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IMPACT OF DIELECTRIC CONSTANT ON THE DIMENSION OF SQUARE MICROSTRIP PATCH L-BAND ANTENNA

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Abstract

Micrsostrip patch antennas are commonly applied in wireless devices such as in computers, mobile phones, wearable medical devices and the arrays are useful in many other applications due to their light weight, ease of fabrication, flexibility, robustness despite their low gain, low efficiency and low bandwidth. The major objective of this paper is to assess the impacts of variation of di-electric constants on the size and bandwidth of a square microstrip patch antenna.

Transmission line model is used in this design with an RT DUROID 5888 dielectric substrate such that its dielectric constant values are varied from 2.0 to 3.0 with 0.2 step size. All the parameters of the antenna are obtained manually and through computational simulations. The results and findings show that the size and bandwidth of a square or rectangular microstrip patch antenna decreases with increase in the values of a dielectric constant of the substrate.

Keywords: Microstrip, dielectric constant, bandwidth, transmission line, substrate

1. Introduction

Antennae are devices used for receiving and transmitting electromagnetic waves signals. Microstrip patch antennae consist of conducting patches of planar or non-planar geometry on one side of a dielectric substrate with a ground plane on other side. It is a printed resonant antenna that is very popularly required for wireless links of narrow- band microwave because of its semi-hemispherical coverage (Vivek *et al.* 2014). Micro strip patch antennas get more and more important in these days. This is mostly due to their versatility in terms of possible geometries that makes them applicable for many different situations (Md. Rabiul et., 2013). It is used to send and/or receive signals in communication devices. Additionally the simplicity of the structures makes this type of antennas suitable for low_cost manufacturing and this is also one key feature of micro strip patch antennas are used in mobile communications applications (Kazi *et al, 2011*).

Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. The radiation increases with frequency increase and using thicker substrates with lower permittivity, and originates mostly at discontinuities (Bahl & Bhartia, 1980; Rop & Konditi, 2012).

As a result of the daily improvement in technology especially in the area of communication devices used in various fields- broadcasting, telecommunication, medical services, telemetry, etc, there is need to assess how the change in a dielectric constant of a mictrostrip patch antenna affects its bandwidth and the overall size.

The three methods for designing microstrip patch antennas are transmission line model method, cavity model method and full wave model method, but transmission line model method were used in this paper.

2. Some fundamental parameters of microstrip patch antenna design

a. Operating frequency: This is the frequency at which the antenna receives and/or transmits signals. Frequency of operation of a microstrip antenna can be calculated when the height of the patch is known or can be selected before the design (Richards, 1982).

b. Dielectric substrate: A dielectric substrate is a substrate that does not conduct direct current and therefore used as insulator. The dielectric constant ε_r is defined as the ratio of permittivity of a substance to the permittivity of free space.

c. Height of the substrate: The height of the substrate to be used in the design can be selected before calculating the operating frequency of the antenna if there is a prior knowledge of the size of the equipment in which the antenna will be used it, or the operating frequency can be used to find the height, or both can be selected before the design. For any height, the condition in (1) must be met.

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

h = height of the dielectric substrate, ε_r is the dielectric constant of the substrate, and λ is the wave length.

3. Methodology and Design procedures

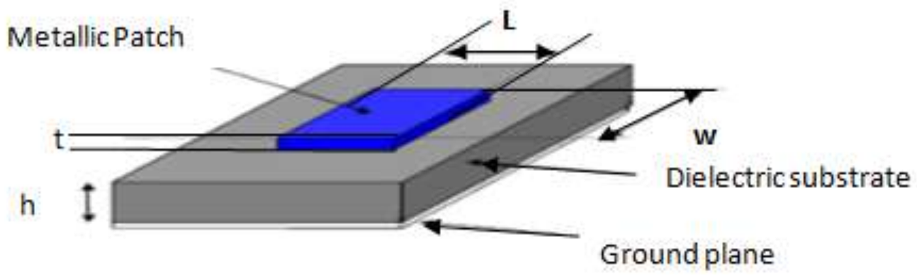

Fig. 1: Schematic diagram of a square microstrip patch antenna

The operating frequency of the antenna can be selected before calculating the height of the substrate or the height before the frequency. When the frequency is first selected before the height, the following steps are followed.

