A Multi-Band CMOS Power Amplifier Using Reconfigurable Adaptive Power Cell Technique

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***Abstract*—A reconfigurable adaptive power cell configuration for a multi-band CMOS power amplifier (PA) is presented, for long-range WLAN applications. The common gate (CG) transistor of a CMOS cascode power cell consists of four differently biased 4-transistor cells to have good linearity, two of which are subsidiary cells and are turned off to cover the higher frequency band. This allows the PA to operate in multi-band properly without any additional switches or paths for multi-band. The chip is fabricated in 40 nm CMOS technology, and its size including the ESD-protected pad is 1.985×1.61 mm^2. The measurement results show that the proposed PA achieves the output power of 27.8 (28.2) dBm with the PAE of 52% (53%) at a high (low) frequency band.**

***Index Terms*—Band switching, CMOS RF power amplifiers, IEEE 802.11ah standards, multi-band, reconfigurable matching.**

I. Introduction

WIRELESS local area network (WLAN), which is currently operating at 2.4 GHz and 5 GHz bands, has been one of the most popular wireless data communication technologies. However, IEEE 802.11ac/n has limited its transmission ranges due to its high operation frequency. Also, the rapid developments in Internet-of-Things (IOT) and Machine-to-Machine (M2M) communication make it necessary to design new communication system. The IEEE 802.11ah/af standardization task group is developing a global wireless LAN standard that will allow wireless access using carrier frequencies below 1 GHz.

The 802.11ah/af systems, which use low frequency bands, are expected to provide a greatly improved transmission range compared with the current WLANs operating at 2.4 GHz and 5 GHz bands. 802.11ah (750$\sim$930 MHz), 802.11af (part of 470$\sim$806 MHz) are the long-range Wi-Fi standards. The operation frequencies of 802.11ah/af are too broad for one power amplifier to cover; therefore, a multiband power amplifier is needed to cover the wide bands [1], [2].

In this work, a reconfigurable adaptive power cell (reconfigurable APC) for multi-band PA operation is proposed for long-range WLAN application. The reconfigurable adaptive power cell selects the frequency without any additional switches or RF paths. Also, it achieves high PAE and linearity in both bands. The adaptive power cell, which reconfigures to select the operation frequency band, was originally invented to increase linearity [3]. In this letter, the operation principle of the reconfigurable APC is presented in Section II. The implementation and measured results of the multi-band PA are reported in Section III.

II. Operation of the Reconfigurable Adaptive Power Cell

A. Schematic

Fig. 1 shows the schematic of the proposed PA with the reconfigurable APC. The inset shows the reconfigurable APC in detail, which consists of four common gate (CG) transistors that are differently biased. To optimize the performance of the reconfigurable APC, the channel width of its power cells were carefully chosen. The channel widths (CG1, CG2: main cells, CG3, CG4: sub cells) are 3.82 mm, 3.82 mm, 0.9 mm, and 0.9 mm, respectively.

The different channel widths lead to different input average capacitance. The input average capacitance variations of CG transistors have different signs because the CG transistors are differently biased. Thus, the total average capacitance variation with respect to the input power can become small due to mutual cancelling [3].

Fig. 1 shows the schematic of the overall reconfigurable APC PA, which is implemented with a two-stage amplifier to obtain sufficient gain. To prevent breakdown, 0.55 um-thick oxide transistors are used in all of the CG power cells. Differential structures are adopted to alleviate bond wire effects and to increase the power gain.

