Equilateral Triangular Microstrip Antenna - A New Design Formula Based on Bhatnagar's Postulate

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Received 11 February 2015, received in revised from 9 April 2015, accepted 9 April 2015

Abstract: **Triangular microstrip antenna is commonly used in wireless communication. Several approximate formulae for its design are in use. This paper presents a new design formulae for equilateral triangular patch antenna. This is based on Bhatnagar's Postulate. The postulate is extended and validated for equilateral triangular patch antenna. Thus a new thinking for estimating physical side length of a triangular microstrip antenna has been presented. The 'H' concept has been used here to put forward a new formula for estimating the physical side length of the triangular patch. It has been postulated that "Extension in physical side length of the patch is directly proportional to the normalized thickness of the antenna substrate and the electrical side length of the patch. The constant of proportionality is independent of the resonant frequency, thickness and Dielectric Constant of the substrate". For a triangular patch also its value is unity.**

Key Words: **Microstrip Antenna, dielectric constant, electric length, fringing fields, triangular patch, Bhatnagar's postulate.**

1. INTRODUCTION

An electrically conducting patch suspended over a ground plane acts as an antenna if it is fed with electromagnetic energy. This function depends critically on the field at the fringes of the patch. These are called "fringing fields". The fringing fields extend beyond the radiating edge of the patch. Electrically the patch is considered to be extended beyond its physical size. This extension in physical length affects the resonant frequency of the patch [1]. Estimation of its value is therefore necessary for designing an antenna patch. This paper presents a new formula for this estimation for an equilateral triangular patch antenna.

The antenna is designed for the given operating frequency (f_r), dielectric constant of substrate (ε_r) and height of dielectric substrate (h).

Fig 1: Equilateral triangular patch antenna with inset feeding

Fig. 1. Shows a typical geometry of an equilateral triangular patch antenna with inset feeding. The resonant frequency of such an antenna is given by [2].

$$f_{m,n,l} = \frac{2c}{3S\sqrt{\varepsilon_r}}\sqrt{m^2 + mn + n^2} \tag{1}$$

Where mn refers to TMmn modes (For equilateral triangle, m+n+l = 0)

S = length of the side of the equilateral triangular patch

c = velocity of light, i.e. 3×10^8 m/s

ε_r = dielectric constant of the substrate.

However, the electrical length is larger than the physical length of the radiating side due to the fringing fields.

$$S_e = S_p + \Delta S \tag{2}$$

Where S_e = electrical length of the radiating side

S_p = physical length of the radiating side

ΔS = extension in S due to fringing fields

Different researchers have used different formulae and different notations for these three quantities. A good description of these is given in [3]. Some of them are

(i)

$$S_e = S_p + \frac{h}{\sqrt{\varepsilon_r}}, \tag{3}$$

and the resonant frequency f_r is

$$f_r = \frac{2c}{3S_p\sqrt{\varepsilon_r}} \tag{4}$$

(ii)

$$f_r = \frac{2c}{3S_e\sqrt{\varepsilon_r}} \tag{5}$$

where, S_e is the electrical side-length. Relation between S_e and S_p is [4]

$$S_e = S_p\left[1 + 2.199\left(\frac{h}{S_p}\right) - 12.853\left(\frac{h}{\varepsilon_r S_p}\right) + 16.436\left(\frac{h}{\varepsilon_r S_p}\right) + 6.182\left(\frac{h}{S_p}\right)^2 - 9.802\left(\frac{1}{\sqrt{\varepsilon_r}}\right)\left(\frac{h}{S_p}\right)^2\right] \tag{6}$$

(iii)

$$S_e = \frac{c}{2f_c\sqrt{\varepsilon_{reff}}} \tag{7}$$

where the effective dielectric constant of the substrate is given by [5]

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + \frac{12h}{W}\right]^{-0.5} \tag{8}$$

Another formula in use for ε_{reff} is [6]

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + \frac{10h}{W}\right]^{-0.5} \tag{9}$$

This study reveals that (i) there is no fixed formula for calculating ΔS, and (ii) the formulae in use do not relate ΔS with S_e .