Calculation of the height (h): This is the height of the dielectric substrate upon which the metallic patch is mounted or placed. The height of the dielectric substrate of a microstrip antenna in calculated using the formula given as;

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

Where C = speed of light, given as 3.0 x 10^8m/s, ε_r = the dielectric substrate

b. Calculation of the width (W) of the patch: The width of the patch is calculated using the formula give as;

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

c. Calculation of the effective dielectric constant (ε_{eff}): The effective dielectric constant is calculated using the formula given as;

$$\varepsilon_{eff} = \frac{(\varepsilon_r + 1)}{2} + \frac{(\varepsilon_r - 1)}{2}\left(1 + \frac{1}{\sqrt{1 + 12\left(\frac{h}{w}\right)}}\right) \qquad 4$$

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. Calculation 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 its extension or the fringe effects.

$$L_{eff} = \frac{C}{2f\sqrt{\varepsilon_{eff}}} \qquad 5$$

e. 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;

$$\Delta L = 0.412h\left[\frac{(\varepsilon_{eff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{w}{h} + 0.8\right)}\right] \qquad 6$$

Where ΔL is the patch length extension, *h* and *w* are the height and width of the patch respectively, and ε_{eff} is the effective dielectric constant of the substrate.

f**. 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;

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

g. 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;

$$L_g = L + 6h \qquad 8$$

$$W_g = w + 6h \qquad 9$$

Where *L* and *w*, are the length and the width of the patch antenna

h. Calculation 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. Coaxial-probe feeding technique is used for this paper. This feeding scheme is advantageous in terms of free and desired placement location in order to match with the input impedance (Sahaya & Anselin, 2013). The formulas for calculating the feed point locations are given as;

$$X_f = \frac{L}{2\sqrt{\varepsilon_{eff}}} \qquad 10$$

$$y_f = \frac{w}{2} \qquad 11$$

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

i. Calculation of bandwidth: The bandwidth of an antenna is defined as “the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard” (Milligan, 1985; Mohammed & Sabidha, 2015). In percentage, bandwidth of a square or rectangular microstrip patch antenna is calculated by the formula given as:

$$BW\,\% = 3.77\left[\frac{(\varepsilon_r - 1)}{\varepsilon_r^{\,2}}\right]\left[\frac{w}{L}\right]\left(\frac{h}{\lambda}\right) \text{x}\, 100 \qquad 12$$

3.1 Methodology

An L-band frequency spectrum has the band width of 1-2GHz. In this design, a frequency of 1Ghz will be used. The design will employ transmission line method of microstrip antenna design, using mathematical computations. The computation processes involve manual and software (ms excel) computations. In the process of the design, same dielectric substrates with different values of dielectric constant will be used. These values are 2.0, 2.2, 2.4, 2.6, 2.8, and 3.0. For simplicity, manual computation will be used to determine the parameters of the antenna when the dielectric constant, ε_r is 2.0. Although, the dielectric constant will be varied during the process, all other parameters such as the frequency, wave length, and the speed of the wave will be the same. The other computations using ε_r = 2.2, 2.4, 2.6, 2.8, and 3.0, will be carried out using Microsoft excel software package.

3.2 Manual Computation Analysis

a. Calculation of the height (h): This is the height of the dielectric substrate upon which the metallic patch is mounted or placed.

Using the equation:

$$h = \frac{0.3C}{2\pi f\sqrt{\varepsilon_r}}$$

Where ε_r = 2.0, f = 1GHz, C = 3 x 10^8m/s, π = 3.142. The substitution of these values will yield;

$$h = \frac{0.3 \text{ x } 3 \text{ x } 10^8}{2 \text{ x } 3.142 \text{ x } 41 \text{ x } 10^9\sqrt{2.0}}$$

= 0.01013m = 10.12mm

b. Calculation of the width: The width of the metallic is calculated using the equation given as:

$$W = \frac{C}{2f\sqrt{\frac{(\varepsilon_r + 1)}{2}}},$$

Thus, substitution gives;

$$W = \frac{3 \text{ x } 10^8}{2 \text{ x } 1 \text{ x } 10^9\sqrt{\frac{2.0+1}{2}}}$$

= 0.1225m =122.5mm

c. Calculation of the effective dielectric constant: The effective dielectric constant is calculated using the equation given as:

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

Thus, a careful substitution gives;

$$\varepsilon_{eff} = \frac{2.0+1}{2} + \frac{(2.0-1)}{2}\left(1+\frac{1}{\sqrt{1+12\left(\frac{0.01013}{0.1225}\right)}}\right)$$

$$\varepsilon_{eff} = 1.85$$

d. Calculation of the effective patch length: The effective length of the patch antenna is the sum of the actual length of the antenna and its extension or the fringing effects. It is given as:

$$L_{eff} = \frac{C}{2f\sqrt{\varepsilon_{eff}}},$$

Then, careful substitution will produce;

$$L_{eff} = \frac{3 \text{ x } 10^8}{2 \text{ x } 1 \text{ x } 10^9 \sqrt{1.85}}$$

$$L_{eff} = 0.1103\text{m} = 110.3\text{mm}$$

e. Calculation of the length extension: This is additional length at both ends of the metallic patch it is calculated using:

