Parametric Study of Rectangular Microstrip Patch Antennas

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Abstract

This paper presents a parametric study of rectangular microstrip patch antenna and their effect on its performance. The antenna has been analyzed using commercially Sonnet 14.53 software based on method of moments (MoM) at resonance frequency of 1.691 GHz. The obtained results show the effect of various parameters such as patch width, height, dielectric constant $\varepsilon_r$, dielectric loss $\delta$ and feed point location on the resonance frequency, return loss, input impedance, bandwidth, directivity and VSWR.

I-Introduction

The idea of microstrip antenna (MSA) can be traced to 1953 by Deschamps [1]. Practical antennas of this type were developed by Munson [2], [3] and Howell [4] in the 1970s. A microstrip patch antenna in its simplest form is a sandwich of two parallel conducting layers separated by a single thin dielectric substrate as shown in Figure 1. The upper conductor is a thin metallic patch generally made of copper or gold which is a small fraction of wavelength Stutzman [5]. The lower conductor is a ground plane which should be infinitely theoretically. The patch and the ground plane are separated by a dielectric substrate which usually non-magnetic.

The essential parameters to design a rectangular microstrip patch antenna are resonance frequency, dielectric constant and height of the substrate. Thin substrate permits to reduce the size and also spurious radiation as surface wave, and low dielectric constant for higher bandwidth, low power loss and better efficiency. However, for good antenna performance a thick dielectric substrate having a low dielectric constant is desirable for higher bandwidth, better efficiency leading to larger antenna size. The dielectric constant of the substrate ranges from 1.07 to about 13, with the loss tangent ranging from 0.0001 to 0.017 [6], while the height is usually $0.003\lambda_0 \leq h \leq 0.05\lambda_0$ Balanis [7].

The patch can assume any shape, such as rectangular, circular, triangular, elliptical, helical, circular ring, etc. The variety in design that is possible with microstrip antennas probably exceeds that of any other type of antenna element.

Microstrip antennas are widely used in many wireless applications because exhibit a very low profile, small size, light weight, low cost, high efficiency and easy methods of fabrication. This is led to the design of...
several configuration for various applications.
The length \( L \) of the rectangular patch for the fundamental TM\(_{10} \) mode excitation is slightly smaller than \( \lambda/2 \), where \( \lambda \) is the wavelength in the dielectric medium, which in terms of free-space wavelength \( \lambda_0 \) is given as \( \lambda_0/\sqrt{\varepsilon_{\text{reff}}} \), where \( \varepsilon_{\text{reff}} \) is the effective dielectric constant of a microstrip line of width \( w \). The value of \( \varepsilon_{\text{reff}} \) is slightly less than the dielectric constant \( \varepsilon_r \) of the substrate because the fringing fields from the patch to the ground plane are not confined in the dielectric only, but are also spread in the air.

II- Antenna Design

A rectangular microstrip antenna is considered to study the serious effects of various parameters on its performance. The initial width (W) and Length (L) of the patch have been determined using the following formulas respectively [8].

\[
W = \frac{c}{2f_0 \sqrt{\left(\varepsilon_r + 1\right)/2}} \\
L = L_{\text{eff}} - 2\Delta L
\]

Where,

\[
L_{\text{eff}} = \frac{c}{2f_0 \sqrt{\varepsilon_{\text{reff}}}} \\
\Delta L = 0.412h \left(\frac{\varepsilon_{\text{reff}} + 3}{\varepsilon_{\text{reff}} - 2.58} + \frac{h}{W} \right) \left(h/W + 0.254\right)
\]

for \( w/h \geq 1 \)

\[
\varepsilon_{\text{reff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[1 + \frac{h}{W} \right]^{1/2}
\]

The expression for approximately calculating the directivity \( D \) of the RMSA is given by [9].

\[
D \approx 0.2W + 6.6 + 10 \log \left(1.6/\sqrt{\varepsilon_r}\right) \text{ dB.}
\]

The three essential parameters for the design of a rectangular microstrip patch antenna are:

- Frequency of operation \( f_o \) is selected to be 1.691 GHz.
- Dielectric constant of the substrate \( \varepsilon_r \) is taken as Rogers RT5880 which has a dielectric constant of 2.2 and loss tangent 0.0009.
- Height of dielectric substrate \( h \) is selected to be 0.0179\( \lambda_0 \) which equals to 3.175 mm.

