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Research Article

A Low-Profile WLAN Antenna with Inductor and Tuning Stub for Broadband Impedance Matching

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This paper presents a low-profile multiband antenna suitable for wireless local area networks (WLANs), using a chip inductor and tuning stub for broadband impedance matching. The proposed antenna is compact $(12 \times 10 \times 1\,\text{mm}^3)$ and covers three bands: 2.4-GHz (2.400–2.484 GHz), 5.2-GHz (5.150–5.350 GHz), and 5.8-GHz (5.725–5.825 GHz). The measured 10-dB bandwidths are 12.0% (2.28–2.57 GHz) in the lower band for 2.4-GHz WLANs and 39.1% (4.81–7.15 GHz) in the upper band for 5 GHz-WLANs. The measured peak gain of the antenna is between 2.7 and 4.39 dBi and the radiation patterns are omnidirectional.

1. Introduction

IEEE 802.11 a/b/g standards for wireless local area networks (WLANs) cover the following frequency bands: 2.4 GHz (2.400–2.484 GHz), 5.2 GHz (5.150–5.350 GHz), and 5.8 GHz (5.725–5.825 GHz). The use of mobile communication devices for WLAN applications is steadily increasing because multiband WLANs provide easy Internet access and compatibility with other devices and applications. Furthermore, because the rapid spread of smartphones has generated increasing demand for seamless Internet service, WLANs have become a common feature of mobile handsets [1]. While this has led to research into WLAN antennas [2–6], most of the resulting antennas are large or have complicated structural geometries that make them impractical for use in mobile phones.

Mobile phones are still evolving to become lighter and thinner with more diverse functions as technology advances. The space available for the antenna in a mobile phone decreases as the number of internal components increases. This poses a challenge for antenna designers because the antenna efficiency requirements remain unchanged. Early mobile phones had external antennas, which were often helical [7]. However, external antennas have been replaced by internal designs for the sake of aesthetics and durability, based on studies that began in early 2000 [8–10]. Internal antennas for mobile phones are characterized by a low profile and a single substrate; they provide multiband coverage and omnidirectional radiation [4]. Impedance matching is essential in low-profile internal antennas to enhance antenna characteristics [1].

Antenna impedance-matching techniques can be classified into two categories: current impedance matching and lumped element matching. Current impedance matching sometimes results in complexity of design and manufacturing due to the modification of antenna geometry, and losses might be induced by the use of dielectric materials. In lumped element matching, the matching network of inductors and capacitors equalizes the impedance mismatch between the source and antenna load. This approach also results in some degree of loss and complexity [11–13].

This paper proposes a triple-band internal antenna for WLAN applications. The proposed antenna is a modified two-strip monopole antenna with a shunt inductor and tuning stub. To reduce the antenna volume and meet performance requirements, the height was fixed at 1 mm and the

