Extended Abstracts of the 2010 International Conference on Solid State Devices and Materials, Tokyo, 2010, pp101-102

A 6-10 GHz CMOS Tunable Power Amplifier for Reconfigurable RF Transceivers

JeeYoung Hong, Daisuke Imanishi, Kenichi Okada and Akira Matsuzawa

Tokyo Institute of Technology, Department of Physical Electronics
2-12-1-S3-27, Ookayama, Meguro-ku, Tokyo 152-8552, Japan
Tel/Fax: +81-3-5734-3764 E-mail: hong@ssc.pe.titech.ac.jp

1. Introduction

Recently, a multi-standard transceiver has started to attract more attention with the overwhelming increase of various wireless standards that covers different frequency bands and uses diverse modulation standards. Moreover, the realization of a single chip that covers all the standards is desired for low-cost and downsizing. For this reason, a power amplifier that can tune the output impedance using a CMOS process is one of the important issues to realize a multi-standard transceiver.

Until now, most of the standards for personal and domestic use such as the cellular network, Wi-Fi, WiMAX and others are concentrated mainly under 6GHz. However, if we think about the growth of millimeter wave applications in the future, it is expected that a multi-standard transceiver at high frequency is necessary. Therefore I designed and measured a multi-band power amplifier for the application in the frequency band from 6 to 10 GHz.

2. Tunable Power Amplifier

Fig. 1 shows a simplified circuit schematic of the proposed power amplifier. The PA adopts a resistive feedback which is commonly used in broadband low noise amplifiers [1]. It can achieve impedance matching in a wide frequency range and improves circuit stability. In case of LNA, it is used for input impedance matching, because the input impedance of LNA is a function of the feedback resistance. Nonetheless this technique can also be applied to the output impedance matching, therefore it is used for output impedance matching in this time.

Fig. 2 shows a resistive feedback common-source amplifier [2,3]. To help readers understand how to match the output impedance, only half the circuit is shown here. Actually, the proposed PA is made as a differential circuit for getting large output power. If the drain impedance of the transistor approaches infinity, the output impedance Z_{out} is expressed by

$$Z_{out} = \frac{R_f + R_s}{g_m R_s + 1} // \frac{1}{j\omega C} // (R_L + j\omega L) \qquad (1)$$

where R_S is the output impedance of the previous stage (assume R_S 50Ω because there is no previous stage), and R_L is the parasitic resistance of the inductor. At the resonance frequency $f = 1/2\pi\sqrt{LC}$, the imaginary part of Eq.(1) is cancelled, and the following equations are derived.

$$Z_{out} = \frac{R_f + R_s}{g_m R_s + 1} // R_P \quad , \quad R_P = \frac{L}{CR_L} \qquad (2)$$

where R_P is the resonance impedance of the LC-resonator. The resonance frequency can be tuned by varying L and C. In this case, a MIM capacitor array is employed to change the resonance frequency. R_P is a function of capacitance, and influence of the resistor's skin effect. Thus, the feedback-resistance R_f also has to be tuned to compensate the output impedance depending on the frequency.

To sustain voltage stress, a thick gate-oxide transistor is used for the common-gate stage. A supply voltage of 3.3-V is used to increase the voltage swing at the output nodes. The switches in the capacitor array are also implemented by thick gate-oxide transistors because of the same reason.

Varactors are also utilized in the switched capacitor array since the value of the needed capacitance to be switched is about 1pF at the band near 10 GHz and few hundred pF near the 6 GHz band.

The feedback resistance is adjusted accordingly for each band to provide the maximum quality factor. The matching frequency can be switched from band 1 to band 5 in this case. Finer frequency tuning can be realized by increasing the number of bands (switches), but this PA consisted of the minimum number (5band) of the bands that S_{22} is less than -10dB in simulation.

