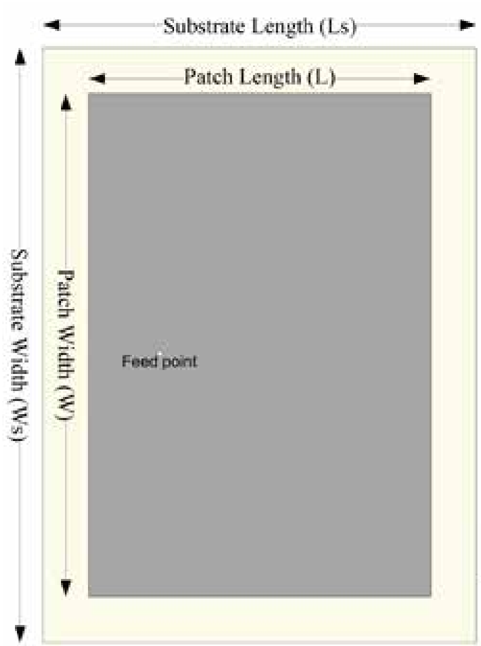


Figure 1b: Bottom view of RMPA

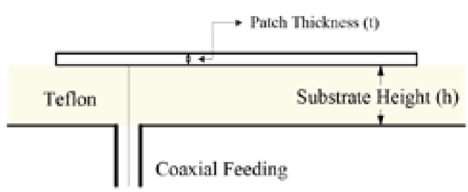


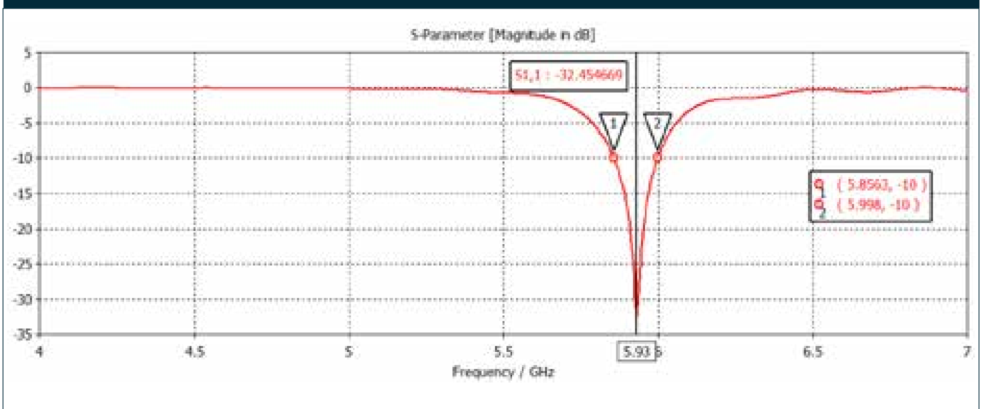
Table 1: RMPA Design Specfications			
Parameter	**Value**	**Unit**	**Material**
Resonant Frequency (fr)	5.9	GHz	-
Substrate Relative Permittivity (εr)	4.3		-
Patch Width (W)	15.62	mm	
Patch Length (L)	11.66	mm	PEC
Patch Thickness (t)	0.035	mm	
Substrate Width (Ws)	18.62	mm	
Substrate Length (Ls)	14.6	mm	FR-4 (lossy)
Substrate Height (h)	0.5	mm	

Antenna design specificationsare given in Table I. The distance between the patch and the ground plane has been taken as 0.5 mm which is denoted by h. Ground dimensions are the same as substrate dimensions except thickness. The ground plane has been created as an extended sheet of PEC from the substrate along the negative vertical axis. In this design,wave-port has been selected; and the simulation boundary is set as 4GHz to 7GHz.

Simulation and Results

Based on the design specification, a RMPA has been designed by using CST MWS 2012. The RMPA performance has been simulated and the parameters of antenna performance have been studied. Return loss plot, VSWR plot, Smith chart, polar plot, 3D radiation plot and surface current, H-field & E-field distribution on the patch are shown in the following figures.

Figure 2: Return Loss Plot of RMPA



From Fig.2 the return loss of the RMPA has been found as -32.45 dB at resonant frequency (f_R) 5.93 GHz. At -10dB it has been found that the lower frequency (f_L) is 5.8563 GHz and higher frequency (f_H) is 5.998 GHz. This is 0.1417 GHz bandwidth, which is sufficient to cover IEEE 802.11p band. From this figure, according to (Balanis, 2007, pp. 869-872), thefractional bandwidth (fBW)can be calculated as follows:

$$fBW = \frac{f_H - f_L}{f_R} = \frac{(5.998 - 5.8563)GHz}{5.93\ GHz} \times 100 = 2.39\%$$

