Compact Meandered Monopole Antenna for Dual-Bands WLAN Application

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Abstract. A compact meandered dual-bands monopole antenna for the application of a wireless local area network (WLAN) is proposed. This antenna has two operating frequency bands which are 2.4 GHz and 5.2 GHz and denoted as lower and upper operating bands respectively. In the antenna design, a meandered arms structure has been proposed to obtain a compact size monopole antenna with an overall dimension of 30 mm x 21 mm. Furthermore, the dual-bands operating frequency is achieved with the contribution of two meandered arms structure as well as a partial ground plane proposed in the antenna design. The copper layer traces with the thickness of 0.035 mm has been used as the radiating patch and the partial ground plane has been printed at the back side of the FR-4 substrate with the permittivity, $\varepsilon_r$ of 4.5 and the thickness of 1.6 mm. The proposed antenna has a simple design, small size, easy to fabricate and low cost. The measured and simulated results were compared to analyse the performance of the designed antenna. From the simulation, the operating frequencies achieved are at 2.44 GHz and 5.23 GHz, while from the measurement at 2.50 GHz and 4.44 GHz. Other antenna parameter such as radiation pattern and gain has also been evaluated and analysed.

1. Introduction

Nowadays, there is a high growing demand for wireless systems technology. A miniaturised multi-purpose antenna is needed at this stage to construct devices for various services of modern communication systems [1]. Multiband antenna will support a multi-frequency operation for desired applications. Wireless local area network (WLAN) applications such as portable computers and smartphones have increasingly grown over the past year. The research on how to design multiband antennas that can be integrated into a mobile wireless communication device with multiple communication standards has gained a lot of interest among the engineers. The standard allocated operational frequency bands for WLAN applications are 2.45 GHz, 5.2 GHz and 5.8 GHz [2].

The demand of WLAN’s innovation is increasing rapidly globally as it provides high-speed connectivity and fast access to the network without utilizing any cable. Due to its low-cost factor, large bandwidth and also easy integration with other systems, the printed monopole antenna has become very popular with this application [3]. The demand for small size monopole antenna in wireless technology
is also widely increased due to its durability and also low-cost efficiency. Hence, it is important to vary the geometry of the printed monopole antenna so that the total size can be reduced.

Several different methods are documented in the literature to reduce the size of the monopole antenna including by using slotted structures [4][5], bending or meandering the monopole radiator [6][7] and using metamaterials reactive loading [9]. Meanwhile, to obtain a multiband frequency, several antenna geometries have been proposed by the researchers for example by loading multiple stubs at the radiating patch [10], implementing fractal geometry [11], defecting the antenna ground plane [12] and implementing asymmetric meandered arms geometry [13].

In this paper, a compact printed monopole antenna with meandered structure and the partial ground plane is proposed for dual-band WLAN operations with the operating frequencies of 2.45 GHz and 5.2 GHz. This design has been due to the modern feature in a wireless communication system which requires a small size antenna with multi-band frequency operations. An intermediate design step has been conducted until the final proposed antenna is achieved.

2. Antenna Structure Design

The design of the proposed monopole antenna consists of double meandered arms structures and a partial ground plane at the back side of the antenna as shown in Figure 1 and Figure 2 respectively. The prototype of the fabricated monopole antenna is depicted in Figure 3. The meandered structure is formed by bending the arms of the monopole antenna continuously close to each other to form a compact size antenna. Meandering the patch increases the direction along which the surface current flows, thus increases the antenna inductance, \( L \), and shifts the resonant frequency, \( f_r \), to the lower frequency as derived from equation (2.1) [7][14].

\[
f_r = \frac{1}{2\pi \sqrt{LC}}
\]

According to Warnagiris et. al., the antenna size reduction factor \( \beta \) highly depends on the number of meander elements per wavelength and the spacing of the elements of the rectangular loops, which can be expressed as in (2.2) [15]. The parameter \( L \) indicates the length of the conventional monopole while \( l \) is the length of the meander antenna with the same resonant frequency.

