Assessing the Effects of Frequency on the Dimension of a 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 in small size. Patch antennas are very compatible with microwave integrated circuits and also compatible with small size electronic systems.
The aim of this design is to determine the effects of change in frequency on the dimension of a rectangular patch antenna. Dimension according to Encarta dictionary deals with the "size or extent of something". According to concise English dictionary, dimension is defined as the "measurable extent such as length, breadth or height".
In order to achieve this aim, transmission line model method of antenna design was used to determine the height, length and width of the antenna at the frequencies of 1.5, 2.0, 2.5, 3.0, 3.5 and 4GHz, and a constant value of the dielectric constant. The dielectric substrate, RT DUROID 5888 of dielectric constant 3.21 was selected for the design.
As the frequency increases from one value to the other, the height, length and width were found to decrease. It was also shown that the rate at which the dimension decreases with increase in frequency is larger at lower frequencies than at higher frequencies.
It can be conclusively seen that frequency is inversely proportional to the height, length and width of the rectangular patch antenna provided the value of the dielectric constant remains unchanged.
KEYWORDS: *Transmission line, Parameters, Microstrip, Dielectric substrate.*

I. INTRODUCTION

An antenna is a device used for converting electromagnetic energy to electrical signal and vice versa. Antenna 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 smaller size of antenna that will allow such size. Microstrip antenna is an example of such antennas. Microstrip is a type of transmission line which can be fabricated using printed circuit board technology, and is used to covey microwave-frequency signals. It has a conducting strip separated from a ground plane by a dielectric layer known as the substrate.
There are different methods of antenna design but the major three methods are transmission model method, cavity model method and full wave model method. In this design, the method of transmission line model is used. There are other forms of microstrip antennas such circular microstrip antenna, square microstrip antenna, and triangular microstrip antenna. Some advantages of microstrip antenna are;
*It is easy and simple to manufacture or fabricate
* Microstrip antennas are cheap
* It is easy to construct array antennas with the radiating elements and the feed network on a single surface. However, microstrip antennas have poor isolation between feed lines and radiating elements, low power handling capability low bandwidth and low gain.

II. BASIC PARAMETERS IN RECTANGULAR MICROSTRIP ANTENNA DESIGN

a. Dielectric substrate: A dielectric substrate is a semiconductor material 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. This design makes use of a substrate; RT DUROID 5880 with dielectric constant of 3.21, and which is constant for different values of the frequency used.

b. Frequency of operation: Frequency of operation is defined as the frequency at which the antenna receives and/or transmits signals. The value can be gotten by calculation when the height is given or can be selected before the design. In this design, various operating frequencies are studied. Operating frequency can be represented by the symbol F_c or F_o.

c. Height of the dielectric substrate: This is the thickness of the substrate of the patch antenna. The height can be selected before determining the operating frequency of the antenna. Also, the operating frequency can be used to find the height, or both can be selected before the design. In any of these cases, the basic condition that must be met is given as in equation 1.

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

Where h is the height of the patch antenna, λ is the wavelength and ε_r is dielectric constant.

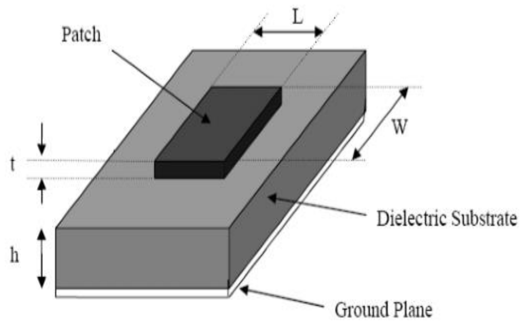

Fig. 1: Schematic diagram of a rectangular microstrip patch antenna

(t = Thickness of the patch)

Review of some related works

Manjari Bharati, 2007, examined the effect of the variation of patch height of microstrip patch antenna on the efficiency using the probe feed technique. It was found out that the efficiency of microstrip patch antenna can be reduced by increasing the height of the antenna. It was concluded that to design a high efficient antenna, there should be lower dielectric constant, lower patch height or substrate thickness which will lead to a wider bandwidth.

De *et al.*, 2016, worked on the topic "Design and Performance Analysis of Microstrip Patch Array Antennas with different configurations". The design and fabrication of a 16 element rectangular microstrip patch array antenna was done by them. An optimization method based on IE3D was also used for designing an inset feed linearly polarized rectangular microstrip patch antenna array which is to operate at a frequency of about 2.45GHz. Other literatures reviewed in this work are by; Rop and Konditi, 2012, entitled "Performance Analysis Of A Rectangular Microstrip Patch Antenna On Different Dielectric Substrates"; Devan and Krishan, 2013, entitled "Design of a Rectangular Microstrip Patch Antenna Using Inset Feed Technique" and the work by Vivek *et al.,2014*, entiltled "Performance Analysis of Rectangular Patch Antenna for Different Substrate Heights". All these works involved the design of microstrip antenna but non examine the effect of frequency on the dimension of a rectangular microstrip antenna, the aim in which this work is targeted at.