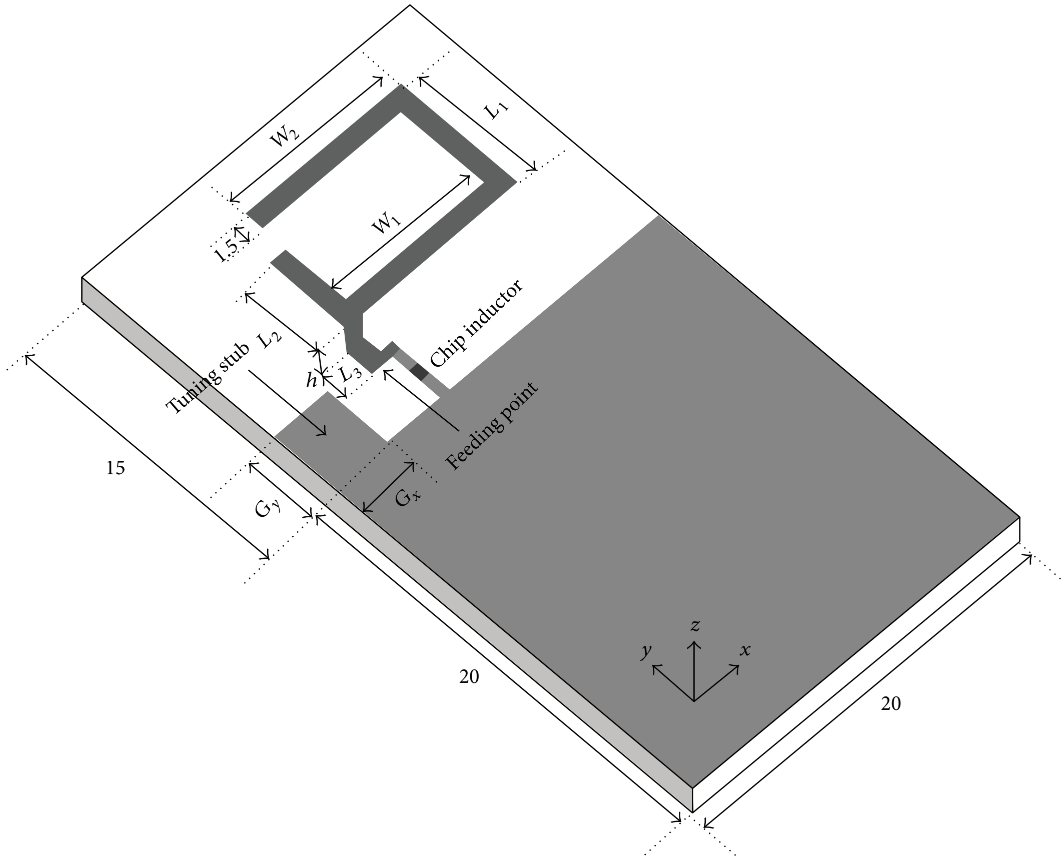


Figure 1: Geometry of the proposed WLAN antenna.

strip was folded. A shunt inductor ($L = 6.8$ nH) was added for impedance matching at approximately 2.4 GHz and a tuning stub was included on the ground plane for broadband impedance matching. The capacitive coupling between the tuning stub and antenna tunes the resonance and broadens the impedance bandwidth in the 5-GHz bands. This antenna was designed and analyzed using the CST Microwave Studio software package [14]. Its performance was evaluated by measuring the actual characteristics of a physical prototype. This antenna could be used for triple-band WLAN operations and is much smaller than previous antennas [2–6]. The proposed impedance-matching technique is easily integrated into a PCB without increasing the antenna volume.

2. Antenna Design

The structure of the proposed antenna is shown in Figure 1. The antenna is built in an FR4 printed circuit board that is 0.8 mm thick and has a permittivity of 4.4; this material is frequently used in mobile phones due to its low cost. The substrate is 20×35 mm and the system ground is 20×20 mm. The antenna is a two-strip monopole with a shunt inductor and tuning stub. As shown in the figure, the folded monopole antenna geometry widely used in mobile handsets is used here to obtain dual resonance, omnidirectional radiation, and compact size.

Figure 2 shows the simulated reflection coefficient of a two-strip monopole antenna as a function of height h. In this simulation, the parameters were set as follows: $L_1 = 8.0$ mm, $L_2 = 4.7$ mm, $L_3 = 2$ mm, $W_1 = 9.0$ mm, and $W_2 = 11.7$ mm. Figure 2 shows that the higher resonance frequency increased with the height, although the height had little effect on the lower resonance frequency. Conversely, an increase in height improved the impedance matching at the lower resonance but degraded that of the higher band. Therefore, we fixed the height at 1 mm to include resonances near 2.5 and 5 GHz while maintaining a low physical profile consistent with the latest trend in slim phones. With the height set at 1 mm, the current path length of strip 1 was 31.7 mm, which corresponded approximately to a quarter wavelength of 2.5 GHz. The overall length of strip 2 was 7.7 mm, corresponding approximately to a one-eighth wavelength of 5 GHz, but this is one-quarter wavelength in relation to $\lambda = c/f\sqrt{\mu\varepsilon}$, where $\mu = 1$ and $\varepsilon = 4.4$ for the high frequency. However, the antenna must enhance impedance matching and bandwidth for WLAN applications.

