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Research Article

The Effect of Variation in Notch Width on Return Loss of Inset-Fed Rectangular Microstrip Patch Antenna for Wi-Fi Applications

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Abstract

In this paper, an inset-fed microstrip patch antenna for Wi-Fi application has been designed and the dependency of return losses on the notch gap has been studied. The study presented in this paper suggests that a narrower notch width results in better impedance matching.

Keywords: *Inset-fed, microstrip antenna, notch width, inset distance*

1. Introduction

Microstrip patch antennas have been extensively used mainly since they are lightweight, compact and cost effective. The input impedance of these antennas depends on their geometrical shape, dimensions, the physical properties of the materials involved, the feed type and location.. The inset-fed microstrip antenna provides a method of impedance control with a planar feed configuration [L. I. Basilio et.al, Jan. 2001, T. Samaras et.al, April 2004]. The experimental and numerical results showed that the input impedance of an inset-fed rectangular patch varied as a Cos^4 function of the normalized inset depth [L. I. Basilio et.al, Jan. 2001]. A more recent study projected a modified shifted Sin^2 form that well characterizes probe-fed patches with a notch [Y. Hu, E. J. Lundgren et.al, July 2005]. It is found that a shifted Cos^2 function works well for the inset-fed patch [Y. Hu, D. R. Jackson et.al, July 2006, Y. Hu, D. R. Jackson et.al, October 2008]. The parameters of the shifted cosine-squared function depend on the notch width for a given patch and substrate geometry. In this paper, we have analyzed the characterization of return loss as a function of notch width for an inset microstrip feed.

2. Basic characteristics of microstrip patch

The microstrip patch is intended such that its pattern maximum is normal to the patch (broadside radiator). This is able through proper choice of the mode (field configuration) of excitation beneath the patch. End-fire radiation can also be accomplished by thoughtful mode selection. The ones that are most wanted for antenna performance are thick substrates whose dielectric constant is in the lower end of the range. This is because they provide better efficiency, larger bandwidth, loosely bound fields for radiation into space, but at the expense of larger element size [D. M. Pozar et.al, January 1992]. Thin substrates with higher dielectric constants are attractive for microwave circuitry because they need tightly bound fields to minimize unwanted radiation and coupling, which lead to smaller element sizes; however, because of their greater losses, they are less efficient and have relatively smaller bandwidths [D. M. Pozar et.al, January 1992]. Since microstrip antennas are often incorporated with other microwave circuitry, a compromise has to be reached between good antenna performance and circuit design. Often microstrip antennas are referred to as patch antennas. The radiating elements and the feed lines are usually photo etched on the dielectric substrate. Square, rectangular, thin strip and circular microstrip patch configurations are the most common because of their ease of analysis, fabrication, and their attractive radiation characteristics, especially the low cross-polarization radiation. There are many configurations that can be used to feed microstrip antennas. The four most popular feeding techniques are the microstrip line, coaxial probe, aperture coupling and proximity coupling [D. M. Pozar et.al, January 1992] [I. J. Bahl and P. Bhartia et.al, 1980, M.A. Matin et.al, Feb, 2007]. In our paper, we have chosen inset feed microstrip line with rectangular microstrip patch.

3. Patch geometry

Fig.1 shows the patch geometry of an inset-fed rectangular patch, where the notch width 'g' is located symmetrically along the width of the patch. The dimensions of the different parameters have been approximated using the procedure discussed in [Constantine A. Balanis,1997] and the final values are determined through extensive numerical simulations which are shown in Table 1. The

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value of 'g' is changed with the ratio of '$W_p/20$', '$W_p/19$', '$W_p/18$', $W_p/17$', '$W_p/16$', '$W_p/15$', '$W_p/14$', $W_p/13$ and '$W_p/12$' where W_p is the width of patch

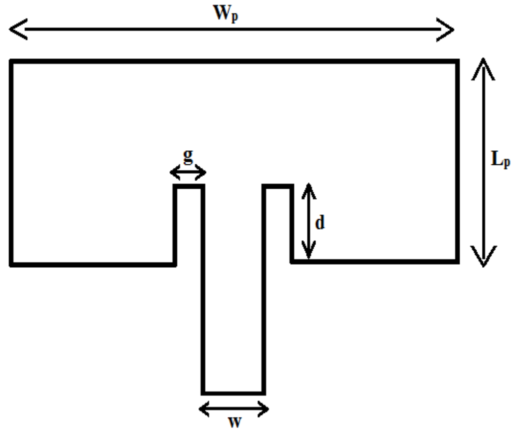

Fig1: Geometry of inset-fed microstrip patch antenna

Table 1: Physical dimensions of inset-fed microstrip patch antenna

Operating Frequency, f in GHz	2.4
Dielectric Constant, ε_r	4.4
Length of Patch, L_p in cm	2.9
Width of Patch, W_p in cm	3.839
Inset Distance, d in cm	0.9768
Width of microstrip feed line, W in cm	0.301

