A 2 × 2 Multiple-Input Multiple-Output (MIMO) Antenna Design for WiFi Triple-Band Antenna Module Applications

Fei-Lung Wu, Jung-Sheng Liu, I-Fong Chen, Chia-Mei Peng, and Yuan-Chen Chen

Abstract – A compact antenna module, measuring 30 mm × 30 mm, with a no-ground portion of 30 mm × 10 mm, is proposed for multiple-input multiple-output WiFi triple-band antenna module applications. The module consists of two printed inverted F antennas (PIFA), each with a size of 16 mm × 9.5 mm. It uses an open-stub, top-loading, tapered and shortened line, with a coplanar waveguide feeding structure to operate at frequencies of 2.4 GHz to 2.5 GHz, 5.150 GHz to 5.85 GHz, and 5.925 GHz to 7.125 GHz. An efficient technique using a tapered and shortened line is introduced to suppress surface wave and near-field coupling, while also improving isolation. This technique allows for achieving more than 18 dB of isolation between the two polarization diversity PIFA antennas.

1. Introduction

Beginning in 2020, the coronavirus disease 19 epidemic reached severe levels, and working from home became a popular trend, resulting in increased use of wireless local area network applications. The development of multiple-input multiple-output (MIMO) antennas for access point (AP) terminals has resulted from the product road map for WiFi versions 4 to 7, aiming to increase the transmission data rate. However, in cases when the WiFi signal does not cover the whole-home environment, using a WiFi extender can improve the network connection. WiFi 6E has emerged as a notable trend for WiFi AP extender applications. Therefore, a new challenge arises in antenna design: achieving optimal integration of multiple antennas and RF circuits on a compact printed circuit board (PCB) for its use as an antenna module. However, the limited size of the PCB's ground plane is not ideal, resulting in reduced isolation between antennas due to surface wave and near-field coupling. In addition, the performance of the antennas is constrained by the environmental scenario. Decoupling elements that protrude from the ground plane to decrease mutual coupling between antennas and increase isolation are a traditional technology [1–3]. However, the impedance bandwidth may be affected by the concentration of surface current on the decoupling elements. This article presents the design of two polarization diversity triple-band printed inverted F antenna (PIFA) elements accompanied by a tapered and shortened line to achieve triple-band performance and high isolation [4, 5]. According to the specifications for wireless products, the triple-band antenna must be capable of functioning in the WiFi triple band, with bandwidths ranging from 2.4 GHz to 2.5 GHz (referred to as the *lower operating band*), 5.15 GHz to 5.85 GHz (referred to as the *middle operating band*), and 5.925 GHz to 7.125 GHz (referred to as the *upper operating band*). This article presents and discusses the design considerations and experimental results of the proposed designs and the constructed prototype.

2. Antenna Structure and Design

A compact antenna module consists of two modified PIFA elements and is specifically designed as a 2 × 2 MIMO antenna for WiFi triple-band applications, as shown in Figure 1a. It is important to design the antenna in combination with its finite-sized ground plane because a ground plane with a limited size can affect the resonant frequency, impedance bandwidth, and radiation pattern of the antenna. The single PIFA antenna is connected to an open-stub, top-loading, tapered and shortened line, along with a coplanar waveguide (CPW) feeding structure. The electrical length of the radiating elements can be determined using one-quarter wavelength at 2.45 GHz, 5.5 GHz, and 6.5 GHz, covering the frequency ranges of WiFi triple band, as shown in Figure 1b. By selecting appropriate dimensions for the modified structure, one can achieve good impedance matching across a wide bandwidth. Figure 1c displays the physical platform used for antenna integration, where two antennas are orthogonally positioned to achieve polarization diversity. The top-loading CPW feeding structure and open-stub functions are used to improve the operating bandwidth of the lower and middle bands.

The tapered and shortened line connects to both the feed and ground lines of the PIFA, dividing the surface current into three paths, as shown in Figure 2a. The lower band current path is labeled for operation in the 2.45 GHz band, the middle band current path is labeled for operation in the 5.5 GHz band, and the upper band

Manuscript received 29 April 2024.

Fei-Lung Wu and Jung-Sheng Liu are with Ph.D. Program of Electrical and Communications Engineering, Feng Chia University, Taichung City, Taiwan; e-mail: dragon.wu@sgs.com.

I-Fong Chen and Yuan-Chen Chen are with School of Electronics and Electrical Engineering, Dongguan Polytechnic, and Jinwen University of Science and Technology, New Taipei City, Taiwan; e-mail: ex0206@just.edu.tw.

Chia-Mei Peng is with Department of Communications Engineering, Feng Chia University, Taichung City, Taiwan; e-mail: chiampeng@fcu.edu.tw.

