# DESIGN AND ANALYSIS OF A RECTANGULAR MICROSTRIP PATCH ANTENNA FOR VARIOUS FREQUENCY BANDS

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**Abstract*:*** The aim of this work is to design a rectangular microstrip patch antenna using a transmission line model. The design was carried out using different frequencies of operation and dielectric constant. The selected frequencies were bands – L (1.6 GHz), S-band (3.5 GHz), C band (7 GHz), X band (10 GHz), and Ku-band (15 GHz). The dielectric constant and the frequency were varied at a separate time to determine the parameters of the designed antennas. Finally, the values of the frequency and the dielectric constant were varied at the same time while the length, width, height, and other parameters were determined. It was observed from the results that the size of the antenna reduces as the frequency increases. It was also observed that the bandwidth of a patch antenna depends on the value of the dielectric constant. It is concluded that a patch antenna with a lower dielectric constant performs better than that with a higher dielectric constant. This result will be useful to antenna designers on the appropriate parameters to use to enable an antenna to function efficiently when designing an antenna. It will also aid satellite communication Engineers, communication Engineers, and radio scientists on the appropriate type of antenna to use in various wireless communication technologies especially when space and weights are important factors to consider.

***Keywords:*** Antenna, Bandwidth, Efficiency, Length, Wireless technology.

## 1.0 Introduction

Over these few years, cellular communication trends are in constant changes, beginning from the first generation (1G) to the fifth generation (5G) (Bala *et al.*, 2021). 5G is a high-frequency technology and has many advantages, especially in 5G radio networks due to limited inter-cell interference, low transmission latency, as well as improved security (Ayalew and Asmare, 2022). An antenna is an electrical device used for receiving and/or transmitting electromagnetic wave signals.

Several applications in aerospace or satellite communications require antenna structures to be lightweight, has a low profile, and have ease of manufacturing as well as low cost. This is where the use of a microstrip patch antenna comes to play (Ibrahim and Jebur, 2020 and Teguh *et al.*, 2021). Also, the use of microstrip patch antennas has become more common in some technologies like portable wireless communication, the internet of things, and biomedical systems (Anooradha, *et al.*, 2009).

Microstrip antennas are simple, lightweight, low cost, and easily compatible with different circuit board technologies, and that is why they are used in numerous microwave frequency technologies(Pozar and Schauber, 1998, Li, *et al.*, 2017, . Sohel *et al.*, 2022, Maruf, 2012). Microstrip patch antennas are used in various applications or areas presently mostly as a result of their versatility in terms of possible geometries that make them applicable to many different situations (Hasan, *et al.,* 2013).

A microstrip patch antenna is used for high-speed moving objects such as satellites, various space aircraft, rockets, and missiles (Li, *et al.*, 2017). Microstrip patch antenna consists of a conducting path having either non-planar or planar geometry (Singh, et al., 2018). Microstrip antennas, in general, can be categorized as Microstrip traveling antenna, printed dipole antenna, and microstrip patch antenna (Singal, *et al.*, 2020). The patch of microstrip antenna structure is usually formed on the top patch layer with the shape in various forms, but in general, the basic shape of the patch is square, circular, rectangular, square, elliptical, triangular, and dipole shapes (Colaco and Lohani, 2020, Teguh *et al*., 2021).

In designing a microstrip patch antenna, the radiation pattern is considered to be normal to the patch for a given configuration, and the length L of the rectangular patch is always within the range of $\lambda o/3< L < \lambda o/2$, given that λo, is the wavelength (Ahmed, *et al.*, 2011). Microstrip antenna is light and has a simple structure making it suitable for mobile communications applications. In addition, it also finds applications in aircraft, satellites, and missile systems, though it has a setback of narrower operating bandwidth and lower gain (Singal, et al., 2020).

The basic components of the patch antenna are the substrate, patch, feeding part, and ground plane. As stated, the patch which radiates is on the substrate, while the substrate "sits" on the ground plane. According to (Bala *et al.*, 2021), Microstrip patch antenna is a type of antenna that has a radiating patch on one side of the dielectric substrate, and a ground plane on the other side, with a substrate material in between such that it is used to provide mechanical support, and also, used to maintain the needed precision spacing between the patch element and its ground plane. The basic antenna geometry of a microstrip antenna comprises a dielectric substrate that is sandwiched between the ground and radiating patch. The substrate provides mechanical strength to the overall antenna design, and also enables surface waves to propagate through it (Richards, 1982).

Though some similar works have been done previously, this work looks into a critical analysis of the relationship between the frequency, dielectric material constant, and bandwidth, along with the antenna size. Also, this works makes use of the transmission line model method of microstrip patch antenna design.