2. BHATNAGAR'S POSTULATE AND ITS EXTENSION

Bhatnagar's Postulate was originally stated for a rectangular microstrip antenna [7, 8]. According to this postulate, the extension in physical length of the radiating side is proportional to its electrical length i.e.

$$\Delta L = \beta * H * L_e \tag{10}$$

Where ΔL = extension in L_p due to fringing fields

L_p = physical length of the rectangular patch

L_e = electrical length of the patch

$H = h/\lambda_g$ is the normalized height of the antenna substrate

λ_g is the guide wavelength (resonant wavelength in the dielectric medium)

β = constant of proportionality and has been termed as Bhatnagar constant. It is independent of the resonant frequency (f_r), thickness (h) and dielectric constant ε_r of the substrate. For a rectangular patch β is unity.

It is proposed to extend this postulate for the case of an equilateral triangular patch and to validate it. "The extension in the length of the radiating side (ΔS) of an equilateral triangular patch of physical side-length S_p is given by

$$\Delta S = \beta * H * S_e \tag{11}$$

Where S_e is the electrical side-length.
H and β have same meaning and β = 1

3. DESIGN, SIMULATION AND VALIDATION

Combining (2) and (11) gives a new design formula for equilateral triangular patch antenna. Physical length of radiating side of the triangular patch is given by

$$\boldsymbol{S_p = (1 - H\beta) \times S_e} \tag{12}$$

S_e is given by simplifying equation (5) as

$$S_e = \frac{2c}{3f_r\sqrt{\varepsilon_r}} \tag{13}$$

Large number of antennas were designed using the new formulae. FR4 epoxy substrate (dielectric constant 4.4) of thickness 1.6 mm was used. The resonant frequency was varied from 1 to 8 GHz. Parameter H was varied from 0.011 to 0.089.

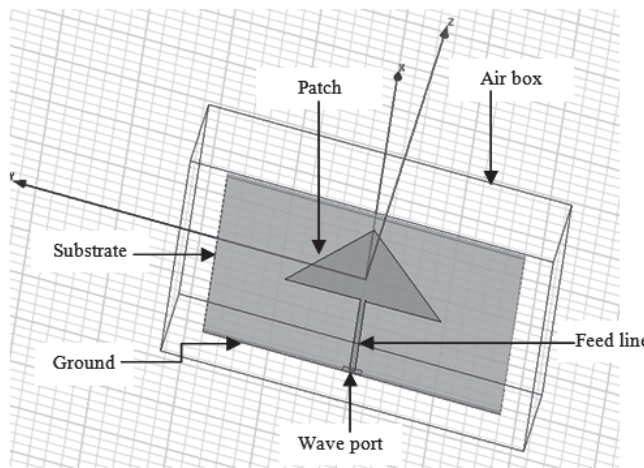


Fig 2: Top view of the Triangular Microstrip patch antenna in HFSS

The HFSS (High Frequency Structure Simulator) software was used for simulation of triangular microstrip patch antenna. Fig. 2. Shows the antenna design in HFSS. Some typical results are shown in figures 3, 4, 5 and 6.

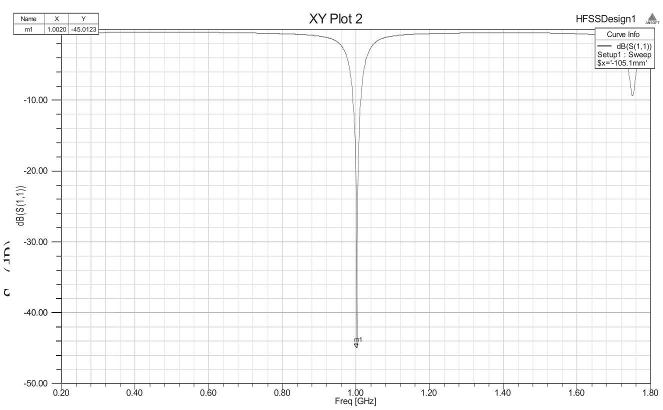


Fig 3: Simulated result: Resonant frequency- designed = 1 GHz, Simulated = 1.002 GHz