Figure 3: VSWR Plot of RMPA

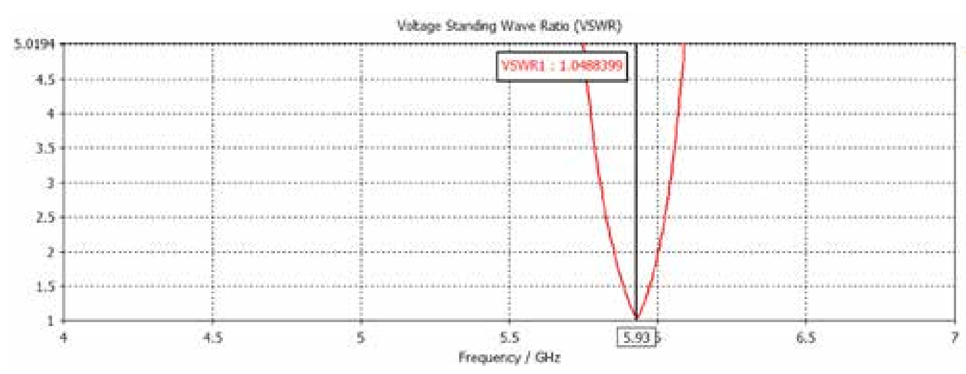
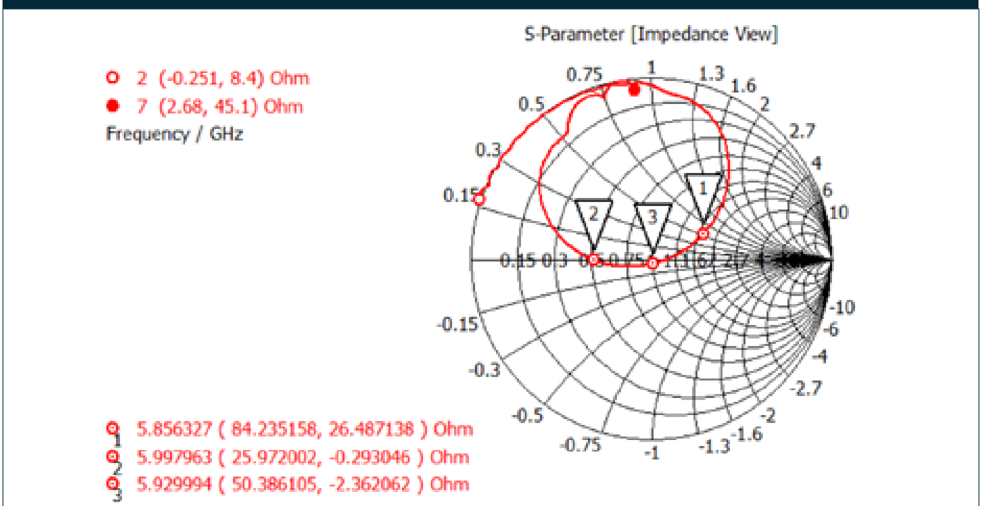


Fig.3 shows the VSWR at resonant frequency which is1.05 and is lower than 2. This result is good enough to continue the simulation.

Figure 4: Smith Chart of RMPA



The Smith Chart of this RMPA operating for the frequency between 2GHz to 7GHz is shown in Figure 4. Curve marker 3 shows that at resonant frequency impedance matches with characteristics impedance 50 Ohm.

The far-field polar plot of the proposed RMPA is shown in Figure 5(a). From the figure, the main lobe magnitude has been found as 5.5 dBi and angular width at 3dB which is 100.9 degree. Figure 5(b) shows the H-plane polar plot of RMPA at 5.9 GHz. In that case, the angular width is 87.2 degree at 3dB and the main lobe magnitude is 5.5dBi.

Figure 5a: E-Plane Polar Plot of RMPA at 5.9GHz (Phi = 0 degree)

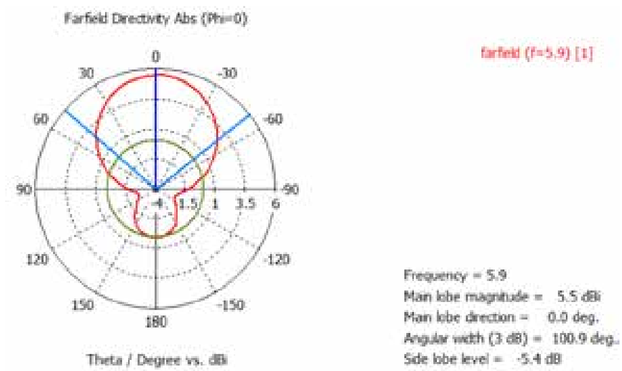


Figure 5b: H-Plane Polar Plot of RMPA at 5.9GHz (Phi = 90 degree)

