Octaband antenna for mobile applications

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Abstract: An octaband micro strip antenna is designed that integrates the current wireless technologies with some of the older and upcoming technologies of the mobile communication. It provides backward compatibility to the technologies like 2G, 3G. It operates in all the three Wi-Fi bands, the proposed 5G band at 3.3 to 3.4 GHz (lower 5G bands) and the Wi-Max band. It is designed with copper as the conductive material and FR-4 as the substrate. Defective ground structure (DGS) has been implemented to improve the return losses. This antenna radiates at 8 different frequencies which are: 2G (1.8 GHz), 3G (2.1 GHz), 4G (2.3 GHz), 5G (3.3GHz), Wi-Fi (2.4 GHz,5.0GHz,5.9 GHz), and Wi-Max (4.2 GHz).

Keywords: octaband; DGS; mobile communication

1. Introduction

Please follow the steps outlined below when submitting your final draft to the EnPress Publisher. These guidelines include complete descriptions of the fonts, spacing, and related information for producing your manuscript. Wireless communication is the paradigm of future. Several antennas have been proposed over the years to accommodate the changing technologies. Whenever a new generation in mobile technology arises a new antenna is developed to support the new frequency band. But some of these antennas are compatible with older technologies only to some extent. Also, these are designed with only a little future scope in mind. Micro strip antennas are becoming more popular due to their simple design, low cost, reliability, easy to embed and light weight. Numerous multi band patch antennas are used in mobile applications these days. The multi band antennas can radiate two or more frequencies at the same time using the same patch. But only one part of the antenna will be active for one frequency. Though the overall gain is less when compared to a single band antenna this antenna serves many purposes. Mainly multi band antennas are used to improve aesthetic value where many antennas can be replaced by a single antenna and for the ease of operation which cannot be obtained when using separate antennas for all the individual frequencies. Considering these points in mind an antenna which operates in eight frequencies have been proposed. This antenna has been designed with three ideas in mind. First is that present day antennas provide backward compatibility only to one earlier generation. But this antenna covers two earlier generations considering the current active generation is 4G LTE. 2G is also covered here to provide uninterrupted mobile communications. Even today some mobile operators in India like Idea provide 2G communication. Secondly, it does not receive all the three Wi-Fi bands centered at 2.4, 5 and 5.9 GHz. Many mobiles are compatible with 2.4 GHz and 5 GHz while some operate at only one of these two. 5.9 GHz is rarely used. Increasing the frequency increases the distance covered which in turn provides seamless connectivity to the internet. These three bands are operable by the same antenna since a large variety of mobiles are compatible at least with one of these frequencies at the same time covers larger distances. The final idea is to cover some of the upcoming wireless technologies like 5G and Wi-Max. Wi-Max provides wireless broadband communication over a larger area. This is better than the typical Wi-Fi hotspots.

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This can replace Wi-Fi well in the future. Also, the 5G band at 3.3 to 3.4 GHz is included. This lower 5G band has been proposed by the Government of India recently.

The software used to simulate this design is computer simulation technology (CST). The material used for substrate is FR-4 epoxy which has a thickness of 1.6mm. The conductive material used for patch and ground plane is copper. The antenna consists of 6 slots of which 4 slots are of equal dimensions. The type of feed used is the offset feed with the notch feed. A pattern like the patch has been etched up in the ground plane which forms a defective ground structure (DGS). DGS provides a filter like response. It is usually implemented to improve the return losses, add or remove some frequencies.

2. Antenna design

The antenna consists of a patch at the top, substrate in the middle, and a defective ground plane at the bottom. The dielectric constant of the substrate is 4.3. The total area of the antenna is 66.02 x 62.60-millimeter square.

2.1 Design anomalies

Initially an antenna which operates at the 1.8 GHz was designed. Later on this design has been modified procedurally by inserting slots to achieve multi band operation. The length and width of the antenna has not remained that of the original 1.8 GHz. They were modified to have the desired operation. Length of the patch has been reduced to shift the frequencies towards the lower frequency range. The width has been increased to have a symmetric design which showed some improvement in the return losses. Due to these modifications to the length and width the feed which was initially a center feed now became an offset feed. Additional notches have been included to the feed to have better performance. A total of 6 slots have been inserted in the patch. These slots have been inserted so as to achieve all the desired bands. The dimensions of some of the slots have also been changed in order to get better results.

