Miniaturized Dual-band Dipole Antenna Loaded with Metamaterial Based Structure

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Abstract: *In this paper, a new miniaturized double-sided printed dipole antenna loaded with balanced Capacitively Loaded Loops (CLLs) as Metamaterial structure is presented. CLLs placed close to the edge of the printed antenna cause the antenna to radiate at two different frequencies, one of which is lower than self-resonant frequency of dipole antenna. In the other words, the loaded dipole antenna can perform at low frequency as compared with natural resonance frequency of unload half wavelength dipole. Finally, the CLL element is integrated with chip capacitor to provide a larger capacitance which in turn allows the resulting CLL element to resonate at a lower frequency. It is demonstrated that the proposed loaded dipole antenna is a dual band radiator with sufficient gain suitable for applications such as mobile communication and Industrial, Scientific and Medical (ISM) system. Prototype of miniaturized double resonant dipole antenna is fabricated and tested. The measured results are in good agreement with those obtained from simulation.*

Keywords: Dipole Antenna, Metamaterial, Capacitively Loaded Loop (*CLL*).

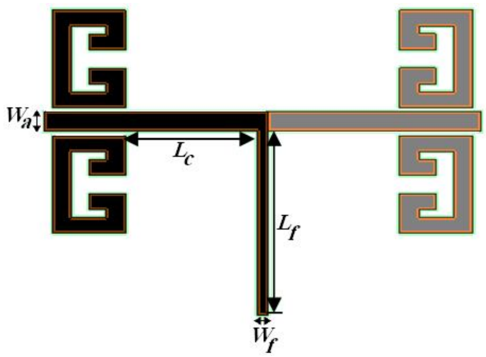
1. Introduction

The increasing demand on multi-function devices develops the multi-frequency printed dipoles which can be integrated into familiar devices such as laptop computers and mobile phones. Compact antennas are important for today's mobile communication systems. Ever-increasing demands for low profile multifunctional antennas have resulted in considerable interest by the electromagnetic research community in metamaterials. Due to unique electromagnetic properties, metamaterials have been widely considered in monopole and dipole antennas to improve their performance [1-4]. It was revealed in [5-6] that an efficient and electrically small magnetic based antenna can be realized by adding a planar interdigitated *CLL* element to a rectangular semi-loop antenna, which is coaxially-fed through a finite ground plane. The performance of a printed dipole antenna near a 3D-*CLL* block has been examined in [7]. Recently, the use of TL-MTM to load antennas has been investigated in [8-10]. A miniaturized printed dipole loaded with left-handed transmission lines is proposed in [11-13].

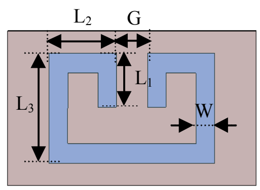
In this paper, we propose a new dual band printed dipole antenna in that *CLL*s as reactive loads are placed close to the edge of the dipole. The losses associated with the *CLL*s are very low in the frequency range of interest, resulting in both the acceptable gain and radiation pattern. The unloaded printed dipole antenna has only one resonance. When the *CLL*s are incorporated the resonant behaviour of the printed dipole antenna changes. As a result, a new resonance is appeared with the frequency determined by the *CLL* dimensions. In fact, the *CLL* element can be easily described as an *LC* resonant circuit in which the resonant frequency is mainly determined by the loop inductance and the gap capacitor. It is worthwhile to point out here that the *CLL* elements integrated with chip capacitors miniaturize the size of the printed dipole antenna. The reason is that when the chip capacitor value is increased, the *CLL* resonant frequency decreases, and thus the second resonant frequency of the dipole shifts down to a lower frequency. The proposed dual band *CLL* loaded dipole antenna radiates effectively at both resonant frequencies with good return losses and gains as well as acceptable omnidirectional radiation patterns. The high-frequency structure simulator (Ansoft HFSS) is adopted for the simulations.

