Design of A 4.5 GHz Rectangular Microstrip Patch Antenna

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Abstract: Micrsostrip antennas are mainly used for high frequency signal transmissions and/or receptions in order that the antenna will be small in size. The aim of this work is to design an antenna that can be used in small-sized devices such as mobile phones, radios, wireless computers and which will operate at the frequency of 4.5 GHz.

The dielectric substrate, RT DUROID 5888 of dielectric constant 2.6 was used for the design, and the dimension of the antenna was obtained using analytical (mathematical) processes as height of 1.97 mm, width of 24.85 mm and length of 19.7 mm. This was done using transmission line method of microstrip patch antenna design. The feed point location (X_f, Y_f) was found along the point along the X-Y coordinates where the impedance is nearly 50Ω to be 6.4 mm and 12.43 mm respectively. The points were found using coaxial feed method.

Keywords: *Microstrip, Dielectric substrate, Feed point location, Transmission line method.*

I. INTRODUCTION

An antenna is a device for receiving and/or transmitting electromagnetic waves signals. It is used to send and/or receive signals in communication devices. As a result of the daily improvement in technology especially in the area of communication devices such as cell phone, radio sets, laptops with wireless connection, etc, there is need for the design of a small size type of antenna that will allow such size.

Microstrip antennas are becoming very widespread within the mobile phone market. Patch antennas are low cost, have a low profile and are easily fabricated. Micro strip antennas find many applications as they are low profile, light weight, conformable to surface and inexpensive to manufacture using printed-circuit technology (Mohamed *et al,. 2015*).

There are three methods for designing microstrip antennas which are; transmission model method, cavity model method and full wave model method, but the one used in this work is transmission line model method. This work gives the step-by-step analysis in the design of rectangular microstrip patch antenna. There are other forms of microstrip antennas, such as circular, square, triangular, E-shape. Microstrip patch antenna has the advantages of simple to manufacture or fabricate, low cost, easy to form a large array and has light weight. However, it has some setbacks such as low gain and low bandwidth, but can be compensated using a thick substrate with low dielectric constants.

II. SOME BASIC PARAMETERS FOR THE ANTENNA DESIGN

A. 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. The value of dielectric constant reduces with the height of the patch antenna. The dielectric constant ε_r is defined as the ratio of permittivity of a substance to the permittivity of free space. This design makes use of a substrate; RT DUROID 5880 with dielectric constant of 2.6

B. Frequency of operation

This is the frequency at which the antenna receives and/or transmits signals. It can be calculated when the height of the patch is known or can be selected before the design. The operating frequency used in this design is 4.5GHz which is within the C-Band frequency range. Operating frequency is represented by the symbol F_c or F_o .

C. 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;

$$\frac{h}{\lambda} \leq \frac{0.3}{2\pi\sqrt{\varepsilon_r}} \quad \text{---------------------------- 1}$$

The parameters in the equation will be explained in the next steps.

III. ANTENNA DESIGN PROCEDURE

When the frequency, (F_O) in which the antenna will operate as well as the dielectric constant of the substrate are selected, the following steps can be taken.

A. Determination of the height (H) of the patch

The height of the patch is calculated using the formula;

$$H = \frac{0.3C}{2\Pi F_o\sqrt{\varepsilon_r}} \quad \text{-------------------- 2}$$

Where C = Speed of light, given as 3.0 x 10^8m/s,

ε_r = The dielectric substrate, which is 2.6 in this design.

The height, H is in millimetre (mm)

B. Determination of the width (W) of the patch

The width of the patch is calculated using the formula give as;

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

The width, W is in millimetre (mm)

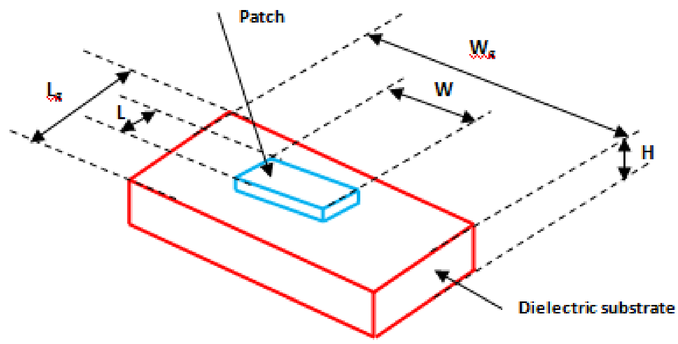

Fig. 3.1: Schematic diagram of a rectangular microstrip patch antenna

C. Determination of the effective dielectric constant (ε_{eff})

It is calculated using the mathematical relation given as;