Figure 3 shows the simulated reflection coefficients of the antenna for different values of the chip inductor for the same parameters and a height of 1 mm. An inductor parallel to the antenna enhances the impedance matching in the 2.4-GHz band. When the inductance increased, the impedance matching improved, although there was little change in impedance

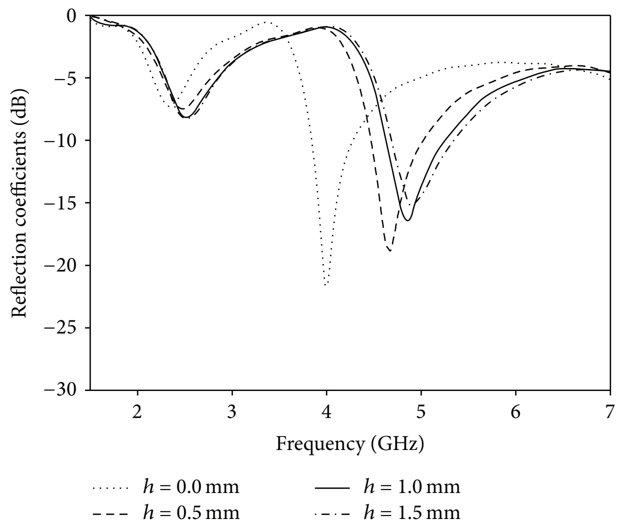


FIGURE 2: Simulated reflection coefficients of a two-strip monopole antenna as a function of height h.

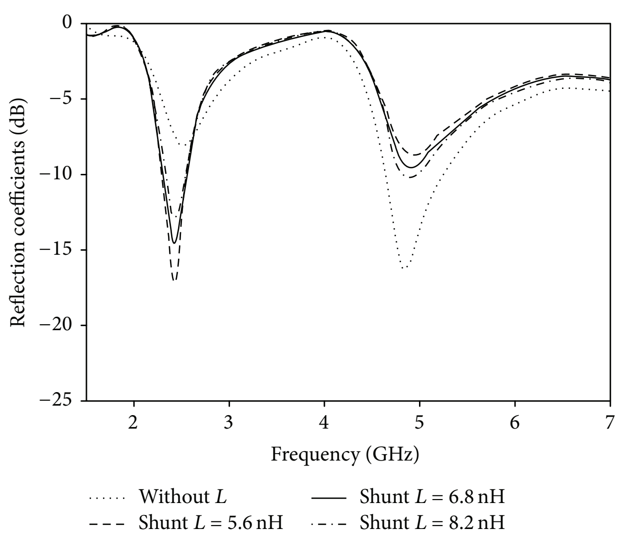


FIGURE 3: Simulated reflection coefficients of the proposed antenna as a function of the chip inductor (L).

matching for the 2.4-GHz band when the value of the inductance was ≤6.8 nH. When the inductance increased, the impedance matching improved, but the measured antenna gain decreased. Hence, an inductance of 6.8 nH was found to be most appropriate. However, the bandwidth and impedance matching had to be enhanced for the 5.2- and 5.8-GHz bands while maintaining the characteristics of the 2.4-GHz band.

Figure 4 shows the enhancement of the bandwidth and impedance when a tuning stub ($G_x = 3.2$ mm, $G_y = 3.4$ mm) is inserted. Without the tuning stub, the input impedance of the 2.4-GHz band is inside the 2 : 1 voltage standing wave ratio (VSWR) circle, but the input impedance of the 5.2 and 5.8-GHz bands is outside. With the tuning stub, however, all frequency bands required for 5.2- and 5.8-GHz WLAN applications are satisfactory because the impedance locus on

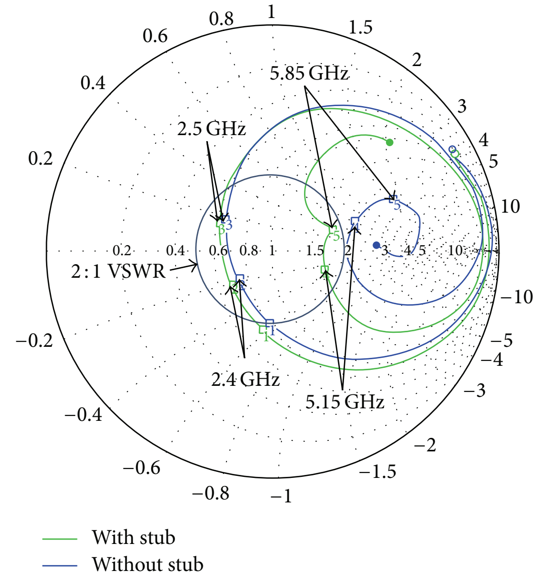


FIGURE 4: Simulated input impedance for the proposed antenna shown on Smith chart with (green) and without (blue) a tuning stub for frequencies 1.50–8.00 GHz.

the Smith chart moves inside the circle. Furthermore, the capacitive coupling between the tuning stub and antenna tunes the higher resonance and enhances bandwidth with little change to the lower band. This means that the proposed antenna covers all frequency bands required for 2.4/5.2/5.8-GHz WLAN applications when we choose a tuning stub with appropriate width G_x and length G_y.

