Conversion of RF waves into Electrical Energy

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Abstract -- Over the past one decade, there is a rapid growth in the development of wireless communication applications. The performance of all such systems completely depends on the design of the antenna. Microstrip antennas are preferred for most of their applications. A low profile microstrip antenna with stable radiation pattern in a relatively wide band is presented for 5G operation. This paper presents a dual band rectangular microstrip patch antenna. This antenna is designed over an operating frequency of 3.48GHz (5G band) and 6.12GHz using the substrate material FR-4 which has a dielectric constant of 4.3. The design antenna can be used for 5G applications such as enhanced Mobile Broadband (eMBB), Massive 00machine type communication (IoT), Ultra reliable low latency communication. The designed antenna has low profile, low cost, easy fabrication and good isolation. The proposed antenna is designed for the purpose of aeronautical radio navigation and mobile satellite communication. The return loss of the proposed antenna is -26.26dB with a good total efficiency of -3.85dB. A prototype of the antenna was fabricated and achieved a good directivity gain of 3.21dBi with a VSWR of 1.1 at the resonant frequency. Experimental validation of technique is carried out and measured results were found to be comparable -with simulated results.

Keywords – Microstrip patch antenna, Operating frequency, and 5G applications, Return loss, Directivity Gain, VSWR

1. Introduction

Microstrip antennas are quite and an obvious choice for wireless devices because of its properties like low cost, easy fabrication, light and weight volume and a low profile configuration as compared to other bulky type of antennas. The size of the microstrip antenna is inversely proportional to its frequency. At frequencies lower than microwave, microstrip patches don't make sense because of the sizes required. Microstrip patch antennas are very simple in construction using a conventional microstrip fabrication technique. Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate (FR-4) that has a ground plane (Cu) on the other side. The dimension of the radiating patch is smaller as compared to the substrate and ground. There are several category of microstrip patch antenna can be cited some of the examples are a square radiating element, the circular, triangular and semicircular etc…but the most common is rectangular element. The patch antenna may be powered with many methods. The feeding techniques are categorized into two methods

- In category contacting, the feeding technique is powered by means of a connecting element such as a microstrip line into the radiating patch.
- Without contact category, a transfer of power between the microstrip line and radiating element is performed by means of electromagnetic filed coupling.

The most famous feeding techniques employed in the microstrip patch antenna are – coaxial probe, microstrip line and aperture or proximity coupling methods.

2. Related Works

A dual layer patch antenna on a FR4 substrate with 1.6mm substrate height at a resonant frequency 4.57GHz -4.71GHz is proposed in [1] with an array of six single elements to achieve return loss of -11dB and gain of 10dB. The authors have proposed an antenna of H shaped patch with circular slot at center of four elements using Duroid with a gain of 4.7dB .and FR4 with gain of 8.4dB. In [3], the authors have designed an antenna of multiband dual polarized slot radiating patch with dual feed and single layer patch using RT/duroid 5880 substrate to achieve return loss of -29 to -40dB. The above paper is exclusively designed for the GSM applications. In [4], a microstrip patch antenna of EBG(Electromagnetic Band Gap) structure used as a defected ground structure for 50% reduction in size. From the above paper, the substrate used was found to be RT/duroid to achieve the return loss of -40dBand gain of 4dB and multiband with five resonant frequencies. In [5], the authors have designed an antenna of dual band microstrip patch at the resonant frequencies of 2.45GHz and 5.25GHz which was fed by 50Ω coaxial probe. From the above paper, antenna is designed by used slot loading technique and short sheet loading technique and used FR4 epoxy substrate with U shaped slot. They have achieved return loss of -16.33dB at 2.45GHz and -12.66dB at 5.25GHz. A dual band microstrip patch antennaof L shaped slot is designed by using slot loading technique and short sheet loading technique at the resonant frequencies 1GHz and 2.48GHz in [6]. From the above paper, the authors have achieved the return loss of -32.28dB at 1 GHz and -14.48dB at 2.48GHz. An antenna with rectangular microstrip patches in log periodic way has been designed with proximity coupled to the microstrip feeding line in [7]. From the above paper, the authors used eleven elements for obtaining an ultrawide band of 2.26 – 6.85GHz. An antenna of microstrip patch with FR4 substrate which is used as a defected ground structure at the resonant frequency 7.94GHz which was fed by coaxial probe. From the above paper, the authors have achieved the return loss -81.25dB and gain of 8.5dB and the bandwidth was found to be too narrow for the resonant frequency.

3. Antenna Design

RECTANGULAR PATCH

The purpose of manufacturing a rectangular narrowband patch was to gain some of the insights to the patch design process. Based on the measurements acquired from the narrow rectangular antenna, the broadband antennaswere designed, especially to calculate the probe feed coordinates and the iterative process. The linearly polarized narrowband antenna was designed to operate at 3.6GHz with input impedance of 50 ohms, using FR_4 substrate.

