Dual-Band WLAN Dipole Antenna Using an Internal Matching Circuit

Zhijun Zhang, *Senior Member, IEEE*, Magdy F. Iskander, *Fellow, IEEE*, Jean-Christophe Langer, and Jim Mathews

***Abstract*—A dual-band dipole antenna for wireless local area network (WLAN) is designed and experimentally tested at both the 2.4 and 5 GHz (IEEE 802.11b/g and 802.11a) WLAN bands. The design procedure involves obtaining a full resonance frequency in the 2.4 GHz band and then using a matching network to achieve a secondary resonance at the 5 GHz band. It is shown that by correctly designing the dipole, the matching network can be simplified to only one series inductor. The design was experimentally verified by constructing a dipole on a FR4 board (12 mm $*$ 45 mm $*$ 0.45 mm) and measuring its input impedance and the radiation characteristics at both bands. The measured VSWR 2:1 bandwidth in the 2.4 GHz band is 710 MHz, and the bandwidth in 5 GHz band is wider than 1 GHz. The VSWR 3:1 bandwidth is more than 3.6 GHz and it covers from 2.32 GHz to above 6 GHz. It is significant that the designed dual-band dipole maintained good radiation efficiency values at both bands. Specifically, and based on the measured radiation patterns, an efficiency value of 85% $\sim$ 87% is obtained at 2.4 GHz and a value in the range of 55 $\sim$ 64% is obtained in 5 GHz band.**

***Index Terms*—Dipole antennas, dual-band antennas, matching circuit, printed antennas.**

I. Introduction

WIRELESS local area network (WLAN) is one of the most important applications of the wireless communication technology. WLAN takes advantage of license free frequency bands, industrial, scientific and medical (ISM) bands and uses both 2.412 to 2.482 GHz (IEEE 802.11b and IEEE 802.11g) and 5.15 to 5.825 GHz (IEEE 802.11a) frequency bands. To integrate both bands into one device, it is important to develop dual-band antennas.

Various kinds of antennas, such as reduced size PIFA [1], dual loop antenna [2] and double T antenna [3] were purposed to provide dual-band operation. Unlike dipole antenna, those antenna could not provide uniform omni-directional coverage, but they are suitable for low profile installation. Suh *et al.* [4] reported a printed dipole antenna for dual-band operation, in which two separate dipoles of different arm lengths were printed on both sides of a dielectric substrate. The longer and shorter dipoles were designed to generate resonant radiation in the 2.4 and 5.2 GHz bands. This kind of printed dipole antenna design, however, occupies a relatively large space and the bandwidth in 5 GHz was also limited. Specifically, the bandwidth of the antenna in 5 GHz band was 400 MHz and thus is not sufficiently broad to cover the entire 5 GHz band. Su *et al.* [5] reported a dual-band dipole in which the two resonances were obtained by cutting a U-slot in the arms of dipole. In this case, the bandwidth in 5 GHz band was 370 MHz and this is once again insufficient to cover the entire band. Chen [6] reported a multiband printed sleeve dipole antenna that uses different strip pairs to compose various resonance frequencies. This antenna actually provided sufficient bandwidth in both the 2.4 and 5 GHz band, but the azimuth average gain in 2.4 GHz was low, around 0 dBi, which means low efficiency.

A novel dual-band dipole antenna for WLAN is purposed in this paper, and a prototype dipole was designed, fabricated, and measured. The measured VSWR 2:1 bandwidths are 710 MHz and wider than 1 GHz in the 2.4 and 5 GHz bands, respectively. The VSWR 3:1 bandwidth of this dipole is wider than 3.6 GHz and it covers from 2.32 GHz to above 6 GHz. The results as well as the estimated radiation efficiencies in both bands will be described in the following sections.

II. Design Approach and Simulation Results

To design a dual-band dipole, there can be two kinds of approaches. One approach is to try to obtain two full resonances at both the desired frequencies, while in the other one tries to design the antenna at one frequency and then uses a matching network to obtain the second resonance. Based on literature data [5], [6], dual-band dipoles that achieved two full resonances were either of low efficiency [6], or had limited bandwidth in the 5 GHz band [4], [5].