3. Tables

The variables in the **Figure 1** and their corresponding values are given in the table below:

Parameters	(mm)
Lp	34.79
Wp	51.00
Lf	22.43
Wf	3.11
L	66.02
W	60.20

Table 1. Parameter values

Achieved bands	Return losses (dB)
1.7115 – 1.830	- 23.69
2.35 – 2.42	- 18.58
5.07 – 5.95	- 10.20 to - 21.86
2.03 – 2.06	- 10.76
2.289 – 2.35	- 15.61
2.950 – 3.40	- 11.50
4.02 – 4.21	- 24.29

Table 2. Return losses at desired bands

From the Table 1, it can be seen that the substrate and the ground extends 4.8mm (6h/2) beyond the combined length and width of the patch and the feed. For a coaxial type of feed the length and width of the ground plane would be (Lp+6h) and (Wp+6h) respectively (h = height of the substrate, here = 1.6mm). But this cannot be applied here due to the length of the feed. The fringing fields below the patch extend not more 6h away from the actual length and width. For this reason the length x width of the substrate or ground plane is taken as 66.02 x 62.60 – millimeter square.

It can be seen from Table 2 that the return losses are less than -10dB for our desired bands. The return loss at Wi-Max band is the lowest (-24.29dB) and the return loss at 5 GHz is the highest (-10.20dB).

Achieved bands	VSWR
1.7115 – 1.830	1.197
2.35 – 2.42	1.318
5.07 – 5.95	1.584
2.03 – 2.06	1.823
2.289 – 2.35	1.401
2.950 – 3.40	1.743
4.02 – 4.21	1.227

Table 3. VSWR values at desired bands

Table 3 shows that the achieved values are in agreement with the actual values.

4. Figures

The basic dimensions of the antenna like width and length of the patch, substrate and feed have been marked.

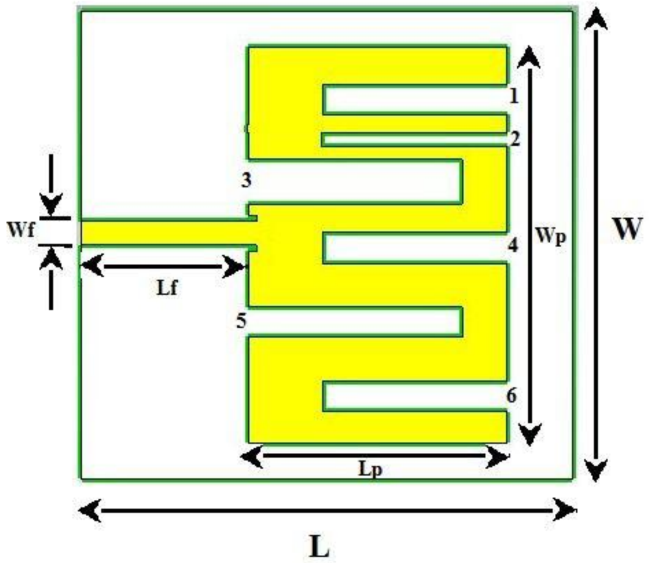

Figure 1. The patch and the feed

Figure 1 shows the length and width of the patch, feed and the substrate or ground.

Now the dimensions of the slots have been marked on the patch and its figure is given below:

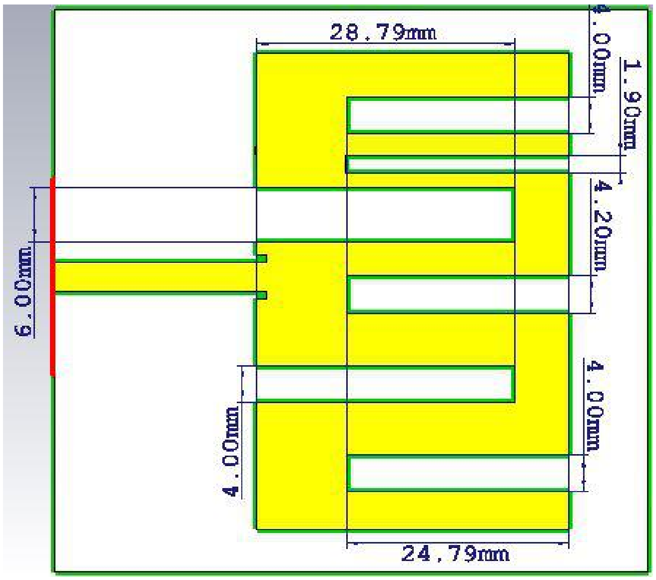

Figure 2. Slot dimensions

From **Figure 2** it can be seen that the slots 1, 5 and 6 (refer **Figure 1** for slot numbering) are of equal dimensions. The width of the center slot has been increased by 0.2mm to have the Wi-Max frequency near to the desired value (4.2 GHz). The 6th slot has been inserted between the 1st and the 2nd slot to achieve the 4G LTE frequency at 2.3 GHz. Also the width of the 3rd slot has been increased by 2mm along the downward direction to have better performance in some of the bands. The 1st slot and the 3rd slot affect 3 frequencies dominantly. Likewise the bottommost two slots affect 3 frequencies dominantly. The center and the 2nd slot affects one frequency dominantly each. The ground plane of this design is shown in the below figure:

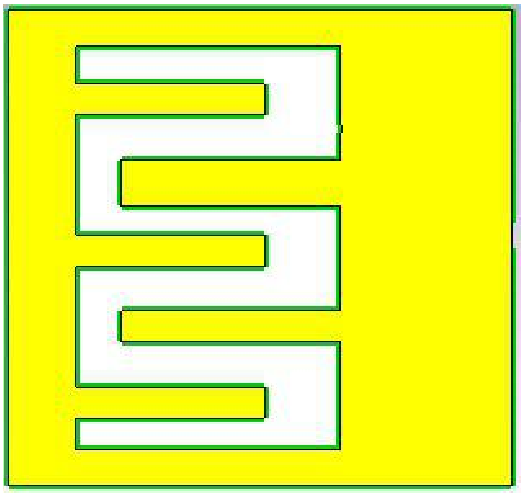

Figure 3. Ground plane with DGS

The ground plane has a defective structure as shown in **Figure 3.** Its pattern is similar to that of the patch but with the difference that only 5 slots (except the 2nd slot) is present and they are of equal dimensions.

Return loss at the frequencies 1.8 GHz, 2.1 GHz, 2.3 GHz, 2.4 GHz, 3.3 GHz, 4.2 GHz and 5.2 to 5.9 GHz are marked in the figure below:

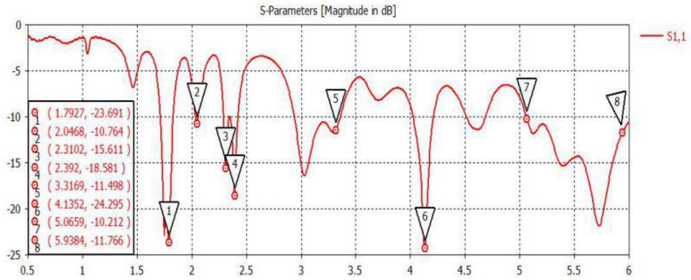

Figure 4. S11 parameter plot

The results obtained as shown in **Figure 4** are simulated with -80dB accuracy. While fabricating and testing this antenna it will yield similar results.

Voltage standing wave ratio tells how much voltage gets reflected. A lower VSWR means more power is getting radiated and less amount of power is getting reflected back to the port. Typical values of VSWR are less than 2 for the needed frequencies.

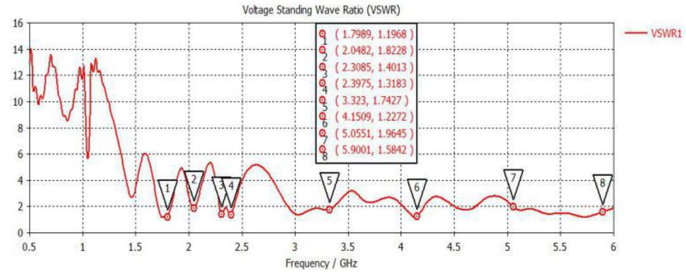

Figure 5. VSWR plot

Figure 5 shows the VSWR plot and the curve is marked for values at the needed frequencies. The bands and their respective VSWR values can be seen from Table 3.

The radiation pattern is useful in analyzing the direction in which the antenna radiates. It helps to find the direction of maximum radiation, major and minor lobe levels and the gain of the radiation in different directions. The direction of maximum radiation is shown by red color. The minimum gain has never fallen below 4.23dB.