It was observed that with the variation in notch width, the resonant frequency does not shift much. It remains almost fixed at 2.4 GHz. Even the bandwidth does not show any considerable change. The bandwidth was almost constant i.e. 27.5MHz.The gain of antenna was also observed and found to be varying between 5.7755dB to 4.1038dB. For most of the iterations the gain remained almost 5.6 dB. The parameter which has shown a considerable change with the change in notch width is return loss. The notch width was varied in proportion of patch width 'Wp '. When the notch width was Wp/20 the return loss was observed to be -14.6855dB. The return loss for notch width wider than $W_p/20$ was lesser so we started to increase the notch width so that the return losses can be further decreased. As we increased the notch width the value of return loss started to decrease and it became maximum negative at notch width equal to $W_p/14$. When the notch width was further increased the return loss again started to increase. The variation of return loss as function of notch width is shown graphically in Figure 2 and Figure 3. It can be seen from the graph that the return loss decreases as the notch width is increased from $W_p/20$ to $W_p/14$. Whereas it again starts to increase as the notch width is further increased. Hence it can be said that there is a range in which if notch width is varied, the return loss first decreases with increasing notch width and after attaining its maximum negative value, the return loss again start to increase on increasing the notch width.

4. Design procedure

We adopt the design strategy of keeping the return loss minimum at the resonant frequencies as close as possible and striving to achieve -10dB return loss over the impedance bandwidth. In practice, the dielectric constants of the materials are not free variables, since discrete values depend on the dielectric material used. Therefore, it is convenient to choose the parameter ε_r in advance and vary other parameters. A further constraint must be placed on the thickness as common laminates are available only with a certain thickness. To account for this constraint, we initially allow a continuous choice of h. On finding an optimum, this thickness value is rounded to an available thickness and then optimization resumes with the available h. Therefore the dielectric constant and thickness above the ground plane are set to constant values that provide a good impedance match for inset-feed patch structure. The design procedure assumes that the specified information includes the dielectric constant of the substrate (ε_r) and a substrate thickness (h) and is stated as below:
Specify the center frequency and select a substrate permittivity ε_r and a substrate thickness h

$$h \geq 0.06 \frac{\lambda_{air}}{\sqrt{\varepsilon_r}} \tag{1}$$

Calculate W_p (width of patch) as [I. J. Bahl et.al, 1980]

$$W_p = \frac{v_o}{2 f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \tag{2}$$

Calculate ε_{reff} (effective dielectric constant) using the following common equation found in [R. P. Owens, 1976]

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[1 + 12 \frac{h}{W_p} \right]^{-1/2} \tag{3}$$

ΔL is the normalized extension of the length and given as:

$$\frac{\Delta L}{h} = 0.412 \frac{(\varepsilon_{reff} + 0.3)\left(\frac{W_p}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W_p}{h} + 0.8\right)} \tag{4}$$

Calculate the value of L_p (length of patch) as:

$$L_p = \frac{v_o}{2 f_r \sqrt{\varepsilon_r}} - 2\Delta L \tag{5}$$

Calculate the value Z_o (terminal input impedance) as:

$$Z_o = R_{in} \left(\cos^2 \frac{\pi}{L_p} d \right) \tag{6}$$

where d is the inset distance from the radiating edge, and R_{in} is the resonant input resistance when the patch is fed at the radiating edge. The inset distance d is selected such that Z_o is equivalent to the feed line impedance. The notch width 'g' is located symmetrically along the width of the patch.

Table 2: Performance analysis as a function of notch width

Notch Width / Performance Properties	$W_p/20$	$W_p/19$	$W_p/18$	$W_p/17$	$W_p/16$	$W_p/15$	$W_p/14$	$W_p/13$	$W_p/12$
Return Loss(d)	-14.68 55	-15.68 60	-16.12 29	-17.58 35	-20.22	-23.31 70	-28.65 34	-19.00 94	-18.96 23
-10dB Bandwidth(MHz)	24.4	27.5	27.5	27.5	27.5	27.5	27.5	27.5	27.5
Antenna Gain(dB)	5.6478	5.5472	5.6604	5.717	5.6604	5.7755	5.6604	4.1038	5.6321

