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Design of a 22 Ghz Rectangular Microstrip Patch Antenna

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Abstract: The aim of this work was to design a rectangular microstrip patch antenna that will be used for signal transmission and/or reception at the frequency of 22 GHz. The design was done using five different values of a dielectric constant, εr; 3.1, 3.2, 3.3, 3.4, 3.5, respectively. The results showfive different antennas with different heights, width, length, and the feed distances, or havingdifferent dimensions were designed from change in the values of the dielectric constants of the substrate at the same frequency of 22 GHz. It was concluded that at constant frequency, the height, width, length and the feed distances of a rectangular microstrip patch antenna is inversely proportional to the value of the dielectric constant of the substrate, and it can be seen in; at the εr of 3.2 value, the length of the patch, L, is 3.75 mm, the width, W, 4.70 mm, the height, h, is 0.364 mm, the ground length, Lg, is 5.94 mm, the ground width, Wg, is 6.89 mm, the feed distance along X-axis, Xf is 1.10 mm, the feed distance along Y-axis, Yf is 2.35 mm, and at the εr of 3.5 value, the length of the patch, L, is 3.59 mm, the width, W, is 4.55 mm, the height, h, is 0.348 mm, the ground length, Lg, is 5.68 mm, the ground width, Wg, is 6.63 mm, the feed distance along X-axis, Xf is 1.01 mm, the feed distance along Y-axis, Yf is 2.27 mm. Future work was recommended on how the varying values of a dielectric constant affects the dimension of other types of patch antenna like the circular one.

Keyword: *Antenna, Communication, Length, Microstrip, Satellite.*

I. INTRODUCTION

An antenna is a device that transmits and/or receives electromagnetic waves. Most antennas are resonant devices, which operate efficiently over a relatively narrow frequency band (Ahmed, 2011). Microstrip antennas consists of patch, substrate, ground plane and feeding point. It is simple to construct and are mostly used in the microwave frequency range (Atser*et al.*, 2013).

Microstrip patch antenna has several applications in aerospace or satellite communications that require antenna structure to be lightweight, has low profile, and ease of manufacturing or low cost. Other advantages of Microstrip patch antenna flexibility and conformability to mounting devices, thus, it is fit for high-speed moving objects such as satellites, various space aircraft, rockets, and missiles (Li et al., 2017).

The basic antenna geometry comprises of a dielectric substrate sandwiched between the ground and radiating patch. The substrate, besides providing mechanical strength to the overall antenna design, also allows surface waves to propagate through it (Suvadeep, 2014).

The microstrip Ultra Wideband antennas is one of the most commonly used antennas in radar applications. It has attracted a lot of attention because of their advantages such as ease of fabrication simple structure, easy integration with microwave integrated circuits (Houda, 2016). In Wireless transmission technology, a microstrip patch antenna is the most popular, especially in microwave systems because of their attractive features such as small in size, light weight and easy to fabricate (Mahmud, et al., 2018).

The microstrip patch antenna is an essential component of wireless communication and consists of a ground plane, dielectric substrate, and a thin copper metallic patch. The rectangular and circular shapes are the most frequently employed shapes for microstrip patch antennas (*Rishitha, 2023*).

The choice of substrate thickness brings effect on bandwidth and radiation efficiency, while substrate permittivity affects transmission efficiency and circuit miniaturization (Teguh, *et al.*, 2021).

The design carried out in this work is different from the previous works reviewed so in the course of the work.

II. SOME OPERATIONAL TERMS

2.1. **Frequency of operation:** This is the frequency at which the antenna receives and/or transmits signals.

2.2 Dielectric substrate: A substrate is a semiconductor used as basis for an integrated circuit or electronic component. A dielectric substrate is a substrate that does not conduct direct current and therefore used as insulator.

2.3 Height of the patch antenna: The height can be selected before calculating the operating frequency of the antenna, or the operating frequency can be used to find the height, or both can be selected before the design but must meet the condition given as (Huang and Kevin, 2008);

$$\frac{h}{\lambda} \leq \frac{0.3}{2\pi\sqrt{\varepsilon_r}} \qquad (1)$$

III. ANTENNA DESIGN METHOD

The method used for the design is mathematical method. Various parameters of the antenna are determined using mathematical equations as shown below.

