1.8-GHz CMOS Power Amplifier with Stage-Convertible Structure Using Differential Line Inductor

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***Abstract* — A 1.8 GHz power amplifier for a polar transmitter application is implemented with 0.18 μm RF CMOS technology, and a differential line inductor is proposed for the differential circuit. The differential line inductor is used as a low power matching network in the stage-convertible power amplifier in order to increase the efficiency of a low output power region. The power amplifier achieved a power-added efficiency of 41% at a maximum output power of 31.5 dBm. The low power efficiency improvement for the power amplifier is 81% at an output power of 20 dBm.**

***Index Terms* — Class E, CMOS, line inductor, polar transmitter, power amplifier, stage-convertible.**

I. INTRODUCTION

Finding a method of improving the efficiency of a power amplifier in a low output power region has recently become one of the major challenges in efforts to increase the life span of batteries for mobile phones. Accordingly, intensive studies have focused on improving efficiency in a low power region [1-3]. In this work, we adapted a power amplifier with stage-convertible architecture to improve the amplifier's efficiency in a low output power region [4, 5]. To improve the efficiency at low output power region of the power amplifier, we need a high load impedance, and, for this type of impedance, an inductor with a high inductance is needed generally. However, in this case, the efficiency improvement may be degraded because of the parasitic resistance of the inductor.

To increase inductance, we propose the use of a differential line inductor with a short length of line in the structure of the differential power amplifier. With this type of differential line inductor, we were able to design a stage-convertible power amplifier with a 0.18 μm RF CMOS process.

II. DIFFERENTIAL LINE INDUCTOR

A. Conventional Spiral Inductor

A spiral-type inductor is generally used in an MMIC to increase inductance. However, conventional inductors have a low quality factor because of the parasitic resistance induced by the metal line. The loss induced by a conventional inductor seriously degrades the efficiency of a power amplifier. However, the inductance is an essential component for the matching networks of the power amplifier. A general solution for the low quality factor of the integrated spiral inductor involves the use of an inductor with bond-wire and an off-chip inductor. However, the additional off-chip components may increase the cost of the power amplifier module. Additionally, the large size of the inductor increases the cost of the MMIC. Thus, it is very desirable to design an inductor with a high quality factor and compact size.

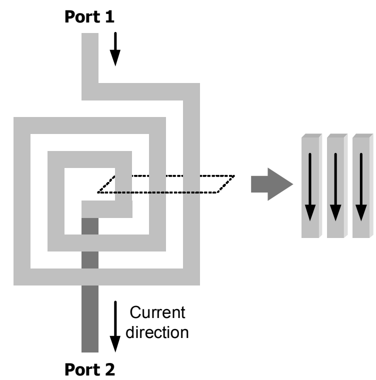
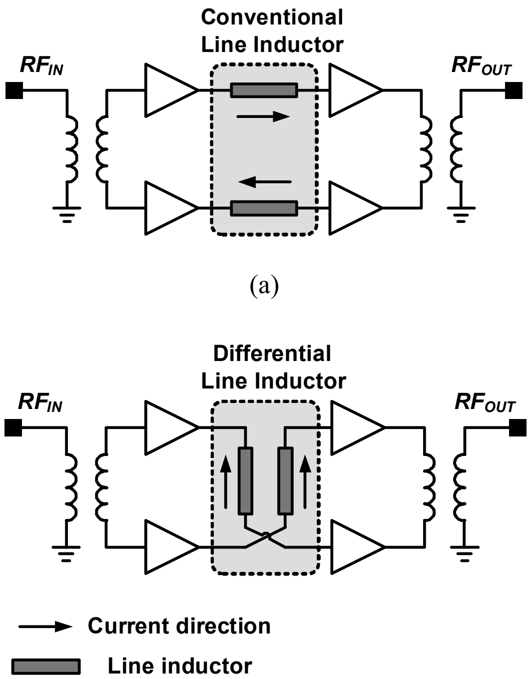