2. Dual Band Printed Dipole Antenna

In order to test the proposed approach, double-sided printed dipole antenna is loaded by *CLL* elements. Fig. 1(a) shows the *CLL*-loaded printed dipole antenna together with the *CLL* element. The dipole and *CLL* elements are printed on a FR4 substrate with a thickness of 0.8mm and a dielectric constant of 4.4 to reduce the cost of the antenna. The *CLL*-loaded printed dipole has also been optimized to realize better performance. The optimized parameters of the proposed *CLL*-loaded dipole antenna are labelled in the Fig. 1(b). Fig. 2 shows the return loss of the proposed dual band printed dipole antenna as well as the unloaded dipole antenna. It is observed that when the *CLL* elements are added, two resonance frequencies become distinguishable from each other and thus two resonances are clearly observed in the return loss curve. The unloaded dipole antenna resonates at around 2.7525GHz. In contrast, the *CLL*-loaded dipole resonates at 2.15 and 4.45GHz, as shown in Fig. 2. The lower resonant frequency corresponds to that of the original printed dipole and remains approximately unchanged while the higher resonant frequency is mainly due to the *CLL* loading.



(a)



(b)

Fig. 1. (a) Geometry of a *CLL*-loaded printed dipole antenna, (b) *CLL* element, L_f=23mm, L_c=13.67mm, W_f=1mm, W_a=2.5mm, L_1=3.73mm, L_2=4.95mm, L_3=7.62mm, G=2.28mm, W=2mm.

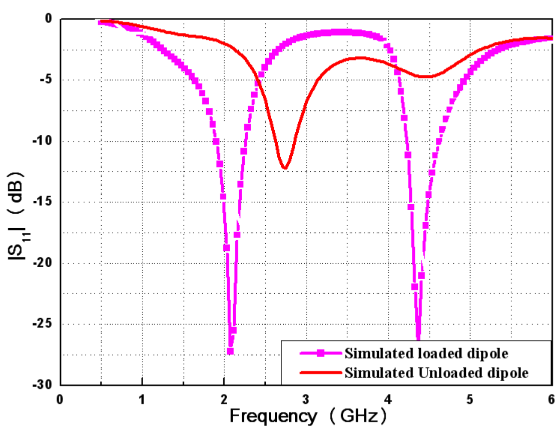


Fig. 2. Return loss comparison between the *CLL*-loaded and unloaded printed dipole antenna.

To further understand the performance of the printed dipole antenna close to the *CLL*s, Fig. 3 shows the magnitude of the S-parameters versus frequency for the *CLL*-based metamaterial. It is observed that the *CLL* element effectively resonates at around 4.5GHz with small loss. This frequency coincides with the second resonant frequency of the *CLL*-loaded printed dipole (see Fig. 3).

Fig. 4 shows the simulated radiation patterns at first and second resonant frequencies. Based on simulated results, the antenna gains at first and second resonant frequencies are 1.4dB, and 3.5dB, respectively. As a result, the losses introduced by the *CLL* elements are significantly low in the frequency range. In the other words, the proposed dual band dipole antenna has acceptable performance in both gain and radiation pattern.