Substituting \( c = 3 \times 10^8 \) m/s, \( \varepsilon_r = 2.2 \), \( f_o = 1.691 \) GHz, and \( h = 3.175 \) mm in equations 1 to 5 we get:

\[
W = 70.127 \text{ mm} \\
L_{\text{eff}} = 61.462 \text{ mm} \\
\Delta L = 1.6681 \text{ mm} \\
L = 58.126 \text{ mm}
\]

The width of the patch have been optimized using Microstrip Antenna Calculator [10] and reduced to 39 mm to resonate the patch at 1.691 GHz.

III- Results and discussions

The performance of this model antenna has firstly been investigated and considered as a reference for comparison sake.

Table 1 summarizes the results of this reference antenna for feed point location \( x = 17.1878 \) mm. The probe diameter is taken as 0.25 mm throughout the simulation. The antenna has been analyzed using Sonnet 14.53 software based on method of moments (MoM) [11].

<table>
<thead>
<tr>
<th>( s_{11} \text{ dB} )</th>
<th>( R_{in} \Omega )</th>
<th>( BW \text{ MHz} )</th>
<th>( VSWR )</th>
<th>( D \text{ dB} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>-30.6</td>
<td>52.98</td>
<td>89</td>
<td>1.06</td>
<td>6.94</td>
</tr>
</tbody>
</table>

Effect of feed location:

The effect of feed point location on the performance of the antenna was investigated by adjusting the position of the feed point location between the centre and the edge of
the patch until resonance occurs at which the return loss is most minimum. Three feed point locations have been selected to illustrate these effects on the performance of the antenna \( x \) (11.3678, 14.2815 and 17.1878 mm). Figure 2 (a,b,c) shows the variation of real part of the input impedance, return loss \( S_{11} \) and VSWR with frequency.

![Figure 2 Effect of feed location \( x \), (a) on real input impedance, (b) on return loss, (c) on VSWR.](image)

It can be seen that as the feed point location \( x \) shifted towards the centre of the patch the resonance frequency increases from 1.677 GHz to 1.691 GHz which is the resonance frequency of the reference antenna at which the return loss is most minimum with value of -30.6 dB. While the input resistance decreases from 84.6 Ω to 52.98 Ω at resonance. The VSWR of the three points of feed location is within the acceptable range i.e < 2 but the lowest value of 1.061 was recorded at resonance.

The bandwidth increases from 67 MHz to 89 MHz as \( x \) shifted toward the point of resonance. The directivity calculated using equation (6) for \( x=17.1878 \) mm and found to be 6.94 dB.

**Effect of dielectric constant:**
The dielectric constant \( \varepsilon_r \) is one of the main parameters of the microstrip antenna and can effect seriously its dimensions and performance. Figure 3 illustrates the plots of real input impedance, return loss and VSWR for three values of \( \varepsilon_r \) (1.96, 2.2 and 3) including that of the reference antenna for comparison sake.
Effect of loss tangent:

By considering the cost of the antenna the dielectric loss of the substrate has to be taken into account and hence it's very important to know the effect of tan δ on the performance of the antenna. Considering the dimensions of reference antenna and feed point location x=17.1878 mm and three different values of tan δ (.0009, .003 and .025) the input impedance (real part), return loss and VSWR plots are shown in figure 4.

