Compact and Wideband Disc Monopole Antenna based on Epsilon Negative Transmission Line for WiFi Applications

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ABSTRACT

In this work, a compact and broadband and planar monopole antenna consists of one unit cell of epsilon negative transmission line (ENG TL) is proposed. A disc-shaped monopole antenna is implemented at 2.45 GHz resonance frequency for 2.4 GHz applications. A $50\ \Omega$ microstrip line is used as a feedline and element of the antenna has $0.1\lambda_0$ of diameter. The size of the antenna is reduced to $0.32\lambda_0 \times 0.32\lambda_0$, and the -10 dB fractional bandwidth is improved to 12.8% due to using metamaterial transmission line. Prototype antenna is fabricated and tested, and the measured results are compared to the simulated results using Ansoft HFSS.

Keywords

Compact antenna, Microstrip feedline, Epsilon negative transmission line, ZOR antenna

1. INTRODUCTION

Small antenna design is a challenging problem for many researchers. The growing interest in this field originated from the widespread use of modern systems which requires broadband antennas with a small form factor. A small electric antenna can be defined as an antenna which possesses geometrical dimension that is small in comparison to the wavelength of the electromagnetic fields they radiate [1, 2]. These antennas have various applications in unmanned vehicles [3, 4, 5], radars [6], and wireless communication [7, 8] which motivate researchers to develop these antennas based on their needs.

Metamaterial structures which are first developed by V. G. Veselago in 1967 provide electromagnetic properties that do not exist in nature and include negative index of refraction, negative permittivity, or negative permeability [9]. Transmission line based metamaterials that are introduced in [10, 11] provide a conceptual route for implementing small resonant antennas [12]. In addition, one type of the transmission line based metamaterials is ENG-TL that has negative effective permittivity at low-frequency ranges and zero at a special frequency. At this zeroth-order resonance frequency, the frequency does not depend on the length of the antenna but on lumped elements of the ENG TL [13].

One of the most interesting applications of the transmission line based metamaterial is designing and implementation of miniaturized antennas. Many studies in this field have been carried out that resulted in designing various electrically small antennas using zeroth-order resonator operating at ZOR frequency [14]. However, while small-size antenna design is feasible at this frequency, many of these antennas possess narrow bandwidth that limits their use for some applications. Due to this deficiency, the bandwidth increment at TL-based metamaterial antennas is now defined as one of the leading research goals.

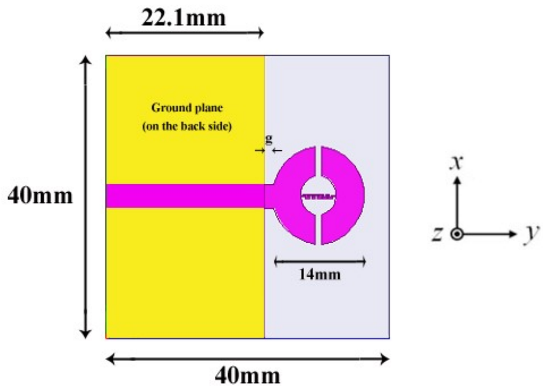

Fig. 1. Configuration of the proposed antenna

Miniaturization of the antenna has been studied in recent years for different applications [15]. In [16] a very small size antenna with dimensions of $0.07\lambda_0 \times 0.04\lambda_0$ at 2.45 GHz for WiFi applications was designed and fabricated that provided 90 MHz of bandwidth. In [17], a circular-shaped monopole antenna which had the same dimensions of $0.07\lambda_0 \times 0.04\lambda_0$ was implemented that had 220 MHz fractional bandwidth at 2.3 GHz resonance frequency.

In this study, a relatively compact ($0.1\lambda_0$ of diameter) monopole antenna with extended bandwidth (up to 320 MHz) at 2.45 GHz of resonant frequency using ENG TL meander lines is proposed for WiFi applications. The simulated return loss and radiation patterns are presented, and the measurement results of the fabricated antenna are compared to the simulations as well.