Fig. 1. Simplified structure of a conventional spiral inductor used in the MMIC

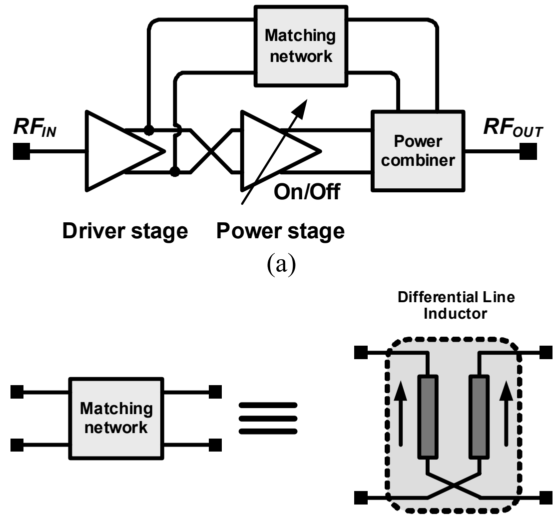
B. Differential Line Inductor

To solve the problems of the integrated spiral inductor, we propose the differential line inductor. Figure 2 shows the concept of the proposed differential line inductor. In Fig. 2(a), the conventional line inductor is used as a component of an inter-stage matching network in the structure of the differential power amplifier. If the two line inductors of Fig. 2(a) are arranged to make the current directions of the two line inductors the same, the configuration of Fig. 2(a) is changed to the configuration



(b)

Fig. 2. (a) Conventional line inductor; (b) differential line inductor



(b)

Fig. 3. (a) Simplified architecture of stage-convertible power amplifier (b) low power matching network

of Fig. 2(b). As a result, the magnetic fields generated by the two line inductors influence each other. Because the current directions of the two line inductors are the same, the mutual inductances of the two line inductors are increased. Thus, the inductance of the differential line inductor is higher than that of the conventional line inductor. With the configuration of the proposed differential line inductor, the inductance of the line inductor can be increased, and the proposed differential line inductor can be used in the structure of the stage-convertible power amplifier [4, 5].

III. STAGE-CONVERTIBLE POWER AMPLIFIER WITH A DIFFERENTIAL LINE INDUCTOR

A. Concept of a Stage-Convertible Power Amplifier with a Differential Line Inductor

Figure 3(a) shows a stage-convertible power amplifier for polar transmitter applications [4, 5]. In the stage-convertible power amplifier, a low power matching network is located parallel to the power stage. For high efficiency in the low output power region, the low power matching network generally needs high inductance for the high load impedance of the driver stage. Thus, as shown in Fig. 3(b), we used the proposed differential line inductor in the design of the low power matching network.

Figure 3(a) shows how we combined the output of the power stage and the output of the matching network in a power combiner. For a high power mode, the power stage is turned on and the driver stage drives the power stage. In addition, a certain amount of driver power is directly coupled to the output through the low power matching network. The load impedance of the power stage is low for the achievement of a high maximum output power. For a low power mode, the power stage is turned off and only the power from the driver is transmitted into the output port through the low power matching network. Moreover, we can select the high and low power modes of the stage-convertible power amplifier by turning the power stage on and off, respectively.

B. Design of the Power Amplifier

The power combiner was designed with a distributed active transformer [6, 7]. We also incorporated a differential line inductor into the low power matching network. Figure 6 shows a schematic of the proposed power amplifier with a differential structure. The driver and power stages were designed as Class E amplifiers. The output of the power stage was connected directly to the primary part of the distributed active transformer with the low load impedance. The output of the driver stage was connected to the input of the power stage through a capacitor and to the primary part of the distributed active transformer through the low power matching network.