\[
\beta = \frac{l}{L}
\]

The total dimension of the antenna is 30 mm x 21 mm. Comparing with the previous monopole antenna reported in [16], there is a marked improvement in the antenna size with approximately 50% reduction of the antenna size. At the front side of the antenna, copper layer traces with the thickness of 0.035 mm has been printed on FR4 substrate with the relative permittivity, \( \varepsilon_r \) of 4.5 and thickness of 1.6 mm. Meanwhile, at the back side of the antenna, a partial copper ground plane with the dimension of 30 mm x 13 mm has been printed on the FR4 substrate. For the antenna feeding point, a sub-miniature-A (SMA) female connector with 50 \( \Omega \) characteristic impedance has been used as the input port. The parameters and dimensions of the proposed monopole antenna are listed in Table 1.
3. Parametric Study

In the antenna design, the parametric study is important because it gives more understanding about the characteristics and the performance of the antenna. Three parametric cases have been investigated in this paper including the comparison between the single meandered arm with the double meandered arms, the length of the folded arm (L4) and the width of the partial ground plane (G2). The results of the parametric study are focusing on the resonant frequency of the antenna and the return loss.
3.1. Different number of meandered arms

The design of the proposed compact monopole antenna begins with a single meandered arm as shown in Figure 4 (a). From the simulation in Figure 5, it can be observed that the single meandered arm monopole antenna resonates at the WLAN operating frequency of 5.2 GHz. Another required WLAN operating frequency, which is 2.4 GHz is not achieved with this single meandered arm monopole antenna since the return loss value is higher than -10 dB at the frequency of 2.4 GHz. Therefore, to achieve a dual-band resonant frequency, the single meandered arm monopole antenna has been mirrored to the x-axis to form a double meandered arms monopole antenna as shown in Figure 4 (b).

From the return loss graph as depicted in Figure 5, the double meandered arms monopole antenna has achieved dual-band resonant frequency, but the lower band is shifted a little bit to the higher frequency than the required operating frequency of 2.4 GHz. With some modification to the dimension of the antenna and the meandered arms, the final design as shown in Figure 1 has been achieved with the resonant frequency of 2.4 GHz and 5.2 GHz. Figure 6 shows the comparison between the single meandered arm monopole antenna with the final proposed antenna design in terms of return loss and resonant frequencies achieved.

![Figure 4. (a) Single meandered arm and (b) Double meandered arms monopole antenna](image)

![Figure 5. Return loss result for single and double meandered arms monopole antenna](image)
3.2. Different folded arm length (L4)
For the second case, the folded arm length, L4 as shown in Figure 7 has been varied from 4 mm to 6 mm to see the effects on the return loss and resonant frequency value. From the graph depicted in Figure 8, it shows that the resonant frequency is shifted slightly to a lower frequency with the increase of the length L4. This is due to the increase of the effective length of the current path by increasing the length L4, which leads to the decrease of the resonant frequency value. Table 2 summarize the values of the resonant frequency and the return loss with respect to the different length of L4. The optimum value of L4 is 6 mm with the antenna resonant frequency values of 2.44 and 5.23 GHz.

Figure 6. Return loss result for single arms monopole antenna and the proposed antenna design

Figure 7. Folded arm length, L4
Figure 8. Return loss result for different folded arm length, L4

Table 2. Resonant frequency and return loss values of different folded arm length, L4

| Folded arm length, L4 (mm) | Resonant frequency (GHz) | Return loss (dB) |
|---------------------------|--------------------------|-----------------|
| 4                         | 2.63 and 5.38            | -12.36 and -22.41 |
| 5                         | 2.54 and 5.32            | -12.10 and -22.45 |
| 6                         | 2.44 and 5.23            | -12.23 and -22.65 |