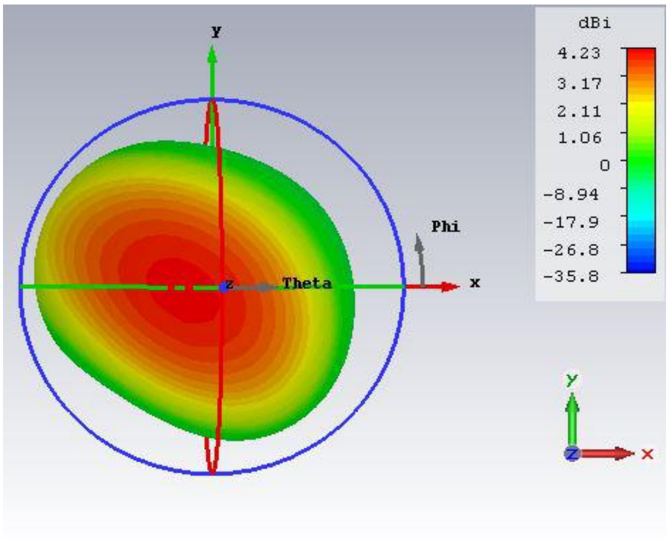

Figure 6. Radiation pattern for 1.8 GHz

From **Figure 6** it can be seen that the radiation for 1.8 GHz takes place along the direction normal to the patch. The radiation pattern looks somewhat like a balloon. The gain along the maximum direction is 4.23dB.

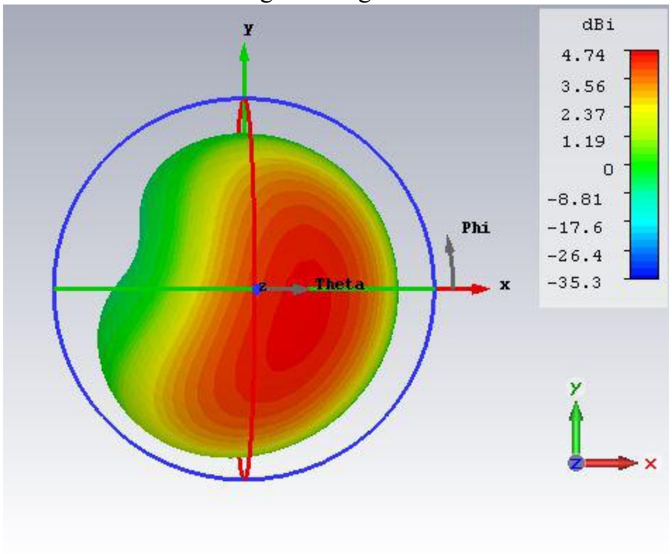

Figure 7. Radiation pattern for 2.1 GHz

Figure 7 shows that the radiation for 2.1 GHz takes place very near to the normal direction of the patch. The gain along the maximum direction is 4.74dB.

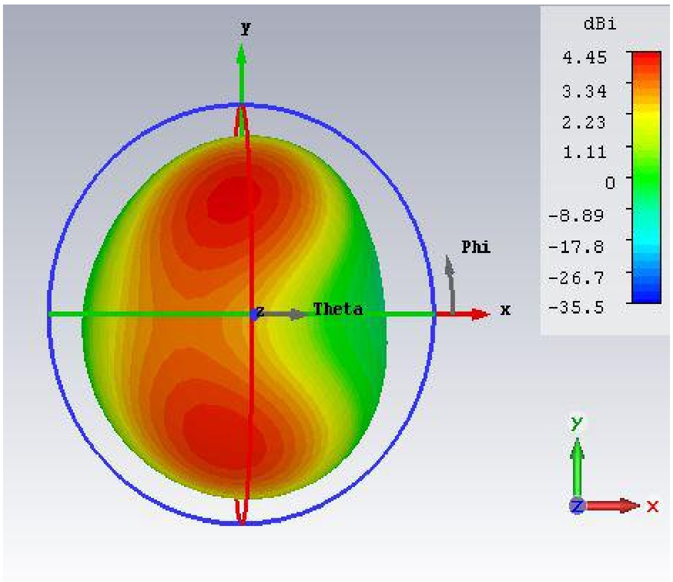

Figure 8. Radiation pattern for 2.3 GHz

The maximum radiation for 2.3 GHz is bidirectional in nature. The directions of maximum radiation are slightly deviated away from the normal. The gain along the maximum direction side is 4.45dB which can be seen from **Figure 8.**