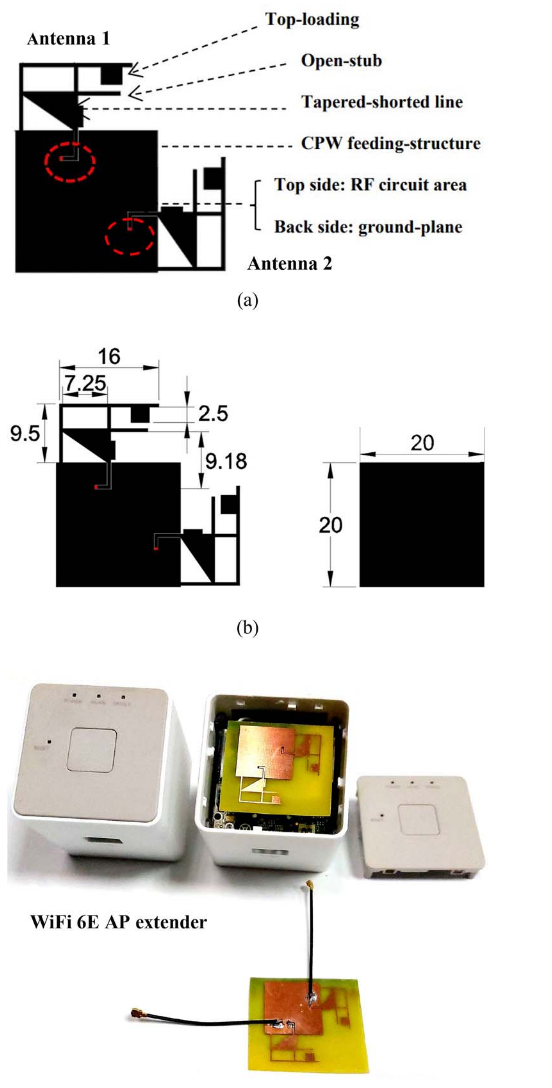


Figure 1. (a) Geometry the proposed antenna module. (b) Dimensions of the proposed antenna module (millimeters). (c) The physical infrastructure of antenna integration.

current path is labeled for operation in the 6.5 GHz band.

The figure displays the simulated current distribution of the antenna proposed in Figure 2b with a diameter of 1.3 mm and a length of 5 cm mini-coaxial cable, helping to expand the operating band and bandwidth of the antennas. Furthermore, this mechanism enhances the isolation between antennas. The design considerations and the experimental results of the constructed prototype are presented and discussed in the following sections.

3. Results and Discussion

In the experiment, the proposed antenna has compact dimensions of 16 mm × 9.5 mm. It is printed on

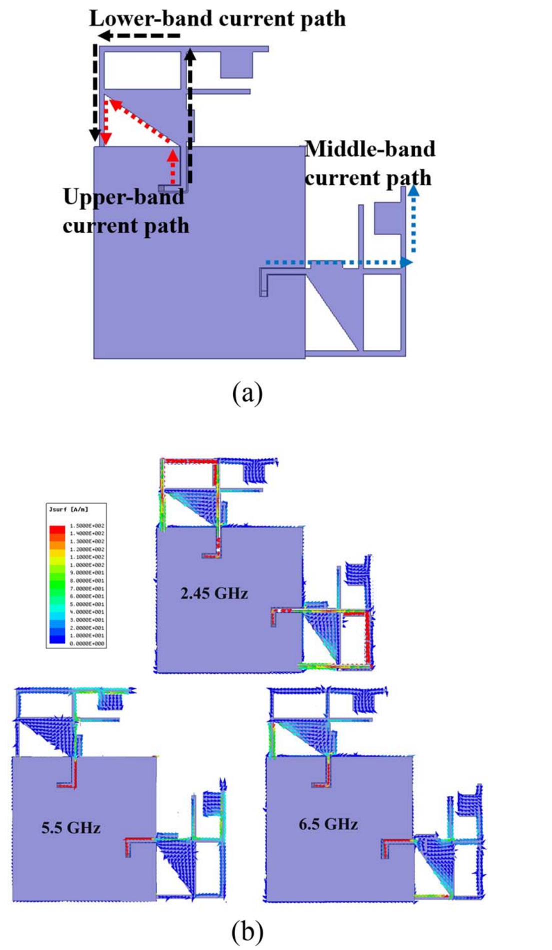
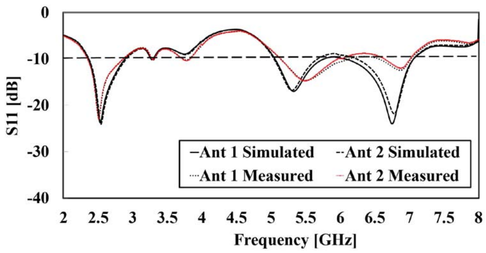
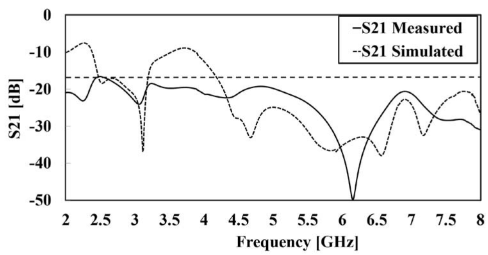


