Patch antenna with circular and rectangular notches and slots for millimeter waves

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Abstract. This manuscript presents Rectangular patch antenna with slots and notches for mm wave. An antenna has dual band with two resonating bands at 24GHz and 39 GHz. First resonating band gives ultra wide band of 27.08% while second resonating band is narrow band. Antenna characteristics have been observed such as radiation pattern, radiation efficiency, impedance and reflection co-efficient. The radiation efficiency of 80% and broadside radiation pattern d has been observed at center frequency. The variation of dielectric constant on the patch has been also observed in achieving dual band. This antenna can be used in various wireless applications such as 5G allocation band of European countries, vehicular communication.

Keywords: Circular slots, Rectangular slots, Patch Antenna, Radiation Pattern, K band, Ka band.

1. Introduction

Microstrip antennas are widely used in wireless communication, since the main advantage of microstrip antenna is low cost and can be integrated with microwave circuits. It has radiating patch on one side built on a substrate. On the other side of a patch there is a ground plane to which variety of feed can be connected. Resonant frequencies of these antennas can be controlled by changing the length and width of the patch, height of substrate and feeding techniques. In this view, lots of manuscripts are reported for various designs depending on above reported parameters to control resonating frequency for mm waves.

As reported in some investigations, antenna works in Ka band where in silicon material below the patch is removed which has increased bandwidth and efficiency. Thereafter, a compact antenna has been suggested where in 2 L shaped slits have been cut on the right edge of the patch which works in GHz range. Further, a rectangular patch having a rectangular slot on lower patch operates in K band range are reported. Furthermore, an author has investigated a miniaturized hexagonal patch which works in k band range. In another paper, it has been described that an antenna consisting of U-Shaped slot fed by a co-axial feed which works in Ka band. In another, an antenna has been conveyed which consists of a rectangular shape patch antenna where in radiating elements are of circular shape. Additionally, an antenna has been described which operates in GHz range where vertical and horizontal slits has been cut and it works in multiple frequency band. Moreover, a paper has been proposed which uses RT-Duroid 5870 which works in Ku and Ka band. Additionally antenna has been reported consisting of PEC material on FR4 substrate operating in K band.[1-9]. These Kband and Ku
band antennas find its applications in astronomy, satellite communications, automotive radar, molecular rotational spectroscopy and many more [1-10].

This design attempt has been made to meet the demand for K band and Ka band applications. As defined by IEEE radar and Everything RFK band range is (18 to 26 GHz) and Ka band is 26 to 40GHz respectively.

2. Construction

Antenna has been designed by etching the parts of the patch at certain places. Circular, rectangular slots and notches have been etched taking appropriate dimensions at various parts of the patch. The dimension of the proposed rectangular patch is length 12.6 mm and width 9.79 mm which is placed on a substrate of dielectric constant $\varepsilon_r=3.5$ Bakelite. The antenna has been co-axially fed via the ground plane. 2x2 notches have been cut at the edges of the patch. 1mm radius circular slot has been cut at the center. The circular slot of radius 1.7 mm has been etched from the patch. Then notches are created along the width near the circular slots. Antenna is fed via co-axial feed. A rectangular slot along the length of the rectangular patch has been cut and is shown in figure 1. Table 1 shows design specification of the antenna.

![Figure 1. Construction of rectangular slot and circular notch etched patch antenna](image)

| Design parameters                          | Values  |
|--------------------------------------------|---------|
| Length of the patch ($L_p$)               | 12.6mm  |
| Width of the patch ($W_p$)                 | 9.79mm  |
| Length of the substrate ($L_s$)            | 21.1mm  |
| Width of the substrate ($W_s$)             | 21.1mm  |
| Two rectangular slots of length and width  | 1mmx5mm |
| Four Circular notches of radius            | 1.7mm   |
| Center circular slot of radius             | 1mm     |
| Four square notches of length              | 2mm     |
| Four rectangular notches of length and width | 1mmx1.89mm |
Figure 2. Current distribution of rectangular slot and circular notch etched patch antenna

Figure 2 shows that current is distributed along the edges of the antenna and the maximum current distribution is observed at the slots and notch edges. Further it is observed that there is two direction of currents flowing on the patch one along the rectangular patch and another across the slot and notch edges which provides dual resonating frequency band.

3. Results and Discussions

The rectangular slot and circular notch etched patch antenna has been simulated using CST design tool and the results obtained are discussed as follows.

Figure 3. Reflection coefficient of rectangular slot and circular notch etched patch antenna

From figure 3 the frequency band at which the patch antenna is resonating is 22.9GHz to 29GHz. Percentage Bandwidth is 27.08% and this comes under UWB. It is also resonating at 40 GHz. The bandwidth of the resonating band is 6GHz. It has got dual bands .These frequencies usually comes
under K and Ka band. These antennas can be used in various wireless application such as 5G allocation band of European countries, vehicular communication.

Figure 4. Radiation Efficiency of rectangular slot and circular notch etched patch antenna

Figure 4 shows that for vacuum dielectric substrate it is showing the radiation efficiency at 0 dB which means that it is 100%. From 22.9 GHz to 29 GHz frequency band the radiation efficiency for Bakelite is 80%.

Figure 5. Comparison of $S_{11}$ for Bakelite and vacuum substrate

From figure 5 it is observed that as the dielectric constant decreases the resonating frequency is shifting towards higher frequency side. Further it is seen that frequencies in the range 15 to 30 GHz
are not resonating for vacuum dielectric substrate. For vacuum it is found that it is resonating at 37.5 GHz.

![Smith Chart](image)

**Figure 6.** Smith chart for input impedance at various resonating frequencies

It is observed from the figure 6 that impedance at 24 GHz and 39 GHz is 53.144336+j774319(Ω) and 37.099866-j1.291910(Ω) respectively. It is seen that there is near impedance matching at these resonating frequencies. Further, it can be observed from the figure at 24 GHz antenna is more inductive in nature while 39 GHz it is more capacitive.

![Group Delay Chart](image)

**Figure 7.** Group delay for input and output response

From figure 7 it is observed that while exciting the patch through a SMA connector input response is 0.125 ns whereas output response is 0.15ns. Further, it is observed that output response is damping type. Antenna is performing well for this input and output response.
Figure 8 shows the far field directivity for rectangular slot and circular notch etched patch antenna. From figure 8(a) it is observed that the angular beam width (3 dB) is 51.5° and antenna radiates shows a broadside pattern. From figure 8(b) it is observed that the angular beam width (3 dB) is 71.9° and antenna radiates shows an endfire pattern.

4. Conclusion

The simulations of coaxial fed patch antenna with finite ground plane have been investigated. The coaxial fed patch antenna depends on rectangular notches, circular slots, rectangular slots and circular notches. A coaxial fed patch antenna with finite ground plane the UWB is observed at 24 GHz of 27.08% bandwidth. The designed antenna can be used for wireless applications wireless application such as 5G allocation band of European countries, vehicular communication.

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