Compact dual band slotted patch antenna for wireless systems

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This paper presents the study on a slot-etched rectangular patch antenna directly fed by the 50 Ω semi miniature A-type (SMA) co-axial connector for wireless systems. The dual frequency behaviour by etching the slots on plane patch surface is studied experimentally. The proposed patch antenna has also achieved 28% compactness with a gain of 9.74 dB. Other antenna parameters such as antenna input impedance, voltage standing wave ratio (VSWR), return loss, gain and bandwidth are presented. Details of antenna geometry, patch design and experimental results are also presented. This antenna finds applications in WiMax, radar communication, WLAN, and fixed satellite service applications covering 3 – 4 GHz frequency range.

Keywords: Patch antenna, Return loss, Dual resonance, Dual band antenna, Broadband microstrip antenna, Gain, Bandwidth, Single low profile, Voltage standing wave ratio (VSWR)

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1 Introduction

In recent years, several methods for obtaining dual band, multiband and/or wideband antenna characteristics have been developed. Communication system applications such as radar, synthetic aperture radar (SAR), etc. often require dual frequency patch antennas in order to avoid the use of two different antennas. A suitable dual frequency antenna should have resembling characteristics in both operating forms (transmitting and receiving) in terms of radiation properties and impedance matching. In general, three techniques for obtaining dual-frequency operation have been mentioned in the literature: (i) the orthogonal mode of polarization, (ii) multi-resonator antennas, and (iii) reactively loaded antennas. Among these, using reactively loaded antennas is one of the most popular techniques for obtaining dual frequency behaviour. In this case, dual resonance can be obtained by introducing slots parallel to the radiating edges of the patch and coaxial or microstrip stubs at the radiating edges of the patch.

Sittiromnarit et al. have presented a dual wideband folded microstrip patch antenna for possible wireless local area network (WLAN) applications in the 3.5 - 4 GHz frequency range. The antenna operated in a wide frequency band by utilizing a unique coupling mechanism between the radiating elements and the ground plane. A similar approach was presented by Khairul et al., where a single low profile printed antenna, which provided dual band operation by having loading from two-step slots embedded close to the radiating edge. A broadband cavity-backed proximity-coupled stacked microstrip antenna is presented. Due to the interaction of the two stacked patches, two associated resonances are produced. These devised methods make the antenna act as multiple resonances, conducing to a broadband impedance matching. The simulated and the measured results demonstrate a bandwidth over one octave (VSWR < 2). A dual-layer microstrip antenna at 1.268 GHz was designed and analyzed. The simulation results indicated that the frequency channels of the antenna was 1.268 GHz, the bandwidth of the microstrip antenna achieved 35 MHz and the gain achieved 6 dB. The concept of etching slot on patch has proven to give remarkable functionality to an antenna and causes it to radiate significantly at different ranges of frequencies, using only one single feed point.

2 Antenna geometry and patch design

The proposed geometry of the antenna is shown in Fig. 1. A single-sided copper cladded FR4 superstrate having permittivity \( \varepsilon_r = 4.4 \) is placed in inverted
configuration forming the radiating patch. The thickness of the superstrate \( h_{\text{sup}} \) is 1.66 mm and there is an air gap \( \Delta \) of 8.5 mm above the ground plane (aluminium plate of thickness \( h_{\text{gnd}} = 1 \) mm). Four cylindrical plastic spacers, each of height 8.5 mm are used to provide thick air gap and also to avoid the shortening of patch. Ground plane size \( (L_g \times W_g) \) 28 x 35 mm is used. In order to get better accuracy, the antenna geometry is designed using computer software (Auto CAD – 2008) and is fabricated using photolithography process. The patch design is as follows:

The patch width \( W \) shown in Fig. 2 is given by Eq. (1)\(^{11} \):

\[
W = \frac{c}{2f_r} \sqrt{\left( \frac{\epsilon_r + 1}{2} \right)}
\]

... (1)

The length of patch \( L \) is given by Eq. (2)\(^{12-14} \):

\[
L = \frac{c}{2f_r \sqrt{\epsilon_r}} \sqrt{\frac{2\Delta l}{\epsilon_r}}
\]

where,

\[
\Delta l = 0.412 h \left( \frac{w}{h} + 0.264 \right)
\]

... (2)

where,

\[
\epsilon_r = \left( \frac{\epsilon_e + 1}{2} \right) + \left( \frac{\epsilon_e - 1}{2} \right) \sqrt{1 + \frac{12h}{w}}
\]

... (3)

The ground plane size \( L_g \) and \( W_g \) are given by Eq. (5)\(^{15} \):

\[
\begin{align*}
L_g &= 6h + l \\
W_g &= 6h + w
\end{align*}
\]