## 2.0. Theory and Design procedure

A microstrip patch antenna can be designed when the frequency and dielectric constant are known or selected. This will then be used to calculate the height of the substrate of the antenna. This was the mode applied in this work.

### 2.1. Design procedure of a rectangular microstrip patch antenna

The design model used in this work is the transmission line model. It involves the step-by-step analysis or computation as shown in equations (1) – (11).

A. Computation of the height (h): This is the height of the dielectric substrate upon which the metallic patch is placed. It is computed using the speed of light, operation frequency, and the dielectric constant value. Height of the dielectric substrate of a microstrip antenna is calculated using the formula given as (Balanis, 2005);

$$h = \frac{0.3C}{2\pi f\sqrt{\varepsilon_r}} \qquad (1)$$

where C = speed of light (3.0 x $10^8$m/s), $\varepsilon_r$ = the dielectric substrate, *f* is the frequency of operation.

**B. Computation of the width (W) of the patch:** The width of the patch is one of the sides of the patch antenna. It is calculated using the speed of light, operation frequency and the dielectric constant. Its formula is given as (Balanis, 2005);

$$w = \frac{c}{2f\sqrt{\frac{(\varepsilon_r+1)}{2}}} \qquad (2)$$

**C. Computation of the effective dielectric constant ($\varepsilon_{eff}$):** While the dielectric constant of a material is the ratio of the electric permeability of a material to the electric permeability of a free space, the effective dielectric constant is the function of the ratio of the width to the height as well as the dielectric constant. It depends on the transmission line geometry. The effective dielectric constant is calculated using the formula given as (James and Hall, 1989);

$$\varepsilon_{eff} = \frac{(\varepsilon_r+1)}{2} + \frac{(\varepsilon_r-1)}{2}\left(1+\frac{1}{\sqrt{1+12\left(\frac{h}{w}\right)}}\right) \qquad (3)$$

where *h* and *w* are the height and the width of the patch in that order. The effective dielectric constant is always less than the dielectric constant itself because of fringe effect.

**D. Computation of the effective length of the patch (*L*$_{eff}$):** The effective length of the patch antenna is the sum of the actual length of the antenna and the extended length or the fringe effects. It is computed with the formula given as (Balanis, 2005):

$$L_{eff} = \frac{C}{2f\sqrt{\varepsilon_{eff}}} \qquad (4)$$

**E. Computation of the length extension ($\Delta$L):** Length extension is the extra length at the end of the patch which is caused by the fringing field along its width. It is computed by the formula given as (Balanis, 2005);

$$\Delta L = 0.412h\left[\frac{(\varepsilon_{eff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{w}{h}+0.8\right)}\right] \qquad (5)$$

where $\varepsilon_{eff}$ is the effective dielectric constant of the substrate. $\Delta L$ is the patch length extension, *h* and *w* are the height and width of the patch respectively.

**F. Computation 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 (Balanis, 2005);

$$L = L_{eff} - 2\Delta L \qquad (6)$$

**G. Computation 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. The two parameters are calculated using the formula (Balanis, 2005);

$$L_g = L + 6h \qquad (7)$$

$$W_g = w + 6h \qquad (8)$$

where $L$ and $w$, are the length and the width of the patch antenna respectively.

**H. Computation of feed point:** The point of fixing the antenna feed to the patch antenna is located in x-y coordinates as $X_f, Y_f$. In this design, coaxial-probe feeding technique is used. This feeding scheme has the advantages of free and desired placement location in order to match with the input impedance (James and Hall, 1989). The formulas for calculating the feed point locations are given as (Balanis, 2005);

$$X_f = \frac{L}{2\sqrt{\varepsilon_{eff}}} \qquad (9)$$

$$y_f = \frac{w}{2} \qquad (10)$$

where $X_F$ and $Y_f$ are the feed point location along X-Y coordinates.

**I. Computation of bandwidth:** The bandwidth of an antenna is “the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard,” (Balanis, 2005). In percentage, bandwidth of a square or rectangular microstrip patch antenna is calculated by the formula given as:

$$BW\,\% = 3.77\left[\frac{(\varepsilon_r - 1)}{{\varepsilon_r}^2}\right]\left[\frac{w}{L}\right]\left(\frac{h}{\lambda}\right) \text{x}\,100 \qquad (11)$$

## 2.2 Method

The design was carried out using different frequencies of operation and dielectric constant. The frequencies were mostly from various frequency bands – L (1.6 GHz), S-band (3.5 GHz), C band (7 GHz), X band (10 GHz), and Ku-band (15 GHz). With this, the length, width, and height as well as other parameters of the antenna were determined at a steady value of the dielectric constant. Also, in the other stage of the design, the value of the dielectric constant was varied (increased) while the frequency value was kept constant. The length, width, and height as well as other parameters such as bandwidth at these various dielectric values were determined.