The design strategy has been adopted to keep minimum return loss nearly at a resonant frequency of 3.48GHz. The proposed rectangular inset fed microstrip patch antenna design method and parameters calculation formulae are taken from [], [] and then optimized with the CST Studio Suite simulation tool.

Dielectric constant (ε_r) of the substrate is not a spare variable as if it depends on the dielectric material to be used. A wearable thin substrate of 4.3 dielectric constant and 1.6 mm height has been used for the proposed antenna. Several parameters are needed for the desire design, therefore with the dielectric constant and thickness of the substrate are set as constant values to provide impedance matching of the inset feed patch antenna.

As a design procedure, with a specified dielectric constant(ε_r), height (h) of the substrate and resonant frequency(f_r), the patch width (W) are calculated with the following formulae

Width

The radiating width of the patch is

$$W = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}} \qquad (3.5)$$

Where C = $3 \times 10^8 m/s$ (Free Space Velocity)

f_r= Resonant frequency.

ϵ_r= Dielectric constant of the substrate. The radiation efficiency of the patch antenna depends largely on the permittivity (ε_r) of the dielectric. Ideally, a thick substrate, low $\varepsilon_r$and low insertion Loss is preferred for broadband purpose and increased efficiency.

Length

The length of the patch determines the resonant frequency thus it is a critical factor because it is a narrowband patch. Since the fringing field cannot be accounted for accurately none of the result are definite. The length of the patch is calculating using:

$$L = \frac{c}{2f_r\sqrt{\epsilon_{eff}}} - 2\Delta_L \qquad (3.1)$$

For frequencies below 2 GHz, the variation in L with h is almost negligible.
This is a good approximation, as long as resonant frequency (f_r) is less than2 GHz.
The Δ_L is the length extension due to the fringing field and can be Calculate using the equation

$$\Delta_L = 0.412h\frac{(\epsilon_{eff}+0.3)(W/_h+0.264)}{(\epsilon_{eff}-0.258)(W/_h+0.8)} \qquad (3.2)$$

The effective dielectric constant is found using

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}[1+12\frac{h}{W}]^{-1/2} \qquad (3.3)$$

Where, h=height of the substrate
The effective length of the patch is

$$L_{eff} = L+2\Delta_L \qquad (3.4)$$

It is very important to measure inset feed length and inset width. Because, input impedance of the inset feed microstrip patch antenna depends in the inset length and to some extent on a inset width. With the variation on inset width produce changes in resonant frequency and with the variation of inset length produce changes in the return loss. Inset width should be more than half of the feed width (W). In the proposed design, inset width has taken as same as the microstrip feed width and inset feed length is optimized value. Feed width and inset feed length are calculated with the following formulae:

$$W_f = \frac{7.48\times h}{e^{(Z_0\frac{\sqrt{\varepsilon_r+1.41}}{87})}} - 1.25 \times t \qquad (3.5)$$

$$y_0 = \frac{L_P}{\pi}\cos^{-1}(\sqrt{\frac{Z_0}{R_{in}}}) \qquad (3.6)$$

Where,
W_f is the microstrip feed width
y_0 is the inset length
Z_0 is the input impedance
R_{in} is the input resistance

Ground plane width(W_g) and ground plane length(L_g) are calculated with the following formulas[2]:

$$W_g = 6h + W_p \qquad (3.7)$$
$$L_g = 6h + L_p \qquad (3.8)$$

The Designed measurement are given as follows:

Parameters	Dimensions
Design Frequencies(f_c)	3,5GHz
Dielectric Constant(ε_r)	4.3

Thickness of the Substrate(Hs)	1.6mm
Width of the Ground Plane(W_g)	30.12mm
Length of the Ground Plane(L_g)	37.6mm
Width of the Substrate(W_g)	30.12mm
Length of the Substrate(L_g)	37.6mm
Length of the Patch(L)	27mm
Width of the Patch(W)	2.52mm
Edge Feed Length()	10.4mm
Edge Feed Width(Wf)	8mm

4. Results and Discussion

Return Loss is an eminent method to characterize the input and output of antenna signal sources. It is also said that, when there is a mismatch in the load, then all the total available power from generator is not delivered to the load. This “loss” is termed as the return loss (RL) and is defined (in dB). The return loss obtained in this antenna is -26.26dB micro strip antenna. It is suitable for wide band operation. The resonation takes place at 3.48GHz the maximum. The resonation is also present throughout the frequencies 6.12GHz and 7.68GHz. The simulation results for the return loss is shown in Figure 4.1

