Design of slot antenna loaded with lumped circuit components

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***Abstract* - A design of slot antenna loaded with circuit components is presented in this paper. The antenna is accommodated at the edge of the printed circuit board and loaded with circuit components. Using the folded slot and loaded with circuit components can miniaturize the antenna area. The slot antenna is deposed into several sub-networks, and the corresponding equivalent circuit is presented. The design equation can be acquired from the equivalent circuit by using the resonant condition. The antenna is operated for both Bluetooth and WLAN applications at 2.45 GHz. The design procedure of the antenna will be described in details. The experimental results of the antenna are shown for validation.**

I. INTRODUCTION

With the development of modern wireless communications, the feature of compactness is important and strongly demanded in handheld devices. In many conventional designs, in order to achieve compact configuration, these antennas could occupy large circuit areas. Therefore, many compact designs are proposed. In [1], the metamaterial ring antenna is proposed, which features a low profile. In [2], LTCC process is used for reducing the antenna size. The antenna can be miniaturized by using capacitive or inductive loading. In [3], a PIFA (planar inverted F antenna) is a compact design using capacitive load. In [4], the antenna is fed by using fork like-tuning stub for reducing the antenna area.

In the paper, a design of slot antenna loaded with circuit components is proposed for Bluetooth and WLAN at 2.45 GHz. For reducing the size of the slot antenna, circuit components can be used across the slot. Antenna measurements regarding with return loss, and radiation patterns are conducted for design validation. It is found that the simulation and measurement are in good agreement. In what follows, antenna design will be mentioned in Section II, and the experimental results are shown in Section III.

II. ANTENNA DESIGN

The proposed folded slot antennas are designed and fabricated on the FR4 printed circuit board (PCB) with dielectric constant of 4.4 and loss tangent of 0.0125. Similar to many mobile phones, the dimension of the PCB is 70×30×0.8 mm^3, as shown in Fig.1. The antenna is deployed within the

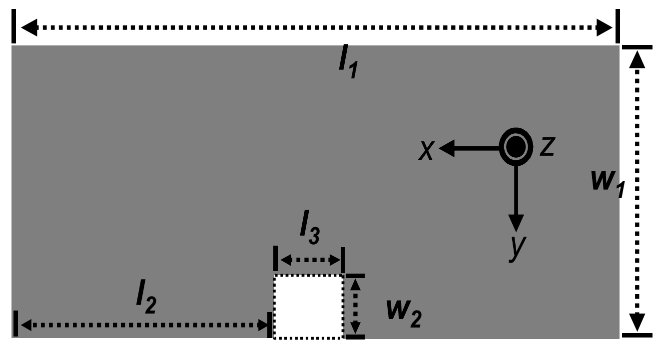
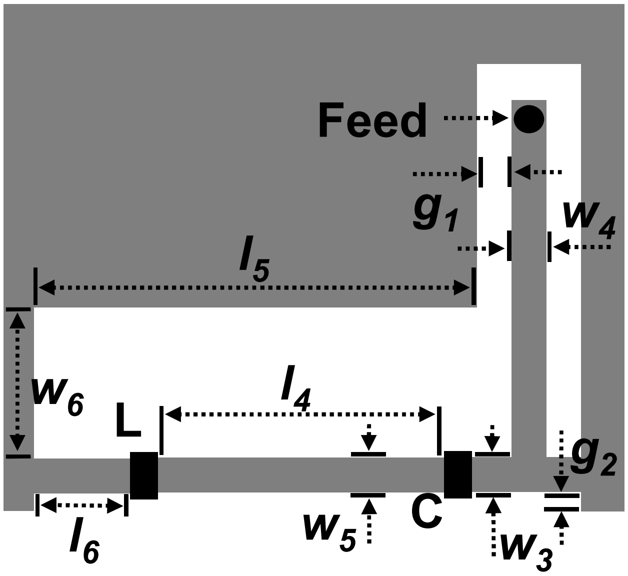


Fig. 1. The configuration of the proposed antenna. l_1 =70, l_2 =30, l_3 =8, w_1=30 and w_2=6.5. All dimensions are in mm.