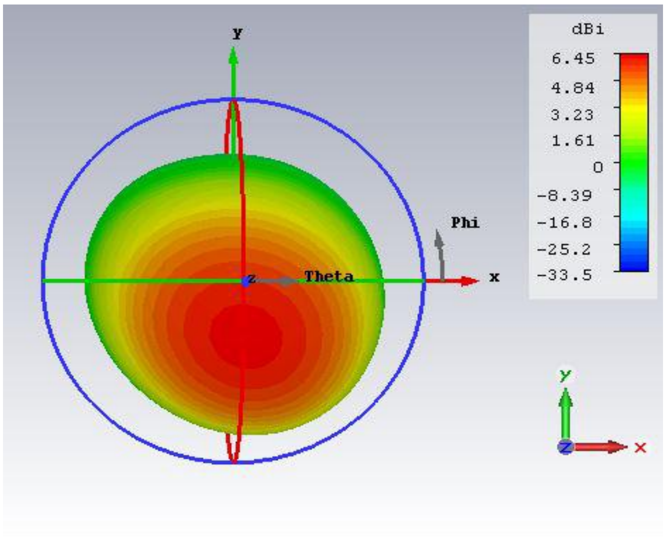

Figure 9. Radiation pattern for 2.4 GHz

From **Figure 9** it can be seen that the direction of maximum radiation occurs very close to the normal direction. The gain along the maximum direction is 6.45dB. Out of the 8 desired frequencies this frequency has the highest gain.

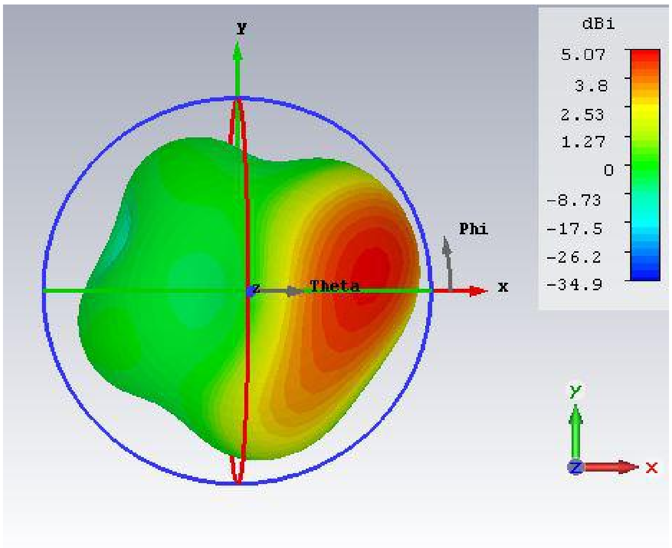

Figure 10. Radiation pattern for 3.3 GHz

The direction of maximum radiation occurs deviated from the normal direction as **Figure 10** shows. The gain along the maximum direction is 5.07dB. Practically an omnidirectional antenna is needed to radiate in all directions. The radiations patterns achieved here are omnidirectional in nature but the maximum radiation occurs in one or more directions. The gain in other directions varies from 3.8dB to 1.27dB mostly.

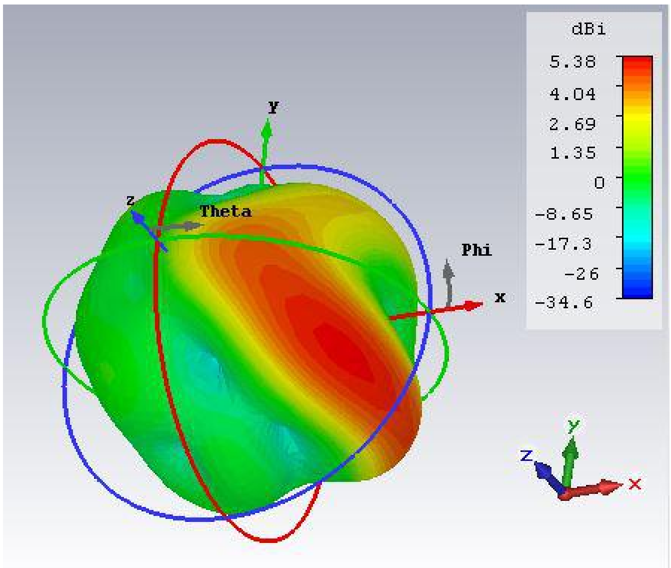

Figure 11. Radiation pattern for 4.2 GHz

Figure 11 shows that this antenna radiates more in a direction too much deviated away from the normal. It radiates almost at 45 degrees away from the normal. The gain along the maximum direction is 5.38dB.