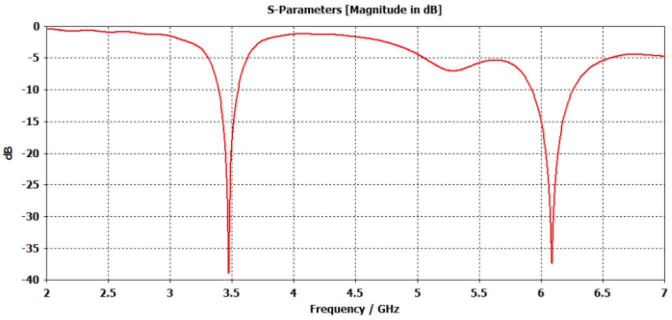
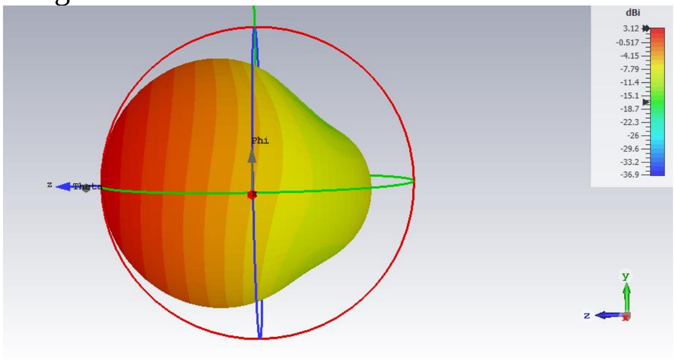


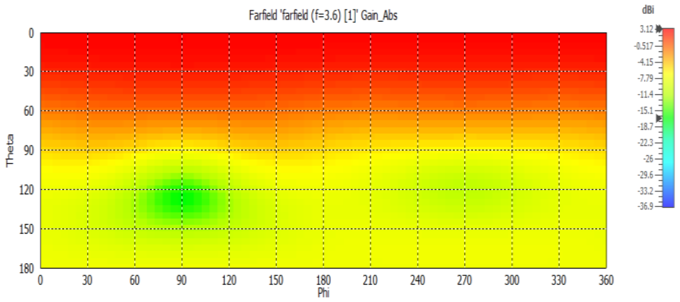
Figure 4.1 Simulation result of Return Loss

4.1 Radiation Pattern

The power radiated or received by an antenna is a function of the angular position and radial distance from the antenna. The radiation pattern is best represented in the form of a three dimension. The pattern is unidirectional in order to protect the human body from frequent radiations. The observed radiation pattern in shown in Figure 4.2



(a)



(b)

Figure 4.2.Radiation Pattern for the Designed Antenna in (a) 3D (b) 2D

4.2 Efficiency

The antenna efficiency is defined as the ratio of total power radiated by the antenna to the input power of the antenna. The antenna will also dissipate power due to conductor loss and dielectric loss. The simulation result for efficiency is shown in Figure 4.3

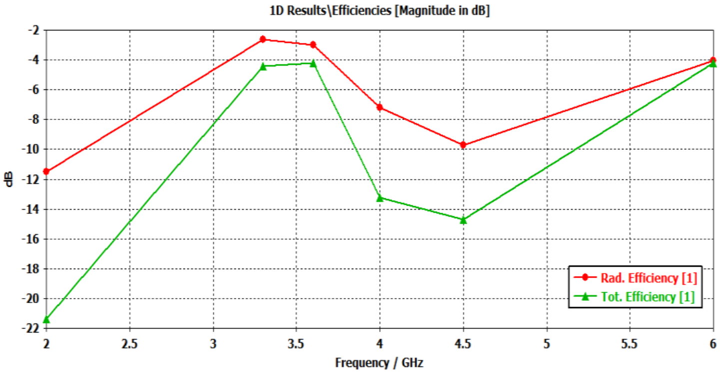


Figure 4.3 Simulation Results of Efficiency

4.3 VSWR

The VSWR is useful in determining the impedance matching of the loads and the characteristic impedance. Any mismatch in the impedance may cause standing waves. The VSWR is also used in the determination of the reflection coefficient. The simulated result is shown in Figure 4.4

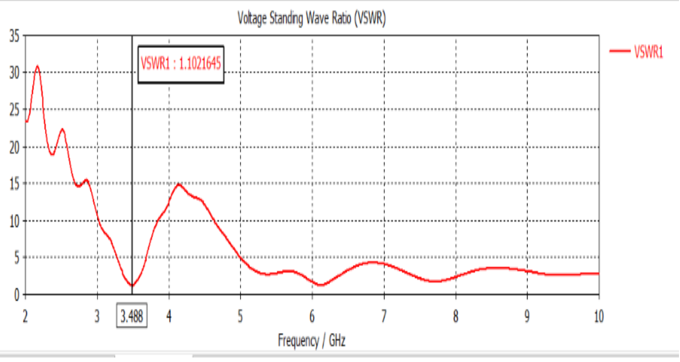


Figure 4.4 Simulation Results of VSWR

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