B. Analysis of Reconfigurable Adaptive Power Cell

The proposed power amplifier supports two bands as summarized in Table I. When the PA is operated at low frequency band, both the main cells and the subsidiary cells are turned on. On

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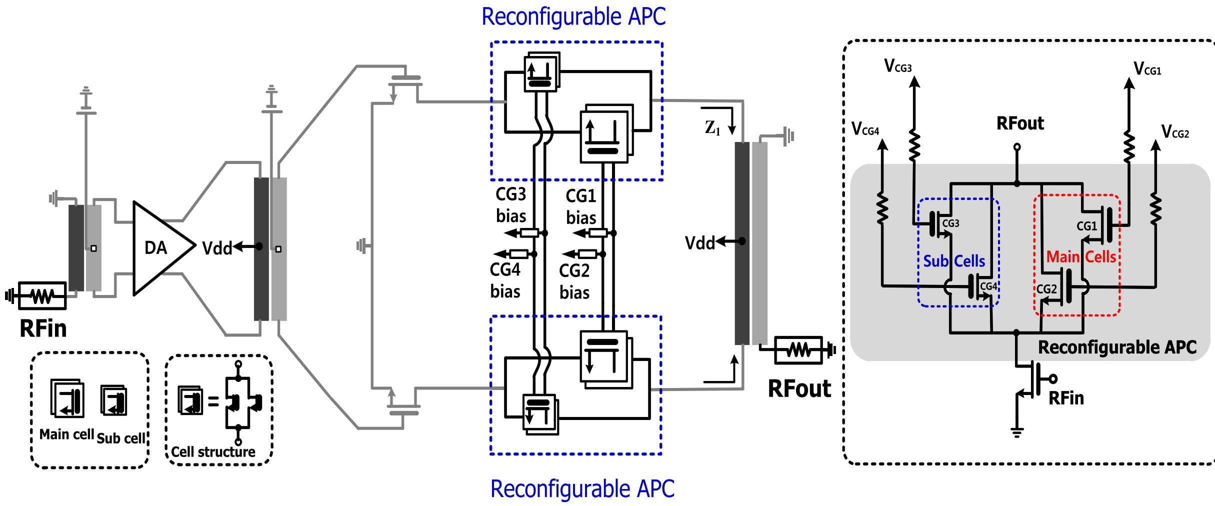
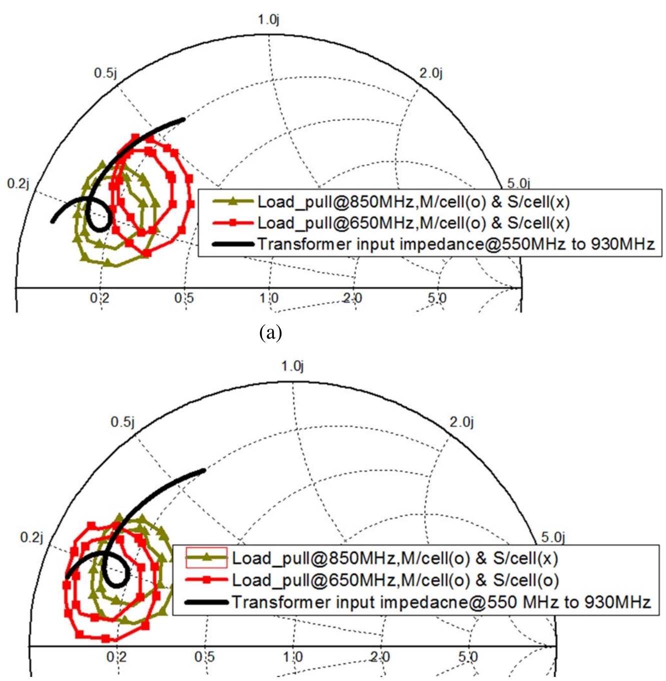


Fig. 1. Overall schematic of the reconfigurable APC PA.

TABLE I
TARGET FREQUENCIES AND RECONFIGURABLE APC OPERATION

	Frequency (MHz)	Target Psat (dBm)	Operation	
			Main cells	Sub cells
Band 1	550~790	28	Turn on	Turn on
Band 2	800~930	28	Turn on	Turn off



(a)

(b)

Fig. 2. Simulated results of the output power load pull contour. (a) Load pull contours of the PA when only the main cells are turned on or off at 850 MHz and 650 MHz. (b) Load pull contours of the PA when both the main and subsidiary cells are turned on at 650 MHz [the bias conditions of the main cells are the same as (a)].

the other hand, when the PA is operated at the high frequency band, only the main cells are turned on (the subsidiary cells are turned off).