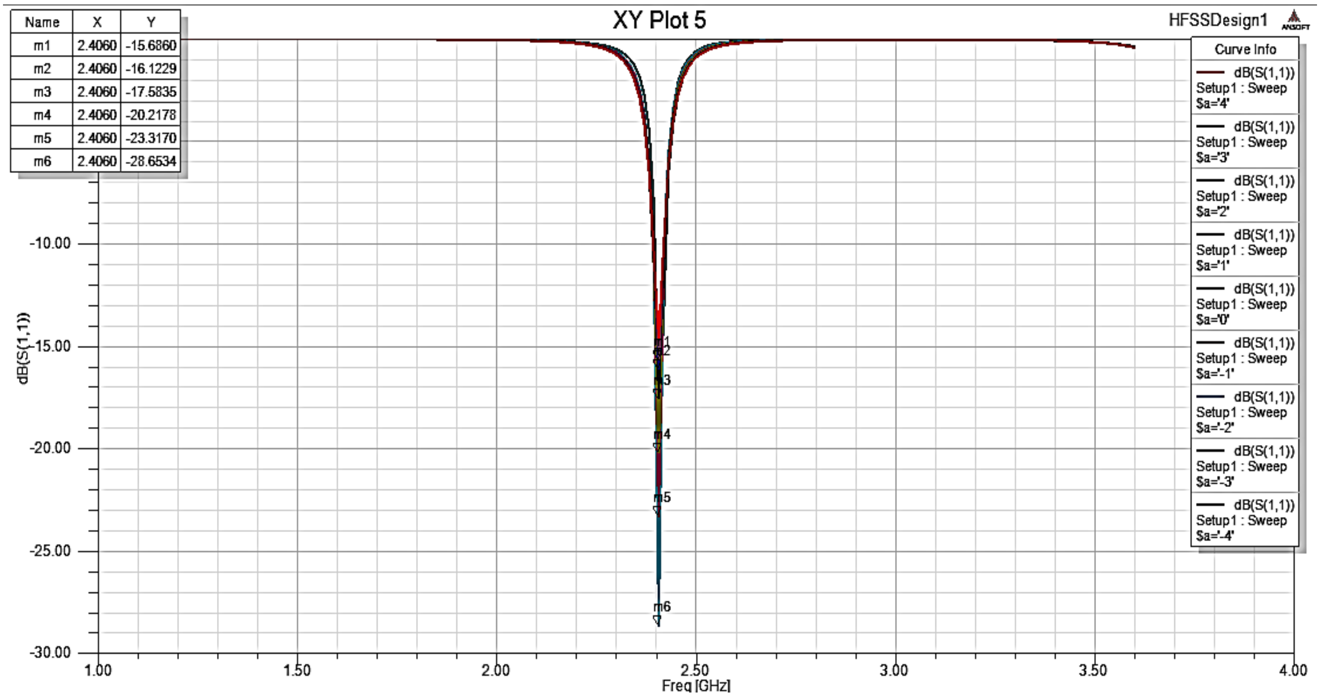

Fig 2: Return Loss with variation in notch width

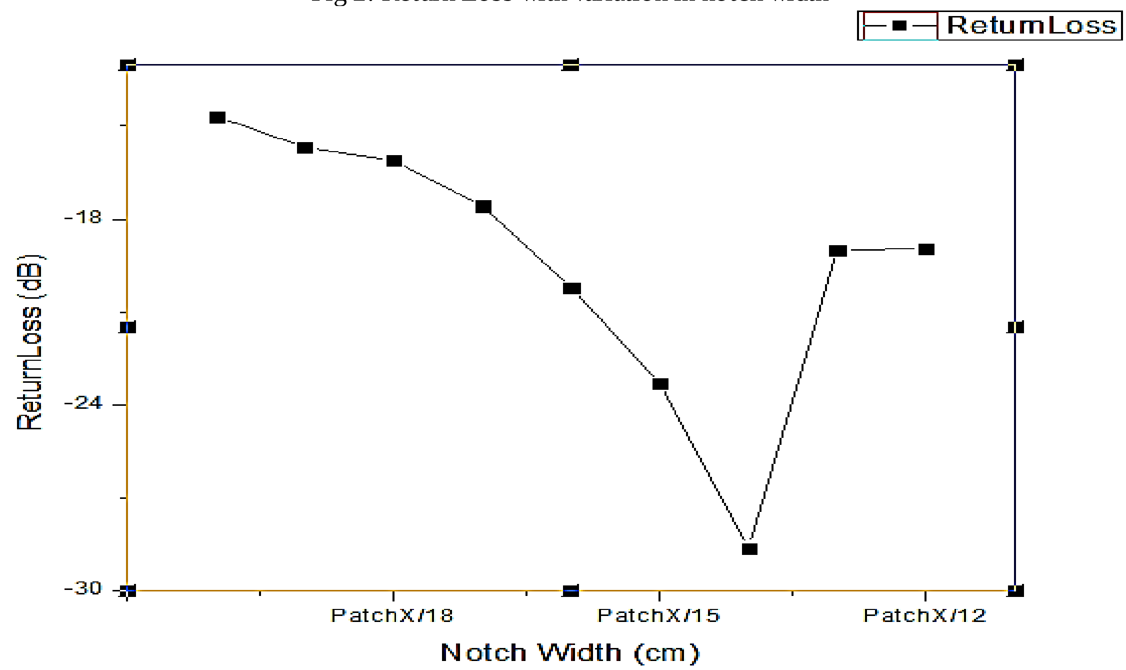

Fig 3: Return Loss as a function of notch width ‘g’

A. The Resonance Input Resistance, R_{in} Calculation

A rectangular patch can be represented as an array of two radiating slots, each of width W_p, height *h* and separated by a distance L_p. Each slot is equivalent to a parallel equivalent admittance *Y* with conductance *G* and susceptance B. The equivalent circuit transmission model of a microstrip patch antenna is shown in Figure 4. The conductance of a single slot can be obtained using the following equation:

$$G_1 = \frac{1}{120\pi^2}\int_0^{\pi}\left[\frac{\sin\left(\frac{k_o W_p}{2}\cos\theta\right)}{\cos\theta}\right]^2 \sin^3\theta d\theta \tag{7}$$

Ideally the two slots should be separated by λ/2 where λ is the wavelength in the dielectric substrate. But in reality, the separation of slots is slightly less than λ/2 because the length of the patch is electrically longer than the actual length due to fringing [Constantine A. Balanis, 1997]. The mutual conductance G_{12} can be calculated using [A. G. Derneryd, 1978].

$$G_1 = \frac{1}{120\pi^2}\int_0^{\pi}\left[\frac{\sin\left(\frac{k_o W_p}{2}\cos\theta\right)}{\cos\theta}\right]^2 * J_o\left(k_o L_p \sin\theta\right)\sin^3\theta d\theta \tag{8}$$

