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Batteryless Transmitter for Biomedical Implant

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Abstract

A batteryless transmitter is implemented using TSMC 0.18-μm CMOS technology for biomedical implants. A 1.6-GHz RF signal can be wireless delivered to the transmitter as the RF source for energy harvesting and reused to generate the MICS-band carrier with an injection-locked frequency divider. At the RF powering level of 7 dBm, the transmitter can deliver an output power of -9.6 dBm at 402 MHz and the carrier exhibits a phase noise of -120.35 dBc/Hz at 1 MHz offset.

1. Introduction

Relying on the wireless transmitter to send out the information collected inside the human body, a medical implant can provide the long-term monitoring function. When the implant operates from energy sources other than batteries, the energy that can be offered is usually very limited. Particularly, the RF transmitter consumes more power than other building blocks due to its operating frequency and the phase noise of the RF carrier should be minimized in order to maintain a reliable wireless link. To fulfill the requirement of energy harvesting and low-noise carrier, this work is focused on the design and implementation of the power conversion circuit, the carrier synthesizer and the transmitter. The block diagram of the transmitter is shown in Fig.1.

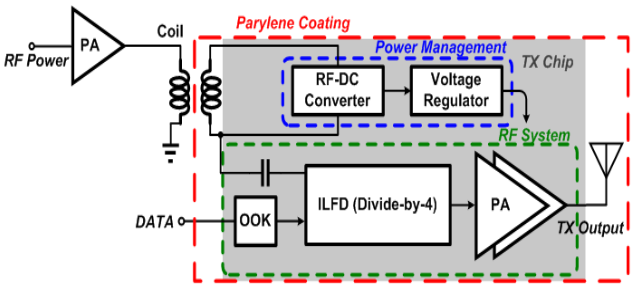

Fig. 1. Block diagram of the low power implantable transmitter

Based on RF powering, a rectifier circuit would convert the RF input into a DC output which is regulated at 1.2 V by a voltage regulator. The other circuit blocks would operate from this regulated voltage supply of 1.2 V. According to [1], the optimal frequency for microwave to be transferred into the human body is 1.6 GHz ~ 1.8 GHz. Using a 1.6 GHz ~ 1.8 GHz powering source can also saving the coil size. Therefore, the external powering source of 1.608 GHz is adopted. Then, through a capacitor, a very little part of the RF powering signal is separately delivered to a divide-by-four circuit to generate the MICS-band carrier of 402 MHz. Note that the implant would be coated with biocompatible material called Parylene to be biocompatible in the future.

2. Circuit Design

RF-DC

The schematic of the RF to DC converter is shown in Fig. 2. The RF to DC converter is realized by cascade differential-drive CMOS rectifier [2]. With sufficient number of stages, the rectifier can generate the required output voltage to drive the regulator. However, the number of the stage of the rectifier is inversely proportional to the power conversion efficiency, and a compromise is made between the output voltage and the conversion efficiency [3]. In this work, the RF to DC converter is realized by the three-stage rectifier.

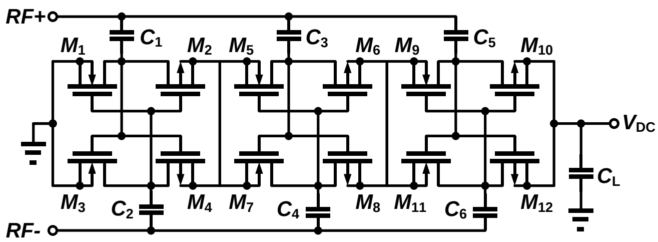

Fig. 2. Schematic of three-stage differential-drive CMOS rectifier.

Injection-Locked Divider

The divide-by-four circuit is formed from two injection-locked divide-by-two circuits in cascade. The schematic of the injection-locked divide-by-two circuit is shown in Fig. 3 [4]. According to [5], the phase noise of the circuit would be greatly reduced when the circuit is injection-locked.

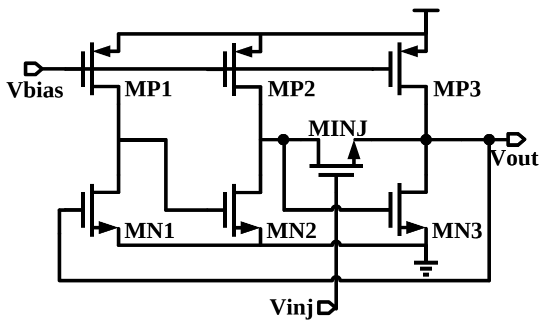

Fig. 3. Schematic of the injection-locked frequency divider [4].

The injection-locked divide-by-two circuit is based on a three-stage ring oscillator. The bias voltage (V_{bias}) determines the bias current. The injection signal is applied to the gate of the MOSFET M_{inj} which behaves as a switch. When the switch is driven by an injected signal, a current will be injected into the ring oscillator periodically as the switch turns on every half the injection cycle. If the frequency of the free-running ring oscillator is close to half the injection frequency, the circuit would deliver an output at half the injection frequency once it is injection-locked.