The design approach in this paper is based on obtaining a full resonant frequency only in 2.4 GHz band and then using a matching network to obtain a secondary resonance at 5 GHz band. The design goal is to optimize the performance and simplify the matching network. To optimize the performance, the antenna impedance should be designed to be as close as possible to source impedance, normally 50 Ω. To simplifying the matching network, the input impedance of the antenna should be inside some special range, thus a matching network can be reduced to a possibly only one component. Due to expected tolerances and fabrication variations in mass manufacturing, the antenna bandwidth has to be designed even wider than the working bandwidth to guarantee good yield. Thus in our design, a 5 to 6 GHz was used as the 5 GHz band instead of the 5.15 to 5.825 GHz one assigned as standard.

Fig. 1 shows the impedance of a thin trace printed dipole. The dipole is designed for 2.4 $\sim$ 2.5 GHz. The dash line circle on the middle of Smith Chart is the VSWR 2:1 circle. Any impedance inside this circle provides a lower VSWR value than

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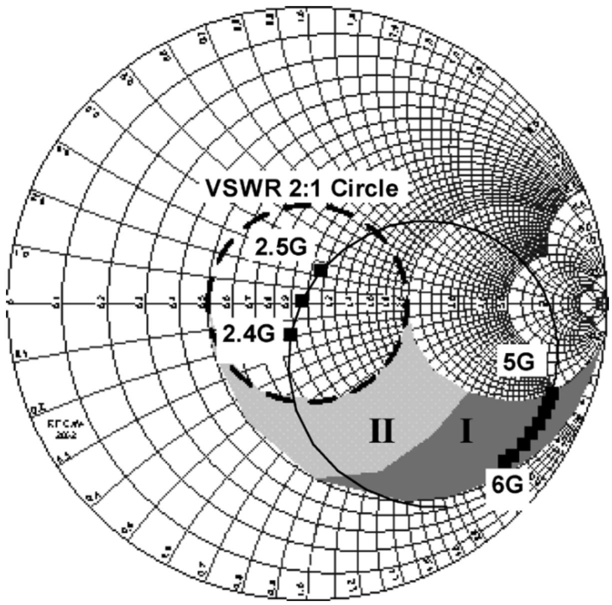


Fig. 1. Impedance of a thin trace printed dipole.

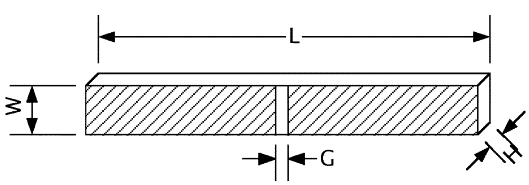


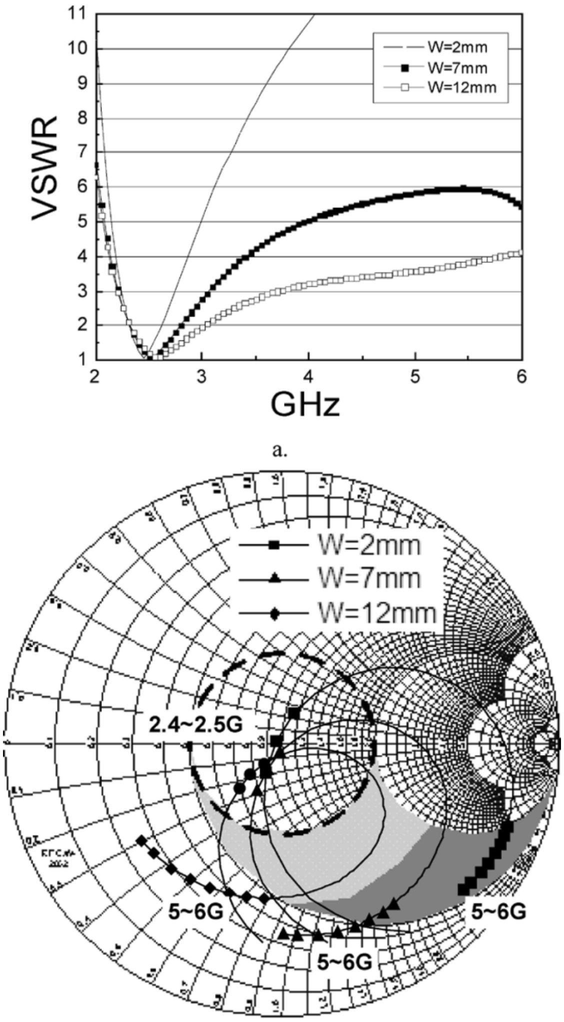
Fig. 2. Schematic of a printed circuit dipole.