where J_o is the Bessel function of the first kind of order zero. The mutual conductance obtained using equation (8) is small compared to the self -conductance. Taking mutual effects into account between the slots, the resonant input impedance can be calculated as [G. Derneryd, 1978]

$$R_{in} = \frac{1}{2\left(G_1 + G_{12}\right)} \tag{9}$$

The inset feed introduces a physical notch, which in turn introduces a junction capacitance. The physical notch and its corresponding junction capacitance influence the resonance frequency. As the inset feed point moves from the edge toward the center of the patch the resonant input impedance decreases monotonically and reaches zero at the center. When the value of the inset feed point approaches the center of the patch, the $\cos^2\left(\frac{\pi}{L_p}d\right)$ varies very rapidly; therefore the input resistance also changes rapidly with the position of the feed point.

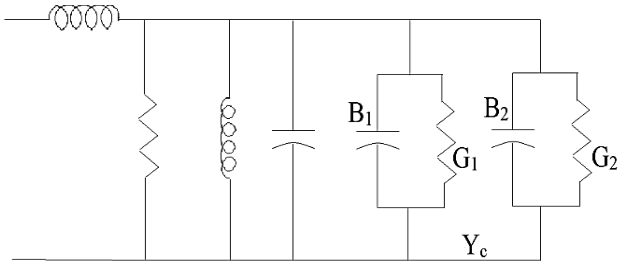

Fig 4: Equivalent circuit of inset fed microstrip patch antenna

6. Design example

The design is intended to operate at 2.4 GHz resonance frequency. The -10dB bandwidth is shown in Fig. This example demonstrates that while the design procedure can do a good job of producing an antenna with designated resonant frequencies, it does not necessarily give a design with good bandwidth characteristics, which are still largely a function of dielectric thickness and feed point position.

