HIGH-GAIN PRINTED DIPOLE ANTENNA

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ABSTRACT: A printed dipole antenna showing high gain (about 6.8 dBi) radiation in the azimuthal plane is presented. The dipole antenna has a narrow width of 10 mm and a total length of about 202 mm (with 1.64 wavelengths of the frequency at 2442 MHz, the center frequency of the 2.4-GHz WLAN band). In each one of the two radiating arms of the dipole antenna, a meandered line is inserted as a phase-reversal device. With this arrangement, the proposed dipole antenna performs as a collinear array antenna with three in-phase half-wavelength radiating elements, leading to constructive radiation in the azimuthal plane and small side lobes in the elevation plane.

Key words: dipole antennas; printed antennas; collinear array antennas; high-gain dipole antennas

1. INTRODUCTION

Conventional dipole antennas are usually constructed from coaxial lines and operated as a half-wavelength resonant structure [1]. This kind of coaxial dipole antenna usually shows an antenna gain of about 2.2 dBi only. However, for some practical applications such as in the access point for wireless local area networks (WLANs) [2], a much larger antenna gain may be required. To achieve a high-gain dipole antenna, one can use several half-wavelength coaxial-line sections, in which their inner and outer conductor connections are reversed at each junction, to form a coaxial collinear antenna with in-phase radiating sections in order to achieve an enhanced gain [3, 4]. A planar or printed type of this design with seven 50Ω microstrip-line sections has been recently demonstrated, and an antenna gain of about 5.0 dBi has been obtained [5]. Another promising method for obtaining a high-gain dipole antenna is to use a meandered-line section to act as a phase-reversal device [6–8] in the radiating arms of a long dipole or monopole antenna. This arrangement has a simpler configuration than the design in [3–5] and can also provide a collinear-array antenna structure with in-phase radiating elements, thus making possible an enhanced antenna gain for the dipole antenna.

Based on the use of a meandered-line section as the phase-reversal device [6–8], we propose in this paper a high-gain printed dipole antenna suitable for replacing the conventional coaxial antennas for WLAN access-point applications. The proposed printed dipole antenna has the advantage of low cost in fabrication, compared to coaxial antennas. Furthermore, the proposed antenna can provide a high antenna gain of about 6.8 dBi for operation in the 2.4-GHz WLAN band (2400–2484 MHz). Design considerations of the proposed antenna are described, and results of the constructed prototype are presented and discussed.

2. DESIGN CONSIDERATIONS OF THE PROPOSED ANTENNA

Figure 1 shows the geometry of the proposed high-gain printed dipole antenna. Note that the dimensions given in the figure are for operating in the 2.4-GHz band. The antenna has two identical radiating arms printed on an inexpensive 0.4-mm-thick FR4 substrate and is fed at points A and B by a 50Ω mini coaxial line with a balun attached. Also note that in this design the antenna is designed to have a narrow width of 10 mm, which is comparable to that of conventional coaxial antennas. This narrow width makes the proposed antenna suitable for replacing the conventional coaxial antennas in practical applications.

The antenna can be divided into five sections: element 1, element 2, elements 3a and 3b, element 4, and element 5. These five sections (from elements 1 to 5) can be considered to correspond to the half-wavelength elements A to E of a conventional 2.5-wavelength dipole antenna, as shown in Figure 2. It can be seen that the currents in elements B and D have a phase opposite to those of elements A, C, and E. In this case, large destructive effects caused by the radiation contributed from the five elements
are expected, which leads to undesired radiation patterns for practical applications.

By compressing elements B and D into densely meandered lines (element 2 from points C to D and element 4 from points E to F in Fig. 1), the currents with a phase opposite to that of elements A, C, and E will be constrained in the meandered line and oriented mainly in the horizontal direction. In this case, the radiation contributed from elements 2 and 4 will be diverted to be mainly with $E_{\parallel}$ (horizontal) polarization. Furthermore, due to the dense meandering, large coupling between adjacent segments (spacing 1 mm in this design) in elements 2 and 4 is expected, which can lead to a much decreased radiation efficiency for the currents in elements 2 and 4. It can thus be expected that the radiated power contributed from elements 2 and 4 will be much less than that from elements 1, 3, and 5. In this case, elements 2 and 4 can be considered as good phase-reversal devices with small or negligible destructive effects on the $E_{\parallel}$ (vertical) radiation contributed from elements 1, 3, and 5. The proposed dipole antenna can thus be treated as a collinear array antenna with three in-phase half-wavelength radiating elements (elements 1, 3, and 5), which leads to enhanced antenna gain for the antenna.

![Figure 2](image.png)  
**Figure 2** Current distribution on a conventional 2.5λ dipole antenna

![Figure 3](image.png)  
**Figure 3** Measured and simulated return loss for the proposed antenna

Also note that, since the half-wavelength elements 2 and 4 are densely meandered, their lengths (only 16 mm in this design) along the dipole arm are now much smaller than a half-wavelength (about 61 mm at 2442 MHz). Given this characteristic, along with...
the presence of the FR4 substrate (with relative permittivity 4.4), which will also reduce the resonant length of the half-wavelength elements 1, 3, and 5, the proposed dipole antenna shows a total length of only 202 mm, about 1.64 wavelengths at 2442 MHz.