2:1, which is normally the specification for wireless communication. The dipole shown in the Fig. 1 is well matching in 2.4 $\sim$ 2.5 GHz, and specifically the simulated VSWR is less than 1.3:1 throughout 2.4 $\sim$ 2.5 GHz.

From the input impedance values in the 5 to 6 GHz shown in Fig. 1, it may be noted that the designed dipole displayed a large capacitive input impedance. Fig. 1, however, has two shaded areas, Area I and Area II, and if the antenna impedance in the 5–6 GHz band falls within these two areas, it would be possible to achieve matching using an only one series inductor (rotation on a constant resistance circle until impedance values fall in the 2:1 VSWR circle). Unfortunately, although a matching circuit can be used to get good VSWR value when the impedance falls inside Area I, the performance of this antenna is expected to be very poor. As a rule of thumb, an acceptable performance of an antenna can be obtained through a matching network when the VSWR without matching network is less than 5:1. The simulated VSWR of the thin trace printed dipole in the 5 GHz band and without matching is above 10:1. To be matched by a single serial-inductor and also obtain a good performance, the impedance of the antenna has to fall into the Area II where VSWR values are less than 5.

In antenna engineering, it is well known that one may be able to broaden the bandwidth of a single band dipole antenna by increasing the diameter of the dipole arms. In this paper the width of printed dipole was widened, but not to increase the bandwidth at 2.4 GHz band (original resonance), but to change the input impedance values in the 5 GHz band.

Fig. 2 shows a schematic of the printed circuit dipole that was used in the simulation. The dipole was printed on a FR4



b.

Fig. 3. Simulated VSWR and impedance of different width dipoles. $L = 45$ mm, $G = 1$ mm FR4 board ($\varepsilon_{\rm r} = 4.5$) thickness $H = 0.45$ mm. a. VSWR; b. impedance.

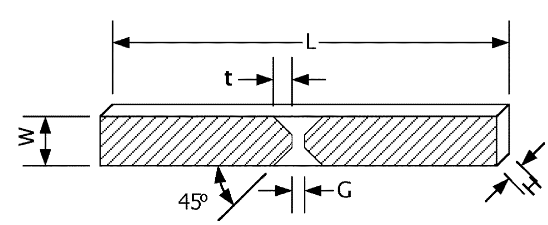
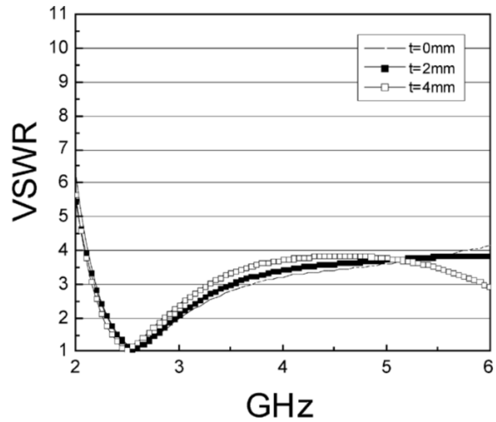


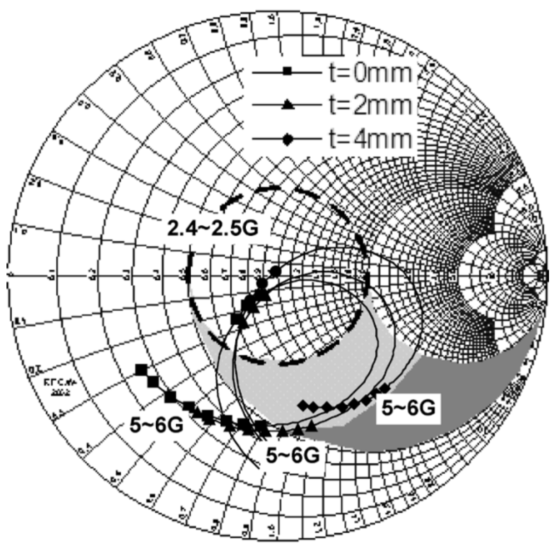
Fig. 4. Diagram of 45° chamfered printed dipole.