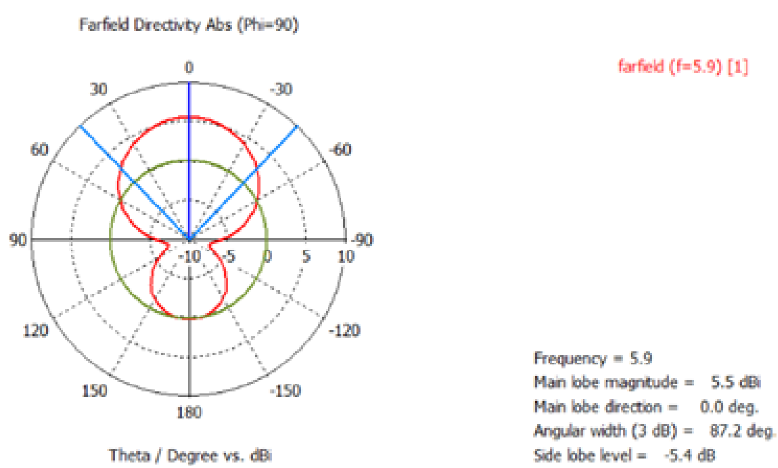
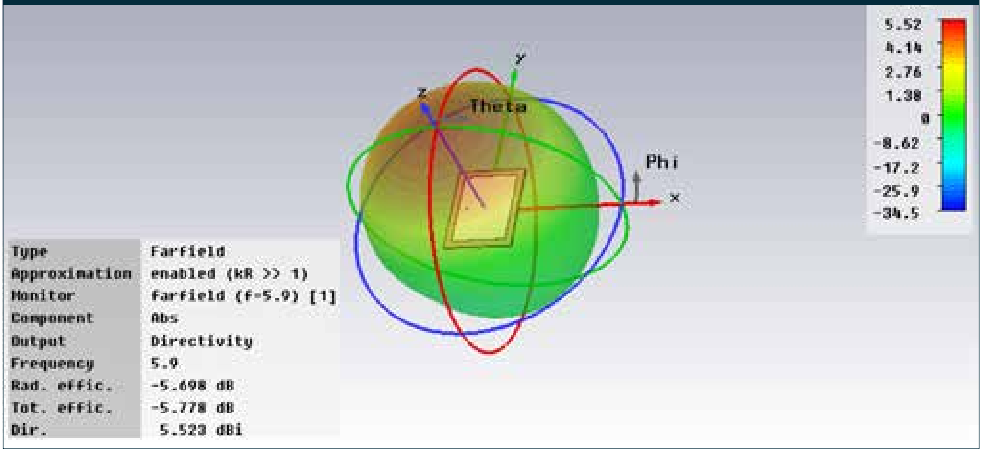
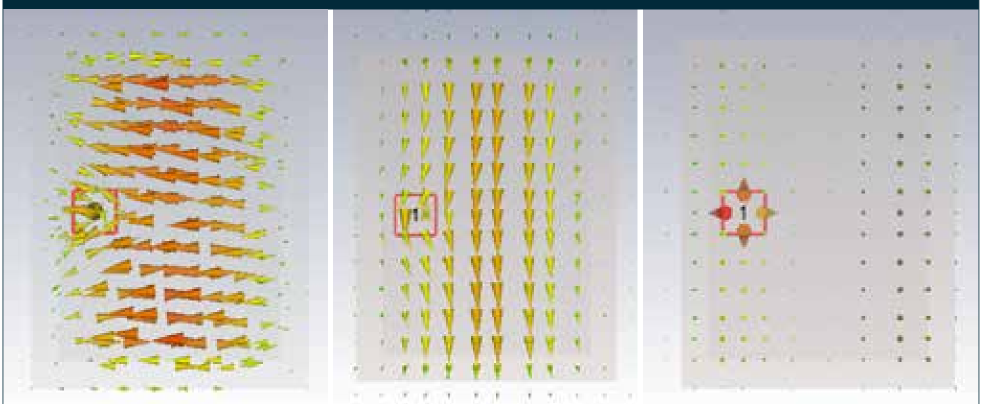


Figure 6: Radiation Pattern of RMPA at 5.9 GHz



Figures 7a: Surface Current 7b: H-Field and 7c: E-Field on RMPA at 5.9 GHz



The radiation pattern of the proposed RMPA at 5.9 GHz (Balanis, 2007; Mitra, 2009) is shown in Figure 6. In that case directivity is 5.52 dBi. Maximum radiation has occurred on the top of the RMPA.

Figure 7(a) shows the surface current density at 5.9 GHz resonant frequency. Figure 7(b) shows the H-field and Figure 7(c) shows the E-field density on the top of the RMPA.

All results are tabulated in Table 2.

The conclusion from Table II is that the proposed RMPA shows acceptable antenna performance.

Table 2: Simulated Results of RMPA	
Parameter	**Result**
Resonant Frequency	5.93 GHz
Return Loss	-32.45 dB
Lower Frequency	5.856 GHz
Upper Frequency	5.998 GHz
Bandwidth	141.7 MHz
Fractional Bandwidth	2.39%
VSWR	1.05
Radiation Efficiency	26.93%
Gain	- 0.17 dB
Directivity	5.52 dBi

Conclusions

In this paper, a simple coaxial-probe fed rectangularmicrostrip patch antenna has been designed by the simulation tool CST Microwave Studiov.2012. The proposed antenna resonates at 5.93 GHz and it fulfills the requirements of this project. It showed reasonable results, useful for compact wireless devices. Almost new IEEE 802.11p protocol requirements have been obtained by this proposed antenna. By making further optimization, such as inserting slot, truncating ground, by using metamaterials, and by introducing fractalsin the patch, it maybe possible to use this proposed compact RMPA for multiband operations. The authors would like to continue this project for further improvement through modifications.

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