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Design and Optimization of a Square Patch Antenna for Millimeter Wave Applications

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Abstract: ***Over the years, there has been significant changes from the early analog mobile generation (1G) to the last implemented third generation (3G) as well as rapidly growing 4G/LTE. The new mobile generations do not only seek to improve voice communication experience but also try to give users access to a new global communication reality. The aim is to make communication possible at all times and from all places. Spectrum scarcity as well as the need for high data rate and mobility has necessitated intense research on 5G systems recently. Presented in this paper is a simple but efficient design for a square-shaped single-port patch antenna that resonates around 28.3GHz, which falls within the anticipated 28GHz band for 5G applications. The antenna has a square patch of 1.8mm by 1.8mm on a Taconic RF-60 substrate with thickness of 0.64mm, dielectric constant of 6.15 and loss tangent of 0.028. The proposed antenna has a total substrate dimension of 6mm x 6mm. HFSS simulation results show that the antenna resonates at 28.3GHz with a bandwidth of 8.45%, a return loss of -38.1dB at the resonant frequency and directional radiation pattern making it suitable for millimeter wave mobile applications.***

Keywords: Microwave, millimeter wave, 5G, Patch antenna, LTE

1. Introduction

The light portion of the electromagnetic spectrum has been in use for optical or visual communications from ages past. It is imperative to say that communications has come a long way since then as long distance communications now use electromagnetic spectrum outside the visible region through the use of radio[1]–[3].

Central to a communication system is a specialized transducer that converts incoming electromagnetic fields into alternating electric currents having the same frequencies (receiving antenna), or converts an alternating current at a specific frequency into an outgoing electromagnetic field at the same frequency (transmitting antenna)[2], [3]. Its shape and geometry has also evolved over time to meet specific requirements as required[4].

A very interesting effort is the introduction of the 5th generation of mobile communications system in the nearest future after worldwide success at 3G and 4G systems[5], [6]. The prospect of ubiquitous computing and a wide variety of new user services has increased research efforts at antenna capable of application for 5G frequencies.[7]–[9]

According to the FCC, the specific bands that will be studied for 5G services include the 27.5 to 28.35 GHz, also known as the 28 GHz band, the 37 to 38.6 GHz band, also known as the 37 GHz band, 38.6 to 40 GHz, known as the 39 GHz band and the 64-71 GHz band[10]. This research work presents a design for a square shape single-port patch antenna operating at 28.2GHz frequency on a Taconic RF-60 substrate. All simulations were done using the HFSS software package. Results were satisfactory.

2. Antenna Size, Structure and Design Equation

In a bid to arrive at the desired results, a number of design factors were put into consideration. This includes:

(i) Metallic strips are very thin
(ii) The conducting patch is placed at 0.64mm from the ground plane which is about $0.06\lambda_0$
(iii) A substrate of high dielectric constant was chosen to significantly reduce the size
(iv) Distance from the patch to the substrate is made greater than thrice the substrate thickness.

The empirical formulas to get the dimensions for the patch are given by equations [i-iii];

$$W = \frac{c}{2f_0\sqrt{\frac{(\varepsilon_r+1)}{2}}} \quad \text{(i)}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2} \quad \text{(ii)}$$

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{eff}}} \quad \text{(iii)}$$

Where $c = 3 \times 10^8 m/s, h = 0.64mm$ and $\varepsilon_r = 6.15$

Since the shape of the patch is desired to be square and with all other factors in mind, the proposed antenna structure and dimensions after optimization procedure is given in Figure 1 and table 1.