Table 1 lists the results of a parameter analysis performed to optimize the tuning stub with the same antenna parameters shown in Figure 3 and an inductance value of 6.8 nH. Resonance and the 10-dB bandwidth of both bands were investigated when the width of tuning stub increased from 2.8 to 3.6 mm and the height increased from 3.0 to 3.8 mm in 0.4-mm increments. Table 1 shows that, without the tuning stub, the 2.4-GHz WLAN band was included, but the 5.2/5.8-GHz band was not. The lower resonance and 10-dB bandwidth were not affected by the size of the tuning stub, but the higher resonance increased with the tuning stub width and length. For a width of 3.0 mm, the 5.8-GHz band was not included. A width of 3.4 mm resulted in a broad 10-dB bandwidth that included the 5.2/5.8-GHz WLAN band for different tuning stub heights, unlike widths of 3.0 and 3.8 mm. Therefore, the width of the tuning stub was fixed at 3.4 mm. Since a width of 3.4 mm and length of 3.2 mm resulted in the maximum 10-dB bandwidth, 3.2 mm was selected as the most appropriate length.

According to the simulation results, the geometry proposed in this paper can be modeled by the equivalent circuit illustrated in Figure 5. The radiating strip 1, configured with L_3, h, W_1, L_1, and W_2, as indicated in Figure 1, is represented by L_{strip1}, C_{strip1}, and R_{strip1}. As Figure 3 shows, the shunt chip inductor L_{chip} is directly related to the resonant frequency of 2.4 GHz. Therefore, the radiating strip and the shunt chip inductor can be grouped together, resulting in the admittance

Table 1: Resonant frequency and 10-dB bandwidth for different tuning stubs.

Tuning stub		Lower band		Upper band	
G_x (mm)	G_y (mm)	f_{low} (GHz)	BW_{low} (%)	f_{high} (GHz)	BW_{high} (%)
0	0	2.42	8.2	4.90	0
2.8	3.0	2.42	8.2	5.15	11.8
	3.4	2.42	8.2	5.31	32.7
	3.8	2.42	8.2	5.41	29.5
3.2	3.0	2.42	8.2	5.20	7.7
	3.4	2.42	8.2	5.36	33.8
	3.8	2.42	8.2	5.46	29.0
3.6	3.0	2.42	8.2	5.23	7.6
	3.4	2.42	8.2	5.41	33.5
	3.8	2.42	8.2	5.52	29.1

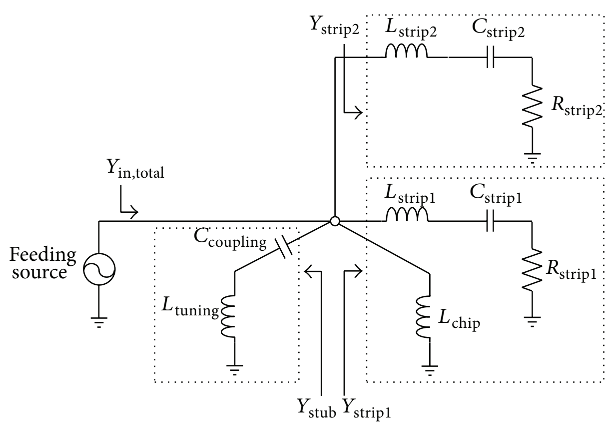


Figure 5: The equivalent circuit for the proposed WLAN antenna.

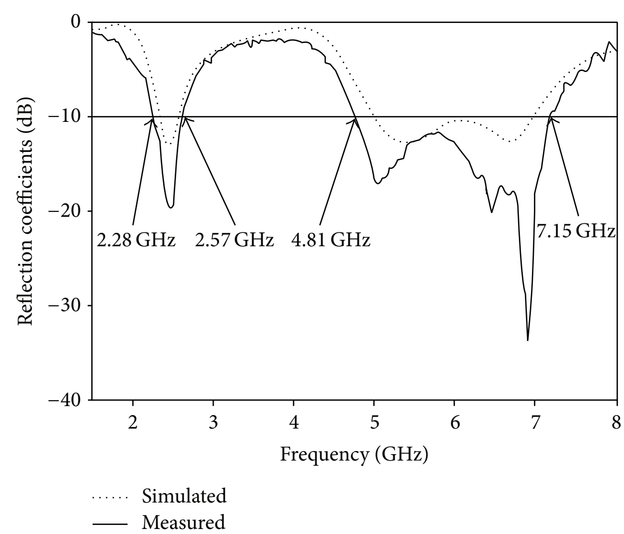


Figure 6: Simulated and measured reflection coefficients of the proposed antenna.