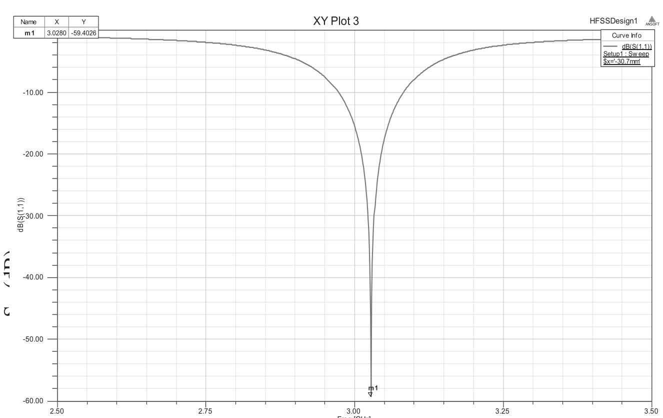
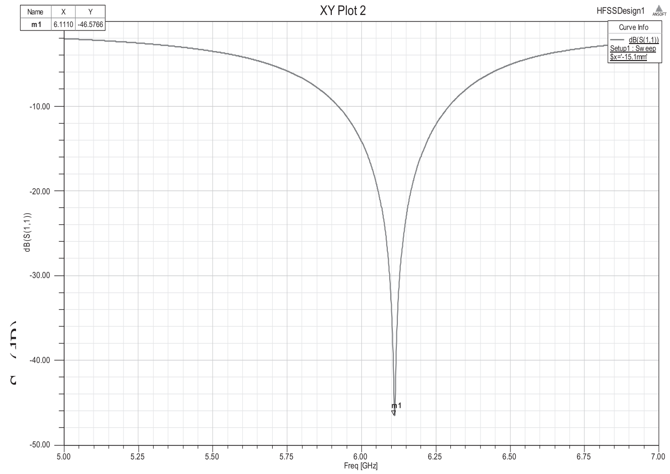
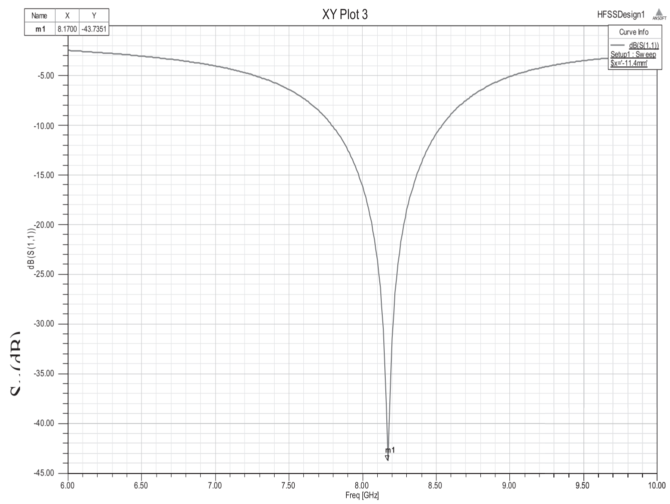


Fig 4: Simulated result: Resonant frequency--- designed = 3 GHz, simulated = 3.028 GHz



Freq [GHz] ⟶

Fig 5: Simulated result: Resonant frequency--- designed = 6 GHz, simulated = 6.111 GHz



Freq [GHz] ⟶

Fig 6: Simulated result: Resonant frequency--- designed = 8 GHz, simulated = 8.170 GHz

New formulae proposed in this paper were used to design antennas for simulation. The results have been summarized in table 1. It can be seen that the resonant frequency of the designed structure matches very well with the corresponding designed value. This is validation of the proposed theory and formulae.

Table 1: Simulated results

Resonant Frequency (GHz)	
Designed	**Simulated**
1	1.002
2	2.016
3	3.028
4	4.038
5	5.044
6	6.111
7	7.2
8	8.17

4. CONCLUSION

Bhatnagar's Postulate for extension in length of the radiating side has been successfully extended for equilateral triangular patch antenna. This extension is due to fringing fields. Thus a new thinking for estimating physical side length of a triangular microstrip antenna has been presented. The 'H' concept has been used here to put forward a new formula for estimating the physical side length of the triangular patch. It has been postulated that "Extension in physical side length of the patch is directly proportional to the normalized thickness of the antenna substrate and the electrical side length of the patch. The constant of proportionality is independent of the resonant frequency, thickness and Dielectric Constant of the substrate". For a triangular patch also its value is unity. New design formulae have been validated. These formulae are simple and straight forward. These do not contain empirical values. They are perhaps more relevant as the extension in length has been directly related with the electrical length of the radiating edge.

5. ACKNOWLEDGMENT

The authors would like to thank Director (Academics) and the Management of SKIT for permission to carry out this work and to publish it.

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