A current-reuse MICS band CMOS RF transmitter for implantable cardioverter telemetry system

Jongsik Kim and Hyunchol Shin^{a)}

*High-Speed Integrated Circuits and Systems Lab., Kwangwoon University,
20 Kwangwoon-Ro, Nowon-gu, Seoul 139–701, Korea*

a) hshin@kw.ac.kr

Abstract: A MICS band CMOS RF transmitter is presented for implantable cardioverter telemetry system. Current-reuse and gain boosting techniques are employed for reducing the current consumption as well as improving the output power. Fabricated in 0.18 μm CMOS, the transmitter dissipates 9.3 mW from a 1.8-V supply. Measurement shows that the gain boosting capability increases the output power by 1.3–5.5 dB, while the image and LO suppression is unaffected. The proposed approach can be effective for a low-power RF transmitter design in implantable telemetry devices.

Keywords: MICS, implantable cardioverter telemetry system, implantable cardioverter defibrillator, transmitter

Classification: Integrated circuits

References

- [1] P. D. Bradley: European Solid-State Circ. Conf. Dig. Tech. Papers (2011) 37.
- [2] J. Pandey and B. P. Otis: IEEE J. Solid-State Circuits **46** (2011) 1049.
- [3] D. Park and S. Cho: IEEE Microw. Wireless Compon. Lett. **19** (2009) 104.
- [4] K. W. Cheng, K. Natarajan and D. Allstot: IEEE J. Solid-State Circuits **45** (2010) 510.
- [5] L. Zheng, H.-C. Yao, F. Tzeng and P. Heydari: Proc. IEEE Int. Symp. Circuits Syst. (2009) 1317.

1 Introduction

Since FCC's establishment of the Medical Implant Communication Service (MICS) and Medical Device Radio Communications Service (MedRadio), single-chip CMOS RF transceivers that can be used in this band are highly demanded for implantable biomedical applications. One of the applications is the implantable cardioverter telemetry system (ICTS) in implantable cardioverter defibrillator (ICD) [1]. ICTS transceiver builds up bidirectional

communication link between an implanted device and an external controller. This telemetry link allows retrieval of stored cardiac signal, update of device operation program, and monitoring of device status, all in a remote way. Typical transceivers of this kind comprise a 400-MHz main transceiver and a 2.4-GHz wake-up receiver. Since battery replacement is not desirable or practical in the implantable devices, increasing the battery lifetime by reducing the power consumption is one of the main focuses of the design efforts [2].

Current reuse structure by stacking various circuit blocks under a single supply is an effective method to reduce the power dissipation. In the literature, various RF circuit blocks adopting the current-reuse technique can be found [3, 4, 5]. For example, stacked VCO and divider [3], stacked LNA, mixer and VCO [4], and stacked VCO and power amplifier [5] can be effective for improving the current dissipation, particularly, in the carrier generation block, receiver block, and transmitter block, respectively, in RF transceivers.

This paper presents a MICS band CMOS RF transmitter based on the current reuse structure. It is designed as part of a 400-MHz main transceiver for ICTS in ICD. An additional gain boosting technique is combined with the current reuse structure, leading to further reduction of the power consumption as well as significant improvement of the power efficiency.

2 Circuit design and results

Fig. 1 (a) shows the transmitter architecture. It comprises a quadrature mixer, a power amplifier (PA), and a tunable LO buffer. The most current-consuming PA block is placed over the mixer and the LO buffer, thus the PA's current is reused by other blocks. The baseband signal is frequency shift keying (FSK) modulated with the frequency deviation of 125 kHz. It is applied to the mixer and up-converted to 400-MHz RF. The incoming I/Q LO signal is amplified by the phase-tunable LO buffers and transferred to the mixer's LO port. Mismatches between the mixer's I/Q LO signals are minimized for the image and LO suppression at the mixer output. For this, a phase interpolating buffer is adopted. It performs the weighted-summation of the incoming LO I/Q and provides the phase/amplitude-controlled accurate quadrature LO signals to the mixer. With 6-bit tuning, the phase mismatch between the I/Q LO can be controlled to less than 1 degree. Finally, the up-converted RF signal is amplified by the power amplifier and transferred to the antenna via an off-chip matching network.