2. ANTENNA DESIGN

The proposed antenna is designed on Rogers/RT duroid 4003 substrate with a thickness of 1.524 mm, $\epsilon_r = 3.55$. The antenna is fed

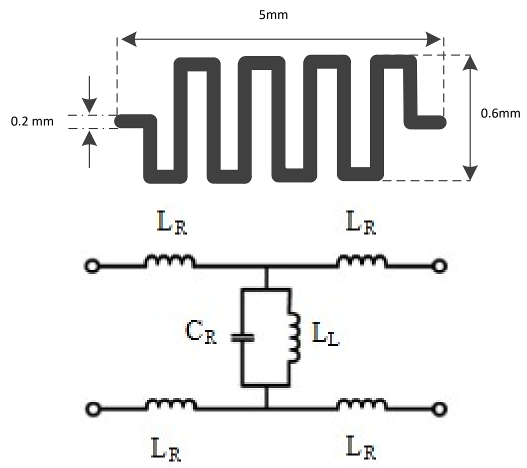

Fig. 2. Unit cell of ENG TL (top) and equivalent circuit model for the unit cell (bottom)

by a 50 Ω microstrip line with a length of 24.1 mm and width of 3.4 mm. The overall size of the monopole antenna used in this study is 40 mm × 40 mm, and the antenna has the disc shape element with 14 mm of diameter.

The structure of the proposed antenna and the unit cell with its equivalent circuit model are depicted in Fig. 1 and Fig. 2. The ZOR antenna is an open-ended resonator, thus independent resonant frequency of the physical size can be achieved through a unit cell of epsilon negative meander transmission line. In this design, throughout the current flow on the meander line and the circular patch, the shunt and series inductances can be obtained, and between the two adjacent lines, the shunt capacitance (C_R) has been formed. The various amount of ZOR frequency can be obtained by changing the length and width of unit cell which results in different amounts of L_R and C_R according to [18]

$$f_0 = \frac{1}{2\pi\sqrt{L_L.C_R}} \tag{1}$$

In this proposed model, the meander line has a width of 0.2 mm. The length and width of the unit cell to adjust the resonant frequency at 2.45 GHz for wireless applications are calculated. The length of the unit cell is 5 mm and the width is 0.6 mm. Based on [19] the quality factor of ZOR antenna is calculated as

$$Q = \frac{1}{G}\sqrt{\frac{C_R}{L_L}} \tag{2}$$

Where G is shunt conductance of the transmission line.

3. SIMULATION AND MESEARMENT RESULTS AND DISCUSSION

An open-ended resonator antenna has a narrow bandwidth since Q depends on C_R and L_L. On the other hand, the fractional bandwidth is the inverse of the quality factor; increases the amount of L_L and decreases the amount of C_R results that improved the bandwidth [19]. In this study, the focus is on a large L_L and small C_R using meander lines which can enhance BW. It should be mentioned that a relatively long microstrip feedline increases the total size of antenna that is important for input impedance matching. The overall size of the antenna can become smaller by using a matching network in substitution of present feedline [18].

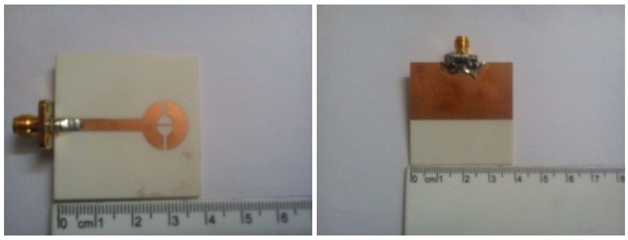

Fig. 3. Top view (Left) and bottom view (Right) of fabricated monopole antenna

The top and bottom views of the fabricated antenna are depicted in Fig.3. Using HFSS software, full-wave simulation results are obtained.

The measured S_{11} parameter compared to the simulated result is shown in Fig. 4. As seen the simulated resonant frequency is 2.45 GHz with S_{11} at -18 dB. The -10 dB bandwidth is 310 MHz from 2.28 GHz to 2.59 Ghz. Compared to [16] and [17] the proposed antenna exhibits more bandwidth of 90 MHz and 220 MHz, respectively. The measured resonant frequency is at 2.5 GHz with S_{11} at -15.5 dB and 320 MHz of 10 dB bandwidth from 2.36 GHz to 2.68 GHz.