III. METHODOLOGY

The methods used in the design are analytical method and software simulation. The analytical method was used to determine the parameters of the antenna based on the formulas and other relations. Microsoft excel package and matlab software were used for the computation. The simulation of the relationship between some parameters of the antenna were carried out with matlab software, and in each case, a graph was produced.

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. Calculation of the height (H) of the substrate: The height, which is the thickness of the substrate as shown in fig. 1 is calculated using the formula given as in equation 2.

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

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

ε_r = The dielectric substrate, which is 3.21 in this design.

The height, H is in millimetre (mm)

b. Calculation of the width (W) of the patch: It is the one of the horizontal sides of the patch. The width of the patch is calculated using the formula give as in equation3.

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

The width, W is in millimeter (mm)

c. Calculation of the effective dielectric constant (ε_{eff}): It is calculated using the mathematical relation given as in equations 4a and 4b.

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

Or, equivalently,

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

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

d. Determination of the effective length of the patch (L_{eff}): Effective length of patch antenna is the sum of the actual length of the patch and the extensions at both ends. The effective length of the patch is given by the formula as in equation 5.

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

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 in equation 6.

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

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**. 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 in equation 7.

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

g. Calculation of the ground plane dimensions: The ground plane dimensions are ground distance of 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 in equations 8a and b;

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

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

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

IV. RESULTS AND DISCUSSION

Table 1: Antenna parameters

Freq (GHz)	ε_r	H (mm)	L (mm)	W (mm)	Lg (mm)	Wg (mm)
1.5	3.21	5.330	53.5	68.9	85.480	100.88
2.0	3.21	3.997	40.2	51.7	64.182	75.682
2.5	3.21	3.198	32.2	41.4	51.388	60.588
3.0	3.21	2.665	26.8	34.5	42.790	50.490
3.5	3.21	2.284	23.0	29.5	36.704	43.204
4.0	3.21	1.998	20.0	25.8	31.988	37.788

Table2: Changes in the antenna parameters due to change in frequency

Change in H (mm)	Change in L (mm)	Change in W (mm)
1.333	13.3	17.2
0.799	8.0	10.3
0.533	5.4	6.9
0.381	3.8	5.0
0.286	3.0	3.7

