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Design of Smart Antenna by Circular Pin-Fed Linearly Polarized Patch Antenna

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Abstract

For the transmission of signals at higher frequencies, there is a requirement for extension of a higher capacity system and higher bandwidth in wireless communication systems. The use of smart antenna increases the system performance with the arrangements of its constituent elements and digital signal processing capacity. Analysis and design of smart antenna arrays can be performed for wireless communication systems using various methods and approaches. One of these methods is circular pin-fed linearly polarized patch antenna has been adopted in this research work.

This work presents the design and analysis of smart antenna by circular pin-fed linearly polarized patch antenna. Patch antenna is a very prominent antenna in the microwave frequency spectrum due to its simplicity and compatibility with the printed circuit board (PCB) technology.

Index Terms: Beamwidth; Path loss; Patch antenna; Signals; Smart Antenna; Wireless Communication.

1. Introduction

As the requirement for the increase in capacity of wireless communication is increasing, antennas with various efficiencies are needed in the various propagations of signal systems. Antennas are the crucial links sandwiched between the controlled signal and the atmosphere in wireless communication system. A circular pin-fed linearly polarized patch antenna is one of the promising antennas needed for the transmission of signals. It is a directional antenna adapted for determining and transmitting of signals in a specified direction, especially for radio broadcast and wireless communication systems due to the unique property of its radiation. To overcome these challenges, smart antenna is a favorable technique. Due to the capability to implement adaptive beamforming and interference suppression, smart antenna can considerably improve the system capacity and

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expand the area within the range of wireless network communication systems [1-6]. The consideration of smart antenna system using a uniform circular pin-fed linearly polarized patch antenna offers the advantages of light weight, low cost, planar or conformal, and ability of integration with the circuitry of signal processing and electronic system [7, 8]. Some of the parameters that determine the performance of the microstrip patch antenna are: dimension, low cost, light weight, frequency of operation, radiation efficiency, directivity, return loss; which is the loss of power in the signal by interruption in a communication line [9-12]. Therefore, patch antennas are exceptionally attractive to use in many applications.

Smart antenna system has attracted a global attention due to its digital signal processing features. One of the ways to approach these features is to design smart antenna by circular pin-fed polarized patch antenna array [13, 14]. Circular pin-fed polarized patch antenna has the ability to reduce the multi-path effects, and also pave a way for the transmission of data independently of the position of transmitter and receiver. This type of antenna is used in wireless communication systems for hand-held and portable applications such as the wireless local network (WLAN) [15, 16], the global positioning system (GPS) [8], and the radio frequency identification (RFID) [5]. When two orthogonal field components with equal amplitude but in phase quadrature are radiated, the antenna used in this kind of operation is said to be circularly polarized [17, 18].

For proper understanding of circular polarization, the concept of an electromagnetic wave is useful. Maxwell's equations can be approached in different ways but the easiest is that of a traveling electromagnetic wave [7]. The reason behind this is that the solutions to Maxwell's equations allow for the prospects of electromagnetic fields and magnetic fields which, while are orthogonal to each other, are both functions of sine and cosine in time with respect to a unit vector direction. Hence, the waves rotate as a function of time as well as travel in a unit vector direction.

A patch antenna is simply a rectangular piece of conducting material placed above a ground, similar to a microstrip [19]. The wavelength of radiation is determined by the length of the patch as the design antenna demonstrates a precise radiation array. The general radiation array switches when numerous antenna elements are joined in an array. This effect is due to the array factor [8]. The fig. 1 shows the diagram of a sample patch, in this case excited by an input microstrip. Circularity can be achieved in various ways [2, 3, 9]. One of these ways, for example, is to feed the antenna with two different lines, one phase shifted by 90^0 from the other. Another way is to perturb the dimensions of the patch [4-8]. The following equations have been used to describe the geometry of the proposed antenna and to determine the various parameters.

