Co-design of an Antenna-Power Amplifier RF Front-end Block Without Matching Network for 2.4 GHz WiFi Application

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***Abstract* — A co-design of an antenna-Power Amplifier (PA) block in RF front-end module is presented. This technique enables the direct integration of PA and antenna without any matching circuits and helps to reduce the loss, power consumption and overall size of the RF front-end modules without affecting the efficiency of the PA. For first two harmonics the impedance matching between the PA and antenna is achieved by utilizing a capacitively coupled feeding mechanism which controls the input impedance of the antenna. By using this integration technique a Class-B PA operating at 2.4 GHz provides a maximum efficiency of 62% which is similar to the performance with the additional matching circuit. Also the design methodology of the antenna is reported. The antenna provides an axial beam with a maximum gain of 6.5 dBi and has a radiation efficiency of 85%.**

***Index Terms* — Class-B power amplifier, capacitively coupled feeding; Impedance matching circuit; power consumption.**

I. Introduction

In recent years, the wireless communication technology has become indispensable part of our daily life. The ever-increasing demand of high-speed voice, multimedia and data communications has brought about the need for compact and fully integrated RF (Radio Frequency) front-end products for modern wireless transceivers [1]. However, on the other hand, the high power consumptions at the front-end devices due to these services become a serious problem for long battery life. Since, the assembly of RF Power Amplifier (PA) and antenna is the most power-consuming block in wireless transceivers, reducing the power consumption of the combined device and its matching circuits is one of the most attractive research areas [2].

PAs with high output power and high efficiencies using low power supply voltages are needed to support over 1Gbit/s speed wireless communication [3]. This induces severe constrain on the impedance matching between the output impedance of PA and input impedance of the antenna. If the output impedance of the PA is matched to the input impedance of the antenna maximum power will transfer between these two blocks. However, in general the input impedance of the commercially available antennas is 50Ω which is different from the output impedance of the PA. Consequently, the matching circuit composed passive components (R, L and C or distributed) are utilized to match the impedances between PA and antenna for optimizing the power transfer. However, the loss in this R-L-C matching circuits degrades efficiency of the PA and increase the power consumption. Recently, in order to increase PA efficiency some researchers have successfully study various impedance matching techniques, such as Dynamic Load Modulation (DLM) [4], variable load technique using tunable matching network [5], reconfigurable matching network [6], load-pull method [7] and 2-pole bandpass filter technique [8]. However, the interstage matching circuit between the PA and antenna adds the supplementary loss in the system performance, enhances the power consumption and increases the size of the RF front-end modules.

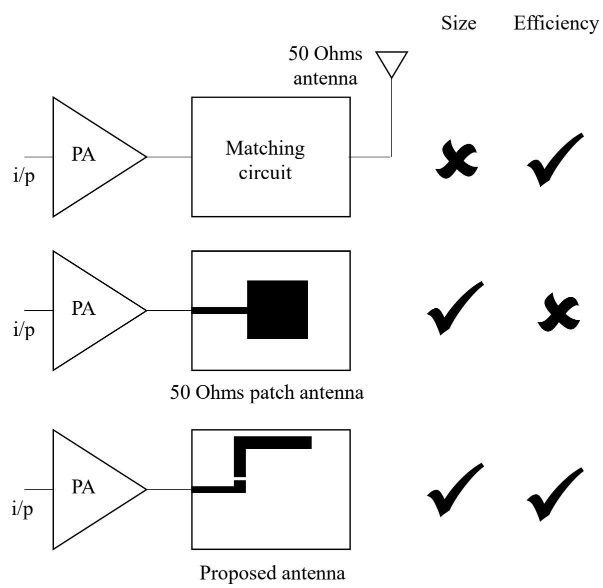

Fig. 1 Three different method of antenna integration with PA.

In this paper, we presented a capacitively coupled feeding mechanism [9] of the antenna which allows the antenna to connect directly with the PA without degrading the efficiency of PA. The impedance matching between the PA and the antenna can be achieved by appropriately designing the antenna. In section II, a comparative study of the PA efficiency is presented when PA is integrated with a 50Ω antenna using a matching circuit, 50Ω antenna without a matching circuit and with the proposed antenna. In section III, the design and development of the antenna structure is presented. The antenna performances are simulated using CST Microwave studio, which is based on Finite Integration Technique in Time Domain (FIT–TD) [10].