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

Thus, substitution gives;

$$\Delta L = 0.412 \text{ x } 0.01013\left[\frac{(1.85+0.3)\left(\frac{0.1225}{0.01013} + 0.264\right)}{(1.85-0.258)\left(\frac{0.1225}{0.01013} + 0.8\right)}\right]$$

ΔL = 0.0053m = 5.3mm

f. Calculation of the actual length of the patch: This is the difference between the effective length and twice the length extension or the length extension at both ends. It is calculated using:

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

Where L_{eff} = 0.1103m and ΔL = 0.0053m.

$\therefore\ L = 0.1103 - (2 \text{ x } 0.0053)$

= 0.099m = 99mm

g. Calculation of the ground dimensions:

The ground length, L_g and the ground width w_g are calculated using $L_g = L + 6h$ and $w_g = w + 6h$

Thus, L_g = 0.099 + *(6* x *0.01013)*

= 0.15978m = 159.78mm

And,

W_g = 0.1225 + *(6* x *0.01013)*

= 0.18328m = 183.28mm

h. Calculation of feed point location: This is the coordinate point of the feed along x-y axes. The feed point is calculated using:

$$X_f = \frac{L}{2\sqrt{\varepsilon_{eff}}} \quad \text{and} \quad Y_f = \frac{w}{2}$$

Where L and w are 0.099m and 0.1225m respectively while ε_{eff} = 1.85

Therefore,

$$X_f = \frac{0.099}{2\sqrt{1.85}}$$

X_f = 0.03639m = 36.39mm, and,

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

$$Y_f = \frac{0.1225}{2}$$

Y_f = 0.06125m = 61.25mm

i. Calculation of bandwidth: The bandwidth of an antenna is defined as "the range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard" (Balanis, 1997). In percentage, bandwidth of a square or rectangular micrcrostrip patch antenna is calculated by the formula given as:

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

Where ε_r = 2.0, w = 0.1225m, h = 0.01013m, L = 0.099m and λ = 0.3m. Thus, when substituted,

$$BW\% = 3.77\left[\frac{(2-1)}{2^2}\right]\left[\frac{0.1225}{0.099}\right]\left(\frac{0.01013}{0.3}\right) x\, 100,$$

$BW\%$ = 3.938%

The above processes were carried out for the value of dielectric constant of the substrate, ε_r , equals 2. The computations for ε_r = 2.2, 2.4, 2.6, 2.8, and 3.0, will be performed in excel worksheet, and the answers will be provided as follows.

When;

i. ε_r = 2.2, h = 0.00966m, w = 0.1186m, ε_{eff} = 2.026713, L_{eff} = 0.105365m, ΔL = 0.005019m, L = 0.095327m, L_g = *0.153287m*, W_g = *0.17656m* , $BW\%$ = 3.744%, X_f = 0.03348m and Y_f = 0.0593m.

ii. ε_r = 2.4, h = 0.009245m, w = 0.115045m, ε_{eff} = 2.1995, L_{eff} = 0.101143m, ΔL = 0.004705m, L = 0.091732m, L_g = *0.147202m*, W_g = *0.170515m*, $BW\%$ = 3.543%, X_f = 0.030926m and Y_f = 0.057225m.

iii. ε_r = 2.6, h = 0.008882m, w = 0.1111803m, ε_{eff} = 2.372403, L_{eff} = 0.097386m, ΔL = 0.00444m, L = 0.088506m, L_g = *0.141798m*, W_g = *0.165095m*, $BW\%$ = 3.3362%, X_f = 0.02873085m and Y_f = 0.0559015m.

iv. ε_r = 2.8, h = 0.008559m, w = 0.108821m, ε_{eff} = 2.545525, L_{eff} = 0.094016m, ΔL = 0.004213m, L = 0.085591m, L_g = *0.136945m*, W_g = *0.160175m*, $BW\%$ = 3.1397%, X_f = 0.02682m and Y_f = 0.05441m.

v. ε_r = 3.0, h = 0.008269m, w = 0.106066m, ε_{eff} = 2.71879, L_{eff} = 0.090971m, ΔL = 0.00415m, L = 0.08294m, L_g = *0.132555m*, W_g = *0.155568m*, $BW\%$ = 2.9531%, X_f = 0.0251508m and Y_f = 0.053033m.