Finally, in the design process, the values of the frequency and the dielectric constant were varied while the length, width, height, and other parameters were determined. The summary of the results was represented in tables and graphs.

## 3.0 Results and discussion

Table 1.0 shows the designed parameters of a rectangular microstrip antenna at a uniform dielectric constant value of 3.2 and varying frequencies, table 2.0 shows the designed parameters of a rectangular microstrip antenna at a varying dielectric constant and a uniform frequency of 7.0 x 106 m/s, and table 3.0 shows the designed parameters of a rectangular microstrip antenna at a varying dielectric constant and a varying frequency respectively. The results (Table 1.0) show the dimensions- lengths (*L*), widths (*w*), and heights (*h*) of the antenna as well as the ground length (*Lg*) and the ground width (*Wg*). Fig. 1.0 represents the parameters of the microstrip patch antenna that will operate at the frequencies of 1.6 (L band)), 3.5 (S-band), 7.0 (c band), 10.0 (X band), and 15.0 GHz (Ku band). From the results, it was discovered that as the frequency was increasing, the size of the antenna (L, w, and h) was decreasing. This implies that at a higher frequency band; the size of the antenna reduces. The same trend is experienced in Tables 2.0 and 3.0 in which the frequency remains constant at 7 GHz but the dielectric constant values increased (table 2.0), and the values of both the frequency and dielectric constant changed (increased) from one value to another (table 2.0). Although, there was a reduction in the size of the antenna designed as the frequency and /or the dielectric constant increased from one value to the other, the change or reduction in the size of the designed patch antennas was most pronounced when it was as a result of a change in frequency than what was observed when it was caused by the change in dielectric constant. For instance, in table 1.0, at a constant dielectric value of 3.2, and the frequency changed from 1.6 GHz to 3.5 GHz, the length and width of the designed patch antenna changed from 51.59 mm to 23.58 mm, and 64.69 mm to 29.57 mm. The height also decreased from 5.00 mm to 2.29 mm. The change in frequency of the operation of the antenna resulted in a decrement by more than half of the initial L, w, and h. In the case of change in dielectric constant (3.2 to 3.4) as the frequency remained unchanged at 7 GHz, the change in the L, w, and h, are from 11.79 mm to 11.45 mm for L, 14.79 mm to 14.45 for w, and 1.14 mm to 1.11 for h, respectively.

Table 1.0: Designed parameters of a rectangular microstrip antenna at a uniform dielectric constant value of 3.2 and varying frequency

| $\varepsilon_r$ | **f (GHz)** | **h (mm)** | **W (mm)** | **L (mm)** | **$L_g$ (mm)** | **$W_g$ (mm)** | $X_f$ **(mm)** | $Y_f$ **(mm)** | **BW (%)** |
|---|---|---|---|---|---|---|---|---|---|
| 3.2 | 1.6 | 5.00 | 64.69 | 51.59 | 81.61 | 94.72 | 15.17 | 32.35 | 2.71 |
| 3.2 | 3.5 | 2.29 | 29.57 | 23.58 | 37.31 | 43.30 | 6.93 | 14.79 | 2.71 |
| 3.2 | 7 | 1.14 | 14.79 | 11.79 | 18.65 | 21.65 | 3.47 | 7.39 | 2.71 |
| 3.2 | 10 | 0.80 | 10.35 | 8.25 | 13.06 | 15.15 | 2.43 | 5.18 | 2.71 |
| 3.2 | 15 | 0.53 | 6.90 | 5.50 | 8.70 | 10.10 | 1.62 | 3.45 | 2.71 |

From this example, it can be seen that the change in the size of the antenna experienced due to frequency change is higher than the change experienced due to the change in the dielectric constant. But from the design in which both the frequency and the dielectric constants were varied, the change in the size of the designed antenna was greater than when it was only done at varying dielectric constants but less than when it was designed at a varying frequency. As the frequency changed from 7 GHz to 10 GHz and the dielectric constant changed from 3.2 to 3.4, the L, w, and h, changed 11.79 mm, 14.79 mm, and 1.14 mm to 8.01 mm, 10.11 mm, and 0.78 mm in that order (Table 3.0).