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_{eff}}} - 2\Delta L \tag{1}$$

Where c is the speed of light, L is the length of the radiating patch.

$$Z_0 = \frac{120\pi h}{W\sqrt{\varepsilon_{eff}}} \tag{2}$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{W}\right)^{-\frac{1}{2}}, \left(\frac{W}{h} \geq 1\right) \tag{3}$$

$$\Delta L = 0.412h\left(\frac{\varepsilon_{eff} + 0.3}{\varepsilon_{eff} - 0.258}\right)\frac{(W/h) + 0.264}{(W/h) + 0.8} \tag{4}$$

$$f_r = \frac{c}{2\sqrt{\varepsilon_{eff}}(L+2\Delta L)} \tag{5}$$

Where

$$(L+2\Delta L) = \frac{\lambda_g}{2} = \frac{\lambda_0}{2\sqrt{\varepsilon_{eff}}} \tag{6}$$

$$W = \frac{c}{2f_r}\left(\frac{\varepsilon_r+1}{2}\right)^{-\frac{1}{2}} \tag{7}$$

where W and ε_{eff} are the width of the radiating patch, and the effective relative permittivity, while f_r and ΔL are the operating frequency, and the fringe factor respectively [11-17]. The effective relative permittivity ε_{eff} of the substrate regulates the fringing field. To obtain a better antenna's radiation, the permittivity must be low so that a wider fringes can be achieved [20-23]. If the permittivity is decreased, the antenna's bandwidth and efficiency will be increased. Hence, antenna's impedance is directly proportional to permittivity.

For a linear array with a uniform excitation, the beamwidth is given as [24-28]

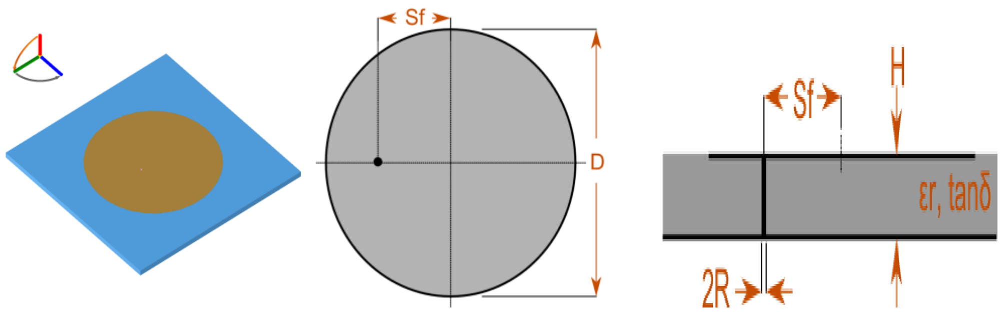
$$\theta_{3db} = \cos^{-1}\left[\sin(\theta_0) - 0.443\frac{\lambda_0}{l}\right] - \cos^{-1}\left[\sin(\theta_0) + 0.443\frac{\lambda_0}{l}\right] \tag{8}$$

where θ_0, $\lambda 0$ and l are the mean beam pointing angle, the free space wavelength and the total array length respectively.

The organization of the paper is as follows. The antenna design and its performances have been modelled in the Section II. The simulation of the antennas array has been observed at different frequencies of operation, mean beam pointing angle, free space wavelength and at the various angles of elevation in Section III. Finally, the Section IV concludes the work and recommends the future works.

2. Antenna Design and its Performance

The design and performance of the proposed antenna were strictly based on the equations stated in section one of this work that is from Equation (1) to Equation (8). The dimension of the model preview square patch is 550x550 mm^2. The horizontal and vertical distance among the patches have the same dimension. In order to support transmission of data at gigabits per second, Equation (5) has been used to calculate the frequencies at 1 GHz and 100 GHz. Using Equation (3), the effective relative permittivity ε_{eff} is $200\text{x}10^{-3}$. The electrical height of the substrate in the medium is 3λ. The height (H) is 5 mm, the substrate height as a percentage of wavelength in the medium is 60%. Increasing the substrate height will upsurge the bandwidth as the height *h* of the substrate also controls the bandwidth, but will the resonant frequency will be decreased. From Equation (7), the value of *W* is calculated for 1 GHz and 100 GHz. It has been discovered that the value of *W* reduces with increase in frequency. The fringe factor can be determined using Equation (4), the value remains the same for all operating frequency.



(a) (b) (c)

Fig. 1. The proposed model antenna design (a) Model preview, (b) Top view, and (c) Side view.