For the high power mode, all of the stages in the power amplifier are turned on to generate a high output power. For the low power mode, on the other hand, the power stage is turned off and the output power is generated only

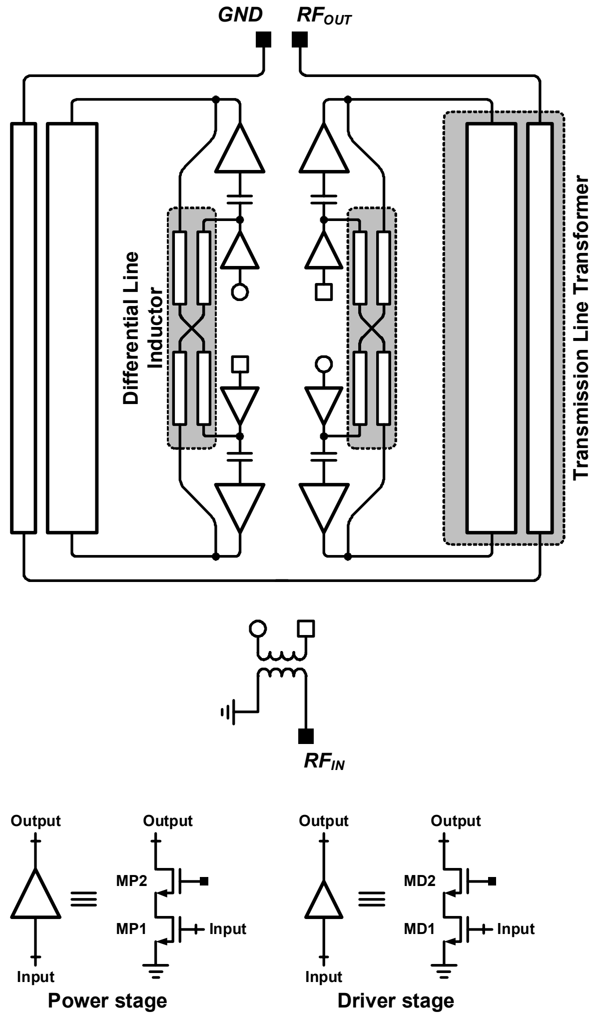


Fig. 4. Schematic of the designed power amplifier

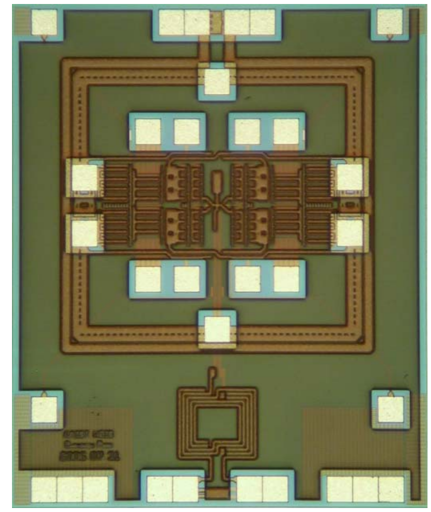


Fig. 5. Chip photograph of the implemented power amplifier

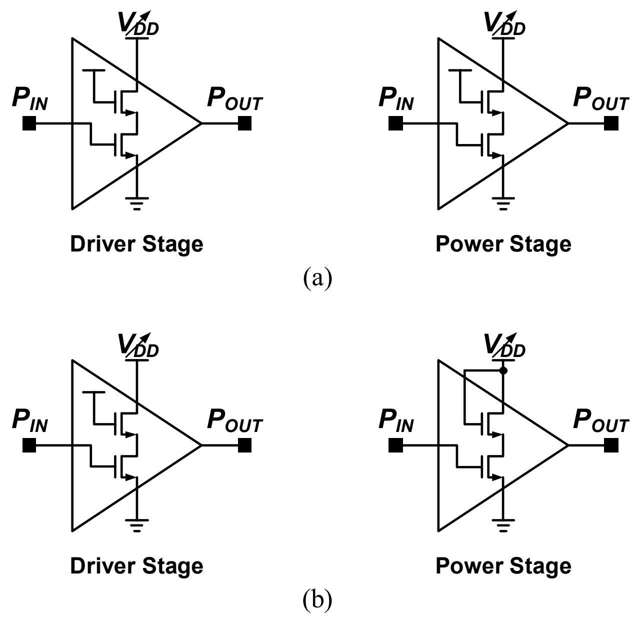


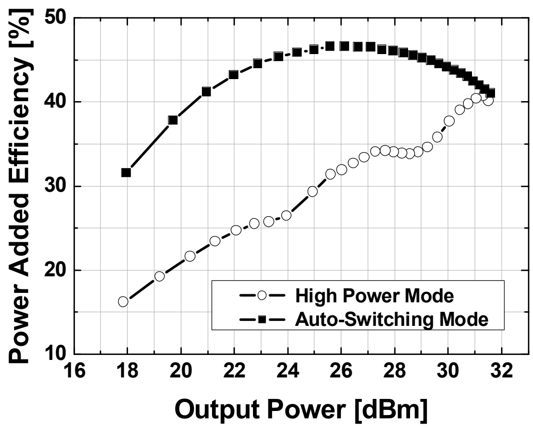
Fig. 6. Circuit configurations of (a) the high power mode, (b) the auto-switching mode. After [5]

by the driver stage. The output power of the driver stage is transmitted into the output while in the low power mode. In the stage-convertible power amplifier, an additional power stage is not needed for the low power mode. Moreover, because the driver stage works as the output stage in the low power mode, the chip size is therefore reduced [4, 5].

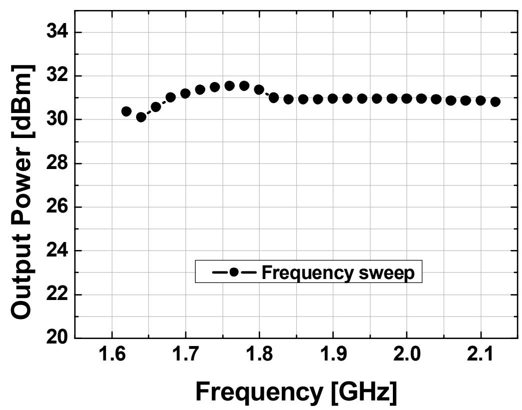
Our voltage combining technique involved the use of the concept of a distributed active transformer [6, 7]; we also used two differential pairs of the power stage and the driver stage. We then implemented the output matching network of the power stage with the distributed active transformers, the drain-source capacitance of the power stage and an additional MIM capacitor. The output matching network of the driver stage was composed of the proposed differential line inductor, the drain-source capacitance of the driver stage, the gate-source capacitance of the power stage and an additional MIM capacitor. Finally, the input transformer consisted of a spiral-type transformer.

