Design and analysis of an inset-fed microstrip patch antenna operating at 2.4 GHz

Ömer Alperen Katı
2021-12-17

***Abstract*—In this paper, an inset-fed microstrip patch antenna is designed to be operate at 2.4 GHz ISM band, and hand calculations for some parameters are presented. Then, some variations in those variables are introduced to demonstrate its effect on resonant frequency, |S11| and bandwidth. Also, the radiation characteristics are discussed.**

***Index Terms*—microstrip patch antenna, inset-feeding method, inset distance, patch length, patch width, substrate thickness, radiation pattern, input impedance, bandwith, resonant frequency.**

I. Introduction

Microstrip patch antennas are one of the type that is commonly used in mobile communications [1]. It consists of a conductive patch element, a substrate below the patch, a feed element and a conductive ground plane at the bottom, and the patch can have any shape like rectangle, circle, triangle etc. [2]. Different feeding mechanism such as edge, inset and probe feeding can be adopted [3].

II. Antenna

A. Antenna Geometry

The overall geometry of the patch antenna and its dimensions can be seen in Fig. 1 and 2, respectively.

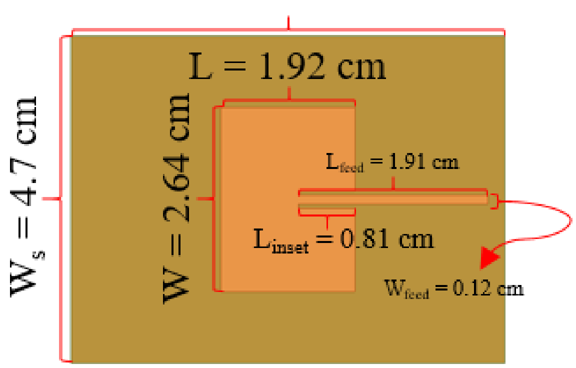

Fig. 1: The geometry of the antenna.

The antenna geometry is generated using ACT Extensions Tool of Ansys HFSS, taking the substrate as Rogers 6010 with a relative permittivity (ϵ_r) of 10.2 and thickness (h) of 0.127 cm [4]. Also, the resonant frequency (f_r) is set to 2.4 GHz. After the first simulation, the generated antenna ended up to resonate at 2.24 GHz with an $|S_{11}|$ value of -7.86. In

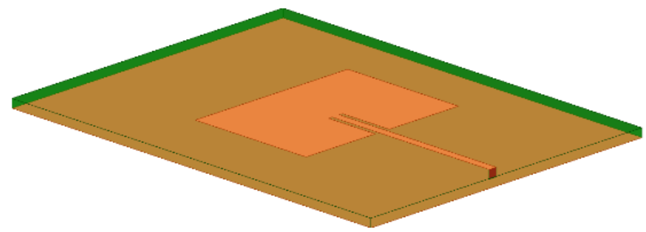

Fig. 2: The model of the antenna from dimetric view.

order to tune the antenna, the following hand calculations are made. Firstly, the following formula is used to calculate the patch width (W):

$$W = \frac{c}{2f_0\sqrt{(\epsilon_r+1)/2}} = \frac{299792458m/s}{22.4e9\sqrt{(10.2+1)/2}} = 2.64cm \quad (1)$$

Then, using W with already given values of ϵ_r and W, the effective relative permittivity of the substrate is calculated as follows:

$$\epsilon_{reff} = \frac{(\epsilon_r+1)}{2} + \frac{(\epsilon_r-1)}{2}[1+15\frac{h}{W}]^{-\frac{1}{2}} \quad (2)$$

$$= \frac{(10.2+1)}{2} + \frac{(1.2-1)}{2}[1+15\frac{0.127cm}{2.64cm}]^{-\frac{1}{2}} = 9.26 \quad (3)$$

In this step, Δ_L is calculated using the following formula with the given and calculated values:

$$\Delta_L = 0.412h\frac{(\epsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \quad (4)$$

$$= 0.412(0.127cm)\frac{(9.26+0.3)(\frac{2.64cm}{0.127cm}+0.264)}{(9.26-0.258)(\frac{2.64cm}{0.127cm}+0.8)} = 0.56mm \quad (5)$$

Also, we calculate the effective length of the patch (L_{eff}):

$$L_{eff} = \frac{c}{2f_0\sqrt{\epsilon_{reff}}} = \frac{299792458m/s}{22.4e6\sqrt{9.26}} = 2.05cm \quad (6)$$