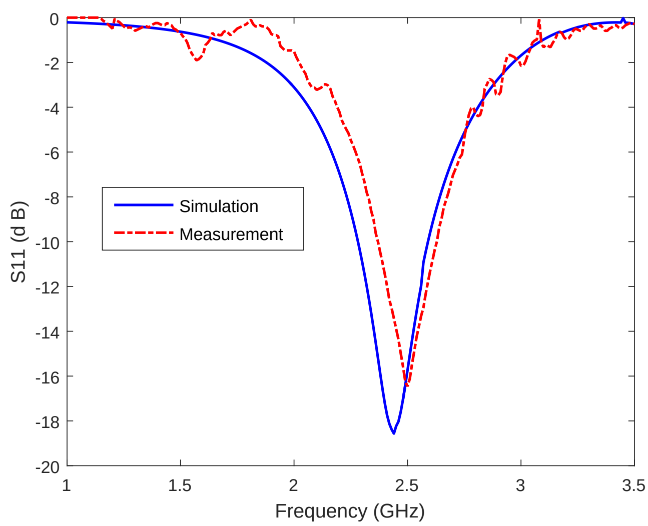

Fig. 4. Simulated and measured return loss of the proposed antenna

Fig. 5 shows HFSS simulated current distribution on the monopole antenna at 2.4 GHz. At the center frequency, there is a strong current on the meander line which acts as a radiation element, and thus it is expected that the radiation pattern of the planar antenna in E-plane is in the shape of 8 at 2.45 GHz. Also, the H-plane radiation pattern is purely omni-directional at the same frequency.

The simulated 2D radiation pattern of the proposed antenna for different frequencies from 1.5 GHz to 3.5 GHz were studied. As predicted, the antenna has approximately a donut-like radiation pattern similar to that short monopole over a small ground plane. It was observed that as the frequency moves toward the upper levels, the radiation pattern is somehow slightly distorted (for fre-

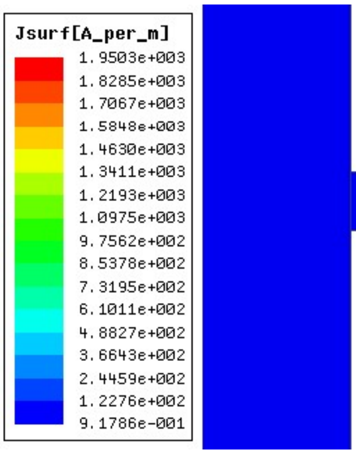

Fig. 5. Simulated current distribution of antenna at 2.4 GH

quencies higher than 3.5 GHz). The transition of the pattern from a dipole-like at the lower frequencies to the slowly distorted pattern at the higher frequencies indicates that this antenna must have experienced great variations in its behavior, however, it preserved omni- directionality all over the frequency band from 1.5 GHz to 3.5 GHz. This is due to the small ground plane, the small gap between the ground plane and the patch, 'g=2 mm', which is a leading factor for good impedance matching of the antenna and appropriate reflection coefficient as a result. In summary, it is obvious that the 2.4 GHz planar monopole antenna almost possesses constant radiation patterns and linear electric field polarization throughout the frequency bandwidth.

In Fig. 6 and 7, measured radiation patterns at 2.4 GHz for co-polarization and cross-polarization in H-plane and E-plane compared to the simulated patterns. As it is obvious, the measured results are in agreement with simulation but slightly distorted due to inaccuracy at the test equipment and fabrication limitations.

The input impedance $(Z_{in} = R + jX)$ of the antenna at the resonant frequency has the 48 Ω of the real part and the $-12\ j\Omega$ of the imaginary component which shows a relatively good impedance matching. Moreover, 1.8 dBi of the HFSS-simulated gain for the proposed antenna at operating frequency is obtained.

