Design of Trapezoidal Monopole Antenna with truncated ground plane for 2.5 GHz Band

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Abstract

In this paper, we share our experience of designing a Trapezoidal Monopole Antenna with truncated ground plane for 2.5 GHz Band. Trapezoidal monopole antenna has an omnidirectional radiation pattern. Point-to Multi-Point WiFi system requires an omnidirectional common main antenna to distribute signal to wireless devices and computers. The proposed antenna uses a relatively cheap substrate FR-4 with permittivity $\varepsilon_r = 4.4$ and loss tangent $\tan\delta = 0.02$. The size of the antenna is $12 \times 12$ cm$^2$. The ground plate is defected to achieve good impedance matching over the desired frequency band. A 50 Ohm microstrip transmission line acts as the feed for the proposed antenna. The antenna has a Voltage Standing Wave Ratio (VSWR) less than 2 in the frequency band 2.4 GHz to 2.75 GHz. The fractional bandwidth is about 13.5% with respect to the center frequency 2.52 GHz. The design and simulation results are presented in this paper.

Keywords: Dielectric substrates; Microstrip antennas; Trapezoidal Monopole antenna; Truncated ground plane; Printed Monopole antenna; WiFi Antenna.

1. Introduction

A monopole antenna consists of a straight rod-shaped conductor, mounted perpendicularly on a conductive surface, called ground plane. Monopole antennas are small in size, have wide bandwidth and are easy to fabricate. They have an omnidirectional radiation pattern i.e. they radiate power equally well in all azimuthal directions perpendicular to the antenna. They have a variety of applications which include radio broadcasting, aircraft communication etc. Handheld radios such as walkie-talkies also use monopole antennas.

B.J. Lamberty proposed the first flat rectangular monopole antenna in 1958 [1]. Monopoles with flat radiator had a wider bandwidth when compared to straight rod-shaped one [7]. In 1922 S. Honda, M. Lto, H. Seki and Y. Jinbo presented a circular disc monopole antenna [1]. Several other monopole configurations, such as square, elliptical,
pentagonal and hexagonal, have been proposed thereafter [2-4]. Trapezoidal flat antenna was proposed in 1999 [1][6]. But all these configurations have limited practical applications because they are not suitable for integration with printed circuit boards. A compact printed monopole antenna with trapezoidal radiator was proposed in [6]. Also a trapezoidal printed monopole antenna with bell-shaped cut was presented in [8]. In this paper we present the design and simulation of a printed trapezoidal monopole at 2.5GHz. The radiation pattern is omnidirectional and stable over the required frequency band 2.391GHz to 2.7335GHz. The antenna has a gain of 5dB to 8.3dB in $\phi = 0^0$ plane and 10dB to 20dB in $\theta = 90^0$ plane.

2. Antenna Design

2.1. Choice of Substrate

The dielectric constant of substrates used for printed microstrip antennas are typically in the range $2.2 < \varepsilon_r < 12$. Lower the permittivity of the substrate, wider the fringing field and better the radiation. The lower the permittivity, the larger the antenna bandwidth and efficiency. But lowering the permittivity decreases the input impedance and increases the size of the antenna. FR-4 substrate with $\varepsilon_r = 4.4$ is chosen for the design of the proposed antenna.

2.2. Thickness of Substrate

A tradeoff has to be made while selecting the substrate thickness. As thickness of substrate increases, surface waves are induced within the substrate. Surface waves results in undesired radiation, decreases antenna efficiency and introduces spurious coupling between different circuits or antenna elements. Also surface waves reaching the outer boundaries of an open microstrip structure are reflected and diffracted by the edges. These diffracted waves provide an additional contribution to radiation, degrading the antenna pattern by increasing the side lobe and cross polarization levels. Thus thickness should be chosen such that surface waves are suppressed. A thick substrate with low dielectric constant yields better efficiency, larger bandwidth and better radiation, whereas a thin substrate with higher dielectric constant yields compact antenna, with less efficiency and narrower bandwidth. Thus a compromise has to be made between the antenna dimensions and antenna performance. Usually the thickness of substrate($h$) is chosen such that

$$h > 0.06\lambda_g$$

(1)

where $\lambda_g$ is the guided wavelength. A 2mm thick FR-4 substrate is used in the proposed design.