Then, the actual length of the patch is calculated to be:

$$L = L_{eff} - \Delta_L = 2.05cm - 2(0.056cm) = 1.94cm \quad (7)$$

All those calculated values turned out to be the same with the ones synthesized by the extension except the feed position. To calculate the feed position. Firstly, the feed is located at the edge of the patch, and the real part of the input impedance value is found. Then the desired inset distance (L_{inset}) is found as follows.

$$R_{in}(y=0) = 50 \times real(RX) = 50 \times 4.30 = 215 \qquad (8)$$

$$R_{in}(y=y0) = R_{in}(y=0)cos^2(\frac{\pi}{L}y_0) \qquad (9)$$

$$50 = 50 \times 215 \times cos^2(\frac{\pi}{1.94cm}y_0) \qquad (10)$$

$$y_0 = 0.66cm \qquad (11)$$

Updating inset distance, the antenna is simulated again, and it resonates at 2.41 GHz. However, the $|S_{11}|$ value at the resonant frequency is -8.57 dB but not lower than -10 dB. Hence, to achive that, W is increased to 3.06 cm and the antenna is matched at 2.4 GHz with an $|S_{11}|$ of -13.11 dB. The final $|S_{11}|$ plot can be seen in Fig. 3.

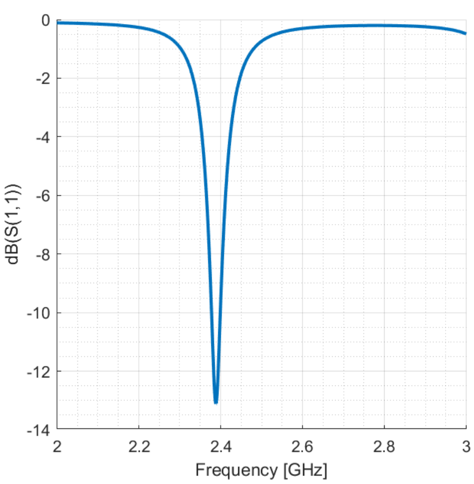

Fig. 3: $|S_{11}|$ plot of the final model.

The final dimensions can be seen in Table I.

Dimension	Value (cm)
W	3.06
L	1.92
h	0.127
W_s	4.7
Ls	6.22
L_{inset}	0.66
Inset gap	0.061
W_{feed}	0.12
L_{feed}	1.91

TABLE I: The final dimensions of the antenna.

B. Radiation Pattern

Radiation pattern of the antenna can be seen in Fig. 4. The maximum gain is 4.97 dB, the main lobe is towards to the +z direction.

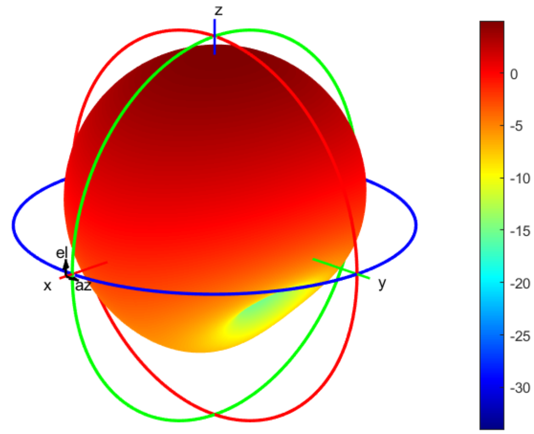

Fig. 4: The radiation pattern.

III. Results and Discussion

A. Patch Width (W)

Patch width is varied from 1.73 cm to 2.11 cm. The $|S_{11}|$ plots can be seen in Fig. 5. A. In Table II, one can conclude that as patch width increases, resonant frequency decreases but bandwidth increases.

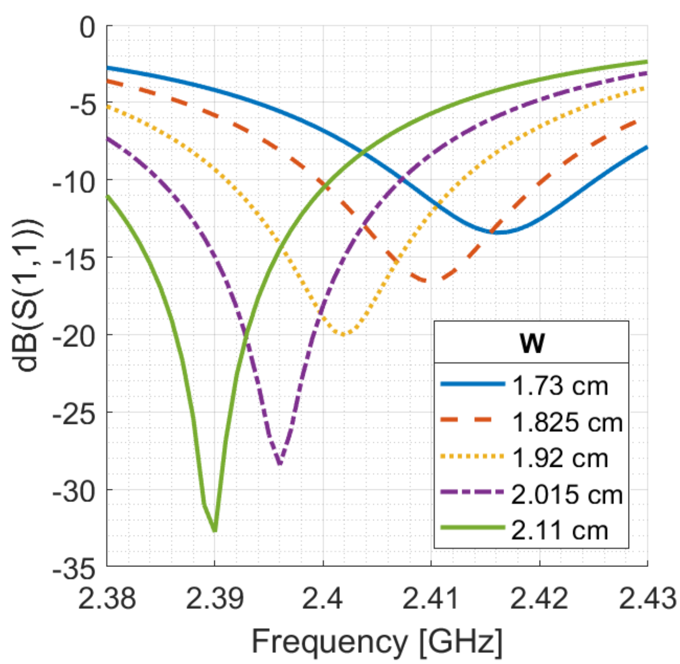

Fig. 5: $|S_{11}|$ plots when a variation in W is introduced.