($\varepsilon_{\rm r} = 4.5$) substrate. The thickness of substrate is H, the length is L, and the width is W. Two hatched rectangular sections in Fig. 2 are copper traces on the top of substrate. The gap between the two traces is G. The printed dipole was fed at the middle of the gap.

HFSS was used in all the simulations presented in this paper. Fig. 3 shows the simulated VSWR and impedance values for different width of the dipole arms. For all simulations in Fig. 3, the length of dipoles $L = 45$ mm, the gap $G = 1$ mm, the thickness $H = 0.45$ mm. The width of dipole arms were changed from 2 to 12 mm. Fig. 3(a) shows that with the increase in width, the bandwidth around 2.4 $\sim$ 2.5 GHz increases. More importantly, however, one may also note that the VSWR values in 5 $\sim$ 6



a.



b.

Fig. 5. Simulated VSWR and impedance of different chamfered dipoles. $L = 45$ mm, $G = 1$ mm, $W = 12$ mm FR4 board ($\varepsilon_r = 4.5$) thickness $H = 0.45$ mm. (a) VSWR and (b) impedance.

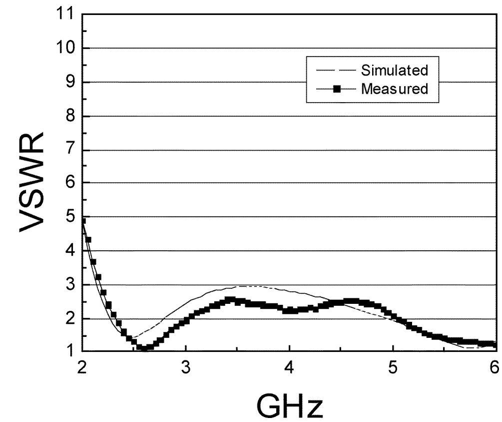


Fig. 6. Simulated VSWR versus measured VSWR.

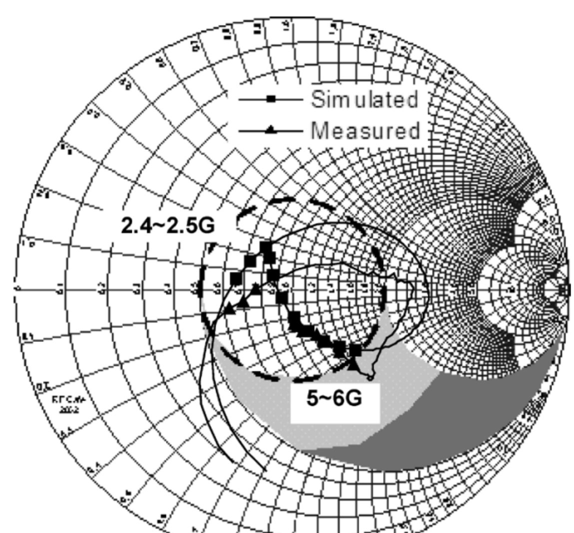


Fig. 7. Simulated versus measured impedance.

GHz band decrease with the width increase. When the width of a dipole is 7 mm the VSWR is about 6:1 in the 5 GHz band. Upon increasing the width to 12 mm, the VSWR values were further improved to around 4:1, and this is expected to provide a good antenna performance after adopting a matching network.

Fig. 3(b) shows the simulated impedance on the Smith Chart. As may be noted, the increase in the dipole width resulted in improved VSWR values, but the dipole impedance in 5 GHz band, on the other hand, moved out of Area II where a single serial inductor can be used to match the antenna. Some modification on the antenna design need to be made to shift the impedance values in the 5 GHz band back to shaded Area II and in the same time keep the antenna response in 2.4 GHz band still within the 2:1 VSWR circle.