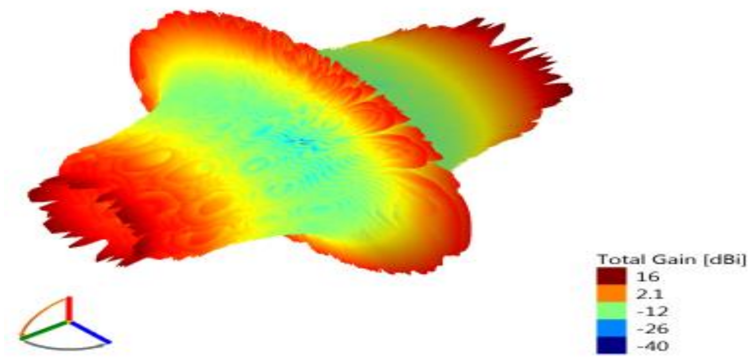


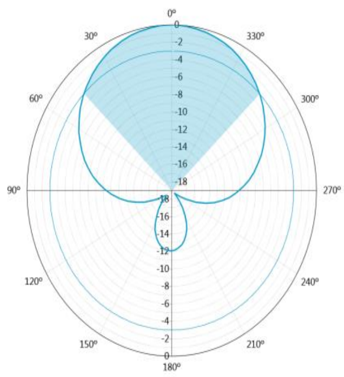
Fig.2. Typical total gain pattern at the centre frequency

Using the parameters above, the value of Z_0 with values obtained from Equations (3) and Equation (7). Fig. 2 shows the 3-dimensional view and the total gain pattern at the centre frequency.

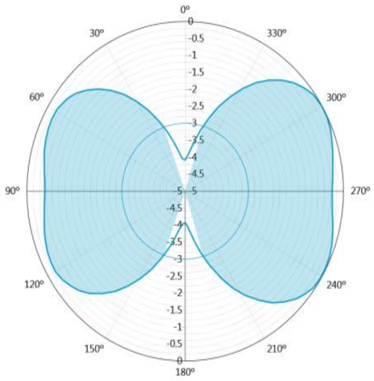
The substrate thickness is 100 µm and relative permittivity = 3.5. Tan delta δ is 11e-3, D is 1.8 mm, s_f is 339 µm and ε_r is 3.5. Frequency band between 1 and 100 GHz, R_{in} = 100 Ω. Derived quantities are: X = 1.8 mm, Y = 1.8 mm and Z = 100 µm. $H(\lambda_g)$ is $970e^{-3}\lambda$ and H is 97%. The loss tangent (δ) is $11x10^{-3}$. The pin-fed patch can be fed by using a circular hole in the substrate and ground plane, and bringing the centre conductor of a coaxial connector or cable into ohmic contact with the patch at an appropriate point.

3. Simulation Results of Antenna

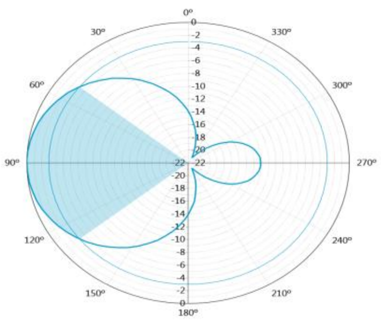
The simulated results for the antenna at 1 GHz and 100 GHz are shown in fig. 3 and fig. 4. Equation (8) has been used for the calculation of the beamwidth, and the simulated results from the calculation are shown in this section.



(a)