According to the equivalent circuit model of unit cell shown in Fig.2 and using HFSS and ADS, L_R is equal to 0.85 nH, also $C_R = 1.11$ pF, and $L_L = 28.4$ nH are obtained that leads to 42.81 GHz of zeroth-order resonant frequency. The size of the ground-plane plays a significant role in the performance of the antenna. In order to investigate how the ground-plane size affect the antenna performance, the simulation has been run for different ground length (in direction of y-axis), and the results are presented in Table 1. As seen the gain and bandwidth are slightly increase with increasing the ground width, and a small decrement in resonant frequency is occured. In Table 2, the proposed antenna performance is compared to some of the previous compact antennas which work at 2.4 GHz. It is clear that the proposed antenna is small and wideband in comparison with the similar antennas.

4. CONCLUSION

A planar monopole disc-shaped antenna based on metamaterial is proposed which is compact in size by loading a unit cell of epsilon negative transmission line. The overall size of antenna is $0.32\lambda_0 \times 0.32\lambda_0$ and the diameter of element is $0.1\lambda_0$ with dipole-like radiation patterns. In addition, the antenna has 1.8 dBi of gain and -10 dB bandwidth of 320 MHz illustrates extended bandwidth. The monopole antenna can be easily matched due to the gap between the patch and feedline. The proposed model is fabricated and tested. The measured return loss and patterns and the simulated results are in agreement. In comparison to the previous studies, this structure is compact, broadband around 2.4 GHz for WiFi applications and it is easy to fabricate.

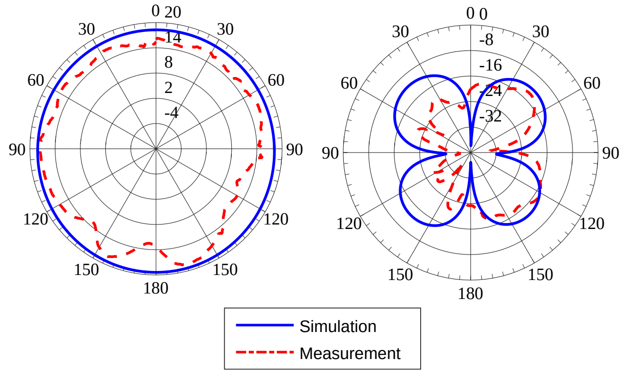

Fig. 6. Simulated and measured radiation patterns at 2.4 GHz in H-plane for co-polarization (Left) and cross-polarization (Right)

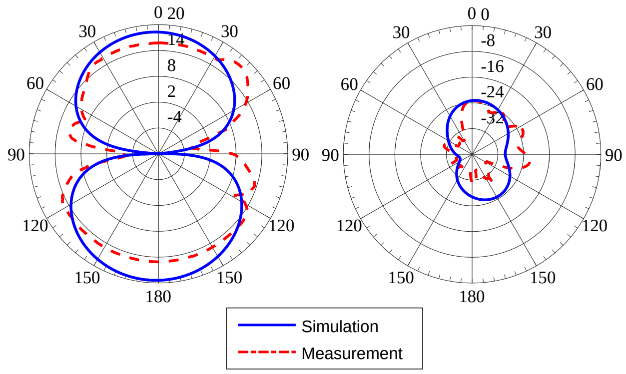

Fig. 7. Simulated and measured radiation patterns at 2.4 GHz in E-plane for co-polarization (Left) and cross-polarization (Right)

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Table 1. Simulated Characteristics of Antenna for Different Sizes of Ground plane

Size of the ground plane ($mm \times mm$)	Resonance frequency (GHz)	-10 dB bandwidth (MHz)	Gain (dBi)
22.1×20	2.53	270	1.70
22.1×30	2.49	300	1.74
22.1×30	2.45	310	1.80

Table 2. Comparison Results of the Proposed Antenna and Some References

References	Element size of the antenna	Overall size of the antenna	-10 dB Bandwidth (MHz)
Proposed antenna	$0.1\lambda_0$ (diameter)	$0.32\lambda_0 \times 0.32\lambda_0$	320
[16]	$0.07\lambda_0 \times 0.04\lambda_0$	$0.26\lambda_0 \times 0.19\lambda_0$	90
[20]	$0.20\lambda_0 \times 0.34\lambda_0$	$0.48\lambda_0 \times 0.80\lambda_0$	120
[21]	$0.09\lambda_0 \times 0.09\lambda_0$	$0.32\lambda_0 \times 0.24\lambda_0$	110