The schematic of the power amplifier is shown in Fig. 4.The bias voltage V_{bp} and V_{bn} are designed specifically to allow M_2 and M_1 to turn on in positive half period and negative half period, respectively, so that the output power can be maximized.

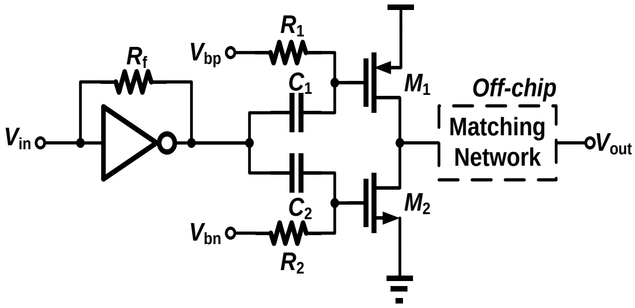

Fig. 4. Schematic of the power amplifier

3. Measurement Results

The conversion efficiency versus the load resistance at different RF powering level is shown in Fig. 5. To obtain the 1 mW DC power required to operate the transmitter, the RF powering level should exceed 6 dBm. The efficiency reaches the peak of 27.1 % as the effective load comes to 1.5 kohm at the powering level of 6 dBm. The efficiency is above 30 % as the powering level exceeds 8 dBm.

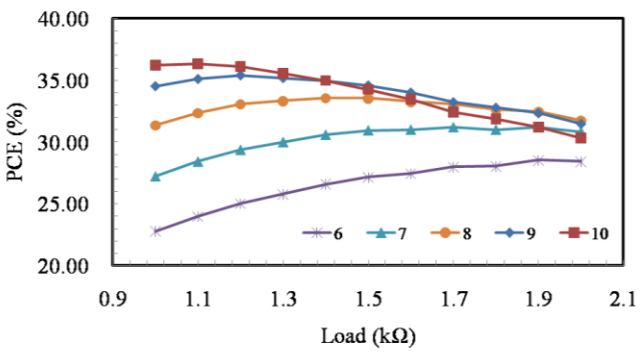

Fig. 5. The power conversion efficiency of the RF to DC converter versus the effective load resistance at different RF powering levels.

Fig. 6 shows the carrier phase noises observed from the transmitter output with the injection-locked divider operating under the free-running and the injection-locked conditions. The free-running carrier shows the phase noise of -89.39 dBc/Hz at 1 MHz offset. With an injection signal of -10 dBm at 1.608 GHz, the phase noise of the 402MHz carrier is reduced down to -131.54dBc/Hz at 1MHz offset. Operating from an external supply, the transmitter can achieve the data rate of 130 kbps. When it operates from RF powering, the data rate drops to 30 kbps. The die photo of the batteryless transmitter is shown in Fig.7. The chip area is 0.71 mm^2.

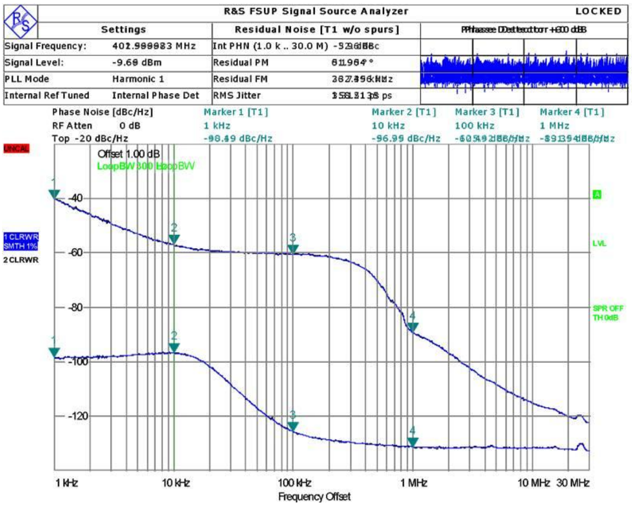

Fig. 6. The phase noise of the divide under the free-running and injection-locked at frequency 402MHz with DC power supply.

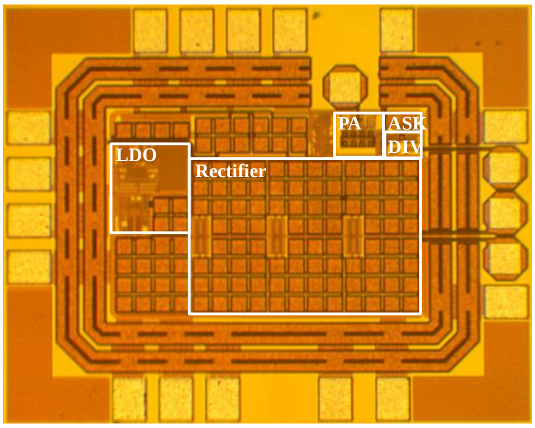

Fig. 7. The die photo of the low power transmitter for biomedical implant.

Acknowledgements

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References

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