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

Or, equivalently,

$$\varepsilon_{eff} = \frac{(\varepsilon_r + 1)}{2} + \frac{(\varepsilon_r - 1)}{2}\left(1 + 12\left(\frac{H}{W}\right)\right)^{-0.5} \quad \text{---------------- 4b}$$

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

D. Determination of the effective length of the patch (L_{eff})

The effective length of the patch is given by the formula;

$$L_{eff} = \frac{C}{2F_o\sqrt{\varepsilon_{eff}}} \quad \text{------------------ 5}$$

E. Determination 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;

$$\Delta L = 0.412H\left[\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{H} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{H} + 0.8\right)}\right] \quad \text{--------6}$$

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.

F. Determination 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;

$$L = L_{eff} - 2\Delta L \quad \text{-------------- 7}$$

G. Determination 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;

$$L_g = L + 6H \quad \text{-------------------- 8a}$$

$$W_g = W + 6H \quad \text{------------------ 8b}$$

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

H. Determination of feed point

The point of location of feed to the patch antenna can be located in x-y coordinates as X_f, Y_f. The formulas for calculating the feed point locations using coaxial method [3] are given as;

$$X_f = \frac{L}{2\sqrt{\varepsilon_{eff}}} \quad \text{---------------- 9a}$$

$$y_f = \frac{w}{2} \quad \text{---------------------- 9b}$$

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

IV. DESIGN CALCULATION ANALYSIS

A. Calculation of the height

Using the equation, $H = \frac{0.3C}{2\Pi F_o\sqrt{\varepsilon_r}}$, and substituting the values of C, F_O, ∏ and ε_r respectively into the equation, the value of H will be gotten.

Given that;

C = 3 x 10^8m/s,

ε_r = 2.6

F_O = 4.5GHz

∏ = 3.142,

$$H = \frac{0.3 \text{ x } 3 \text{ x } 10^8}{2 \text{ x } 3.142 \text{ x } 4.5 \text{ x } 10^9 \sqrt{2.6}}$$

= 0.00197m = 1.97mm

B. Calculation of the width

Using the equation, $W = \frac{C}{2F_o\sqrt{\frac{(\varepsilon_r + 1)}{2}}}$,

$$W = \frac{3 \text{ x } 10^8}{2 \text{ x } 4.5 \text{ x } 10^9 \sqrt{\frac{2.6+1}{2}}}$$

$$= \frac{3 \text{ x } 10^8}{2 \text{ x } 4.5 \text{ x } 10^9 \sqrt{\frac{3.6}{2}}}$$

= 0.02485m =24.85mm

C. Calculation of the effective dielectric constant

Using the formula,

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

$$\varepsilon_{eff} = \frac{2.6+1}{2} + \frac{(2.6-1)}{2}\left(1+\frac{1}{\sqrt{1+12\left(\frac{0.00197}{0.02485}\right)}}\right)$$

= 2.372mm

D. Calculation of the effective patch length

Using the formula, $L_{eff} = \frac{C}{2F_o\sqrt{\varepsilon_{eff}}}$,

$$L_{eff} = \frac{3 \text{ x } 10^8}{2 \text{ x } 4.5 \text{ x } 10^9 \sqrt{2.372}}$$

= 0.02164m = 21.64mm

E. Calculation of the length extension

Using the formula,

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

$$\Delta L = 0.412 \text{ x } 0.00197\left[\frac{(2.372 + 0.3)\left(\frac{0.0248}{0.00197} + 0.264\right)}{(2.372 - 0.258)\left(\frac{0.0248}{0.00197} + 0.8\right)}\right]$$