3.1 Calculation of the height (H) of the patch: The height of the patch is calculated using the formula (Huang and Kevin, 2008);

$$H = \frac{0.3C}{2\Pi F_o \sqrt{\varepsilon_r}} \quad (2)$$

Where C = Speed of light, given as 3.0 x 108m/s,

ε_r = The dielectric substrate, which varies from 2.0 to 4.0 in this design and analysis.

The height, H is in millimetres (mm)

3.2. Calculation of the width (W) of the patch: The width of the patch is calculated using the formula give as (Huang and Kevin, 2008);

$$W = \frac{C}{2F_o\sqrt{\frac{(\varepsilon_r + 1)}{2}}} \quad (3)$$

The width, W is in millimetres (mm)

3.3. Calculation of the effective dielectric constant (ε_{eff}):

It is calculated using the mathematical relation given as (Huang and Kevin, 2008);

$$\varepsilon_{eff} = \frac{(\varepsilon_r + 1)}{2} + \frac{(\varepsilon_r - 1)}{2}\left(1 + \frac{1}{\sqrt{1 + 12\left(\frac{H}{W}\right)}}\right) \quad (4)$$

Or, equivalently,

$$\varepsilon_{eff} = \frac{(\varepsilon_r + 1)}{2} + \frac{(\varepsilon_r - 1)}{2}\left(1 + 12\left(\frac{H}{W}\right)\right)^{-0.5} \quad (5)$$

H and W are the height and the width of the patch in that other.

3.4. Calculation of the effective length of the patch (Leff): The effective length of the patch is given by the formula (Huang and Kevin, 2008);

$$L_{eff} = \frac{C}{2F_o\sqrt{\varepsilon_{eff}}} \quad (6)$$

3.5 Calculation of the length extension (ΔL): Length extension is the additional length at the end of the patch as a result of the fringing field along its width. It is calculated using the formula given as (Huang and Kevin, 2008);

$$\Delta L = 0.412H\left[\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{H} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{H} + 0.8\right)}\right] \quad (7)$$

Where ΔL is the patch length extension in millimetre, H and W are the height and width of the patch respectively, and ε_{eff} is the effective dielectric constant of the substrate, and is dimensionless.

3.6. Calculation of the actual length (L) of the patch: The actual length of the patch, L is the difference between the effective length and twice of the length extension of the patch. It is represented mathematically as (Huang and Kevin, 2008);

$$L = L_{eff} - 2\Delta L \quad (8)$$

3.7. Calculation of the ground plane dimensions: The ground plane dimensions are calculated for the length and the width. The ground plane length and width dimensions are more than the length and width in that order by six times thickness or height of the patch. They are calculated using the formula given as (Huang and Kevin, 2008);

$$L_g = L + 6H \quad (9)$$

$$W_g = W + 6H \quad (10)$$

L and W, are the length and the width of the patch antenna accordingly.

3.8 Calculation of feed point: The point of location of feed to the patch antenna can be located in x-y coordinates as Xf,Yf. The formulas for calculating the feed point locations are given as (Huang and Kevin, 2008);

$$X_f = \frac{L}{2\sqrt{\varepsilon_{eff}}} \quad (11)$$

$$y_f = \frac{w}{2} \quad (12)$$

Where XF and Y fare the feed point location along X-Y coordinates.

IV. RESULTS AND DISCUSSION

Table 1 shows the designed features of a rectangular microstrip patch antenna at a frequency of resonant of 22 GHz, which is in K band frequency range. The table shows the Width, W (mm) of the patch antenna, Length, L (mm) of the patch antenna, height, h(mm) of the substrate or the dielectric material. Also, the length of the ground plane of the substrate as Lg (mm), the width of the ground plane as Wg(mm), the distance of the point of feed which is the connection of the coaxial cable to the end along the X-axis as Xf(mm), while the distance of the point of feed which is the connection of the coaxial cable to the end along the Y-axis as Yf(mm). The design was carried out using variable values of the dielectric constant (εr) beginning from 3.1, 3.2, 3.3, 3.4, and 3.5. In all these variations or changing of the constants of the dielectric, the design frequency of operation was kept constant.