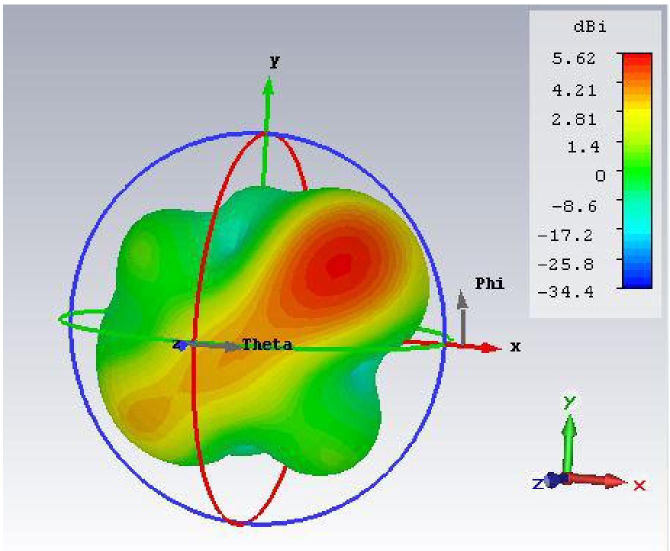

Figure 12. Radiation pattern for 5 GHz

Figure 12 shows that the direction of maximum radiation occurs somewhere around 60 degrees away from the normal. The gain in the direction of maximum radiation is 5.62dB.

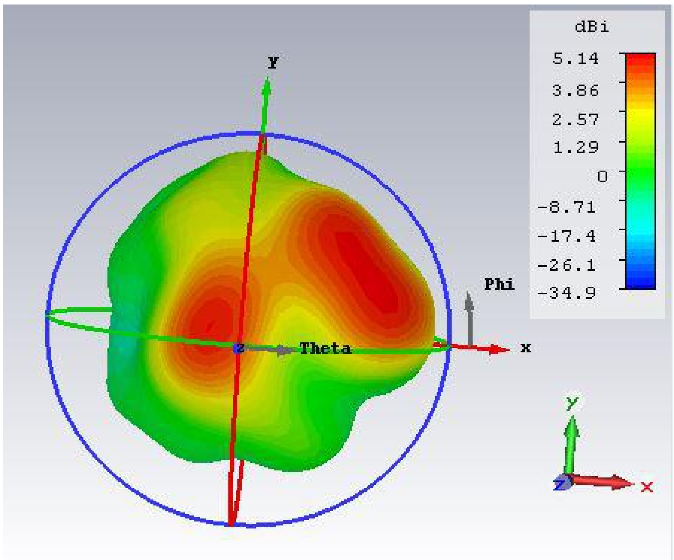

Figure 13. Radiation pattern for 5.9 GHz

From **Figure 13** it can be seen that the direction of maximum radiation occurs in the normal direction as well as away from the normal. The gain in the maximum direction is 5.14dB.

5. Equations

The width of the patch is given by,

$$Width = \frac{c}{2f_o\sqrt{\frac{\varepsilon_R+1}{2}}} \tag{1}$$

The length of the patch antenna is given by,

$$Length = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}\right) \tag{2}$$

The effective dielectric constant is given by,

$$\varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \frac{\varepsilon_R-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right] \tag{3}$$

Where

c = velocity of light

f_0 = desired frequency

h = height of substrate

W = width of the patch

ε_R and ε_r = dielectric constant of substrate

ε_{eff} = effective dielectric constant (due to fringing fields)

Equations (1), (2) and (3) give the formulas for calculating the length, width and effective dielectric constant respectively. The effective dielectric constant is calculated because the fringing fields below the patch extends somewhat away from the length and width calculated using (1) and (2). So the design length and width are different from the calculated values.

Author Contributions

Rajarajan.K and Sudarsanan.S conceived the idea, designed the antenna, simulated the results and fabricated the structure.

Conflict of Interest

No conflict of interest was reported by the authors.

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