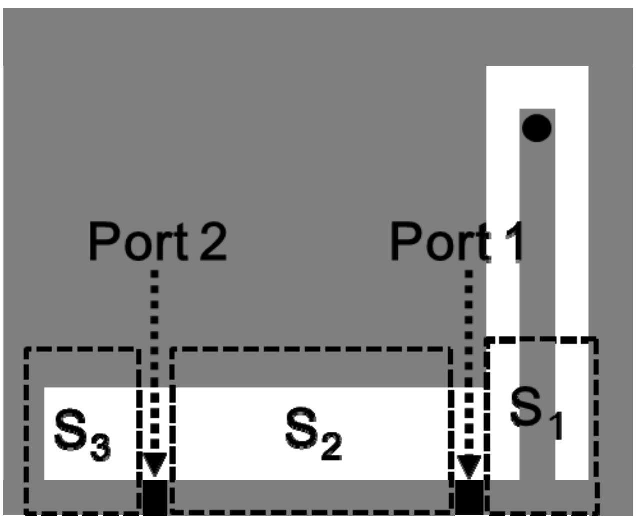
antenna region in the middle of the upper edge, and is fed with 50-Ω coaxial cable. The full-wave and circuit simulation of antennas are carried out by using High Frequency Structure Simulator (HFSS) and Advanced Design System (ADS), respectively.

Figure 2(a) shows the configuration of the proposed single-band folded slot antenna loaded with circuit elements. By using the folded configuration, it is flexible to adjust the length of the antenna. The circuit elements are placed along the edge of the slot. It is also found that the component can be placed across the slot in other applications [5]. Due to the high-pass (capacitor) or low-pass (inductor) characteristics of the components, placing the components across the slot could significantly shorted the length of the slot, thus affecting the antenna gain. For single-band operation of antenna, two components are used in the design. Although one component is sufficient for the design, using two components with provide more flexibility and it will be explained later.

To conduct the circuit analysis and determine the circuit components of the antenna, the antenna structure is decomposed into three circuit sub-networks, as shown in Fig. 2(b). From circuit point of view, the antenna is considered as a three-port circuit, as shown in Fig. 3(a). Conducting full-wave simulation by using HFSS, scattering matrices ($[S_1]$, $[S_2]$ and



(a)



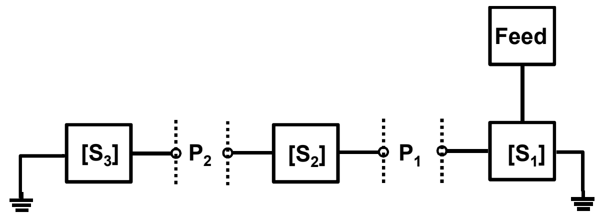
(b)

Fig. 2. The configuration of the single band antenna (a). The corresponding network decomposition (b).

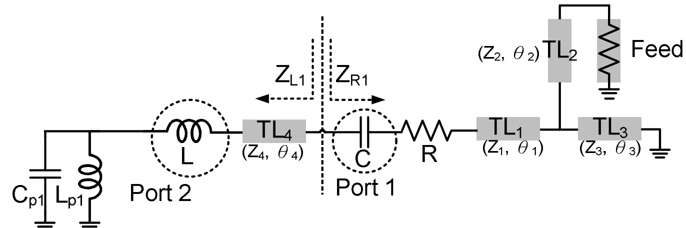
[S_3]) for those three sub-network can be obtained. Three scattering matrices are can be further transformed into impedance (or admittance) matrices [6]. With the impedance (or admittance) matrices, equivalent circuits for three sub-network can be built by using T (or π) equivalent circuits [6]. The proposed equivalent circuit for the antenna in Fig. 2 is shown in Fig. 3 (b). A capacitor (C) is placed in Port #1, while a inductor (L) is placed in Port #2. The sub-network S_1 is basically a T-connection of three transmission lines and a resistor. The sub-network S_2 is simply a uniform transmission line. The sub-network S_3 obtained by using the T-equivalent

TABLE I
ALL DIMENSIONS ARE IN MM.

Parameter	l_4	l_5	l_6	w_3	w_4
Value (mm)	4.2	6.5	1.4	0.5	0.5
Parameter	w_4	w_5	w_6	g_1	g_2
Value (mm)	0.5	0.5	4.2	0.5	0.2



(a)



(b)

Fig. 3. Block diagram (a) and the equivalent circuit (b) of the antenna in Fig. 2.

circuit mentioned above. In Fig. 3 (b), a reference line is set between Port #1 and sub-network S_2. When the antenna is at the center frequency, it is operating at resonance. One of the conditions of resonant circuit is that, at any point in the circuit, the sum of the input impedances seen looking into either side must be zero. Therefore, as shown in Fig. 3 (b) at the reference line, it is found that

$$\mathrm{Im}\{Z_{L1}\} + \mathrm{Im}\{Z_{R1}\} = 0\,, \tag{1}$$

where

$$Z_{L1} = Z_1 \cdot \frac{\left[\dfrac{j2\pi f L_{p1}}{1-(2\pi f)^2 L_{p1} C_{p1}} + j2\pi f L\right] + jZ_1 \tan\theta_1}{Z_1 + j\left[\dfrac{j2\pi f L_{p1}}{1-(2\pi f)^2 L_{p1} C_{p1}} + j2\pi f L\right] \cdot \tan\theta_1}\,, \tag{2}$$