3.3. Different ground width (G2)
The other part of the antenna design that has been investigated is the width of the partial ground plane, G2 as shown in Figure 9. The width of the ground G2 has been varied from 8 mm to 10 mm to see the effects on the return loss and resonant frequency value. From the graph depicted in Figure 10, it shows that not only the antenna resonant frequency and return loss is changed, but the bandwidth of the upper operating band is also decreased with the increase of the ground width G2. This result proves that by defecting the ground plane of the antenna, the bandwidth can be improved as well as producing multiple bands antenna [12]. Table 3 summarize the values of the resonant frequency, the return loss and the bandwidth of the upper band frequency with respect to the different width of the partial ground plane G2. The optimum value of width G2 is 8 mm with dual-band resonant frequency values of 2.44 and 5.23 GHz and the bandwidth achieved by the upper operating band is 2.21 GHz.
Table 3  Resonant frequency, return loss and bandwidth values of different ground width, G2

| Ground width (mm) | Frequency (GHz) | Return loss | Bandwidth upper band frequency |
|------------------|----------------|-------------|--------------------------------|
| 8                | 2.42 and 5.23  | -12.23 and 22.65 | 3.86 GHz – 6.08 GHz (2.21 GHz) |
| 9                | 2.48 and 5.57  | -8.24 and -12.93 | 4.92 GHz -6.00 GHz (1.08 GHz) |
| 10               | 2.51 and 5.96  | -5.59 and -11.74 | 5.59 GHz - 6.00 GHz (0.41 GHz) |

4. Result and Discussion
The measurement of S-Parameter, $S_{11}$, was carried out by using Vector Network Analyzer (VNA) as shown in Figure 11. Figure 12 shows the measurement setup for antenna radiation pattern in an anechoic chamber. The measured return loss and radiation pattern have been compared with the simulation results.
4.1. S-Parameter results
From the simulation, the proposed monopole antenna has successfully achieved the required resonant frequencies for WLAN application, which are 2.44 GHz and 5.23 GHz as depicted in Figure 13. However, from the measurement of the fabricated monopole antenna, the S-Parameter result shows some deviation from the simulation result, especially for the upper band frequency. The fabricated antenna resonated at the operating frequency of 2.5 GHz and 4.4 GHz. The lower band resonant frequency from the simulation and the measurement agree well with each other. Whereas, for the upper band frequency, the measured resonant frequency is shifted around 15.4 % to the lower frequency. This is might be due to the unwanted loss during the fabrication processes of UV exposure, developing and etching stage as well as impedance mismatched due to the existence of some parasitic elements for example soldering paste and also inaccurate line impedance measurement.

4.2. Radiation pattern and gain
Another performance that has been investigated is the radiation pattern of the antenna. The simulated and measured radiation patterns of the proposed monopole antenna at the operating frequency of 2.4 GHz and 5.2 GHz are illustrated in Figure 14 and Figure 15 respectively. From the results, it shows that all radiation pattern for every frequency band is almost omni-directional and the simulated and measured results agree well with each other. However, the gain obtained from the simulation by the proposed monopole antenna is very small at 2.4 GHz with a value of -0.0268 dB. Meanwhile, at 5.2 GHz, the gain is satisfactory which is 1.721 GHz. The small gain of the antenna is might be due to the electrically small size of the antenna, which reduces the antenna efficiency.
5. Conclusions
In conclusion, the design and analysis of a dual-band monopole antenna with double meandered arms and partial ground plane structure has been effectively demonstrated. The proposed antenna has a simple design, easy to fabricate and can be operated at 2.44 GHz and 5.23 GHz frequencies which are suitable for WLAN application. Other than that, the meandered arms structure implemented in the antenna design results in the small size of the proposed monopole antenna, which is useful to be integrated with small devices such as a smartphone. Besides, the analysis of the partial ground plane that has been conducted shows that the ground plane can be a suitable parameter to be changed to achieve better bandwidth and multiple bands antenna. Lastly, the design, simulation and fabrication of the antenna also need to be improved in the future to obtain better results in terms of gain and also measured resonant frequency.

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