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Miniaturized active stepped impedance planar inverted-F antenna using common ground

Ashok Gundumalla *, Sachin Agrawal, Manoj Singh Parihar

Indian Institute of Information Technology, Design and Manufacturing, Jabalpur, India

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ABSTRACT

This paper presents a compact active integrated antenna (AIA) comprising of class-A power amplifier (PA) and stepped impedance planar inverted-F antenna (PIFA). In the proposed design, a common ground is used for both PA and PIFA, resulting a compact antenna of size $0.14\lambda_0 \times 0.11\lambda_0 \times 0.01\lambda_0$ (λ_0 is free space wavelength at 0.85 GHz). Moreover, it is demonstrated that by using the stepped impedance radiator the operating frequency of the active PIFA is shifted down from its natural resonant frequency of 1.36 GHz to 0.85 GHz, offering an extensive size reduction of 80%. This active integration increases the passive antenna gain through the effective loading of the antenna to the power amplifier. The measured result indicates that the active and passive antennas achieved the gain of 15.7 dB and 3.81 dBi, respectively after the integration. In addition, the maximum SAR value of antenna is found to be 0.64 W/kg.

1. Introduction

Small size antennas are the requirement of the present wireless communication systems. Essentially in the mobile handsets, compact antennas are essential due to limited availability of space. However, miniaturization of antenna relaxes the space problems but at the cost of degraded performance in terms of gain, bandwidth, and efficiency. Therefore, achieving compactness along with better characteristics of the antenna has always been the goal of the research community. Typical designs focus in miniaturized antennas are small H-shaped antenna [1], shorted T-shaped microstrip antenna [2], compact PIFA [3], stacked shorted antenna [4]. These designs mainly focus on the miniaturization, but not on the gain. Generally, passive antenna alone unable to satisfy both the compactness and high gain, so there is a necessity to accommodate active components along with the passive antennas. This concept leads to the integration of subsystems to make single entity known as active integrated antenna [5]. In this method, antenna is integrated with an active device like power amplifier which considerably reduces the losses that occur due to the interconnection mismatches in the individual entities as in conventional RF frontend system. Moreover, the active integration in metamaterials for polarization and phase manipulation is reported in [6–8]. From the early stages, the method AIA is adopted for the improvement in the efficiency, gain and decrease in the mutual coupling. In the high-efficiency AIA design, antenna acts as harmonic terminator which results in better efficiency [9–15]. In the case of improvements in the antenna, co-design approach is used to miniaturize the antenna effectively [16–18].

To achieve miniaturized AIA design, antenna selection plays a major role. Microstrip patch antennas are very much suitable because of their fabrication simplicity, but it requires separate ground plane, results in the larger AIA size. Moreover, it is a $\lambda/2$ resonator whose dimensions are considerably larger at lower frequencies. However, the recent method uses slot antenna [12], lumped elements [16], and multilayer PCB design [19] and miniaturization of the active patch antennas. In addition to these techniques, the miniaturized active integrated metamaterials are reported in [20,21]. The main reasons behind the selection of PIFA are compact size and antenna can be integrated on the backside of the power amplifier circuit [22,23]. It facilitates the compact active integrated antenna design by providing common ground for both the PA and PIFA [15].

In this work, proposed PIFA is effectively miniaturized through integration with the power amplifier. This active integration helps in the improvement of passive antenna gain and the overall system performance. The output port of the power amplifier is loaded with the PIFA through an intermediate matching network. Firstly, the antenna is miniaturized through the stepped impedance design, results in the frequency down shifting from 1.36 GHz to 0.95 GHz, with a radiator dimension of 30 mm × 25 mm. After power amplifier integration the size reduction is increased up to

* Corresponding author.
E-mail addresses: gundumalla.ashok@gmail.com (A. Gundumalla), sachin.agrawal@iiitdmj.ac.in (S. Agrawal), mparihar@iiitdmj.ac.in (M.S. Parihar).

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80% with a total volume of 50 × 40 × 4 mm^3 The AIA starts with the design of antenna followed by the power amplifier circuit and then combining both of them through the matching network as follows.

2. Antenna design

Planar inverted-F antenna is opted as a radiator to integrate with active circuit. The 3-D view of the proposed PIFA is shown in the Fig. 1.

It can be seen that feed and short plates connected to the output of active circuit and ground plane respectively. The dimensions of the ground plane are chosen according to the area occupied by the power amplifier circuit. This is optimized in the layout simulations of the PA. However, this section is focused on the design and optimization of the radiating patch. Fig. 2a illustrates the design of the proposed radiating patch of PIFA. This antenna is fabricated on Gil GML 1000 substrate (thickness = 0.77 mm, ε_r = 3.2). The fabricated photograph of the radiating patch is depicted in Fig. 2b. Stepped impedance radiating patch is used in this section to obtain the miniaturized antenna. Here, the entire radiating patch is divided into two parts in accordance to their widths. This clearly indicates that, the wider width line acts as a shorted shunt capacitance and thinner width line as a shunt inductor, which forms a parallel L-C resonator as shown in Fig. 2c.