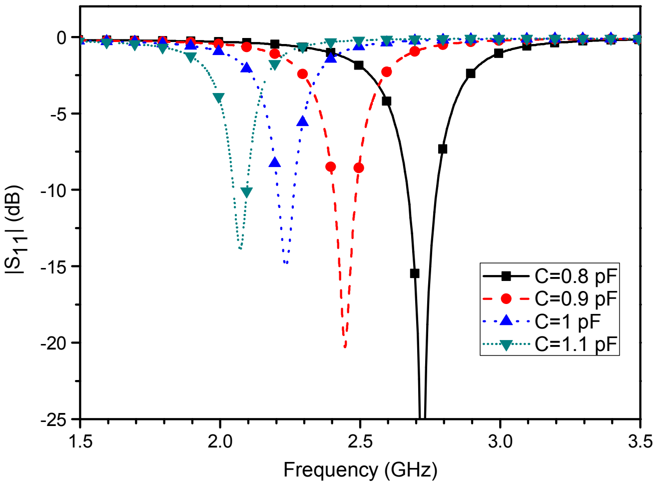


Fig. 4. The simulated reflection coefficients of the proposed antenna by adjusting the C from 0.9 to 1.1 pF.

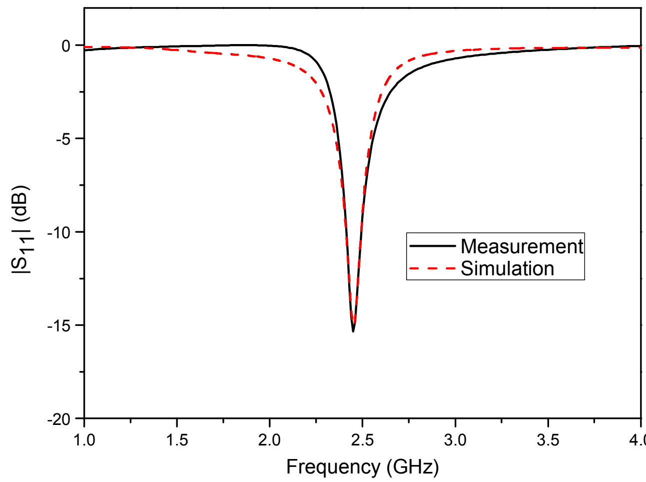


Fig. 6. The simulated and measured reflection coefficients of the proposed antenna.

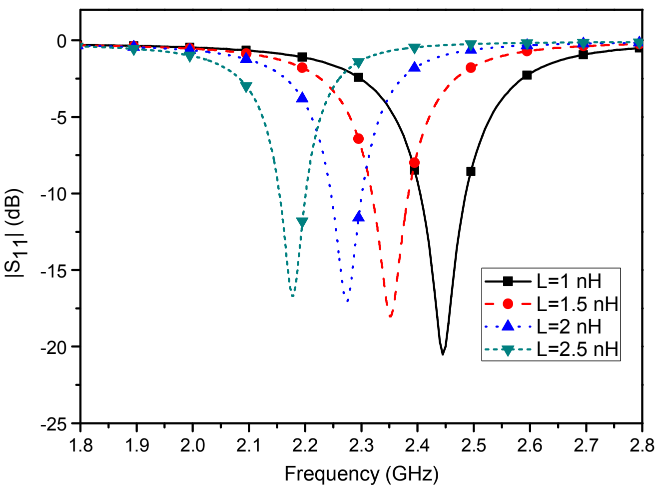


Fig. 5. The simulated reflection coefficients of the proposed antenna by adjusting the L from 1 to 2.5 nH.