There are several ways to shift the 5 GHz band impedances on Smith chart and possibly place these values within the shaded Area II. One way is to cut slots in the dipole, while another is by using a variable width dipole. As shown in Fig. 4, the technique used in the paper is by chamfering the feeding point of a dipole. Only a 45° chamfered was used in this paper, but different chamfered angles could also be used for tuning the antenna. This particular design parameter was not optimized in this paper, (L, W, G, H) are kept the same as introduced in Fig. 3, and an additional dimension involving the chamfered length t is introduced and optimized in our design. The dimension t may take values between 0 to W/2. The $t = 0$ case is equivalent to an unchamfered antenna.

Fig. 5 shows simulated VSWR and impedance results for dipoles of different chamfered lengths. For all simulations in Fig. 5, the length of dipoles $L = 45$ mm, the gap $G = 1$ mm, the thickness $H = 0.45$ mm, and the width $W = 12$ mm. The chamfered length of the dipole changed from 0 to 4 mm. Fig. 5(a) shows that with the increase of the chamfered length, the bandwidth around $2.4 \sim 2.5$ GHz decreased slightly, and the impedance values in $5 \sim 6$ GHz band continued to shift toward the shaded Area II. It is important, however, to note that throughout the process of increasing t, the antenna performance in the 2.4 GHz band stayed well within the required specifications, and specifically continued to be at least seven times wider than the required working bandwidth of approximately 100 MHz. Additional simulation results showed that further increase in t results in impedance values in the higher band (5–6 GHz) that would be diffcult to match using our proposed procuder of a single series inductor.