When the value of the dielectric constant $\varepsilon_r$ decreases below that of the reference antenna the resonance frequency increases to 1.781 GHz, the bandwidth increases to 99 MHz for a feed location of $x=17.1878$ mm. It is very clear from the plots that when $\varepsilon_r$ increased above the value of the reference antenna the resonance frequency decreases to 1.468 GHz, and the bandwidth decreases to 59 MHz. The decrease in bandwidth is due to decrease in the dimensions ($w$ and $l$) of the patch. The input resistance and VSWR for the three values of $\varepsilon_r$ remains quite the same. The directivity decreases slightly from 7.19 dB to 6.26 dB as $\varepsilon_r$ increases from 1.96 to 3.
Figure 4 Effect of loss tangent $\tan \delta$, (a) on real input impedance, (b) on return loss, (c) on VSWR. Figure 4 plots show that as the dielectric loss increases from 0.0009 to 0.025 the input resistance decreases from 52.98 $\Omega$ to 40.738 $\Omega$ which due to the increase of the loss in the dielectric material leading to an increase in bandwidth from 89 MHz to 96 MHz. The resonance frequency remains at 1.691 MHz and the directivity around 6.94 dB.

**Effect of substrate height**: Because the dimensions of the patch are finite along the width and length, the fields at the edges of the patch undergo fringing [7]. The amount of fringing is a function of the patch dimensions and the height of the substrate. Figure 5 illustrates the plots of the input impedance (real part), return loss and VSWR for two different heights of $h$ (3.175 and 6.35 mm) and feed point location of $x=17.1878$ mm.

![Figure 5](image)

The plots in figure 5 show that with an increase of the substrate height $h$ from 3.175 mm to 6.35 mm the fringing fields from the patch edge increase which in fact increases the extension in length $\Delta l$ and hence increase the effective length of the patch and thereby influence the resonance frequency which clearly seen from the plots i.e. the resonance frequency decreases from 1.691 GHz to 1.637 GHz. The bandwidth increases from 89 MHz to 164 MHz.

The input impedance $z_{in}$ of both heights found to be $(52.98-j.578)\Omega$ and $(45+j.3.264)\Omega$ respectively. This means that an inductive shift occurs due to the increase in the probe inductance. The VSWR is quite the same for both heights. The directivity of the antenna increases because the effective aperture is increased due to increase of $\Delta l$. The directivity of the antenna for both heights calculated and found to be 6.94 dB and 8.58 dB respectively.

**Effect of the width**: The width of a rectangular microstrip antenna has a significant effect on the input
impedance, gain and bandwidth. And can be used to vary the input impedance with wide patches having lower impedances but should not exceed one wavelength to avoid higher modes [12]. Four different widths of $w$ (19, 29, 39 and 49 mm) had been simulated. The input impedance (real part), return loss and VSWR plots for feed point location of $x=17.1878$ mm are shown in figure 6. Table 2 summarized the obtained results. From table 2 it can be seen that as the width of the patch increases from 19 mm to 49 mm the performance of the antenna altered very seriously compared to that of the reference antenna.

The obtained results show that the resonance frequency decreases from 1.738 GHz to 1.677 GHz which due to the increase of the length extension $\Delta l$ and the effective dielectric constant [6]. The return loss and VSWR decreases from -7.47 dB to -30.61 dB and 2.467 to 1.06 respectively. But for width greater than that of the reference antenna the return loss and VSWR increase slightly by more than that of the reference antenna values.

The input resistance also decreases from 120.51 $\Omega$ to 41.51 $\Omega$ at resonance because

![Figure 6](image_url)

Figure 6 Effect of substrate width, (a) on real input impedance, (b) on return loss, (c) on VSWR.

...the radiation from radiating edges increases. The aperture area of the patch will also increase resulting an increase in the directivity. The bandwidth of the antenna decreases for width greater than that of the reference antenna. For width of 19 mm the return loss is less than 9.5 dB so the bandwidth calculation had been dropped.

As mentioned above the input impedance decreases as the width increase, so to obtain input resistance in the range of 50 $\Omega$ to 65 $\Omega$ the feed point location must be adjusted for each width.

Table 3 summarizes the obtained results. As the width increases from 19 mm to 49 mm the resonance frequency decreases, bandwidth increases, and directivity increases from 6.93 dB to 9.4 dB while VSWR remains quite constant.