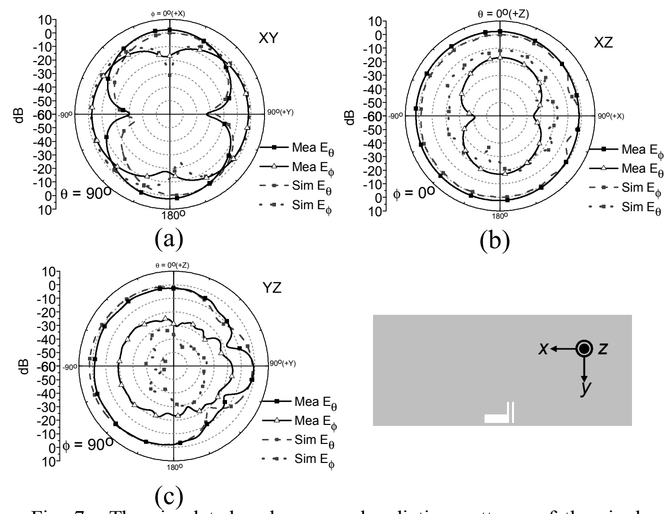


Fig. 7. The simulated and measured radiation patterns of the single band antenna. (a) XY-plane, (b) XZ-plane and (c) YZ-plane.

$$Z_{R1} = \frac{1}{j2\pi fC} + R + Z_4 \cdot \frac{\dfrac{jZ_2 \cdot Z_3 \tan\theta_2 \cdot \tan\theta_3}{Z_2 \tan\theta_2 + Z_3 \tan\theta_3} + jZ_4 \tan\theta_4}{Z_4 - \dfrac{Z_2 \cdot Z_3 \cdot \tan\theta_2 \cdot \tan\theta_3}{Z_2 \tan\theta_2 + Z_3 \tan\theta_3} \cdot \tan\theta_4}. \quad (3)$$

where R=76.25, Z_1=105, θ_1=15.8, Z_2=46.5, θ_2=12.5, Z_3=46.5, θ_3=17, Z_4=30.48, θ_4=78.14, L_1=1.683, C_1=0.982.

In (1), f is set at the 2.45 GHz and two unknown parameters, C and L, are to be determined. Since there is only one equation in (1), either L or C should be determined in advance. In this design, L is first chosen with 1.7 nH. By using (1), C is calculated as 0.982 pF. It should be noted that the values of the inductor and capacitor obtained from (1) could be impractical, that is, those components my not be commercially available. With two parameters, C and L, the designer can choose practical values to satisfy (1). In order to validate the calculated values of C and L, the Full-wave simulation is applied. In Fig. 4 and Fig. 5, the value of capacitance and inductance are varied from 0.8 to 1.1 pF and 1 to 2.7 nH, respectively. In the figure, the values of C and L are closely meet with the calculated values. Even though, the final value of C is set in 1 pF, which is slightly different from the calculated value. To make the antenna operate at exactly 2.45 GHz, the dimension of the antenna could be slightly adjusted.

III. Results

Figure 6 shows the simulated and measured reflection coefficients of the antenna in Fig. 2 (a). In Fig. 6, the center frequency in both simulation and measurement are at 2.47 GHz, which is due to the discrepancy between the real (1 pF)

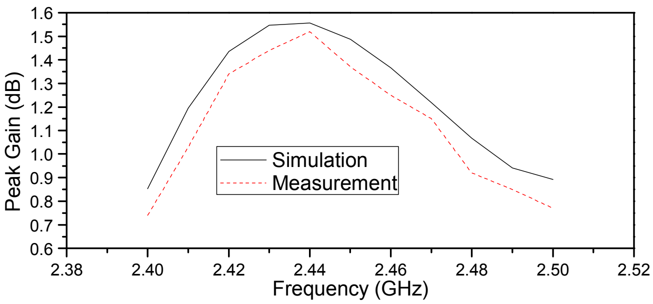


Fig. 8. The simulated and measured peak gains of the proposed antenna.

and calculated (0.982 pF) values of C. Figure 7 shows the simulated and measured radiation patterns. In the XZ-plane pattern, the electric field is mainly polarized in $\hat{\phi}$ direction. In the YZ-plane pattern, the electric field is mainly polarized in $\hat{\theta}$ direction. Considering that the electric field over the slot aperture of the unfolded section is in y direction, it is concluded that the unfolded section of the slot is responsible for the most of the radiation. Figure 6 shows the simulated and measured peak gain of the antenna in Fig. 2 (a). Based on the results shown in Fig. 6, 7, and 8, the proposed design is validated.

IV. Conclusions

In this paper, a design of slot antenna loaded with circuit components has been proposed. The proposed configuration is based on a typical folded slot with an edge branch of strip loaded with inductors and capacitors. The equivalent circuit and design equations are conducted. The values of the circuit components can be determined by using the design equations. The proposed designs also have been realized and validated by measurement. Both experimental and simulation results has good agreement with each other.

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