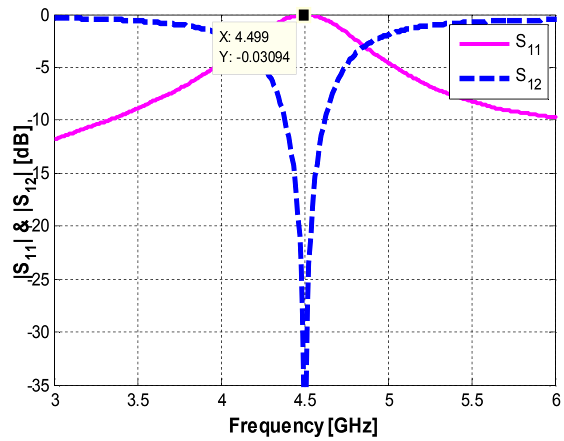
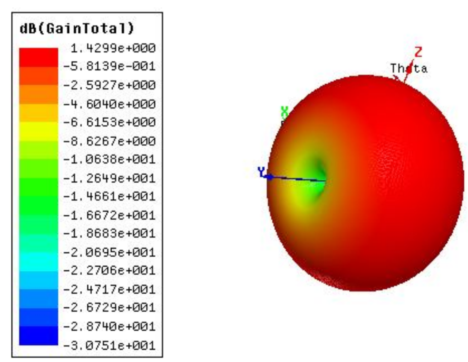
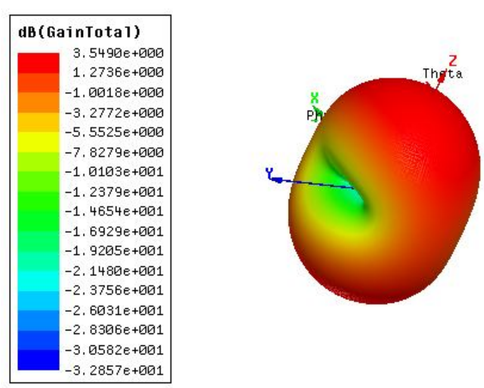


Fig. 3. Magnitude of the S-parameters vs. frequency for the *CLL*-based metamaterial.



(a)



(b)

Fig. 4 3-D simulated radiation patterns of the *CLL*-loaded printed dipole antenna at (a) 2.15GHz, and (b) 4.45GHz.

In order to meet the specification of both the *ISM* system and mobile communication, the *CLL*-loaded printed dipole should radiate linearly polarized waves at 1.8GHz and 2.45GHz. Toward this aim, the *CLL* elements can be loaded with chip capacitors. Capacitive loading of *CLL*-elements shifts down the resonance frequency of *CLL* to a lower frequency. The size reduction can be arbitrarily achieved if it would be feasible to fabricate a proper metamaterial element that has a negative permeability at a frequency lower than the natural resonance frequency of the corresponding unloaded dipole antenna. For a metamaterial comprised of resonant *CLL* elements, this can be achieved by capacitive loading of the *CLL* elements. To verify and confirm the proposed approach, a prototype of a *CLL*-loaded dipole antenna, in which each *CLL* ring is loaded with a 0.68pF chip capacitor, is fabricated and measured. A photograph of the fabricated miniaturized printed dipole antenna is shown in Fig. 5.

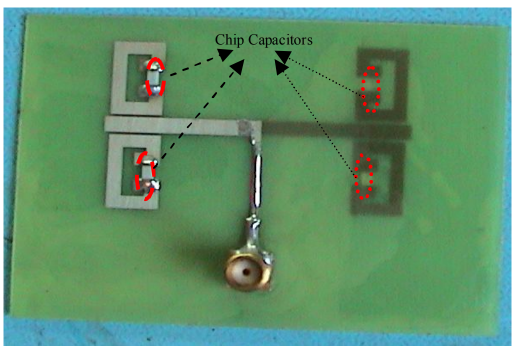


Fig. 5 Photograph of the miniaturized *CLL*-loaded printed dipole antenna (incorporating 0.68pF chip capacitors).

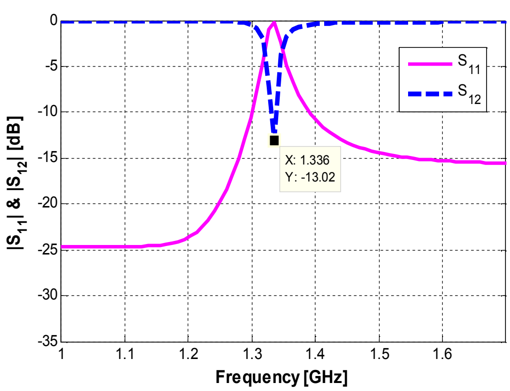


Fig. 6 Magnitude of the S-parameters vs. frequency for the *CLL* based metamaterial loaded with a 0.68pF chip capacitor.