Figure 2. (a) The current path for lower, middle, and upper operating band. (b) The simulated current distribution of the proposed antenna at 2.45 GHz, 5.5 GHz, and 6.5 GHz.

the topside of a PCB, with a backside ground plane measuring 30 mm × 30 mm. The ground plane includes a nonground portion measuring 30 mm × 10 mm. In Figure 1a, the two orthogonal PIFAs are connected to a coaxial cable. The feed and ground points are linked to a miniature coaxial cable with a 1.3 Ø 5 cm length and a 50 Ω I-PEX connector. Following the described design procedure, a triple-band antenna was built for operation within the WiFi 6E system range. Figure 3 shows the simulated and measured S11 and S21 plot of the triple-band antenna due to the presented geometry. The measured bandwidths for S11 below −10 dB are 2.36 GHz to 2.88 GHz (with a percentage of 20.4% at 2.45 GHz), 5.06 GHz to 5.85 GHz (with a percentage of 14.3% at 5.5 GHz), and 5.93 GHz to 7.13 GHz (with a percentage of 18.5% at 6.5 GHz). However, there is a slight difference between the measured and simulated results in the middle and upper operating bands. This difference can be attributed to the assumption made in the simulation that the 50 Ω 1.3 Ø miniature coaxial cable is lossless. The measured and simulated S21, which refers to isolation, between these two PIFAs is greater than 18 dB, because



(a)



(b)

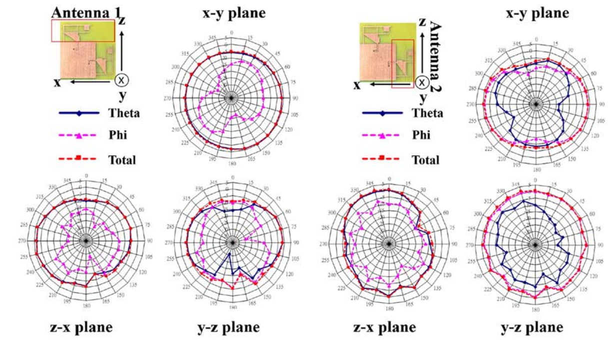
Figure 3. (a) Measured and simulated S11 against frequency. (b) Measured and simulated S21 against frequency.

the tapered and shortened line reduces the undesired current caused by an imperfect ground plane. It ensures that the surface current is concentrated on the antenna to minimize near-field coupling. Furthermore, the polarization diversity of these two PIFAs will contribute to weak coupling.

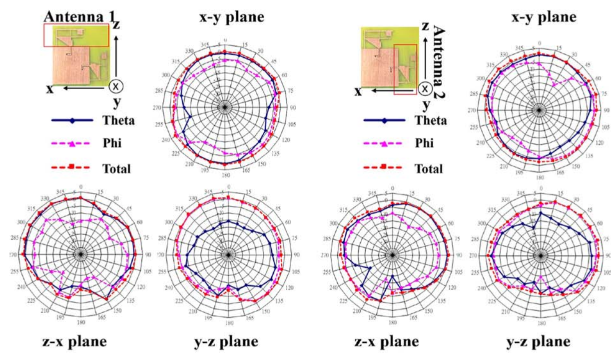
The two proposed antennas are orthogonally set to provide polarization diversity. Figure 4 presents the measured 2D radiation patterns at 2.45 GHz, 5.5 GHz, and 6.5 GHz for free space, respectively. It is obvious that two orthogonal patterns are generated by feeding the PIFA in an orthogonal manner. Both the horizontally polarized and vertically polarized beams form omnidirectional radiation patterns through the use of two complementary PIFA elements. Table 1 shows the measured antenna's peak gains and 3D pattern efficiency within the operating frequencies of the proposed antenna. The far-field patterns over a sphere were measured, and total efficiency was determined using pattern integration in the ETS-Lindgren (AMS-8500) anechoic chamber. The total efficiency is defined as (gain/directivity) $\times$ 100%. The proposed antenna exhibits acceptable radiation characteristics for practical applications.