... (5)

The antenna is fed by a 50 \( \Omega \) SMA co-axial connector. The inner conductor of SMA connector has radius \( r = 0.4 \) mm and serves as a feed for microwave power. This coaxial feed is used to excite the microstrip patch. The feed point for the patch antenna is found using Eq. (6)\(^{16} \):

\[
R(x) = R_o \cos^2 \left( \frac{\pi x}{L} \right)
\]

... (6)

where, \( R(x) \), is input resistance at resonance for the dominant TM\(_{10} \) mode; \( R_o \), the radiation resistance at resonance when the patch is fed at radiating edge; \( L \), the patch length; \( x \), distance from the patch edge with constant \( \pi = 3.142 \). Hence, the feed point location is placed on the conducting patch element on the \( y \) axis at a distance \( x = 4.2 \) mm from the top edge of the patch as shown in Fig. 1. The techniques adopted offer easy patch fabrication for array structures.

With the equations mentioned above, the calculated dimensions of simple rectangular patch antenna (SRPA) in length and width \( (L \times W) \) are 17.76 x 23.28 mm and its geometry is as shown in Fig. 2. Figure 3 illustrates the geometry of slotted rectangular patch antenna (SLRPA). The dimensions of slots with length \( A_{s1} = A_{s3} = 19.14 \) mm; \( A_{s2} = 2 \) mm and width \( B_{s1} = B_{s3} = 4.86 \) mm; \( B_{s2} = 4.51 \) mm are used. The space between slots are \( S_{p1} = S_{p4} = 4.17 \) mm; \( S_{p2} = S_{p3} = 2.01 \) mm; \( S_{p5} = S_{p7} = 0.68 \) mm; and \( S_{p6} = 9.25 \) mm. The calculated slot dimensions are function of \( \lambda_{v} \), where \( \lambda_{v} \) is free space wavelength.
3 Experimental verification

The designed frequency for SRPA is 3.85 GHz using the fundamental equations presented in literature. Practical impedance bandwidth of SRPA is 230 MHz (3%) at fr1 = 3.85 GHz which is in good agreement with theoretical impedance bandwidth (4.7%) with return loss (RL) of -15 dB as shown in Fig. 4. The practical impedance bandwidth of this antenna is calculated using Eq. (7):

\[
\text{Bandwidth} = \left( \frac{f_H - f_L}{f_C} \right) \times 100\%
\]

where, f_h and f_l are the upper and lower cut-off frequencies; and f_c, the center frequency. The theoretical bandwidth of this antenna is calculated using Eq. (8):

\[
\text{Bandwidth (\%)} = \frac{A \times \frac{h}{\lambda}}{\sqrt{\frac{W}{L} \times \sqrt{e_r}}} \times 100\%
\]

where, \(A\), is the correction factor, which is found to be 180 as per Kumar & Ray. The gain of the proposed antenna SRPA at resonant frequency 3.85 GHz is 3 dB which is in good agreement with the theoretical result (2.88 dB). However, when a single vertical and pair of horizontal slots are etched on the patch surface (SLRPA), the antenna resonates at two different frequencies 3.29 and 4.31 GHz as shown in Fig. 5 achieving impedance bandwidth of 180 (2.46%) and 130 MHz (3%) with return loss (RL) of -14.18 and -37.73 dB, respectively and attaining gain of 9.74 and 5.76 dB as shown in Fig. 6. This lowers
the resonant frequency of SLRPA offering 28% compactness compared to SRPA.

The measured VSWR of SRPA and SLRPA are depicted in Fig. 7 signifying less reflected power. Proposed patch antennas also exhibit good broadsided radiation pattern with linear polarization characteristics as shown in Fig. 8. The 3 dB half power beam widths of SRPA and SLRPA at their resonating frequencies are 41°, 15° and 49°, respectively. Figure 9 shows impedance characteristics of SLRPA where it is seen that the input impedance is 52.63+j20.10 at 3.26 GHz and 50.43+j1.452 at 4.31 GHz with two loops in Smith chart that signifies its dual frequency operation.

4 Conclusions
In this paper, a slot etched rectangular patch antenna exhibiting dual frequency operation has been designed from single frequency operation with linearly polarized broadsided radiation patterns. The resonant frequency of SRPA is 3.85 GHz and SLRPA resonates at 3.29 and 4.31 GHz. A compactness of 28% is achieved. Proposed patch antenna achieved a gain of 9.74 and 5.76 dB, respectively at its resonating frequencies. The proposed antenna can find applications in WiMax, operating in the frequency range 3.3-3.6 GHz, fixed satellite services, aeronautical mobile applications and maritime mobile services (3-4 GHz).

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