4. Results and Discussions

Table 1 shows the summary of the results with operating frequency, $f = 1GHz$ and Dielectric substrate: RT DUROID 5888.

Table 1: Parameters of the designed antenna

s/n	ε_r	h (mm)	w (mm)	ε_{eff}	L_{eff} (mm)	ΔL (mm)	L(mm)	L_g (mm)	W_g (mm)	$BW\%$	X_f (mm)	Y_f (mm)
1	2.0	10.10	122.50	1.8525	110.30	5.30	99.40	159.78	183.28	3.938	36.39	61.25
2	2.2	9.66	118.60	2.0267	105.37	5.02	95.33	153.29	176.56	3.744	33.48	59.30
3	2.4	9.24	115.05	2.1995	101.14	4.71	91.73	147.20	170.52	3.543	30.93	57.23
4	2.6	8.88	111.80	2.3724	97.39	4.44	88.51	141.80	165.10	3.336	28.73	55.90
5	2.8	8.56	108.82	2.5255	94.02	4.21	85.59	136.95	160.175	3.140	26.82	54.41
6	3.0	8.27	106.07	2.7188	90.97	4.15	82.94	132.56	155.57	2.953	25.15	53.03

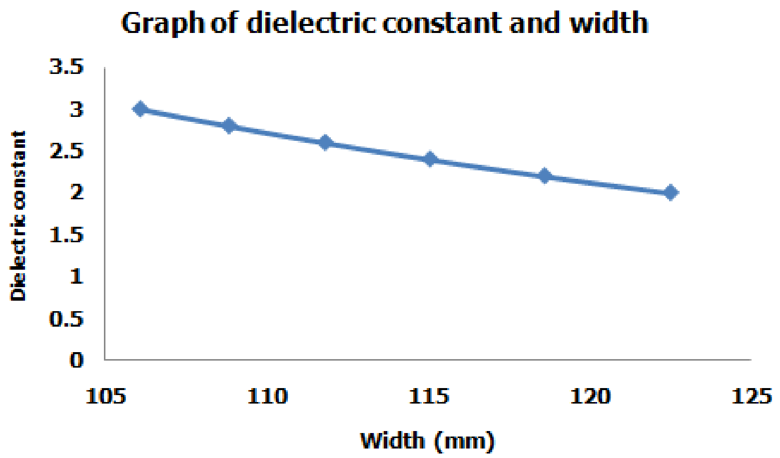

Fig. 2: Graph of dielectric constant (ε_r) against the width (w)

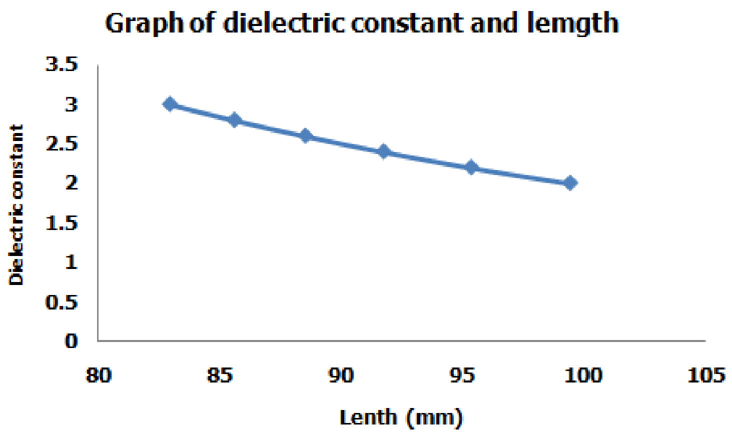

Fig. 3: Graph of dielectric constant (ε_r) against the length (L)