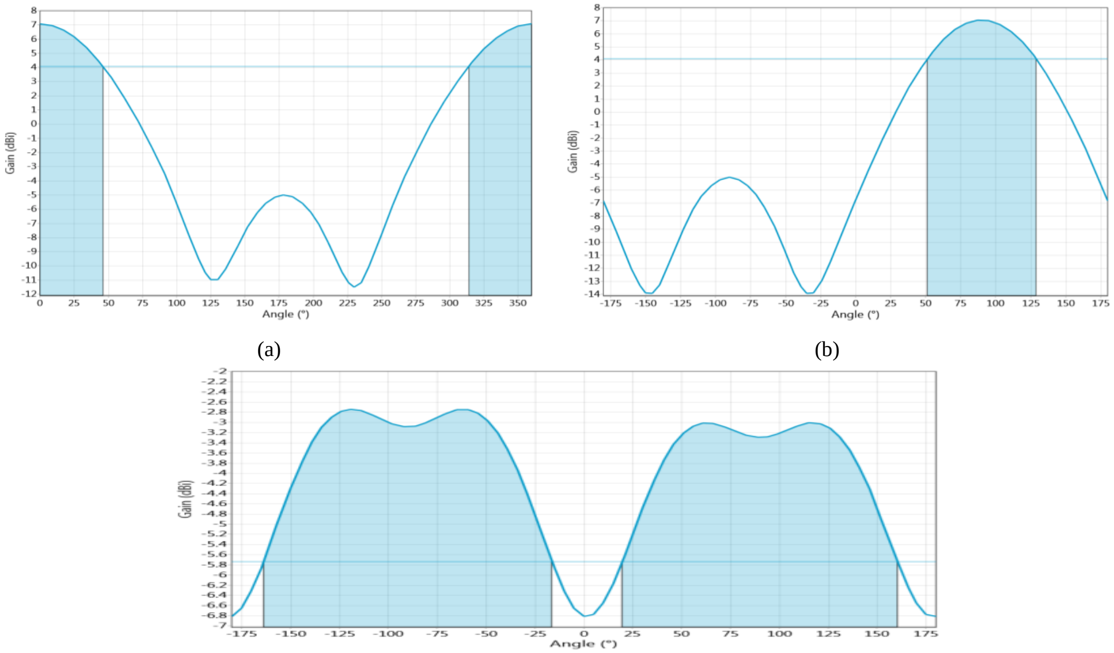
(b)



(c)

Fig.3. The polar radiation pattern measured along for (a) XY-Plane cut polar, (b) YZ-Plane cut polar, and (c) XZ-Plane cut at 1 GHz.

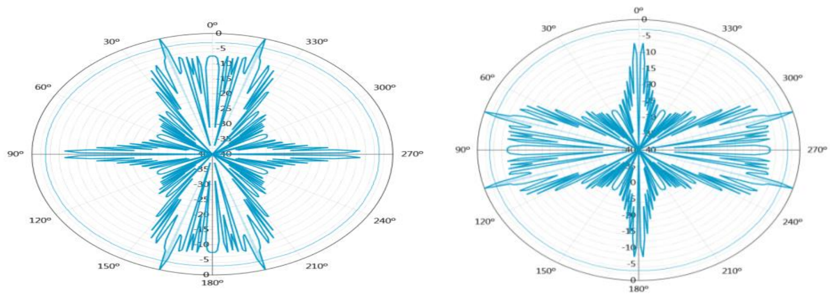
The polar radiation pattern shown in fig. 3 is really moderately easy to create using antenna arrays. The radiation pattern of the array depends on the individual patch element, feed network layout and spacing arrangement of the array. The feed network fed the individual antenna element's in the array. Feed network complexity can be determined by its ability to perform beam steering. The region about the direction of extreme radiation is the main beam. This is the area that is contained by 3 dB of the peak of the main beam in fig. 3(a). This region is concentrated at 90^0. The smaller beam that is away from the main beam is the sidelobe. The sidelobe is radiated in undesired direction and occur at 0^0. The angular separation in which the magnitude of the radiation pattern decreases from the peak of the main beam that is the half power beamwidth [18-22] is 0^0. Null-null beamwidth which is the angle that separated the magnitude of beam radiation pattern decreases to zero away from the main beam. Here, null-null beamwidth is (315^0 - 45^0) which equals 270^0. The sidelobe level (S_{ll}) which is the maximum level of the sidelobes away from the main radiation beam pattern is 7.1 dBi. In fig. 3(b), main beam occurs at 0^0, Main 3dB beamwidth (frequency) [$\varphi = 0^0$] = 78^0, -7.1 dBi at $\theta = 90^0$.