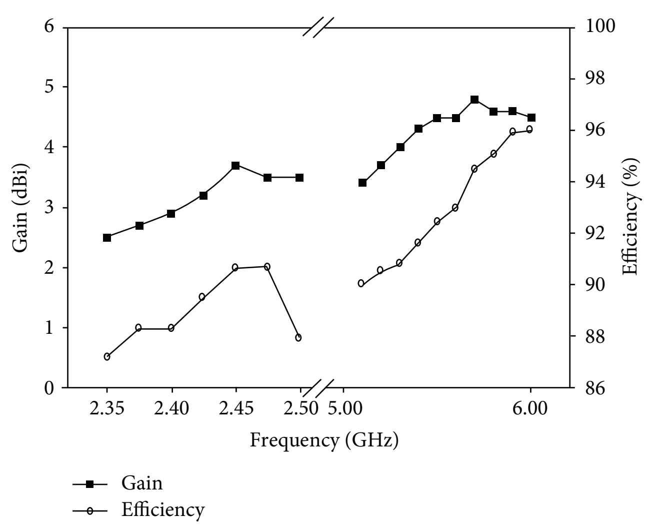
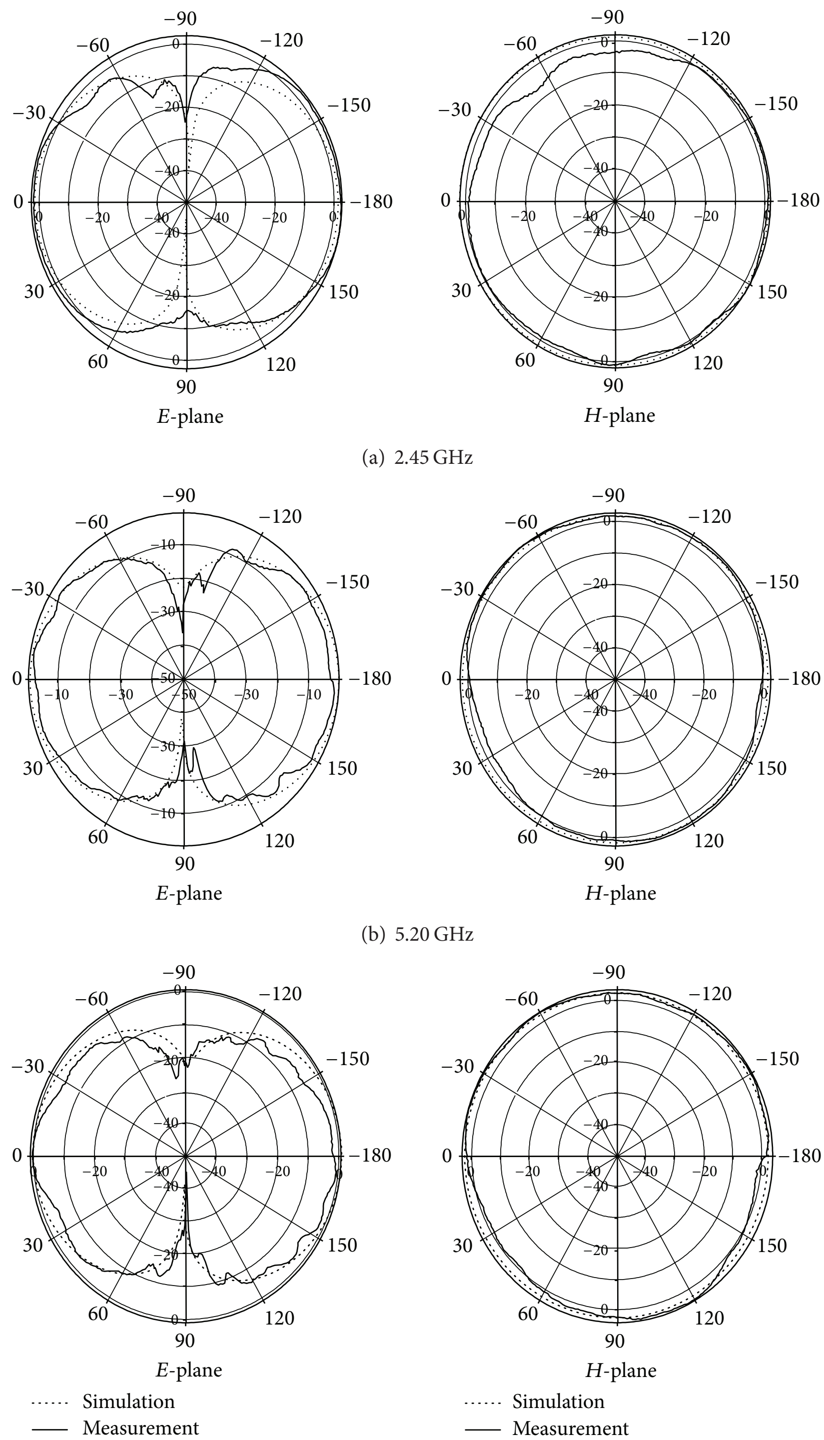