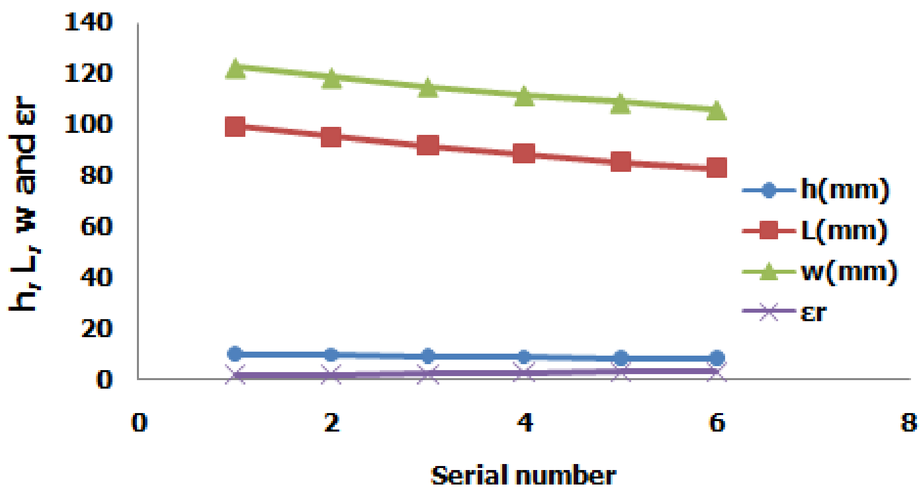

Fig. 4: Graph of h, w, L and ε_r

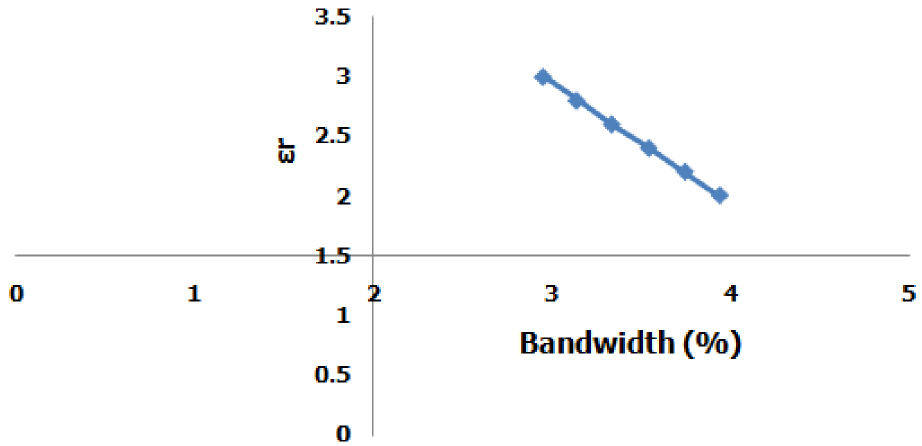

Fig. 5: Graph of dielectric constant (ε_r) against bandwidth (BW)

4.1 Discussion

Transmission line model method of antenna design which is one of the methods of microstrip patch antenna design was used for this design. The frequency at which the square microstrip antenna will operate is 1GHz, an L-band frequency. This design made use of an RT-DUROID 5880 dielectric substrate, and its dielectric constant values were varied from 2.0 to 3.0units with an increment of 0.2 unit. The parameters of the designed antenna(s) are shown in table 1. The result indicates that the height, length and the width of the antenna decreases as the dielectric constant. This means that, in order to have a reduced size of micrsotrip patch antenna, higher value of the dielectric substrate should be used. Figures 2, 3, and 4 show the graphical comparisons between the dielectric constant and height, dielectric constant and length as well as dielectric constant and width of the patch.

Figure 2 shows the sloping downward from left to right of the graph which indicates that the width of the antenna increases with decrease in dielectric constant. Also, figure 3 shows the same trend in terms of length, while figure 4 shows the combination of the four parameters in which it was seen that the length, height and width decreased as the dielectric constant values were increasing. Thus, the size of a square or rectangular microstrip antenna is inversely proportional to a dielectric constant.

Furthermore, from figure 5, it was observed that the relationship between the dielectric constant and the bandwidth of the antenna is inversely proportional. Thus, the bandwidths at lower values of the dielectric constant are larger than the bandwidths at the higher values of the dielectric constant.

4.2 Conclusion

The design of a square microstrip antenna that will operate at a frequency of 1GHz has been done using transmission line method. The various parameters of the antenna have been gotten while varying the dielectric constant and keeping the frequency of operation constant. One of the common dielectric substrate for micrsotrip patch antenna design-RT DUROID 5888 dielectric substrate was used in this paper. The results show that the size of a square or rectangular microstrip antenna will reduce when the value of dielectric constant is large and vice versa. In an antenna design for equipment in which space is a problem, higher values of dielectric constant is to be used. However, the higher the value of a dielectric constant, the lesser the bandwidth as in fig. 6, thus, in a design for an equipment where space is a problem and higher bandwidth is needed, array of it will be used. Finally, it can be concluded that increase in dielectric constant causes decrease in microstrip patch antenna size as well as its bandwidth, and vice versa.

4.3 Recommendation

The design of this antenna was done using transmission line model and RT DUROID 5888 dielectric substrate. Future work in this area can carried out using efficeint antenna design methods with different but better dielectric substrate rather than RT DUROID.

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