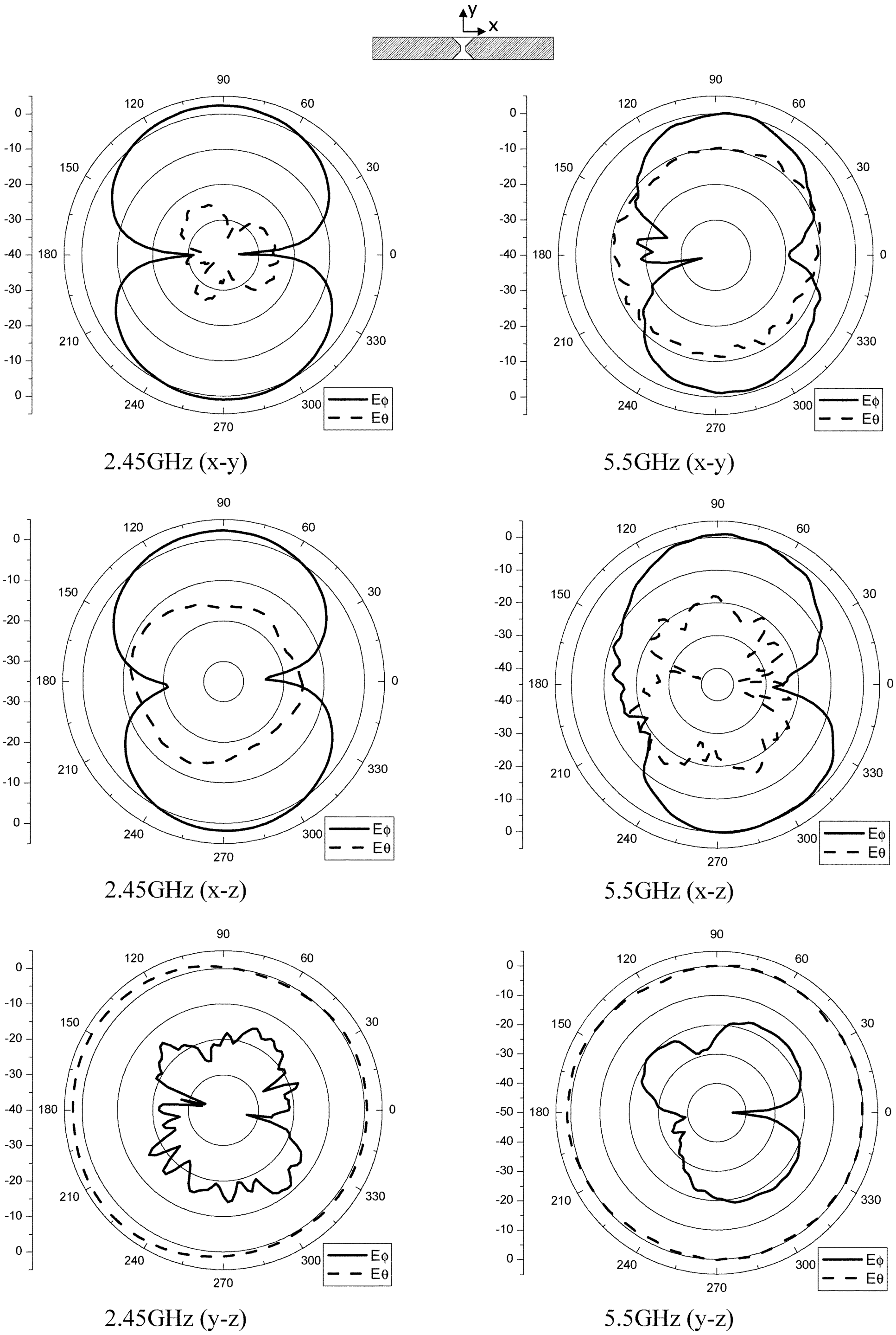


Fig. 8. Measured antenna radiation patterns.

Fig. 5(b) shows the antenna impedance on Smith chart, and as can be seen the input impedance values in the 5 GHz band continued to move in the counterclockwise direction and toward Area II with the increase in the chamfered length. When t is equal to 4 mm, the 5 GHz band impedance values were well within the light shaded Area II, where the antenna can be matched by a single series inductor and at the same time obtain good radiation efficiency. Thus 4 mm was chosen as the chamfered length in the final design and a 1.5 nH serial inductor was used as the matching component. The impact of the internal resistance of the inductor (estimated at 0.13 Ohms) was neglected. Simulation results of the finial design with the matching network are presented in the next session together with the experimentally measured data.

III. Experimental Measurements and Results

The final dipole was built on a FR4 board, the thickness of FR4 board is $H = 0.45$ mm. The length of the dipole is 45 mm, the gap is 1 mm, the width is 12 mm and the chamfered length is 4 mm. A Johanson Technology 1.5 nH inductor was connected in series between the center wire of coaxial cable and

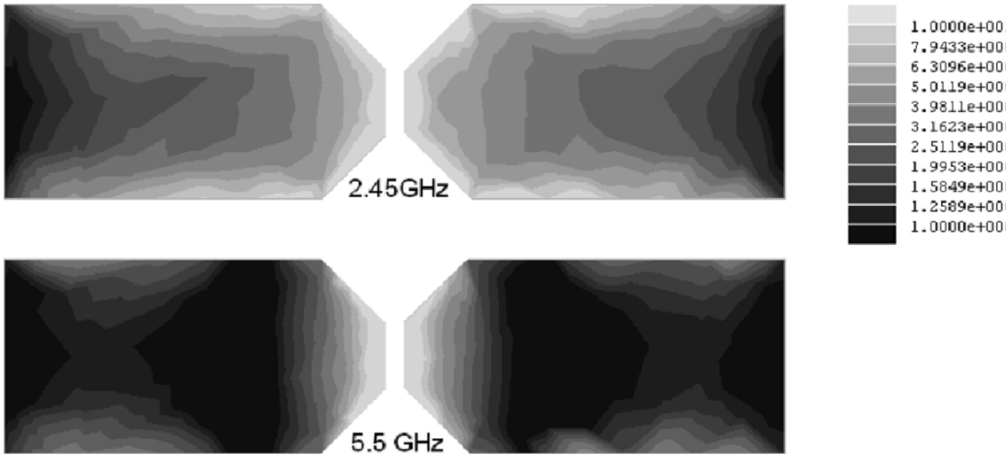


Fig. 9. Simulated current distributions at both 2.4 and 5 GHz.

one arm of the dipole as matching network. The outer conductor of the coaxial cable was connected to the other arm of the dipole. The self-resonant frequency of the 1.5 nH inductor is higher than 15 GHz, which is much higher than the highest operating frequency of the dipole proposed in this paper. The feed cable runs perpendicular to the plane of the antenna (z-direction).

