Dual-band metamaterial-inspired small monopole antenna for WiFi applications

J. Zhu and G.V. Eleftheriades

A simple dual-band metamaterial-inspired small monopole antenna is proposed for WiFi applications. In addition to the regular monopole resonance, the metamaterial-inspired loading is exploited to create a second resonance for the lower WiFi band while maintaining the antenna's small form-factor. The measured S parameters and radiation patterns show that the proposed design is suitable for emerging WLAN applications.

Introduction: The challenge in designing a WiFi system is to design compact, low-cost and dual-band antennas. The planar monopole is considered a good candidate for WLAN applications because it is low profile, etched on a single substrate and can provide the feature of multi-band operation. In order to achieve multi-band operation, the traditional approach is to use multi-branched strips [1], which generally leads to a large volume or requires a large ground-plane. In [2], Kuo *et al.* proposed a dual-band double T monopole antenna, which achieves a certain miniaturisation factor but with a narrow bandwidth at the upper WiFi band. Metamaterials (MTM), on the other hand, provide a conceptual route for implementing small resonant antennas [3, 4]. In this Letter, a dual-band monopole antenna is proposed that employs metamaterial-inspired reactive loading. The MTM-based loading creates a second resonance covering the lower WiFi band of 2.40–2.48 GHz, in addition to the monopole resonance over the 5.15–5.80 GHz upper WiFi band. A prototype antenna has been fabricated and tested. The measured S parameters and the radiation patterns are given and discussed.

Antenna design: The configuration of the proposed antenna is shown in Fig. 1. The antenna was designed on a low-cost FR4 substrate with a thickness of 1.59 mm. It was fed by a coplanar waveguide (CPW) transmission-line, which can be easily integrated with other CPW-based microwave circuits printed on the same substrate. It comprises a two-arm fork-like monopole with a thin-strip inductor loaded on top of the monopole and an interdigital capacitor loaded on the right-side arm. Alternatively, it can be seen as a T-shaped slot cut out of the rectangular patch with a capacitor loaded on its right. The T-shaped slot has a width of 0.5 mm and the thin strip inductor has a width of 0.25 mm. The smallest feature size of the design is 0.2 mm, which is the finger width of the interdigital capacitor. The monopole element has dimensions of 9.2 × 5.7 mm (or $1/13.3\ \lambda_0 \times 1/21.4\ \lambda_0$ at 2.45 GHz) and the overall size of the antenna including the ground plane is 32 × 24 mm. The proposed design is single-layered, via-free and can therefore be easily fabricated at a very low cost.

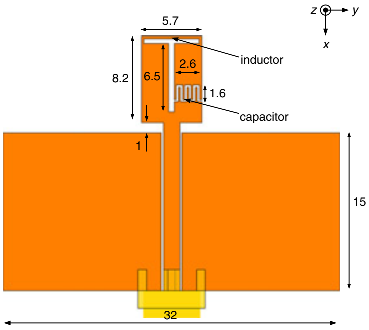


Fig. 1 *Geometry of proposed dual-band MTM-inspired small monopole antenna (mm)*

The reactive loading of the monopole is inspired by transmission-line metamaterials, specifically the concept of a zero-index of refraction. The structure only contains a single unit cell and it can therefore be argued that the interpretation of this antenna as a 'metamaterial' antenna is somewhat questionable. Nevertheless, thinking in terms of the metamaterial paradigm, useful metamaterial-inspired structures can be conceived that contain only a few unit cells [5]. The metamaterial-inspired loading enables the antenna to operate in two modes, covering both WiFi bands. The first mode is a monopole mode, operating at the upper WiFi band, where the capacitor becomes short and the inductor becomes open. Fig. 2 shows the HFSS-simulated current distribution on the monopole element of the proposed antenna at both WiFi bands. It can be seen that at the upper WiFi band, in-phase currents are flowing along both arms of the fork-like monopole, which enables the x-directed even-mode currents on the antenna to radiate.