To achieve good impedance matching for the proposed antenna, it is found that the feed gap $d$ between elements 3a and 3b is an important factor. The optimal feed gap in this study is found to be 2 mm, and the effects of various feed gaps on the impedance matching will be discussed in section 3. As for varying the width $w$ of elements 3a and 3b, it has a large effect on the achievable impedance bandwidth for the proposed dipole antenna. To achieve a large impedance bandwidth to easily cover the 2.4-GHz band (2400–2484 MHz), the width $w$ is chosen to be 10 mm in this design, the same as that of the FR4 substrate. With regard to elements 1 and 5, their width has a relatively small effect on the impedance bandwidth of the antenna and is thus fixed to be 1 mm in this design; their length $t$, however, shows a large effect on the resonant frequency of the antenna. The optimal length $t$ is determined to be 56 mm (about 0.46 wavelength at 2442 MHz), close to a half-wavelength at 2442 MHz. The effects of the width $w$ and length $t$ will be discussed in more detail in section 3.

3. RESULTS AND DISCUSSION

Based on the design dimensions given in Figure 1, a prototype of the proposed antenna was constructed and tested. Figure 3 shows the measured and simulated return loss for the constructed prototype. The simulated results are obtained using the Ansoft simulation software High-Frequency Structure Simulator (HFSS), and good agreement between the measurement and simulation is seen. From the measured results, the impedance bandwidth reaches about 220 MHz (2330–2550 MHz), thus allowing the proposed antenna easily cover the 2.4-GHz band for WLAN operation.

Figure 4 shows the HFSS simulated surface current distribution at 2442 MHz for the proposed dipole antenna. It is clearly seen that elements 1, 3, and 5 have in-phase and vertically-oriented excited currents. Null excited currents are also seen near points C, D, E, and F, which indicates that phase reversals occur and the out-of-phase currents are now compressed in elements 2 and 4. These characteristics agree with the prediction described in section 2.

To analyze the effects of various dimensions on the antenna performances, a parametric study for the proposed antenna was also conducted using Ansoft HFSS simulation software. Figure 5 shows the simulated return loss as a function of the feed gap $d$ between elements 3a and 3b. A large effect of the feed gap on the impedance matching is seen, and the optimal feed gap in this design is determined to be 2 mm, which is the same as the result obtained for a printed dipole antenna shown in [9]. Figure 6 shows the simulated return loss as a function of the width $w$ of elements 3a and 3b. The impedance bandwidth is seen to increase with an increase in $w$. This behavior is very similar to the known result that the thicker the wire dipole, the wider is its bandwidth [10]. Similar results have also been obtained for a printed monopole antenna with a wider strip width [11]. For this reason, the width $w$ is selected to be the same as that (10 mm) of the FR4 substrate in this design.

<table>
<thead>
<tr>
<th>Length $t$ of Elements 1, 5 [mm]</th>
<th>Directivity [dBi]</th>
<th>Gain [dBi]</th>
<th>Center Frequency [MHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>6.87</td>
<td>6.65</td>
<td>2420</td>
</tr>
<tr>
<td>56</td>
<td>7.13</td>
<td>6.85</td>
<td>2442</td>
</tr>
<tr>
<td>50</td>
<td>6.44</td>
<td>6.28</td>
<td>2500</td>
</tr>
<tr>
<td>45</td>
<td>6.34</td>
<td>6.23</td>
<td>2550</td>
</tr>
</tbody>
</table>

NOTE—The directivity and gain are computed at the center frequency of the antenna’s impedance bandwidth.
Figure 8  Measured radiation patterns at 2442 MHz for the proposed antenna

Figure 9  Simulated radiation patterns at 2442 MHz for the proposed antenna
The effects of the length $t$ of elements 1 and 5 are also analyzed, and the results are shown in Figure 7. It is observed that when the length $t$ decreases, the resonant frequency of the antenna is shifted to high frequencies and the impedance matching is also degraded. On the other hand, when the length $t$ increases, the resonant frequency of the antenna decreases and the impedance matching is also degraded. The antenna directivity and gain are also computed and listed in Table 1 for comparison. The results indicate that there exists an optimal length $t$ for achieving a maximum antenna gain. This is largely because, with an optimal length $t$ chosen, the null excited currents will occur near points C, D, E, and F (see Fig. 4), as desired. In this case all portions in elements 1, 3, and 5 are of the same phase, thus optimal constructive radiation for the proposed antenna can be expected. Also note that the optimal length $t$ (56 mm) for achieving a maximum antenna gain (see Table 1) is the same as that for achieving a maximum impedance bandwidth (see Fig. 7).

Figure 8 plots the measured radiation patterns at 2442 MHz for the constructed prototype. Good omnidirectional radiation pattern in the azimuthal plane ($x$–$z$ plane) is seen. In the elevation plane ($x$–$y$ and $y$–$z$ planes), small or negligible side lobes are also seen. The measured results in general also agree with the simulated radiation patterns shown in Figure 9. Figure 10 presents the measured and simulated antenna gain against frequency for the constructed prototype. Good agreement between the measured and simulated results is observed. A high antenna gain of about 6.6–6.8 dBi for frequencies across the 2.4-GHz band is obtained, which is much higher than that of a conventional half-wavelength dipole antenna.

4. CONCLUSION

A high-gain printed dipole antenna has been proposed, constructed, and tested. The proposed antenna has a simple configuration and is easy to implement with a low cost. A constructed prototype suitable for application in the 2.4-GHz band for WLAN operation has been studied. The prototype has a narrow width of 10 mm and a total length of 202 mm only (1.64 wavelengths at 2442 MHz) and performs as a good collinear array antenna with three in-phase half-wavelength resonant elements. A high antenna gain level of about 6.6–6.8 dBi for frequencies across the 2.4-GHz band has been obtained. This antenna gain level is much larger than that of a conventional half-wavelength dipole antenna.

REFERENCES


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