The magnitude of the S-parameters for the *CLL*-based metamaterial loaded with a 0.68pF chip capacitor is shown in Fig. 6. As can be seen, the resonant frequency of the *CLL* element shifts down to 1.33GHz by incorporating 0.68pF chip capacitor (see Figs. 3, 6).

Fig. 7 compares the measured and simulated return losses of the proposed miniaturized *CLL*-loaded printed dipole antenna.

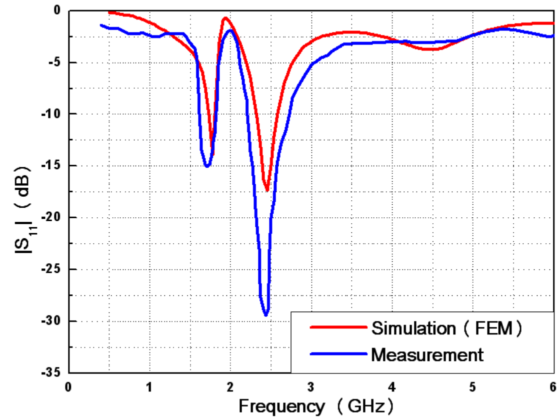
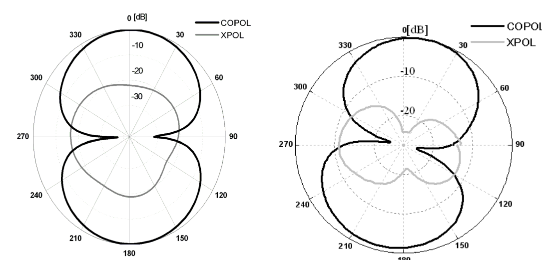


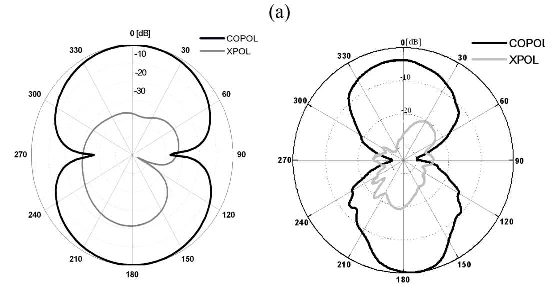
Fig. 7 Measured return losses of the miniaturized *CLL*-loaded printed dipole antenna, the simulation result is also reported for comparison.

As can be seen, the second resonant frequency of the first *CLL*-loaded dipole considerably shifts down to a lower frequency by incorporating chip capacitors. The resonant frequencies of the proposed miniaturized *CLL*-loaded printed dipole are lower than the main resonant frequency of the unloaded dipole antenna.

It should be pointed out that the antenna radiation patterns at both resonant frequencies are quite similar to that of a half wavelength dipole, as shown in Fig. 8. The antenna gains at first and second resonant frequencies are 0.62dB, and 2.26dB, respectively.



(a)



(b)

Fig. 8 E-plane normalized radiation patterns of the miniaturized *CLL*-loaded printed dipole antenna of Section III at (a) 1.713GHz, and (b) 2.434GHz. (Right hand figures are measurements).

3. Conclusion

In this paper, the behaviour of a double-sided printed dipole antenna loaded with *CLL* elements is examined. It is revealed that placing *CLL* elements in close proximity of a printed dipole antenna creates a double resonant antenna, the response of which is a function of *CLL* dimensions as well as of relative spacing between the antenna and *CLL*s. An important advantage of the proposed dual-band printed dipole is its capability to resonate omni-directional radiation pattern at both resonant frequencies. In addition, the antenna gain at the second resonant frequency is twice that in the case of unloaded dipole antenna. The behaviour of *CLL*s loaded with chip capacitors in the close to the printed dipole is also examined to miniaturize the antenna size. These chip capacitors can reduce the antenna size at its new resonance frequency. Prototype of a *CLL*-loaded printed dipole antenna with chip capacitors is fabricated and tested. A good agreement between the measured and simulated results is obtained.

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