2.3. Antenna Configuration

The configuration of trapezoidal printed monopole antenna is shown in Figure 1(a) and Figure 1(b). It is fabricated on 2mm thick FR-4 substrate which has a relative permittivity of 4.4 and loss tangent $\tan\delta = 0.002$. It consists of a trapezoidal patch of dimension $W_b = 2.892mm, W_t = 61.42mm, L_e = 32.27mm$. The trapezoidal patch is fed via a 50 ohm microstrip feed line with width $W_f = 2.892mm$ and length $L_f = 33.52mm$. The feed gap $S_f$ is chosen as 1.247 mm. The trapezoidal patch and 50 ohm microstrip feed line are printed on the same side of the dielectric substrate as shown in Figure 1(a). The length($L$) and width($W$) of the dielectric substrate are 122.8 mm and 121.3 mm respectively. The conducting ground plane is rectangular in shape with a dimensions $W_g = 122.8mm$ and $L_g = 64.54mm$. It is defected to achieve impedance matching over the desired frequency band as shown in the Figure 1(a). The return loss and bandwidth of the proposed antenna is found to vary with the dimensions $a$ and $b$ [6]. The dimensions $a$ and $b$ are varied to yield the best impedance match and fixed by trial and error. The optimized dimensions $a$ and $b$ were 28.3 mm and 28.8 mm respectively. Bandwidth and return loss of the antenna varies with $W_t$ [6]. $W_t = 61.42mm$ is chosen for best performance of the proposed antenna. Different geometrical parameters were thus tuned and optimized for best performance.

3. Simulation Results

The antenna is simulated using Finite-difference time-domain(FDFTD) method using EMPro software.
Table 1. Variation of antenna parameters with substrate permittivity $\varepsilon_r$

<table>
<thead>
<tr>
<th>$\varepsilon_r$</th>
<th>$f_0$ (GHz)</th>
<th>BW(MHz)</th>
<th>FBW</th>
<th>Q factor</th>
<th>$Z_{in}$ at $f_0$ (Ohms)</th>
<th>ReturnLoss (dBa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.9</td>
<td>2.8606</td>
<td>366.3</td>
<td>11.8%</td>
<td>7.8</td>
<td>63.802 - j10.214</td>
<td>-16.462</td>
</tr>
<tr>
<td>4.4</td>
<td>2.5269</td>
<td>365.6</td>
<td>13.5%</td>
<td>6.9</td>
<td>48.68 + j3.9448</td>
<td>-27.51</td>
</tr>
<tr>
<td>6.45</td>
<td>2.5745</td>
<td>132.3</td>
<td>2.78%</td>
<td>19.45</td>
<td>43.874 - j0.8462</td>
<td>-32.165</td>
</tr>
</tbody>
</table>

3.1. Variation of antenna parameters with substrate

A series of simulations were performed by varying the substrate permittivity and different antenna parameters such as input impedance, VSWR and return loss were analysed. The simulation results for various substrates are presented in Table 1. The Voltage Standing Wave Ratio (VSWR) is an indication of how good is the impedance match. Usually a VSWR of 2 or less is considered to be good. VSWR vs frequency plot is shown in Figure 3(a). The VSWR varies from 1.15 to 2 in the frequency range 2.4GHz to 2.75GHz. Thus the frequency band of the proposed antenna is 2.4GHz to 2.75GHz for the VSWR less than 2. Bandwidth can be defined in terms of VSWR. Bandwidth (BW) is calculated as the range of frequencies for which $\text{VSWR} < 2$. From Table 1 it is inferred that bandwidth decreases with substrate permittivity.