Fig. 1 (b) is the circuit schematic, in which only a single chain of the I/Q paths is drawn for simplicity. The internal supply V_{mid} is chosen as 1.2 V while the V_{DD} is 1.8 V. C_{mid} regulates V_{mid} and minimizes the second-harmonic ripple noise at the node. In simulation, 20 pF was found to be enough for this purpose. However, in actual layout, 400 pF was put for sufficient regulation since the die area was sufficient. In mixer, N-FET transconductance stage and P-FET switching core stage are connected in a folded cascode type for low voltage operation. The mixer load is an off-chip inductor L_L ($=12$ nH) and a tunable capacitor C_L , and optimally tuned at the

Fig. 1. Current-reuse MICS band transmitter, (a) architecture, (b) circuit schematic.

operating frequency. The mixer output signal is fed to the common-source power amplifier stage. The output signal is fed to the differential-to-single balun and subsequently to the off-chip output matching network. For improving the Q-factor of the PA's load and boosting the gain, a cross-coupled latch is added at the drain node. The dc gate voltage for the PA and the latch is generated by using the common-mode voltage of the PA's drain node, which is not shown in the figure. Since the latch's negative transconductance should be set properly to avoid circuit instability, the latch FET size is designed to be switchable in three steps.

The designed RF transmitter is fabricated in $0.18\ \mu\text{m}$ RF CMOS process. It consumes 5.2 mA from a 1.8-V supply voltage. At the power amplifier output, a differential-to-single balun and a subsequent T-type output matching network is added. S22 measurement shows that the output return loss is less than $-15\ \text{dB}$ over the entire MICS band (402–405 MHz). Fig. 2 (a) shows the measured output spectrum when the gain boosting is disabled. The base-band and RF frequencies are set to 300 kHz and 403 MHz, respectively. The output power is $-6.8\ \text{dBm}$, and the power gain is 6 dB. The LO and image suppressions are 45.5 and 35.0 dBc, respectively. The same measurement is performed again with the gain boosting enabled (Fig. 2 (b)). Comparison of Fig. 2 (a) and (b) clearly indicates the gain boosting effect. The output power is boosted to $-3.1\ \text{dBm}$ (3.7 dB boosting) and also the LO/image suppression is improved by 3–4 dB. The measured output power against the input power is shown in Fig. 3 (a). The output 1 dB compression point is $-6.2\ \text{dBm}$. The performance with the gain boosting enabled at the input power greater than $-15\ \text{dBm}$ is shown together for comparison. Measurement results show that the output power is increased from $-9.4\ \text{dBm}$ to $-3.9\ \text{dBm}$ (5.5 dB boosting) at the input power of $-15\ \text{dBm}$, and from $-3.3\ \text{dBm}$ to $-2.0\ \text{dBm}$ (1.3 dB

Fig. 2. Measured output spectrum with the baseband and RF frequencies of 300 kHz and 403 MHz. (a) Gain boosting disabled. (b) Gain boosting enabled.

Fig. 3. (a) Measured output power and image/carrier suppression against the input power. (b) Chip micrograph.

boosting) at the input power of -5 dBm. Note that the amount of gain boosting decreases as the output power increases since the loaded Q of the PA decreases. A chip micrograph is shown in Fig. 3 (b). The active area of the current-reuse transmitter is 0.45 mm^2 , which includes 0.12 mm^2 of C_{mid} .

3 Conclusion

A 400-MHz MICS band CMOS RF transmitter is presented for ICTS in ICD. It employs the current-reuse technique to reduce the current consumption and the gain boosting technique to further enhance the output power. Realized in $0.18 \mu\text{m}$ CMOS, the transmitter consumes 9.3 mW. With the gain boosting enabled, the output power increases by 1.3–5.5 dB, while the image and LO suppression is almost unaffected. The combined current-reuse and gain boosting techniques can be effective in improving the overall power efficiency in the low power RF transmitter.

Acknowledgments

This work has been supported by the University ITRC program (NIPA-2013-H0301-12-1013), and IT R&D program of MOTIE/KEIT (10044092), and Kwangwoon Research Grant 2012.