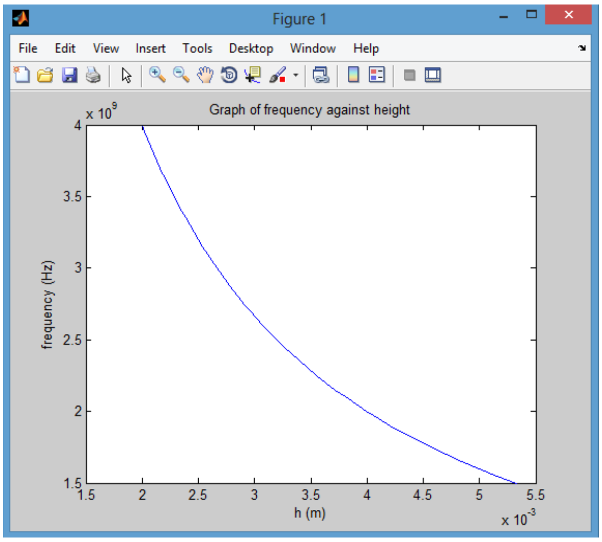

Fig. 2: Graph of frequency against height

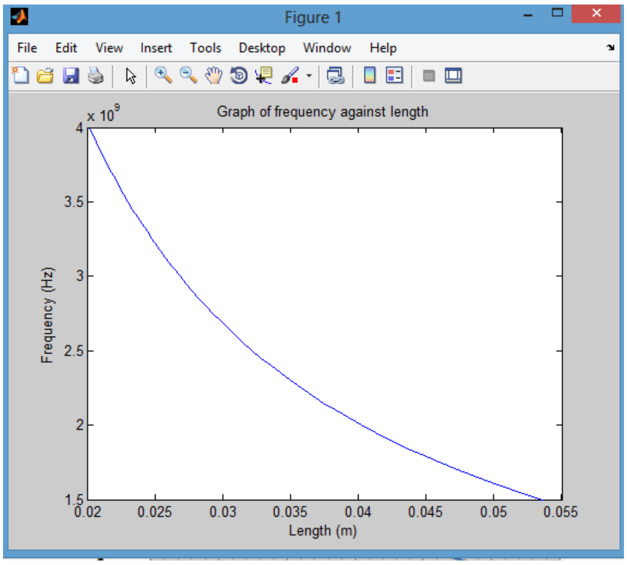

Fig. 3: Graph of frequency against length

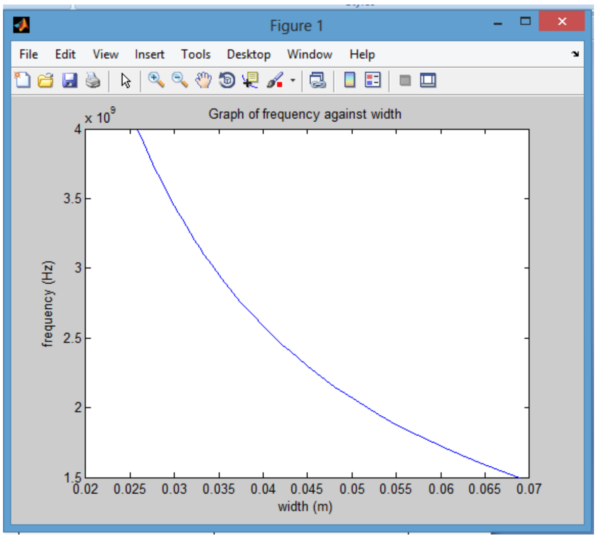

Fig. 4: Graph of frequency against width

DISCUSSION

From the results, it shows that at constant value of dielectric material, as the frequency is being increased from one value to the other, the height of the dielectric substrate reduces. Also, as the frequency is being increased from one value to the other, by 0.5GHz in this case, the length and the width of the patch also increase.

As shown in figure 2, the graph of frequency against the height slopes downward from left to right, though not linearly. The sloping of the graph from left to right shows that the height of the substrate of a rectangular microstirp antenna is inversely proportional to the frequency, provided the dielectric constant of the material remains unchanged. In other word, when the frequency is low, the height of the patch antenna generally will be high, and when the frequency is high, the height will be low. In a device which does not accommodate "tall" components, it is advantageous as signal can now be transmitted at higher frequency.

From figures 3 and 4, similar trends are observed just like in the case of the height. The graph slopes downward from left to right in each case which shows that the frequency of propagation of signal is inversely proportional to the length and the width of the patch antenna. This implies that designing a rectangular patch antenna for high frequency signal propagation will help to reduce the size of the antenna in terms of total dimension. This also means rectangular microstip patch antenna is to be used for higher frequency signal transmission and/or reception devices especially when space is of greatest concern. It gives an antenna designer an idea of what is expected even before start designing hence allowing him or her to make proper choices of either lower frequency with larger size or higher frequency with smaller antenna. As for the curving nature of the graphs, it is as a result of the non-uniformity in the decrease of the values of the height, length and width as the frequency increases at regular or equal interval. The nature of the graph is also due to the faster decrease of the height, length and the width at the lower values than at the higher values of the frequency. As the frequency changes from 1.5 – 2.0GHz, the height changes by 1.333mm, the length by 13.3mm, and the width by 17.2mm. As the frequency changes from 2.0 – 2.5GHz, the height changes by 0.799mm, the length by 8.0 mm, and the width by 10.3mm. It follows that as the frequency changes to 3, 3.5, and 4.0GHz, the height changes by 0.533, 0.381 and 0.286mm, the length decreases by 5.4, 3.8 and 3mm, and the width decreases by 6.9, 5.0, and 3.7mm respectively. With this, it can be seen that the rate at which the dimension decreases at lower frequencies is more than at higher frequencies. This is as shown in table 2 above.

V. CONCLUSION

The substrate selected for this design is RT DUROID 5888 with dielectric constant 3.21, and this same material (value) was used for all other frequencies to determine the relationship between varying frequency and constant dielectric constant value and the dimensions of the rectangular patch antenna.

The height of the patch at each frequency was calculated, as well as the values of the respective length and width of the patch antenna at these frequencies. The comparison of the rate of decrease in the values of these parameters where made between the lower values and the higher values of the frequency as used in this design. It shows that values by which each of them decreases is larger at lower frequencies compared to the values at higher frequencies. The design therefore shows that smaller dimension of the rectangular patch antenna can be achieved at higher frequency if the value of the dielectric constant of the material will remain unchanged.

VI. RECOMMENDATION

The method used in this design is analytical (or mathematical) method. The analysis of the antenna using antenna design software should be looked into as further work.

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