The fractional bandwidth (FBW) can be calculated as

$$f_r = \frac{BW}{f_0} \times 100\%$$

For FR-4 substrate the fractional bandwidth is 13.5%. Fractional bandwidth (FBW) decreases with increase in substrate permittivity. Input impedance($Z_{in}$) at resonant frequency is 48.68 + j3.9448 and 43.874 − j0.8462 for FR-4 and RT/duroid 6006 respectively. The input impedance is almost real at the resonant frequency and could be easily matched to the characteristic impedance which is assumed to be 50Ohms. From Figure 3(b), it is observed that the antenna resonates at 2.5269GHz and has a return loss of -27.51dBa at the resonant frequency. Return loss is more for high permittivity substrates. Also it is noted that the resonant frequency varies with substrate permittivity. Q factor is a measure of frequency selectivity and is highest for RT/duroid 6006 and least for FR-4. Q factor of antenna is calculated as

$$Q = \frac{f_0}{BW}$$

Q factor is higher when high permittivity substrate is used. From the above discussions, it can be concluded that for the antenna dimensions presented in section 2.2, FR-4 substrate gives the best performance.

3.2. Antenna Radiation Pattern

Figure 1(c) shows the three dimensional radiation pattern. The radiation pattern is further analysed by taking ‘cuts’ at various azimuthal angle $\phi$. The electric field variation along the plane $\phi = 0^0$ and elevation angle $\theta$ varying from $0^0$ to $360^0$ is presented in Figure 2(a). Figure 2(c) shows the horizontal ‘cut’ of the radiation pattern ($\theta = 0^0$ and $\phi$ varying from $0^0$ to $360^0$). The electric field variation along the plane $\phi = 0^0$ and elevation angle $\theta$ varying from $0^0$ to $360^0$ is presented in Figure 2(c). The radiation pattern is omnidirectional and stable over the required frequency band 2.391GHz to 2.7335GHz.

The field distribution in the antenna is depicted in Figure 4(a) and Figure 4(b). Fringing fields could be observed in the field pattern. It may also be noted that the electric field is maximum at the radiator edges.

3.3. Gain

From Figure 2(b) and 2(d) it is observed that the gain varies from 5dB to 8.3dB in $\phi = 0^0$ plane and 0.2dB to 0.6dB in $\phi = 180^0$ plane. Figure 2(f) shows the gain variation along the horizontal ‘cut’($\theta = 90^0$ and $\phi$ varying from $0^0$ to $360^0$). Gain varies from 10dB to 20dB in $\theta = 90^0$ plane. It could be noticed that the gain does not vary with frequency in the required frequency band.
All these characteristics makes the proposed antenna suitable for point-to multi-point communication where an omnidirectional common main antenna is required to distribute signal to wireless devices.

4. Conclusion

In this paper the design and simulation results of a trapezoidal monopole antenna has been presented. The antenna resonates at 2.5 GHz and has a VSWR $\leq 2$ in 2.4-2.75 GHz frequency band. A better impedance matching over the frequency band is achieved by using truncated ground plane. Simulated results show the antenna pattern is omnidirectional. The antenna once fabricated could be used in WLAN transceivers.

5. References

Fig. 1. (a) Top view of the Antenna (b) Bottom view of the Antenna (c) 3D Radiation Pattern
Fig. 2. (a) Electric Field vs. $\theta, \phi = 0^\circ$ (b) Gain vs. $\theta, \phi = 0^\circ$ (c) Electric Field vs. $\theta, \phi = 180^\circ$ (d) Gain vs. $\theta, \phi = 180^\circ$ (e) Electric Field vs. $\phi, \theta = 90^\circ$ (f) Gain vs. $\phi, \theta = 90^\circ$
Fig. 3. (a) Variation of VSWR for different substrates (b) Variation of return loss for different substrates (c) Variation of Impedance (real part) for different substrates (d) Variation of Impedance (imaginary part) for different substrates
Fig. 4. (a) Magnetic Field (B) Pattern in the antenna (b) Electric Field (E) Pattern in the antenna