(a) (b)

(c)

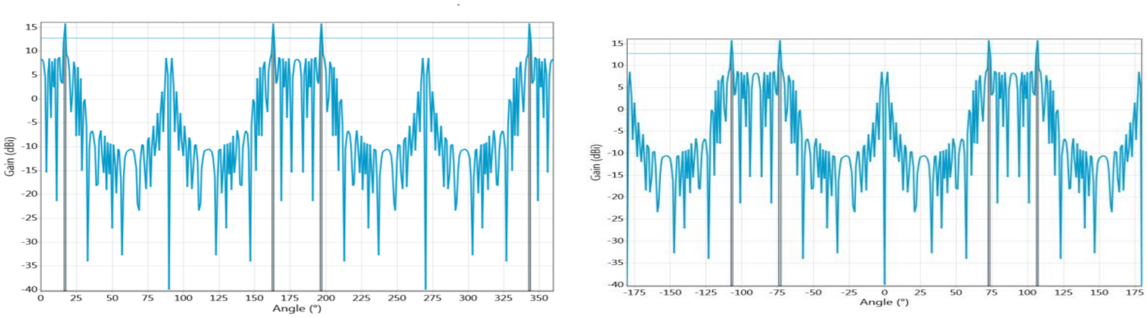
Fig.4. Polar plane cut at 1 GHz for (a) XY-Plane cut, (b) XZ-polar plane cut, and (c) YZ-polar plane cut.



(a) (b)

Fig.5. Cartesian plane cut at 100 GHz for (a) XY-polar plane cut, and (b) XZ-polar plane cut

The fig. 3(c), Peak gain at angle (frequency) [$\varphi = 90^0$], Main 3 dB beamwidth (frequency) [$\varphi = 90^0$] = 147^0, -2.7 dBi at $\theta = 120^0$. Fig. 4 shows the plane cut in polar form. The normalized radiation pattern in dB was computed against the H-plane E_θ, degrees. The measured – 3dB beamwidth in figure 4a are 0^0, 45^0, 320^0 and 355^0. In fig. 4(b), it occurs at 50^0 and 125^0. Fig. 4(c) has -3 dB beamwidth as -162.5^0, -12.5^0, 23^0 and 162.5^0 respectively. Figure 5 (a), the main 3dB beamwidth (frequency) [$\theta = 90^0$] = 1.2^0, 16 dBi at $\varphi = 163^0$. In figure 5 (b), Peak gain at angle (frequency) [$\varphi = 0^0$], Main 3 dB beamwidth (frequency) [$\varphi = 0^0$] = 1.2^0, 16 dBi at $\theta = -107^0$.



(a) (b)

Fig.6. Polar plane cut at 100 GHz

Figure 6 shows the beamwidth waveform. In (a), the highest gain occurs at 20^0, 160^0, 200^0 and 345^0. In (b) it occurs at -75^0, -90^0, 75^0 and 110^0.

The design of antenna using a circular pin-fed linearly polarized patch antenna can be used synthesize the needed radiation pattern [15-18], improve the antenna gain in which very high gain can be obtained with only a small number of feeders [19, 20].

4. Conclusion and Future Recommendations

This work examines the beam radiation pattern at various levels of frequencies and waveform beam for circular pin-fed linearly polarized patch antenna at their respective frequencies of operation. Circular pin-fed linearly polarized patch antenna is one of the chosen antennas for transmission and reception of signals due to its ability to mitigate interference and multipath signals. Circular pin-fed linearly polarized patch antenna can also be referred to as microstrip antennas. This is a popular antenna in the microwave frequency range. Antenna designer find it useful due to its simplicity and capability using circuit board technology. This circular pin-fed can also be referred to as circular polarization.

It is recommended in this research work that in order to achieve a radiation pattern that does not depend on distance for a certain limitation, planar array will be most suitable for the design. Optimization of the substrate and thickness and the aspect ratio of the driven patch may provide even wider bandwidth [29, 30]. In addition, optimization program can also be used so that the user can determine the lower and upper bound frequency for the bandwidth derivation.

Smart antenna using a circular pin-fed linearly polarized patch antenna can be used for frequency agility application and antenna diversity polarization. The polarization diversity has the benefits of frequency reuse for amplifying the system capacity and a great amount of polarization to enhance system performance. The application of this work can also be used to achieve re-configurability that give a better-quality effectiveness in receiving the wireless communication signal and have a unique capability of decreasing multipath fading [31-35].

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