= 0.000987 = 0.987mm

F. Calculation of the actual length of the patch

Using the formula, $L = L_{eff} - 2\Delta L$,

Where L_{eff} = 21.64mm and ΔL =0.987mm,

Then, $L = 21.64 - (2 \text{ x } 0.987)$

= 19.7mm

G. Calculation of the ground dimensions:

The ground length, L_g is given as;

$$L_g = L + 6H,$$

L =19.7mm, H =1.97mm

Then, L_g *= 19.7 + (6 x 1.97)*

= 31.52mm

W_g *= 24.85+ (6 x 1.97)*

= 36.67mm

H. Calculation of feed point location

Using the formulas;

$$X_f = \frac{L}{2\sqrt{\varepsilon_{eff}}} \quad \text{---------------- -8a}$$

$$Y_f = \frac{W}{2} \quad \text{------------------ 8b}$$

Where L and W are the length and the width, and are 19.7mm and 24.85mm in that order while ε_{eff} = 2.372.

Then,

$$X_f = \frac{19.7}{2\sqrt{2.372}}$$

= 6.4mm

For $Y_{F,}$

$$Y_f = \frac{W}{2}$$

$$Y_f = \frac{24.85}{2}$$

= 12.43mm

Therefore, the feed will be at the coordinate point 6.4mm, 12.43mm along X-Y coordinate as X_f and Y_f. Based on the design, the antenna is as in fig.4.1

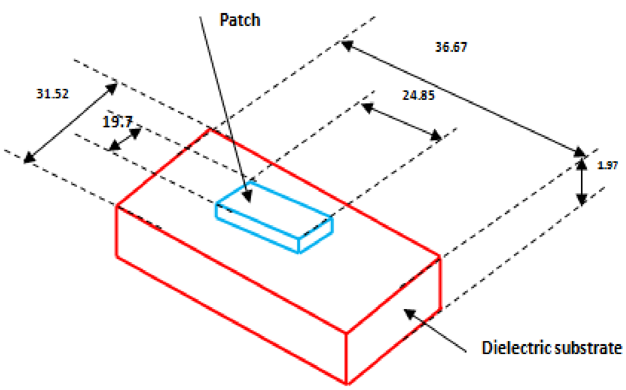

Fig. 4.1: Schematic diagram showing the dimensions of the designed antenna (All dimensions in mm)

V. RESULTS AND DISCUSSION

A. Results

Substrate dielectric constant, $\varepsilon_r = 2.6$

Operating frequency, $F_o = 4.5GHz$

Table 5.0: Parameters of the designed antenna

S/N	Parameters	Values
1	Height of the patch, H	19.7mm
2	Width of the patch, W	24.85mm
3	Effective dielectric constant, ε_{eff}	2.372mm
4	Effective length of the patch, L_{eff}	21.64mm
5	Actual length of the patch, L	19.7mm
6	Ground length dimension, L_g	31.52mm
7	Ground width dimension, W_g	36.67mm
8	Feed point location along x-axis, X_f	6.4mm
9	Feed point location along y-axis, Y_f	12.43mm

B. Discussion

In this design, the transmission line model method of antenna design was used. The design employs the use of the RT-DUROID 5880 dielectric substrate of dielectric constant, 2.6. The height of the patch was gotten to be 1.97mm, while the length and the width are 19.7mm and 24.85mm respectively. Using the coaxial line feed method [3] of feed point location, the feed point is at point 6.4mm, 12.43mm along the X-Y coordinates on the antenna.

In rectangular antenna designed, the width is longer than the length. This is to allow an increase in power radiated power from the antenna, increases its bandwidth and reduces the resonant resistance of the antenna. As a result of the small size of the designed antenna, it can be used with very portable communication or wireless devices such mobile phones, radios and computers with wireless internet connection.

CONCLUSION

The aim of designing this antenna is for it to be used in small-sized devices such as mobile phones, and is achieved at the frequency of 4.5 GHz, with the height of 1.97mm, width of 24.85mm and length of 19.7mm. This size is also as a result of the value of the RT DUROID 5888 dielectric substrate used, which has dielectric constant of 2.6. The feed point location along the X-Y coordinate in which the impedance is nearly 50Ω are 6.4mm, 12.43mm (X_f, Y_f).

Recommendation

The design of microstrip patch antenna can be done using three models such as transmission line model, cavity model and full wave model. This work makes use of transmission line model method. Further research works should be carried out using the cavity model and full wave model.

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