B. Patch Length (L)

In Fig. 6, $|S_{11}|$ plots for different patch length values are presented. As the patch length increases, the resonant frequency shifts left, and other parameters are not monotonous in their change.

patchX (cm)	Min	XAtYmin	XatYval(-10)
2.38	-13.42	2.42	17.8e-3
2.51	-16.58	2.41	20.8e-3
2.64	-20.03	2.40	21.8e-3
2.77	-28.42	2.40	22.4e-3
2.9	-32.76	2.39	22.1e-3

TABLE II: $|S_{11}|$ at resonant frequency, resonant frequency and bandwidth values as patch width changes.

patchY (cm)	Min	XAtYmin	XAtYval (-10)
1.73	-19.29	2.56	18.1e-3
1.825	-33.78	2.50	20.8e-3
1.92	-20.04	2.40	21.8e-3
2.015	-12.30	2.26	15.5e-3
2.11	-12.25	2.16	6.0e-3

TABLE III: $|S_{11}|$ at resonant frequency, resonant frequency and bandwidth values as patch length changes.

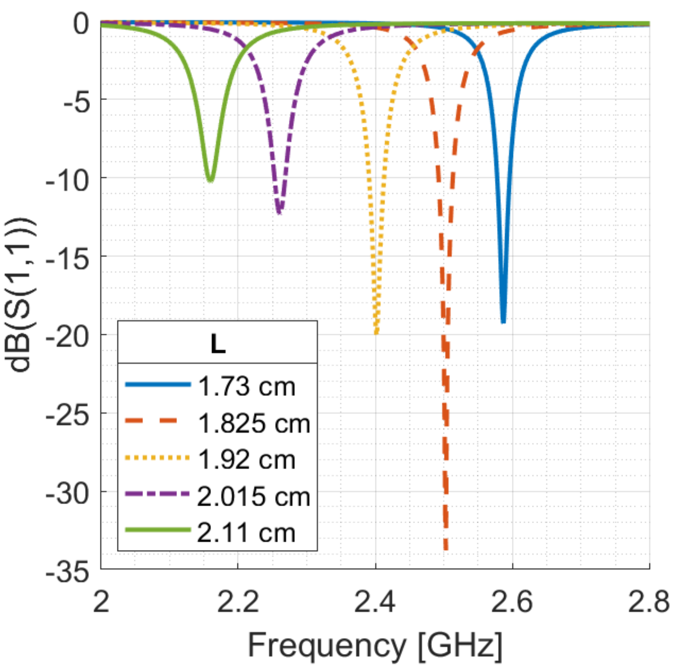

Fig. 6: $|S_{11}|$ plots when a variation in L is introduced.

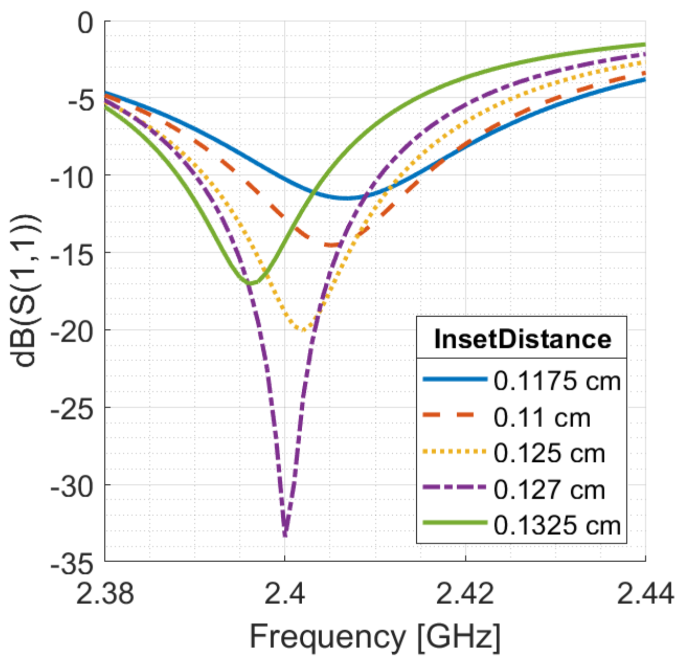

Fig. 7: $|S_{11}|$ plots when a variation in inset distance is introduced.