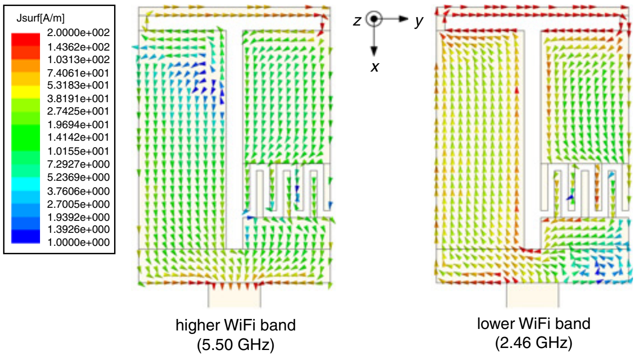


Fig. 2 *HFSS-simulated surface current distribution on radiating elements of dual-band antenna at upper and lower WiFi bands*

In addition to the monopole resonance at the upper WiFi band, the MTM-inspired reactive loading introduces a second resonance around the lower WiFi band. At this frequency, the antenna no longer acts as a monopole along the x-axis, but rather as a slot along the x-axis, as shown in Fig. 2. The MTM loading forces the current to wrap around the slot perimeter and induce an E-field distribution along the y-axis within the slot, both contributing to the slot-mode radiation. Besides, the loading inductor and capacitor are adjusted such that radiation efficiency and bandwidth are traded off in order to meet the WiFi requirements while still maintaining the antenna's small form-factor. An alternative view to look at the operation of the proposed antenna at the lower WiFi band is that it can be seen as a T-shaped top-loaded monopole antenna [2, 6], but in its dual slot form. In this case, instead of having the capacitive top loading, an inductive top-loaded feature is realised. The loading interdigital capacitor is therefore exploited in order to compensate the inductive imaginary part of the input impedance and match it to 50 Ω.

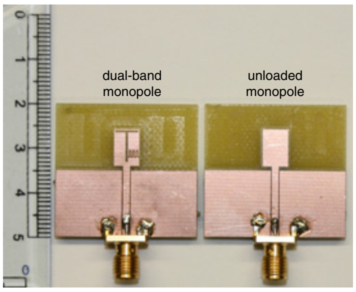


Fig. 3 *Fabricated prototype of proposed dual-band MTM-inspired small monopole antenna, compared with unloaded monopole antenna*

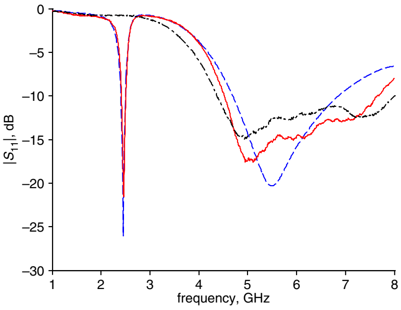
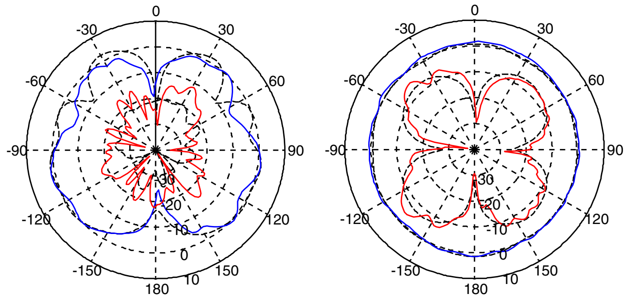


Fig. 4 *Simulated and measured S_{11} for proposed dual-band antenna compared with unloaded monopole antenna*

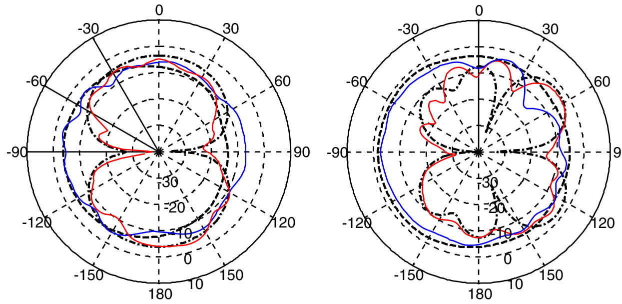
—— measured dual-band MTM-inspired small monopole antenna
- - - -simulated dual-band MTM-inspired small monopole antenna
- · - · measured unloaded monopole antenna