Table 2.0: Designed parameters of a rectangular microstrip antenna at a varying dielectric constant and a uniform frequency of 7.0 x $10^6$ m/s

| $\varepsilon_r$ | F (GHz) | h (mm) | W (mm) | L (mm) | $L_g$ (mm) | $W_g$ (mm) | $X_f$ (mm) | $Y_f$ (mm) | BW (%) |
|---|---|---|---|---|---|---|---|---|---|
| 3.2 | 7 | 1.14 | 14.79 | 11.79 | 18.65 | 21.65 | 3.47 | 7.39 | 2.71 |
| 3.4 | 7 | 1.11 | 14.45 | 11.45 | 18.10 | 21.10 | 3.27 | 7.22 | 2.56 |
| 3.6 | 7 | 1.08 | 14.13 | 11.13 | 17.60 | 20.60 | 3.09 | 7.06 | 2.42 |
| 3.8 | 7 | 1.05 | 13.83 | 10.84 | 17.13 | 20.13 | 2.93 | 6.92 | 2.29 |
| 4 | 7 | 1.02 | 13.55 | 10.56 | 16.70 | 19.69 | 2.79 | 6.78 | 2.16 |

Table 3.0: Designed parameters of a rectangular microstrip antenna at a varying dielectric constant and a varying frequency

| $\varepsilon_r$ | F (GHz) | h (mm) | W (mm) | L (mm) | $L_g$ (mm) | $W_g$ (mm) | $X_f$ (mm) | $Y_f$ (mm) | BW (%) |
|---|---|---|---|---|---|---|---|---|---|
| 3.2 | 7 | 1.14 | 14.79 | 11.79 | 18.65 | 21.65 | 3.47 | 7.39 | 2.71 |
| 3.4 | 10 | 0.78 | 10.11 | 8.01 | 12.67 | 14.77 | 2.29 | 5.06 | 2.56 |
| 3.6 | 13 | 0.58 | 7.61 | 5.99 | 9.48 | 11.09 | 1.66 | 3.80 | 2.42 |
| 3.8 | 16 | 0.46 | 6.05 | 4.74 | 7.50 | 8.81 | 1.28 | 3.03 | 2.29 |
| 4 | 20 | 0.36 | 4.74 | 3.70 | 5.85 | 6.89 | 0.98 | 2.37 | 2.16 |

Figs. 1.0 – 3.0 show the graphical representations of the Frequency, Bandwidth, and dielectric constant at; varying frequency and uniform dielectric constant, at a uniform frequency and varying

dielectric constant, and a varying frequency and varying dielectric constant. It can be observed from fig.1.0 that as the frequency of operation increases and the constant dielectric value remained unchanged, the bandwidth of the designed antennas remained constant irrespective of the change in the size of the antenna. This means that at a constant dielectric value, the change in frequency does not increase or decrease the bandwidth of the antenna designed. In fig.2.0, it is observed that while the frequency remains constant, and the dielectric value changes, it resulted in a change in the bandwidth, in such a way that an increase in the value of the dielectric constant at a constant value of frequency resulted in the decrease in a bandwidth of the antenna as its trend line slopes downward while that of dielectric constant slopes upward.

In fig. 3.0, as the frequency and the dielectric constant slope upward (increase), the bandwidth also increases. But one thing that is peculiar in this is that even as the varied parameters in fig. 3 were frequency and dielectric constant, while the only varied parameter in fig. 2 was the dielectric constant, the change in bandwidth in fig. 2.0 is the same change in fig. 3.0. This means that the frequency change does not contribute to any change in fig 3. This implies that the bandwidth of a rectangular microstrip patch antenna depends only on the value of the dielectric constant and not the frequency. In addition, an antenna with a lower dielectric constant value will have higher bandwidth than the one designed with a higher value of a dielectric constant. In other words, the microstrip patch antenna with a lower dielectric value or permittivity has more efficiency or performs better than the one with a higher dielectric constant value. This conforms with the works by (Roy, et al, 2013, Choudhury, 2014), in their separate works on – the “Effect of Dielectric Permittivity and Height on a Microstrip-Fed Rectangular Patch Antenna” and “Effect of dielectric constant on the design of rectangular microstrip antenna”. The results of both works revealed that with an increase in dielectric constant, the bandwidth of the microstrip antenna decreases; leading to greater losses, and less efficient.