C. Inset Distance

The effect of the change in inset distance on $|S_{11}|$ can be seen in Fig. 7. By looking into the values provided in Table IV, it can be concluded that as the inset distance increases, the resonant frequency decreases but it is very low and can be ignored. On the other hand, both bandwidth and minimum $|S_{11}|$ fluctuates, showing no monotonic relation.

D. Substrate thickness (h)

The substrate thickness is varied to show the effect of it on $|S_{11}|$ in Fig D. Table V presents the observed changes in Fig. 8. As substrate thickness increases, resonant frequency slightly shifts to the left while $|S_{11}|$ worsens. A monotonic increase in bandwidth is also observed.

IV. Conclusion

A microstrip patch antenna can be designed to operate at different frequencies with different feeding methods using different substrate types. While the model is updated according to the feeding method, the model dimensions can be calculated independent of the selected feeding method. After reaching an approximate design, the antenna can be tuned considering that increase in patch width results in an increase in bandwidth but a decrease in resonant frequency, and an increase in patch length causes the resonant frequency to shift left. Also, the feeding point can be approximated using the formulas with simulations.

References

[1] Constantine A. Balanis Antenna Theory: Analysis and Design, 4rd ed. p.805, Hoboken, NJ: John Wiley, 2016.
[2] https://en.wikipedia.org/wiki/Patch_antenna
[3] Constantine A. Balanis Antenna Theory: Analysis and Design, 4rd ed. p.808, Hoboken, NJ: John Wiley, 2016.
[4] https://www.everythingrf.com/products/laminates/rogers-corporation

InsetDistance (cm)	Min	XAtYmin	XAtYval (-10)
0.73	-11.50	2.4070	15.2e-3
0.77	-14.54	2.4050	20.6e-3
0.81	-20.03	2.4020	21.8e-3
0.85	-33.41	2.40	20.6e-3
0.89	-17.03	2.3960	16.5e-3

TABLE IV: $|S_{11}|$ at resonant frequency, resonant frequency and bandwidth values as inset distance changes.

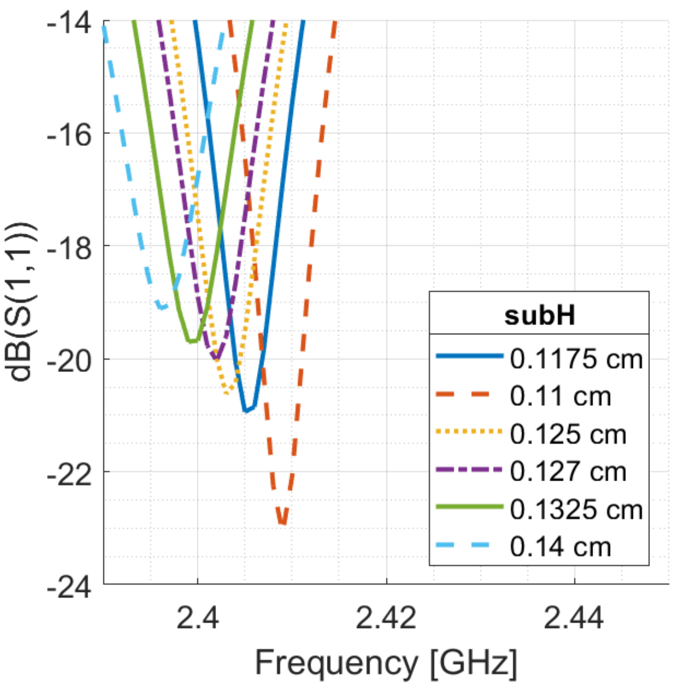

Fig. 8: $|S_{11}|$ plots when a variation in h is introduced.

subH (cm)	Min	XAtYmin	XAtYval (-10)
11.0e-2	-23.09	2.409	1.91e-2
11.75e-2	-20.1	2.405	2.02e-2
12.50e-2	-20.6	2.403	2.16e-2
12.7e-2	-20.0	2.402	2.18e-2
13.25e-2	-19.7	2.399	2.28e-2
14.0e-2	-19.1	2.396	2.40e-2

TABLE V: $|S_{11}|$ at resonant frequency, resonant frequency and bandwidth values as substrate thickness changes.