Figure 7: Measured radiation efficiency and peak gain of the proposed antenna.

Y_{strip1}, as shown in Figure 5. Similarly, the radiating strip 2, configured with L_3, h, and L_2, is represented by L_{strip2}, C_{strip2}, and R_{strip2}. The corresponding input admittance is Y_{strip2}. The tuning stub, represented by L_{tuning}, is connected to the feeding source via the coupling capacitor $C_{coupling}$. The corresponding input admittance is Y_{stub}. The approximate value of the admittance for each separate structure can be calculated using the full-wave simulation tool CST Microwave Studio. The resulting values of Y_{strip1}, Y_{strip2}, and Y_{stub} are $0.0292 + j0.0068$, $0.0057 + j0.0034$, and $0.0078 - j0.0019$ mho, respectively, for 2.4 GHz; $0.0004 + j0.0056$, $0.0148 + j0.0064$, and $0.0176 + j0.0005$ mho, respectively, for 5.2 GHz; and $0.0001 + j0.0038$, $0.0022 + j0.0121$, and $0.0033 + j0.0164$ mho, respectively, for 5.8 GHz. The total input impedance $Y_{in,total}$ can be approximately calculated as $Y_{in,total} \approx Y_{strip1} + Y_{strip2} + Y_{stub}$ by ignoring the redundancy and coupling between equivalent blocks.

3. Measurement Results

A prototype antenna was fabricated using the optimized parameters obtained as described in the previous section. The performance of this prototype was characterized in terms of the reflection coefficient, gain, and radiation pattern, which were measured in an anechoic chamber.



(a) 2.45 GHz

(b) 5.20 GHz

(c) 5.80 GHz

FIGURE 8: Simulated and measured radiation patterns of the proposed antenna.

The compact antennae [2–6] of multiband WLAN services occupy a lot of space and are not easy to integrate with other circuitry. The proposed antenna is smaller than Chiu's antenna [2] and Kim's antenna [3] by 56% and 12%, respectively. In addition, its bandwidths are wider than those in [2, 3] by 6.7% and 7.0%, respectively, at 2.4 GHz and by 15.0% and 13.9%, respectively, at 5 GHz.

Figure 6 shows that the simulated and measured reflection coefficients of the antenna agreed closely. The 10-dB bandwidth of the prototype was 12.0% in the lower band (2.28–2.57 GHz) and 39.1% in the higher band (4.81–7.15 GHz). These results show that broadband impedance matching was achieved and the proposed antenna satisfies the impedance conditions in all frequency bands required for 2.4/5.2/5.8-GHz WLAN applications.

Figure 7 shows the measured peak gain of the prototype antenna. The measured peak gain in the 2.4-GHz band ranges from 2.7 to 3.2 dBi. In the 5.2/5.8-GHz band, the measured peak gain varies between 2.95 and 4.39 dBi. These results are suitable for mobile terminals.

Figure 8 shows the simulated and measured radiation patterns of the prototype antenna at 2.45, 5.20, and 5.80 GHz measured from 0° to 360° at 5°-intervals. Good agreement was obtained between the simulated and measured results. These radiation patterns are omnidirectional over all the WLAN operating bands.