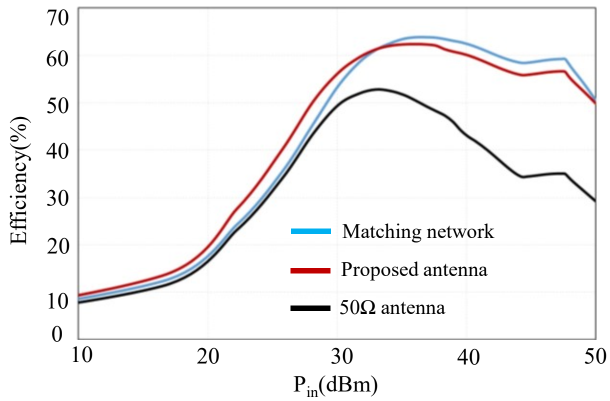

Fig. 2. PA efficiency for three configurations shown in Fig. 1.

II. Integration of Antenna with Power Amplifier

Fig. 1 shows the three different cases of antenna integration with the PA. For this study we used class-B type power amplifier and all the simulations are done using Advanced Design System (ADS) [11]. Fig. 1 (a) shows the classical approach where the antenna input impedance is matched to the PA output impedance by using an additional matching circuit. This configuration provides a maximum efficiency of 63% as shown in the Fig. 2. But due to the matching circuit it requires larger space which is not suitable for modern wireless transceivers. In addition, the matching circuit introduces additional losses and consume more power. To overcome the space and power consumption issue one possible solution is to remove the matching circuit and connect the antenna directly as shown in Fig. 1(b). However, this configuration exhibits very low efficiency with a maximum efficiency of 52% only (Fig. 2). In this paper we proposed an antenna integration technique (Fig 1 (c)) which can solve both the space and power consumption issues. The input impedance of the antenna at first two harmonics (2.4 and 4.8 GHz) can be adjusted to match the output impedance of PA. This enables the antenna to be integrated directly to the PA without any matching circuit. Moreover, this design technique provides high efficiency performance with a maximum efficiency of 62% at 2.4 GHz as shown in Fig. 2. The design method and performance of the proposed antenna are discussed next.

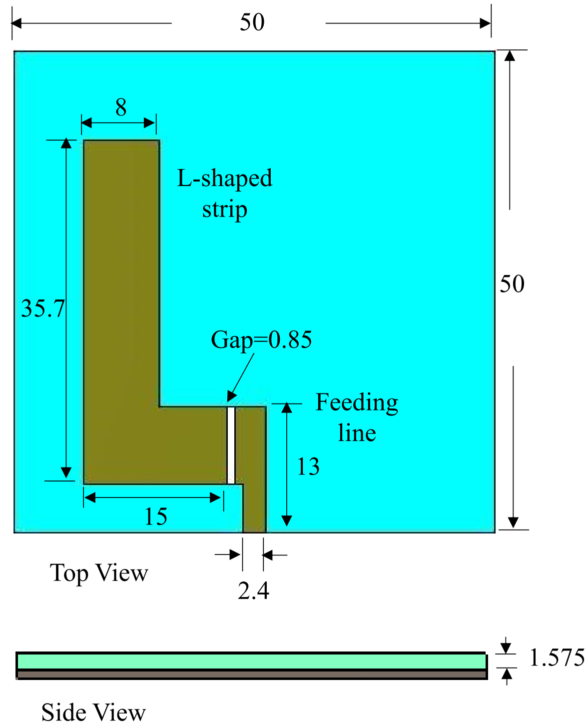

Fig. 3. Top and side views of the antenna (dimensions are in mm).

III. Antenna Configuration And Results

The main challenge in designing low profile antenna for PA is the matching of the antenna input impedance to the output impedance of the PA. In this paper, an antenna structure composed of an L-shaped microstrip line which is capacitively coupled to a small feeding line is presented for achieving the input impedance matching. The L-shape strip is capacitively coupled to the small feeding line via an air gap. Fig. 3 shows the top and side view of the antenna. The close proximity of the ground plane introduces high inductance to the antenna input impedance. This capacitive coupling introduces capacitance into the antenna input impedance. Thus by controlling the coupling mechanism it is possible to match the reactance part of the PA output impedance. Further by varying the length of the L-shaped strip and feeding line the resistive part of the PA output impedance can be matched. It is worth mentioning that the additional length of the strip required for achieving desirable impedance is negligible compared to the size of the matching circuit. Finally, the length of the L-shaped strip determines the operating frequency (2.4 GHz) of the antenna. The antenna is designed on top surface of a Rogers 5880 substrate (permittivity ε_r=2.2, loss tangent $\tan\delta$ =0.0009), having a thickness of h = 1.575 mm. The whole structure is backed by a conducting metal ground plane.