Load pull simulations were performed to confirm the operation principle of the reconfigurable APC. Fig. 2(a) shows

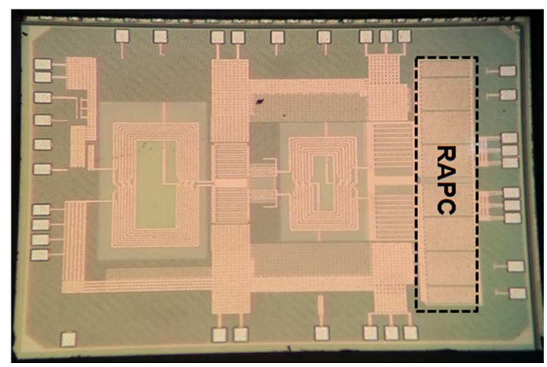


Fig. 3. Chip photograph.

the load pull result obtained at 650 MHz and 850 MHz with turned-on main cells and turned-off subsidiary cells. The result shows that the maximum output power contours at 850 MHz overlap well with the transformer input impedance (Z_1). On the other hand, the maximum output power contours at 650 MHz do not show good overlap. Fig. 2(b) shows the load pull results obtained at 650 MHz and 850 MHz with on and off subsidiary cells. When the subsidiary cells are turned on at 650 MHz, the maximum output power contours at 650 MHz overlap well with the transformer input impedance (Z_1). Thus, the maximum output power contours at both frequencies are perfectly matched to the transformer input impedance (Z_1). Note that load pull contours are changed to cover the frequency bands properly by switching of the subsidiary cells.

III. MEASUREMENT RESULTS

The PA with a reconfigurable APC for double bands was fabricated in 40 nm CMOS technology as shown in Fig. 3. The gates of CG1, CG2, CG3, and CG4 are biased at 2.9 V, 2.7 V, 2.4 V, and 2.1 V, respectively. The layout size, including the ESD pads, is 1.985 mm $\times$ 1.61 mm. The output transformer was fabricated in PCB. Fig. 4 shows the S-parameter measurement results and peak PAE with CW input at both bands. The blue line represents the S21 results obtained at 650 MHz with both turned-on main cells and subsidiary cells, while the

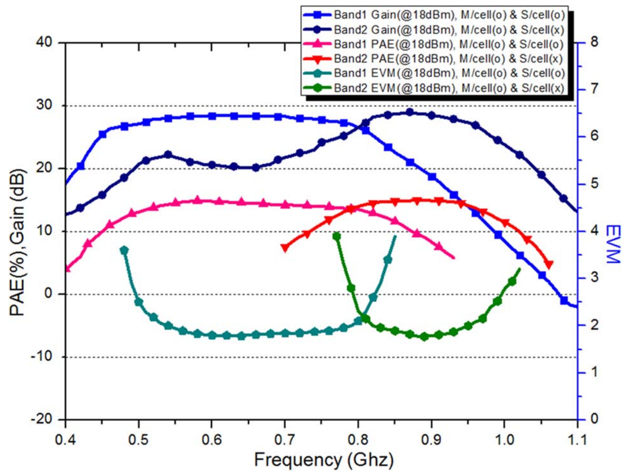


Fig. 4. Measured results of gain, PAE and EVM versus Frequency.