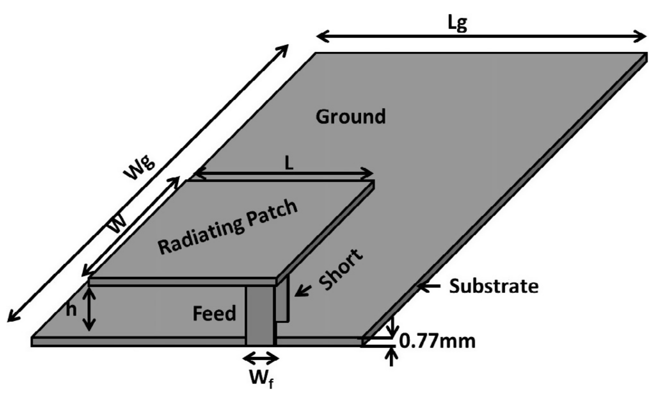

Fig. 1. 3-D of the proposed PIFA.

The lumped elements related to the transmission line model are given by Eqs. (1) and (2) [2].

$$\omega L = Z_1 \tan \theta_L \tag{1}$$

$$\omega C = Y_2 \tan \theta_C \tag{2}$$

It could be seen that the electrical lengths of these transmission lines depend on the impedance ratio is given in Eq. (3).

$$\tan \theta_L \tan \theta_C = \frac{Z_2}{Z_1} \tag{3}$$

However, the factor Z_2/Z_1 decides the miniaturization level and it is denoted by K. The corresponding graph has been plotted for the different K value is shown in Fig. 3a. It can be concluded that the W_2 should be wider than W_1 to obtain the miniaturized PIFA. So there is a compromise between miniaturization and easiness of fabrication in the selection of the K value. For K = 0.4, the

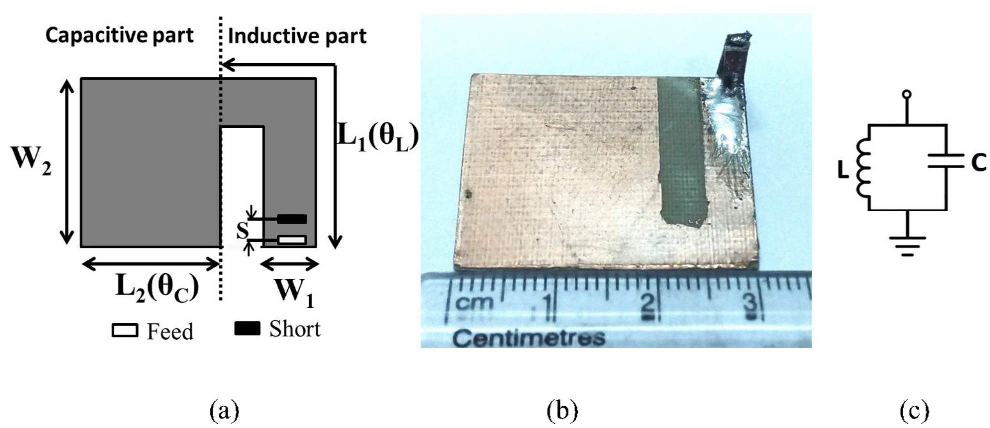

Fig. 2. The geometry of the proposed PIFA (a) radiating patch, (b) fabricated photo of radiating patch, and (c) lumped element model.

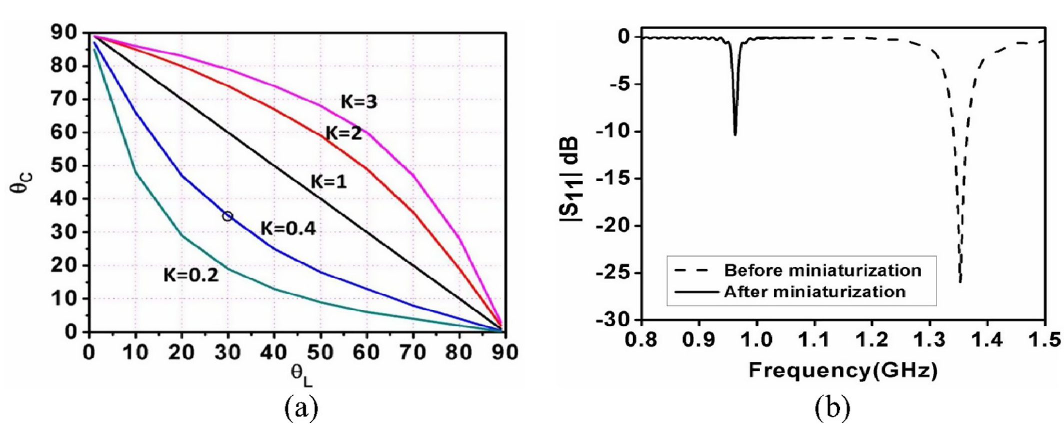

Fig. 3. Miniaturization of antenna (a) selected K value and (b) S_{11} plot of the proposed antenna.