Results: The fabricated prototype is shown in Fig. 3. An unloaded monopole antenna with the same monopole and ground plane size is fabricated and tested for comparison. Fig. 4 shows the HFSS-simulated and measured *S* parameters, where a dual-band performance can be clearly seen from the proposed antenna against the single-band performance from the regular CPW-fed monopole antenna within the frequency range of interest. The antenna exhibits a measured -10 dB bandwidth of 90 MHz for the lower WiFi band from 2.42 to 2.51 GHz and a bandwidth of 3.2 GHz from 4.52 to 7.72 GHz for the upper WiFi band, which agree with simulation results.



E-plane (*xy*-plane) at 5.50 GHz
a

H-plane (*yz*-plane) at 5.50 GHz
b



E-plane (*yz*-plane) at 2.46 GHz
c

H-plane (*xz*-plane) at 2.46 GHz
d

Fig. 5 *Simulated and measured radiation patterns for proposed dual-band small monopole antenna*

—— measured gain$_\theta$
—— measured gain$_\Phi$
- · - · simulated gain$_\theta$
- - - - simulated gain$_\Phi$

The simulated and measured radiation patterns for the proposed dual-band MTM-inspired small antenna are plotted in Fig. 5, where E-plane and H-plane radiation patterns at 5.50 and 2.46 GHz are shown. Fig. 5*a* and *b* show the radiation patterns at 5.50 GHz for the E-plane (*xy*-plane, $\theta = 90°$) and the H-plane (*yz*-plane, $\Phi = 90°$). An *x*-directed linear E-field polarisation is exhibited, which verifies that the antenna operates in a monopole mode around this frequency owing to the *x*-directed in phase currents along the two arms of the monopole, as shown in Fig. 2. A small amount of the *y*-directed current along the thin horizontal inductive strip have a contribution to the cross-polarisation. At 2.46 GHz, the radiation patterns in the *yz*-plane and *xz*-plane ($\Phi = 0°$) correspond to the E-plane and H-plane, respectively, as shown in Fig. 5*c* and *d*, which indicates that the structure radiates in an *x*-directed slot fashion at this frequency. The *y*-directed slot formed by the two arms of the monopole and the inductive strip has a contribution to the cross-polarisation. The measured radiation efficiencies using the Wheeler cap method are 89.2% at 5.50 GHz and 64.0% at 2.46 GHz, compared with 94.8% and 61.2%, respectively, in HFSS simulation. The size of the Wheeler cap used in the measurements is determined such that its resonant frequency is well below the operating range of the dual-band antenna. During the efficiency measurements at the two distinct resonant frequencies, special attention was paid in order to avoid any of the cavity resonances by slightly re-adjusting the position of the antenna within the Wheeler cap. Since the antenna was completely enclosed by the Wheeler cap sphere during the measurements, this eliminated any potential radiation from the feed cable. The measured gains are 1.53 at 5.50 GHz and 0.71 at 2.46 GHz, compared with 1.73 and 0.91, respectively, in simulation. The discrepancy is mainly due to the ferrite beads used in the radiation pattern measurement (not in simulation), which bring in additional losses.

Conclusion: A dual-band metamaterial-inspired small monopole antenna is proposed for WiFi applications. The metamaterial-based loading enables a slot resonance at the lower WiFi band in addition to the monopole resonance. The fabricated prototype with the monopole element size of $1/13.3\ \lambda_0 \times 1/21.4\ \lambda_0$ provides 90 MHz and 3.2 GHz bandwidth for the lower and upper WiFi bands, respectively. Reasonable radiation efficiencies are obtained for both bands. Fed by the CPW transmission-line, the proposed design can be easily integrated to CPW-based microwave circuits.

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