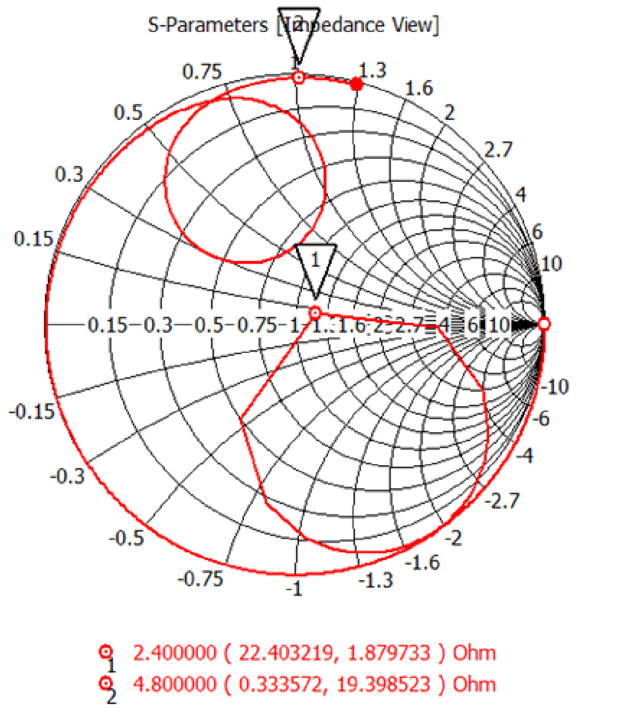

Fig. 4. Antenna input impedance (the reference impedance of the smith chart is 22Ω).

Fig. 4 shows the input impedance of the antenna when the reference impedance of the smith chart is normalized to 22Ω. It can be seen that at 2.4 GHz the antenna input impedance is 22.4+j1.9Ω and at second harmonic, 4.8 GHz the impedance is 0.3+j19.4Ω. Therefore the antenna input impedance matches well to the output impedance of the PA and this enables the antenna to be integrated directly to the PA without any additional matching network.

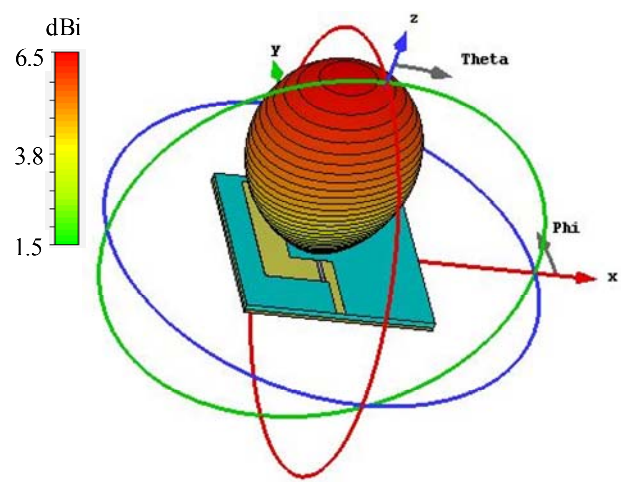

Fig. 5.radiation pattern of the antenna.

Fig. 5 shows the radiation pattern of the antenna at 2.4 GHz. The antenna provides an axial beam with a maximum gain of 6.5 dBi. The antenna has radiation efficiency of 85% and Half Power Beam Width (HPBW) of approximately 90°.

IV. Conclusion

A new integration technique of a Power Amplifier (PA) and Antenna is presented which allows the antenna to connect directly to the PA without any matching circuits. This design technique contributes to reduce the loss, increase the battery life and miniaturization of the RF front-end modules. The proposed antenna utilizes a capacitively coupled feeding technique to match the antenna input impedance to the output impedance of the PA. This method offers a maximum PA efficiency of 62%. Therefore, the proposed technique helps to suppress the matching circuit completely without affecting the performance of the PA.

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