3. Measurement Result

Fig. 3 shows the chip micrograph of the proposed PA. It is fabricated in 0.18μm CMOS process using thick gate-oxide transistors and MIM capacitors. The total size and the core size are 0.87 × 0.97 mm^2 and 0.50 × 0.39 mm^2. On-chip inductor is implemented on metal 6 layer with thick metal

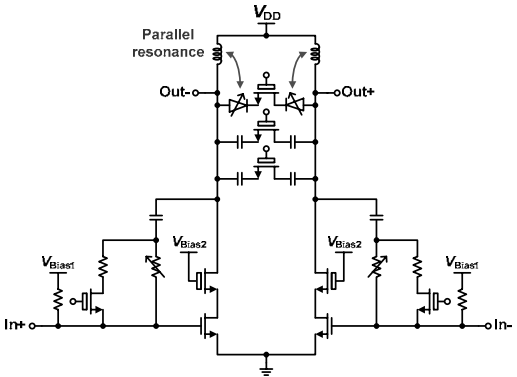

Fig. 1 Schematic of the proposed power amplifier

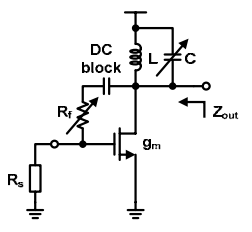

Fig. 2 A resistive feedback amplifier with parallel resonator

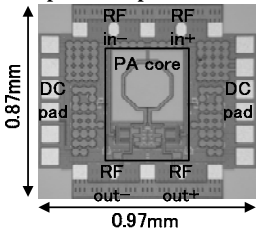

Fig. 3 Chip micrograph

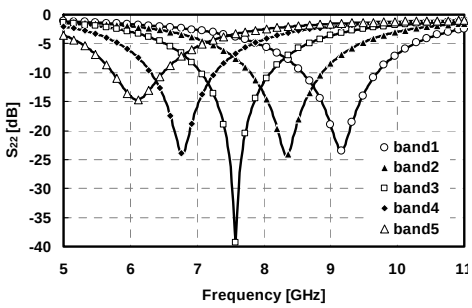

Fig. 4 Measured S_{22}

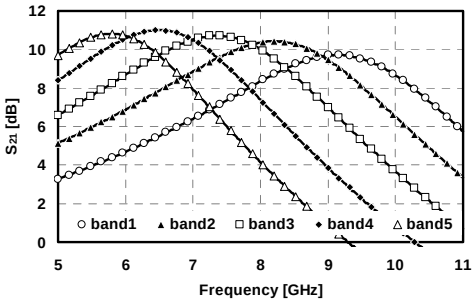

Fig. 5 Measured S_{21}

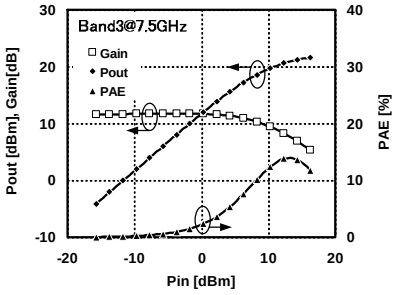

Fig. 6 Gain, P_{out}, PAE vs. P_{in} at band 3(7.5GHz)

option that extends the metal thickness to 4.2μm. The power amplifier is evaluated with a 3.3-V power supply. The chip was measured by using RF probes with external DC blocks at input and output nodes. Figs. 4 and 5 show the measured S_{22} and S_{21} of each frequency band, which are the differential-mode S-parameters calculated from the measured 4-port S-parameters. The output matching frequency is shifted according to switching bands. From 5.74 GHz to 9.68 GHz, S_{22} keeps lower than -10 dB and S_{21} is larger than 9.27 dB.