**IV-Conclusions**

The effect of various parameters of rectangular microstrip patch antenna on its performance were presented. From the obtained results summarized in table 2 we can conclude that the width of the patch has a pronounced effect on the resonance.
frequency, input impedance and bandwidth. On other hand to keep the input resistance in the range of 50 Ω to 65 Ω the feed point location must be adjusted for each width. Substrate height variation can also effect the resonance frequency, input impedance and bandwidth of the antenna. The resonance frequency and bandwidth found to be inversely proportional with $\varepsilon_r$, while dielectric loss $\delta$ alter the bandwidth and input impedance but has no effect on the resonance frequency, VSWR and directivity. The effect of shifting the feed point location between the edge and the centre of the patch seriously alter the antenna performance since there will be a point at which resonance occurs.

Table 2: Effect of width on the performance of RMSA for $x=17.1878$ mm.

<table>
<thead>
<tr>
<th>w (mm)</th>
<th>f (GHz)</th>
<th>$R_{in}$ (Ω)</th>
<th>BW (MHz)</th>
<th>D (dB)</th>
<th>VSWR</th>
<th>$S_{11}$ (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>1.738</td>
<td>120.51</td>
<td>-</td>
<td>6.93</td>
<td>2.47</td>
<td>-7.47</td>
</tr>
<tr>
<td>29</td>
<td>1.707</td>
<td>78.66</td>
<td>68</td>
<td>6.93</td>
<td>1.61</td>
<td>-12.58</td>
</tr>
<tr>
<td>39</td>
<td>1.691</td>
<td>52.98</td>
<td>89</td>
<td>6.94</td>
<td>1.06</td>
<td>-30.61</td>
</tr>
<tr>
<td>49</td>
<td>1.677</td>
<td>41.51</td>
<td>77</td>
<td>6.94</td>
<td>1.22</td>
<td>-20.06</td>
</tr>
</tbody>
</table>

Table 3: Effect of width on the performance of RMSA for different feed locations $x$.

<table>
<thead>
<tr>
<th>w (mm)</th>
<th>x (mm)</th>
<th>f (GHz)</th>
<th>$R_{in}$ (Ω)</th>
<th>BW (MHz)</th>
<th>D (dB)</th>
<th>VSWR</th>
<th>$S_{11}$ (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>21.8278</td>
<td>1.713</td>
<td>59.64</td>
<td>71</td>
<td>6.93</td>
<td>1.23</td>
<td>-19.81</td>
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<tr>
<td>29</td>
<td>18.71</td>
<td>1.693</td>
<td>59.13</td>
<td>76</td>
<td>6.93</td>
<td>1.21</td>
<td>-20.4</td>
</tr>
<tr>
<td>39</td>
<td>17.1878</td>
<td>1.691</td>
<td>52.98</td>
<td>89</td>
<td>6.94</td>
<td>1.06</td>
<td>-30.61</td>
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<tr>
<td>49</td>
<td>14.2778</td>
<td>1.678</td>
<td>58.66</td>
<td>93</td>
<td>9.4</td>
<td>1.19</td>
<td>-21.35</td>
</tr>
</tbody>
</table>

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دراسة لعوامل الرقعة الشريطي الدقيق مستطيل الشكل
محمد مسعود أبوالعوينات
قسم الفيزياء - كلية العلوم - جامعة سبها

تم تقديم هذه الورقة دراسة لعوامل (بارامترات) الرقعة الشريطي الدقيق مستطيل الشكل (rectangular microstrip) وتأثيرها على أداءها، حيث تم ذلك باستخدام برنامج المحاكاة التجاري Sonnet 14.53 المعتمد (patch antenna) على طريقة العزوم عند تردد رنين $f_{ren}=1.691$ GHz ود. وقد أظهرت النتائج المتحصل عليها أن هذه العوامل المختلفة مثل...
عرض وارتفاع الرقعة، ثابت العزل $\varepsilon_r$، فقد العزل $\varepsilon_r$، و موقع نقطة التغذية تأثيرات بالغة على تردد الرنين، فقد العودة، معاكاة الدخول، المدى الترددي، الاتجاهية و نسبة فولتية الموجة المستقرة VSWR.

VI-References