Fig. 6 shows results of the simulated versus measured VSWR values. The VSWR 2:1 bandwidth at 2.4 GHz band is 710 MHz, from 2.32 to 3.03 GHz. The VSWR 2:1 bandwidth at 5 GHz band starts from 5 GHz and is larger than 1 GHz. Due to the frequency limitation of the network analyzer is 6 GHz, the upper limit of the working frequency band could not be measured. If VSWR 3:1 is used to calculate the bandwidth, the bandwidth of purposed antenna would be more than 3.6 GHz and would certainly covers from 2.32 GHz to above 6 GHz. The VSWR 2:1 bandwidth in both the 5 and 2.4 GHz band exceeds the requirement of any dual band WLAN application. Fig. 7 shows the simulated versus measured impedance results, and both values agree well.

Fig. 8 shows measured radiation patterns. A Satimo 3-D near field chamber [7] was used to measure the pattern of the dual band dipole. As mentioned earlier, the coaxial feed cables run out perpendicular to the plane of the antenna (z-direction) and this caused interference with the measured radiation patterns in the $x - z$ and $y - z$ planes. To help reduce this effect, ferrite beads were used to cover the part of test cable that is close to antenna. The length of ferrite-bead covered section of the feed cable is about 400 mm. These ferrite beads were expected to suppress the surface current along the feed cable and hence improve the radiation pattern results. As a result, the measured radiation pattern in the 2.4 GHz band, was close to that of an ideal dipole pattern. At 5.5 GHz band, however, surface currents still caused interferences, even with the presence of ferrite beads, and the azimuth ($y - z$ plane, with the z axis along the feed cable) average gain is round 1.3 to 1.5 dBi in the 2.4 GHz band, and -0.2 to 0.3 dBi in the 5 GHz band. These radiation patterns were further confirmed using HFSS simulations. In particular, an HFSS gap source was used in the simulations and symmetric patterns in both E- and H-planes were observed. Furthermore, an improved gain in the 5 GHz band may be obtained by using high frequency board (e.g., Roger instead of FR4) in fabricating the antenna. FR4 board, however, was used exclusively in our design because of cost.

The Satimo 3-D chamber can also provide an estimated value of the radiation efficiency of the measured antenna. The efficiency is defined as the ratio of radiated power versus total available power from power source. Thus the efficiency value includes all impacts from mismatch loss, dielectric loss, conductor loss and matching component loss. The efficiency of the dipole in 2.4 GHz band is from 85% to 87%. The efficiency is from 55% to 64% in the 5 GHz band.

Fig. 9 shows the simulated current distribution. It can be seen that in the 2.4 GHz band, the current distribution is similar to a traditional single band dipole antenna. The measured antenna patterns shown in Fig. 8 also provide a similar observation. In the 5 GHz band, however, the current tends to concentrate on the edge near the feed points with some residual currents further down the dipole length. These combination of currents may explain the narrower than usual beam width in the elevation ($x - y$ and $x - z$ plane) planes when compared with a traditional single frequency dipole.

IV. Conclusion

The design of a new dual-band dipole was described in this paper. The dipole uses a single series inductor as matching network and to obtain good impedance matching and radiation efficiency performance in both the 2.4 and 5 GHz bands. The design methodology was discussed in details and simulation results were presented to illustrate the various implemented design steps. A dual-band dipole was also fabricated and tested. The measured results were found to agree very well with simulated data. Specifically, the VSWR 2:1 bandwidth in the 2.4 GHz band is 710 MHz, while the VSWR 2:1 bandwidth in the 5 GHz band is wider than 1 GHz. Both of these bandwidths exceed the requirement of any WLAN application. Radiation efficiencies were also estimated using the Satimo 3-D chamber calculator and values in the range 85% $\sim$ 87% in the 2.4 GHz band and 55% $\sim$ 64% in the 5 GHz band were reported. Efficiency calculations were based on the measured radiation patterns and known values of available power from the source.

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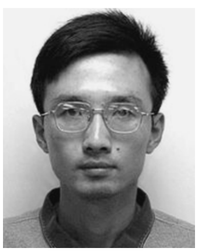

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