IV. Measurement Results

Figure 5 shows the implemented power amplifier, which is based on 0.18 μm RF CMOS technology. The size of the chip, including all the pads, is 1.15 mm × 1.51 mm. The area of the transformer is 1.0 mm × 1.0 mm.



(a)



(b)

Fig. 7. (a) Measurement results for circuit configurations of high power mode and auto-switching mode (b) measured frequency response

The amplifier's measured performance includes the losses of the bond-wires, input transformer, output transformer and printed circuit board interconnections. The input power of the power amplifier is fixed at 9.75 dBm because the power amplifier was designed for polar transmitter applications. Figure 7(a) shows the measured power added efficiency versus output power, P_{OUT} while the supply voltage, V_{DD} varies from 0.7 V to 3.3 V. The operation frequency is fixed at 1.78 GHz. The measured maximum output power of this work is almost 31.5 dBm. Figure 7(a) also shows the measurement results for the circuit configurations of Fig. 6, and Fig. 7(b) shows the frequency response under the maximum output power conditions.

VII. Conclusion

Using 0.18 μm RF CMOS technology, we implemented a 1.8 GHz power amplifier for a polar transmitter application and we propose a differential line inductor for a differential circuit. The differential line inductor is used as a low power matching network in a stage-convertible power amplifier in order to increase the efficiency in the low output power region. The improvement in the low power efficiency for the power amplifier is 81% at an output power of 20 dBm.

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