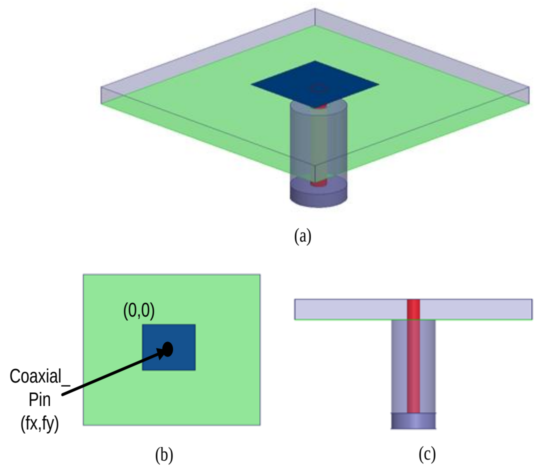


Figure 1: Antenna Structure; (a) 3D View (b) Top View (c) Side View

Table 1: Antenna Dimension

Patch	W	1.80mm
	L	1.80mm
Ground Plane	Wg	6.00mm
	Lg	6.00mm

3. Feeding Technique

In a radio antenna, the feed line refers to the cable or other transmission line that connects the antenna with the radio transmitter or receiver. In a transmitting antenna, it feeds the radio frequency (RF) current from the transmitter to the antenna, where it is radiated as radio waves. In a receiving antenna it transfers the tiny RF voltage induced in the antenna by the radio wave to the receiver. In order to carry RF current efficiently, feed lines are made of specialized types of cable called transmission line. Microstrip Patch antenna can be fed by a variety of methods[1]–[3].However, the methods can be classified into contacting and non-contacting methods. The most widely used types of feed line are coaxial cable, twin-lead, ladder line, and at microwave frequencies, waveguide. For this work, the co-axial cable method was adopted. The feed position was (1mm, 1.1mm) from the reference point indicated in Figure 1b. Its structure and equivalent circuit are presented in Figure 2 while the properties of the SMA connector used are as given in Table 2.A slot of radius 0.227mm was made on the ground plane about the pin of the coaxial cable with (1mm, 1mm) as its origin.

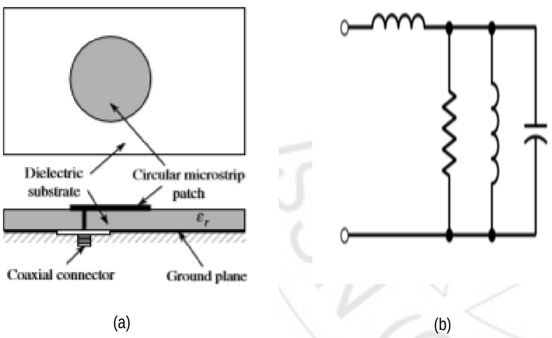


Figure 2: Coaxial Probe Feeding; (a) Structure (b) Equivalent Circuit[1]

Table 2: SMA Connector Properties

Parameter	Value
Inner Conductor Radius	0.167mm
Outer Coax Radius	0.565mm
Characteristic Impedance	29.5Ω
Cut-off Frequency	52.6GHz
Capacitance	85.4pF/ft.
Inductance	74.3nH/ft
Velocity of Propagation	40.3%

4. Simulation Results

The proposed square-shaped microstrip patch antenna was designed using ANSYS HFSS.Fig. 3 shows the measured reflection coefficients and antenna gains of the proposed antenna. It can be seen from the figure that the antenna has a 10-dB impedance bandwidths ($|S_{11}|$ < -10 dB) of 8.45% (27.2–29.6 GHz) with a center frequency of 28.3GHz. This adequately covers the proposed28GHz band. The proposed antenna is also shown to have a total realized gain of 5.56dB and 5.37dB at 27.2GHz and 29.6GHz respectively in the azimuthal (*x-y*) plane (θ = 0°), with the peak gain of 6.01dB at 28.3GHz.

Figure 4 shows the Voltage Standing Wave Ratio (VSWR) for the proposed antenna. The antenna has a VSWR of 1.89 at 27.2GHz and 1.91 at 29.6GHz. The minimum value is 1.02 at 28.3GHz. These are within the acceptable range of 1≤VSWR≤2.

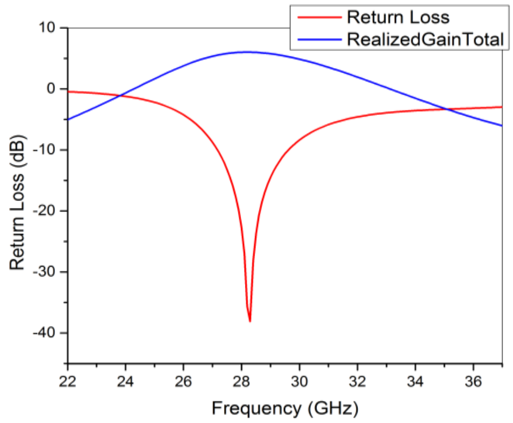


Figure 3: Return Loss and Gain

The radiation behavior of the proposed antenna is presented by Figures 5 and 6. With reference to the figure, broadside radiation pattern is observed. The difference between the co-polarization and the cross-polarization is around 5dB.