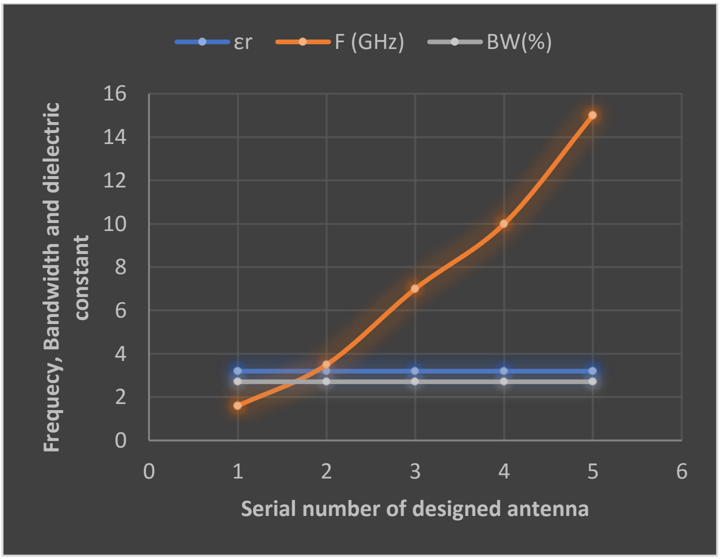

Fig.1.0: Graphical representation of frequency, Bandwidth and dielectric constant at varying frequency and uniform dielectric constant

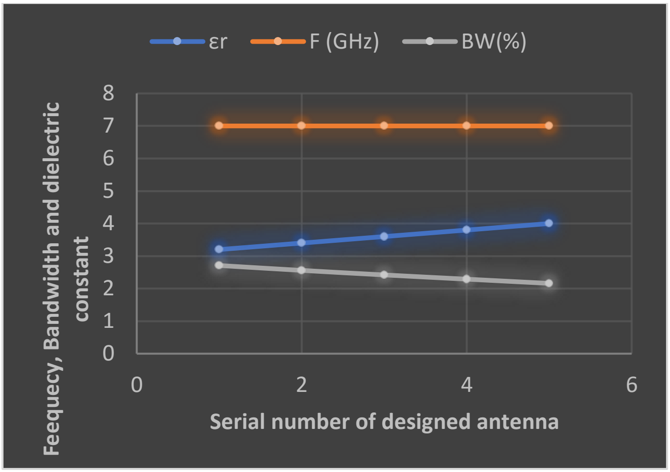

Fig. 2.0: Graphical representation of frequency, Bandwidth and dielectric constant at a uniform frequency and varying dielectric constant

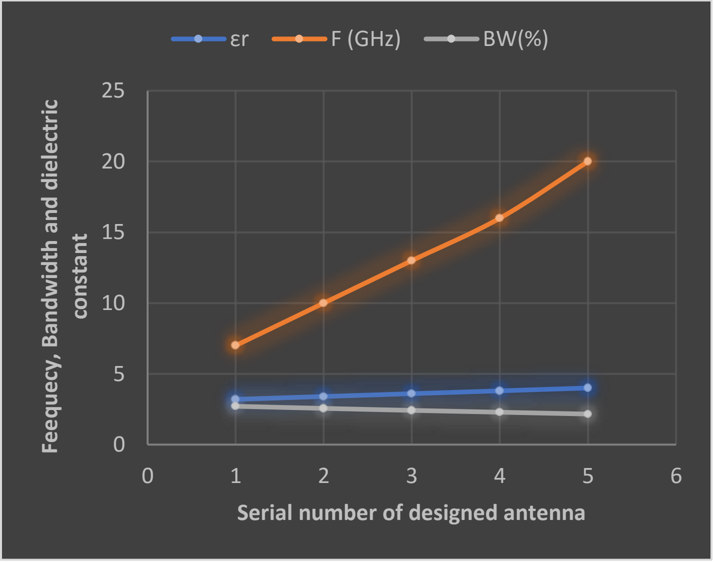

Fig. 3.0: Graphical representation of frequency, Bandwidth and dielectric constant at a varying frequency and varying dielectric constant

## 4.0 Conclusion

The design of various rectangular microstrip patch antenna has been carried out to be used at various frequencies and dielectric constant values. It was observed from the result that the size or dimension of the antenna reduces as the frequency increases. From the result, it can be concluded that the bandwidth of a patch antenna is dependent on the value of the dielectric constant or permittivity, and that the bandwidth of the antenna is indirectly proportional to the dielectric constant. It can also be concluded that a patch antenna with a lower dielectric constant has higher efficiency, and performs better than that of a higher dielectric constant. This result will guide antenna designers on the appropriate parameters to use to enable an antenna to function efficiently when designing an antenna. It will also guide satellite communication Engineers, communication Engineers, and radio scientists on the appropriate type of antenna to use in various wireless communication technologies especially when space and weights are important factors to consider.

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