4. Conclusions

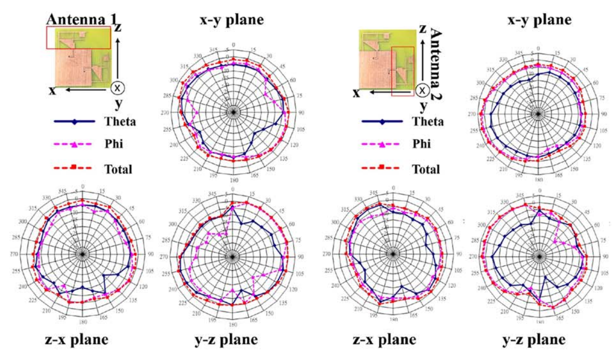
In this article, a PIFA with a top-loading, open-stub, tapered and shortened line with a CPW feeding structure is demonstrated to provide triple-band operation. Two orthogonally polarized PIFAs are set up in an antenna module with a board size of 30 mm $\times$ 30 mm and no-ground portion size of 30 mm $\times$ 10 mm. Three impedance bandwidths are defined for a S11 below -10 dB, namely, 20.4% at 2.45 GHz, 14.3% at 5.5 GHz, and 18.5% at 6.5 GHz in each PIFA. The isolation between



(a)



(b)



(c)

Figure 4. The measured 2D radiation patterns for the proposed antenna: (a) 2.45 GHz; (b) 5.5 GHz; and (c) 6.5 GHz.

these two PIFAs is more than 18 dB. The mechanism of the tapered and shortened line is not only to increase the operating band and bandwidth of the antenna but also to decrease the unwanted current induced by the imperfect ground plane, which allows the surface current to be concentrated on the antenna itself and suppress the near-field coupling. The contribution of this article is the implementation of a simple and compact antenna for practical 2 $\times$ 2 MIMO WiFi triple-band operation. Due to the limited space available for setting up the antenna, the peak gain and radiated efficiency of the antenna are challenging to significantly enhance, as it was designed to be used as a

Table 1. The antennas' peak gains and efficiency were measured within the operating frequencies of the proposed antennas (Ant1 is denoted as antenna 1, and Ant2 is denoted as antenna 2)

Ant1 Frequency (GHz)	2.4	2.45	2.5	5.15	5.5	5.85	5.925	6.225	6.525	6.825	7.125
Peak gain (dBi)	1.98	1.77	1.96	3.16	2.57	2.38	1.13	2.07	1.97	3.34	2.43
Efficiency (%)	49.28	49.59	52.78	48.42	76.07	65.58	58.86	67.33	58.01	59.14	53.70
Ant2 Frequency (GHz)	2.4	2.45	2.5	5.15	5.5	5.85	5.925	6.225	6.525	6.825	7.125
Peak gain (dBi)	1.05	1.49	2.16	0.88	2.79	2.16	1.8	2.35	3.36	2.98	3.34
Efficiency (%)	54.88	56.86	52.7	43.75	71.02	63.14	59.52	62.88	58.92	68.18	57.19

WiFi AP extender. Nevertheless, the proposed antenna attained a compact size, multiple bands, and broadband capabilities, along with high isolation when integrated into a MIMO antenna system. This design concept has the potential to be extended to massive MIMO systems.

5. References

1. I-Fong Chen, Chia-Mei Peng, and Han-Lin Zhan, "Isolation Enhancement in WiFi Dual-Band Two PIFAs for Compact Size Antenna Module Applications," IEEE International Symposium on Antennas and Propagation, Boston, MA, USA, July 8–13, 2018, pp. 1819–1820.
2. J. Y. Deng, J. Y. Li, L. Zhao, and L. X. Guo, "A Dual-Band Inverted-F MIMO Antenna With Enhanced Isolation for WLAN," *IEEE Antennas and Wireless Propagation Letters*, **16**, June 2017, pp. 2270–2273.
3. J. N. Hwang and S. J. Chung, "Isolation Enhancement Between Two Packed Antennas With Coupling Element," *IEEE Antennas Wireless Propagation Letters*, **10**, November 2011, pp. 1263–1266.
4. Jian Chen, Shuai Pi, Yang Zhang, and Ting-Ting Lin, "Weak Coupling Technology With Noncoplanar Bucking Coil in a Small-Loop Transient Electromagnetic System," *IEEE Transactions on Industrial Electronics*, **69**, 3, March 2022, pp. 3151–3160.
5. Zhijun Tang, Xiaofeng Wu, Jie Zhan, Shigang Hu, Zaifang Xi, et al., "Compact UWB-MIMO Antenna With High Isolation and Triple Band-Notched Characteristics," *IEEE Access*, **7**, February 2019, pp. 19856–19865.