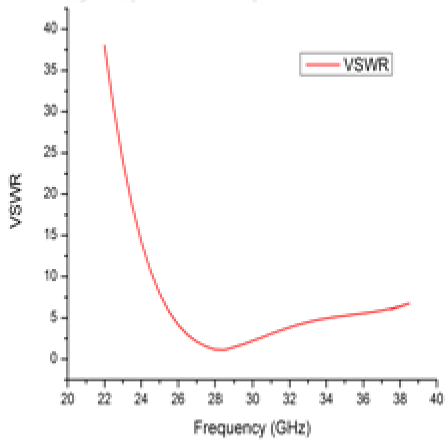


Figure 4: Voltage Standing Wave Ratio

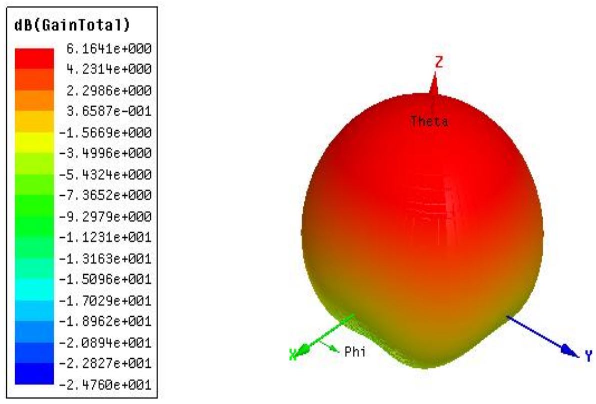
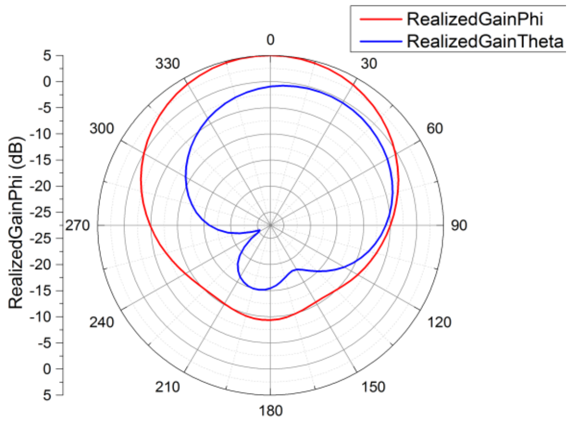
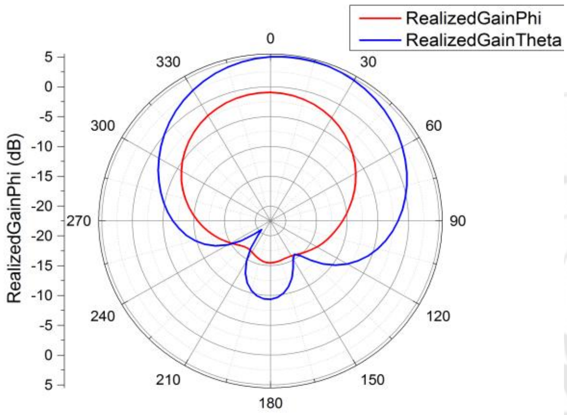


Figure 5: 3D Radiation Pattern of the proposed antenna at 28.3GHz



(a)



(b)

Figure 6: Radiation Pattern of the proposed antenna at 28.3GHz; (a) Phi=0º (b) Phi=90º

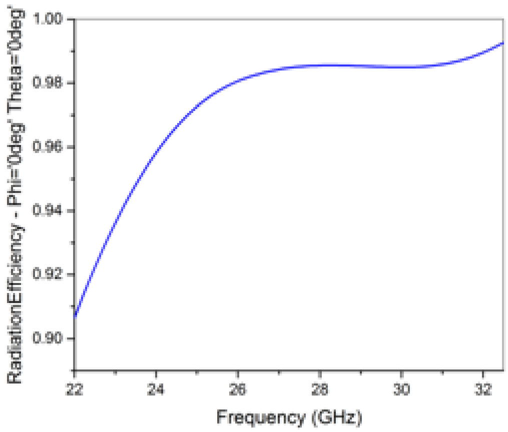


Figure 7: Radiation Efficiency

HFSS Simulations also computed the proposed antenna accepted power to be 0.65893W at the center frequency with a radiated power of 0.64418W, resulting in a radiation efficiency of 97.76% at the resonant frequency. The radiation efficiency over the frequency range is presented in Figure 7.

5. Applications

As evident from the results of the simulation, the antenna has a reasonable bandwidth that extends over the anticipated 28GHz band and a directional radiation pattern. The radiation efficiency and VSWR are also in good agreement with acceptable standards. It is therefore hoped that the proposed antenna will be applicable for use in 5G wireless communication devices.

6. Conclusion

In this research work, a square-shaped microstrip patch antenna fed through a 50Ω SMA connector was proposed and its performance was simulated using ANSYS HFSS software. The antenna resonates at 28.2GHz with a bandwidth of 8.82%, a return loss of -38.1dB at the resonant frequency and directional radiation pattern making it suitable for 5G mobile applications.

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