F (GHz)	er	h (mm)	W (mm)	L (mm)	Lg	Wg	Xf (mm)	Yf (mm)
22	3.1	0.370	4.76	3.81	6.03	6.98	1.14	2.38
22	3.2	0.364	4.70	3.75	5.94	6.89	1.10	2.35
22	3.3	0.358	4.65	3.70	5.85	6.80	1.07	2.32
22	3.4	0.353	4.60	3.64	5.76	6.72	1.04	2.30
22	3.5	0.348	4.55	3.59	5.68	6.63	1.01	2.27

From the results, it is shown that at the frequency of 22 GHz and the dielectric constant of 3.1, the height of the patch is 0.370 mm. Also, at the εr of 3.1 value, the length of the patch, L, is 3.81 mm, the width, W, 4.76 mm, the ground length, Lg, is 6.03 mm, the ground width, Wg, is 6.98 mm, the feed distance along X-axis, Xf is 1.14 mm, the feed distance along Y-axis, Yf is 2.38 mm.

At the εr of 3.2 value, the length of the patch, L, is 3.75 mm, the width, W, 4.70 mm, the height, h, is 0.364 mm, the ground length, Lg, is 5.94 mm, the ground width, Wg, is 6.89 mm, the feed distance along X-axis, Xf is 1.10 mm, the feed distance along Y-axis, Yf is 2.35 mm.

At the εr of 3.3 value, the length of the patch, L, is 3.70 mm, the width, W, 4.65 mm, the height, h, is 0.358 mm, the ground length, Lg, is 5.85 mm, the ground width, Wg, is 6.80 mm, the feed distance along X-axis, Xf is 1.07 mm, the feed distance along Y-axis, Yf is 2.32 mm.

At the εr of 3.4 value, the length of the patch, L, is 3.64 mm, the width, W, 4.60 mm, the height, h, is 0.353 mm, the ground length, Lg, is 5.76 mm, the ground width, Wg, is 6.72 mm, the feed distance along X-axis, Xf is 1.04 mm, the feed distance along Y-axis, Yf is 2.30 mm.

At the εr of 3.5 value, the length of the patch, L, is 3.59 mm, the width, W, 4.55 mm, the height, h, is 0.348 mm, the ground length, Lg, is 5.68 mm, the ground width, Wg, is 6.63 mm, the feed distance along X-axis, Xf is 1.01 mm, the feed distance along Y-axis, Yf is 2.27 mm.

In other words, at the operating frequency of 22 GHz, five different antennas have been designed from various values of dielectric constants. This shows that at varying values of the dielectric constant,as the frequency remains constant, different microstrip antenna of different design parameters or sizes can be made, as demonstrated in the table 1.0. In addition, it can be observed from the result that as the dielectric constant increases in values, the height, patch length and width, the ground length and width, decrease in values. In a simple term, it means that the size of the dimension of a rectangular microstrip patch antenna is indirectly proportional to the value of the dielectric constant of the substrate, provided the frequency remains constant.

CONCLUSION

The design of a rectangular microstrip patch antenna, using computational method has been achieved in this work. The results show the parameters of five different rectangular microstrip patch antennas designed to operate at the frequency of 22 GHz. The five different antennas have different heights, width, length, and the feed distances, and these different dimensions or sizes were as a result of the change in the values of the dielectric constants of the substrate. It can be concluded that different sizes of a rectangular microstrip patch antenna can be designed to be used for the same frequency of operation when the values of the dielectric substrate are altered. It can also be concluded that at constant frequency, the height, width, length and the feed distances of a rectangular microstrip patch antenna is inversely proportional to the value of the dielectric constant of the substrate. This is seen as follows:

At the εr of 3.2 value, the length of the patch, L, is 3.75 mm, the width, W, 4.70 mm, the height, h, is 0.364 mm, the ground length, Lg, is 5.94 mm, the ground width, Wg, is 6.89 mm, the feed distance along X-axis, Xf is 1.10 mm, the feed distance along Y-axis, Yf is 2.35 mm, and at the εr of 3.5 value, the length of the patch, L, is 3.59 mm, the width, W, 4.55 mm, the height, h, is 0.348 mm, the ground length, Lg, is 5.68 mm, the ground width, Wg, is 6.63 mm, the feed distance along X-axis, Xf is 1.01 mm, the feed distance along Y-axis, Yf is 2.27 mm. The increase in the values of the dielectric constant from 3.2 to 3.5 saw the decrease in the designed antenna parameters at 3.5 value of εr.

Recommendation

Future work is recommended on how the varying values of a dielectric constant affect the dimension of other types of patch antenna like the circular one.

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