The radiation pattern at notch width $W_p/14$ is shown in Figure 6 and Figure 7 Simulations are performed for fixed notch width and depth. Increasing either the notch width or depth results in greater disturbance of patch currents

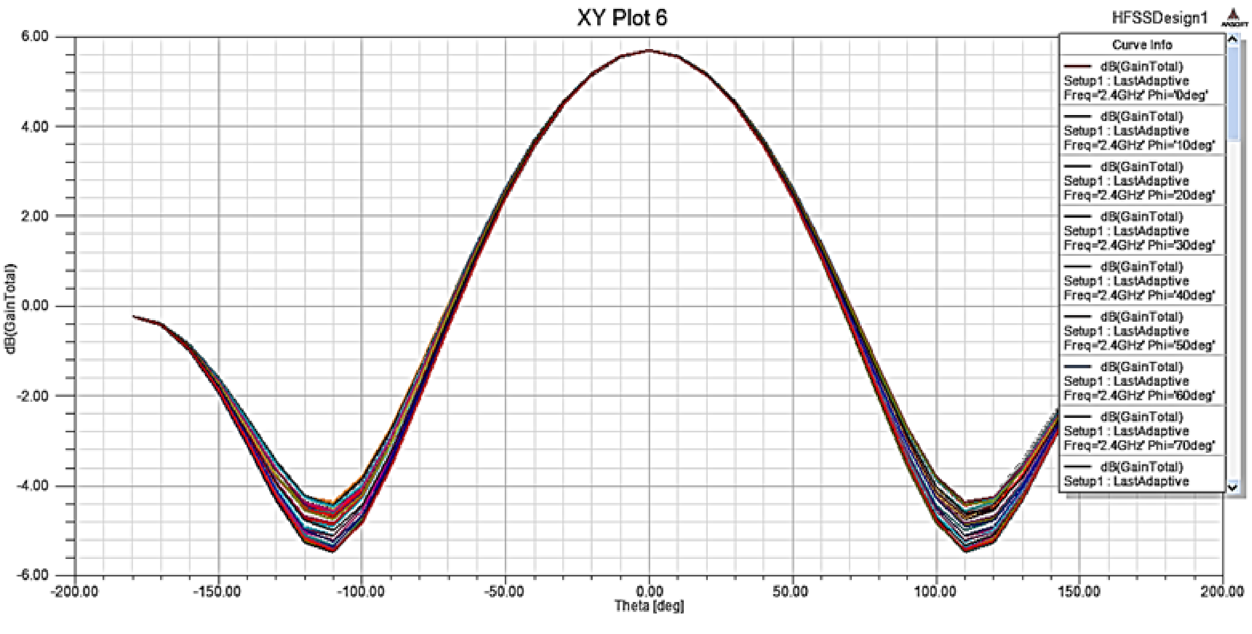

Fig 5: Gain

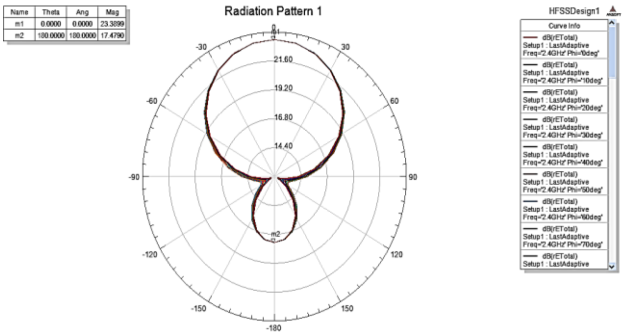

Fig 6: Radiation Pattern

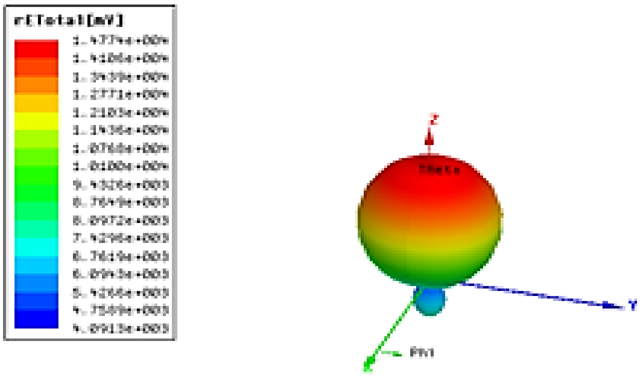

Fig 7: 3-D Polar Plot

Conclusion

In this paper the inset fed rectangular microstrip patch antenna for wi-fi application has been designed. The dependency of return loss on notch width has been studied and the corresponding results have been simulated for 50ohm microstrip line. When the notch width was Wp/20 the return loss were observed to be -14.6855dB. The return loss for notch width wider than $W_p/20$ was lesser so we started to increase the notch width so that the return loss can be further decreased. As we increased the notch width the value of return loss started to decrease and it became maximum negative at notch width equal to $W_p/14$. When the notch width was further decreased the return loss again started to increase. Hence it can be concluded that there is a range in which when notch width is varied, the return loss first decreases with increasing notch width and after attaining its maximum negative, the return loss again start to increase.

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