4. Conclusion

This paper presents a low-profile two-strip monopole antenna with an inductor and tuning stub that can cover the 2.4/5.2/5.8-GHz WLAN frequencies. The narrow bandwidth and poor impedance matching due to the low-profile geometry were enhanced with a tuning stub and shunt inductor. A prototype constructed using optimized parameters had a fractional bandwidth of 12.0% in the lower band (2.28–2.57 GHz) and 39.1% in the higher band (4.81–7.15 GHz). The radiation pattern of the antenna was omnidirectional with a high peak gain of 2.7–4.39 dBi. Furthermore, at $12 \times 10 \times 1$ mm, the overall size of the antenna makes it very promising for compact mobile terminals.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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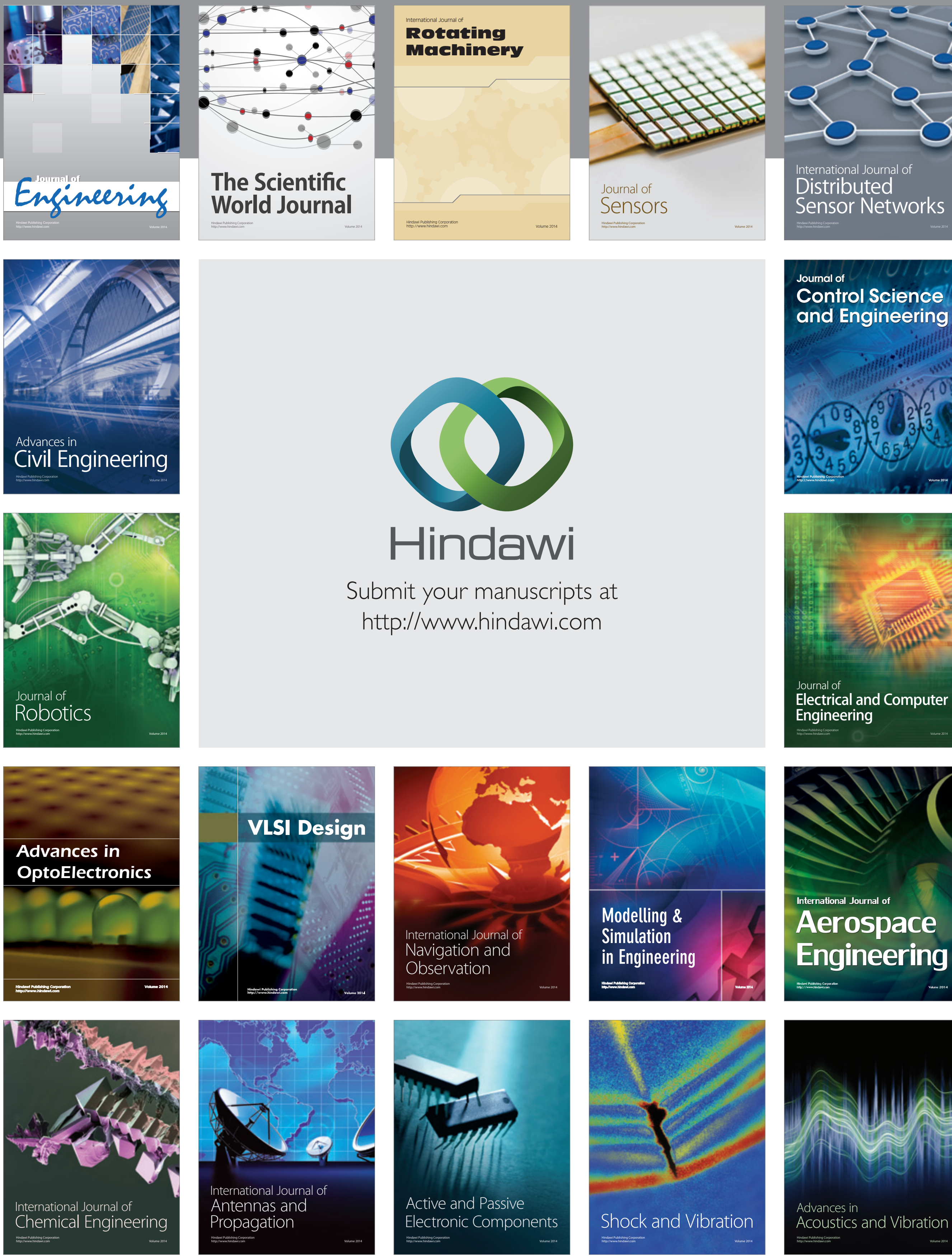
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