Fig. 6 shows output power, power gain, and power added efficiency (PAE) versus input power at band 3 (7.5 GHz). The saturated output power is 21.6 dBm, the output 1-dB compression point is 18.0 dBm with 9.3 % of the PAE, the small signal gain is 11.6 dB, and the maximum PAE is 14.0 %. The output power and PAE at other bands with different signal frequency was also measured. Fig. 7 shows the saturated output power, the output 1-dB compression point, the PAE at 1-dB compression point, and the maximum PAE versus frequency. The output 1-dB compression point is larger than 15.5 dBm, and the PAE is larger than 4.7 % at 1-dB compression point over all the frequency range.

4. Conclusions

In this paper, a CMOS PA with a tunable output impedance matching is proposed for a multi-standard transceiver that operates at frequencies higher than 6GHz. The prototype utilizing resistive feedback and parallel resonance is fabricated in 0.18μm CMOS process. As the result, the PA achieves an output impedance matching from 5.74 to 9.68 GHz. With a 3.3-V power supply, the PA realizes output 1-dB compression point of larger than 15.5dBm, output return loss S_{22} of smaller than -10dB, and a maximum power added efficiency of larger than 7.1%.

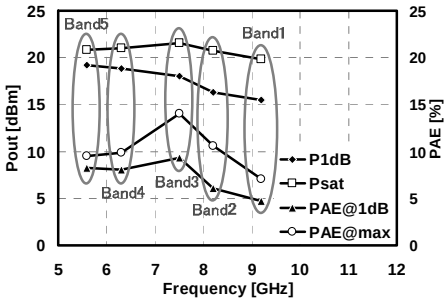

Fig. 7 P_{1dB}, P_{sat}, PAE@P_{1dB}, and PAE_{max} vs. frequency

Acknowledgements

This work was partially supported by MIC, STARC, NEDO, Canon Foundation, and VDEC in collaboration with Cadence Design Systems, Inc., and Agilent Technologies Japan, Ltd.

References

[1] J. Zhan, et al., "A 5GHz Resistive-Feedback CMOS LNA for Low-Cost Multi-Standard Applications", *ISSCC*, Feb. 2006.

[2] D. Imanishi, et al., "A 0.9-3.0 GHz Fully Integrated Tunable CMOS Power Amplifier for Multi-Band Transmitters", *ASSCC*, Feb. 2010

[3] D. Imanishi, et al., "A 2-6 GHz Fully Integrated Tunable CMOS Power Amplifier for Multi-Standard Transmitters", *ASP-DAC*, pp. 351-352, Feb. 2010

[4] H. Chung, et al., "A 6-10-GHz CMOS Power Amplifier with an Inter-stage Wideband Impedance Transformer for UWB Transmitters", *EuMC*, pp. 305-308, Oct. 2008.

[5] C. Lu, et al., "A CMOS Power Amplifier for Full-Band UWB Transmitters", *RFIC*, pp.397-400, June. 2006.

[6] C. Lu, et al., "Linearization of CMOS Broadband Power Amplifiers Through Combined Multigated Transistors and Capacitance Compensation", *TMTT*, pp.2320-2328, Nov. 2007.

[7] H.Wang, et al., "A 5.2-to-13GHz Class-AB CMOS Power Amplifier with a 25.2dBm Peak Output Power at 21.6% PAE", *ISSCC*, pp. 44-46, Feb. 2010

Table I Performance Comparison

	Technology	V_{DD} [V]	Frequency [GHz]	P_{1dB} [dBm]	P_{sat} [dBm]	PAE_{peak} [%]	Area [mm^2]	
[4]	0.18μm CMOS	1.5	6~10	*5	—	17.6	1.08	* Average P_{1dB}
[5]	0.18μm CMOS	2.0	3~10	5.6~9.4	—	—	1.76	
[6]	0.18μm CMOS	—	3.7~8.8	~15.6	19	25	2.8	
[7]	0.09μm CMOS	—	**5.2~13	—	25.2	21.6	***0.70	** S_{22} < -3dB, ***core size
This work	0.18μm CMOS	3.3	5.74~9.68	**15.5~19.2**	19.8~21.6	7.1~14.0	***0.20	Tunable