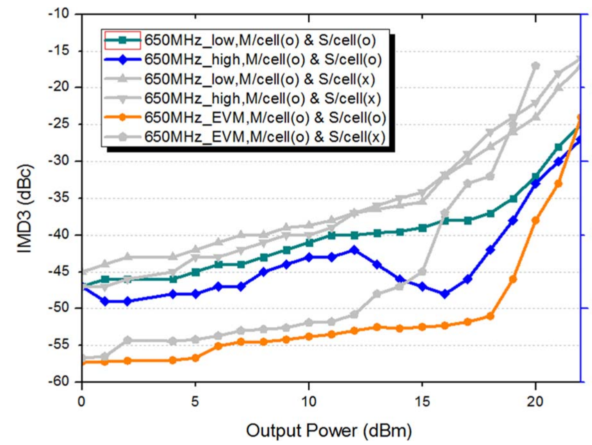


Fig. 6. Measured IMD an d EVM result at 650 MHz.

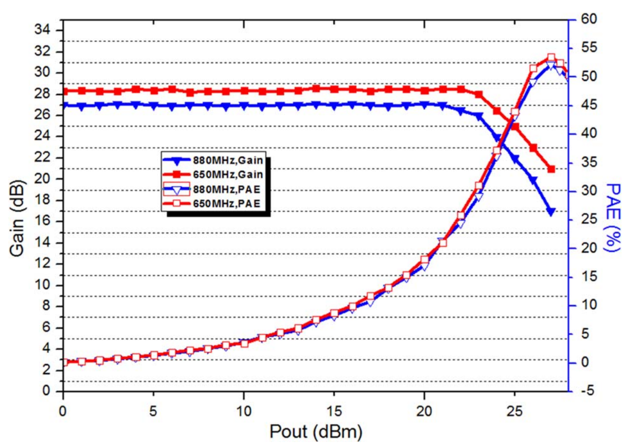


Fig. 5. Single tone power sweep measurement results of gain and PAE.

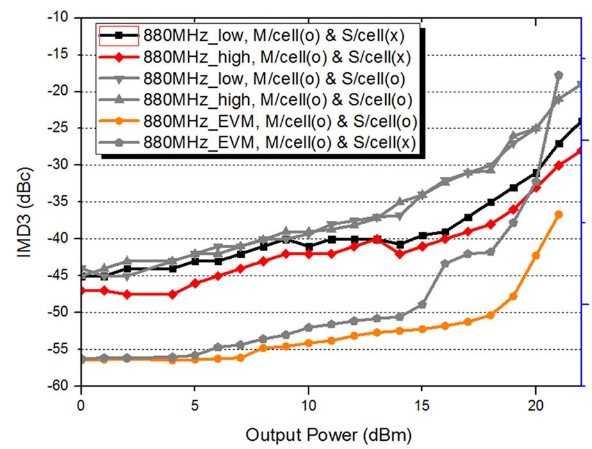


Fig. 7. Measured IMD and EVM result at 880 MHz.

black line represents the S21 results obtained at 850 MHz with turned-on main cells and turned-off subsidiary cells. The frequency band was selected by only switching the subsidiary cells.

Single-tone measurement was performed as shown in Fig. 5. The power gain was 27.5 (28.3) dB and the output saturation power was 27.8 (28.2) dBm with 52.2 (53.5) % peak PAE at 880 MHz (650 MHz)

Figs. 6 and 7 show the measurement results obtained with two-tone and modulated signals. The linear output power at −35 dBc third-order-intermodulation (IMD3) were 17.5 (17.8) dBm at 650 MHz (880 MHz) with the tone spacing of 20 MHz. This reflects an improvement of 3.4 dB linear output power with the reconfigurable APC at 650 MHz (880 MHz). For the EVM test, we used 802.11n (64 QAM, 20 MHz) signal, and the output power at 2% EVM was 18.2 (18.4) dBm [4]–[8].

IV. Conclusion

A CMOS linear power amplifier for long-range WLAN has been presented, which operates at dual frequency bands. This dual-band PA is implemented by using the proposed reconfigurable APC. The reconfigurable APC successfully realizes multi-band operation without any additional switches or RF paths. Therefore, the reconfigurable APC not only enhances the linear power and PAE of a PA but also switches operating frequency bands maintaining optimum operation.

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