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Fully integrated UHF RFID mobile reader with power amplifiers using System-in-Package (SiP)

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Abstract: A fully integrated system-in-package (SiP) for UHF (860–960 MHz) RFID mobile reader is presented. The SiP is made up of an UHF transceiver, a power amplifier (PA), and two baluns. The UHF transceiver was designed in TSMC 0.18 μm Si CMOS and the PA was developed with InGaP/GaAs hetero-junction-bipolar transistor (HBT) technology. The transceiver IC is fully integrated for mobile UHF RFID applications and the PA has high efficiency and linearity with 24 dBm output power for wireless RFID communications over a distance of 1 m. The total size of the SiP module is 11 mm $\times$ 11 mm. The measured data show a transmitter gain of 19.2 dB, total current of 253 mA and adjacent channel power ratio (ACPR) of -41.8 dBc with the second harmonic performance of -57.6 dBc. Also, TX-RX leakage was reduced by careful power amplifier and board designs in small SIP module implementation.

Keywords: UHF RFID, mobile reader, SiP, transceiver, power amplifiers

Classification: Wireless circuits and devices

References

[1] F. Finkenzeller, *RFID Handbook*, 2nd ed., John Wiley & Sons.
[2] S. Chiu, "A 900 MHz UHF RFID reader transceiver IC," *IEEE J. Solid State Circuits*, vol. 42, no. 12, pp. 28222–2833, Dec.
[3] K. Penttila, "Implementation of Tx/Rx isolation in an RFID reader," *Int. J. Radio Frequency Identification Technology and Applications*, vol. 1, no. 1, pp. 74–89, 2006.

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[4] EPC Radio frequency identity protocols class-1 generation-2 UHF RFID protocol for communications at 860 MHz – 960 MHz, version 1.0.9, Jan. 2005.

1 Introduction

Radio frequency identification (RFID) systems are widely used in a lot of industries. As developing the RFID technologies, not only tags, but the readers are also emphasized for the manufacturing cost. Especially, ultra-high frequency (UHF) mobile RFID readers for distribution identifying and tracking applications demand compact size to be integrated into handset. Also, the UHF RFID mobile systems in the 860–960 MHz bands should have high performances to meet the RFID global standard specifications.

Most common RFID readers have a type of integration on an evaluation board with each packaged device and other passive components of a surface mount device (SMD). It causes large board area and complex circuits among the various components. Particularly, the UHF transceiver takes up large area because of a variety of functional blocks. So it needs to be integrated onto single die with reduced size.

In order to develop a mobile RFID reader with a compact size and a good performance, this paper presents an UHF reader transceiver fully integrated in Si CMOS and a linear power amplifier (PA) using InGaP/GaAs HBTs with low current consumption. Moreover, these chips were integrated as single module with system-in-package (SIP) technology as shown in Fig. 1. Thus, a simple and compact module was realized with high performances.

The fabricated mobile reader module was verified with the amplitude shift keying (ASK) modulation signals for communication between the readers and the tags for the UHF RFID applications [1]. The standards governing interactions between the tags and the readers are referred to as the EPC^{TM} global specifications (RFID protocols Class-1 generation-2 UHF RFID protocol for communications at 860–960 MHz) [4].

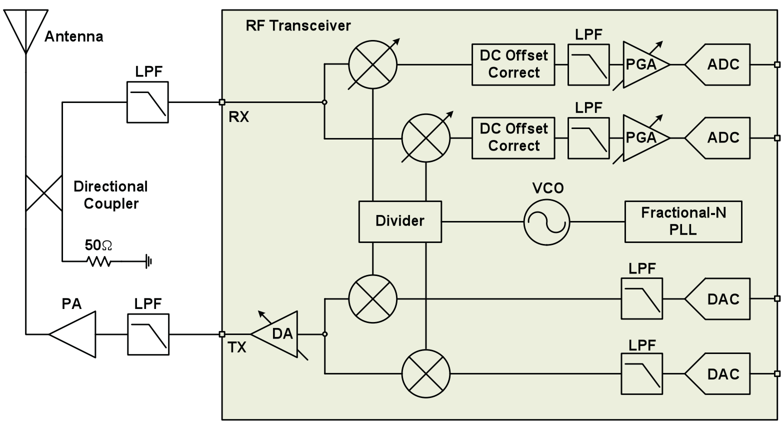

Fig. 1. SIP diagram for UHF RFID mobile reader.

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2 Implementation

The linear power amplifier (PA) for the wireless communication over a distance of 1–3 m was designed with the high linearity and efficiency performances. The SIP implementation offers the smaller size solution with the integration in these devices than individually packaged ICs. Also it has higher performance through shorter interconnect paths by using the four metal layers of the substrate.

A. Transceiver

The main functional blacks of the reader chipset are categorized into modem, radio, MCU and so on. The UHF transceiver was developed into a system-on-chip (SoC) technology with high functional performances. The RF transceiver can be categorized into 3 blocks – receiver, transmitter, and frequency synthesizer [2].

Receiver path consists of down conversion mixer, DC offset corrector, low pass filter (LPF), programmable gain amplifier (PGA) and analog-to-digital converter (ADC). The differential RF signal is down converted to a baseband signal by a mixer. DC offset is corrected by DC offset cancelation circuit. Channel selectivity is performed using an integrated low pass filter. Its tunable bandwidth is determined by RF register values. A programmable gain amplifier provides sufficient gain to demodulate received signal. The succeeding analog-to-digital converter generates a digital baseband signal. The digital baseband signal feeds MODEM to process in digital domain.

Transmitter path consists of drive amplifier (DA), up conversion mixer, low pass filter (LPF), and digital-to-analog converter (DAC). The ASK modulated signal is converted from digital domain to analog domain by digital-to-analog converter. The succeeding low pass filter suppresses un-wanted harmonics. An up conversion mixer translates a baseband signal to the RF signal which is amplified by drive amplifier.

All the blocks except the passive component that forms loop filter are being integrated onto frequency synthesizer which is implemented in $\Delta\Sigma$ fractional-N architecture. LC VCO generates signal ranged from 3.2 GHz $\sim$ 4 GHz and these signals go through divide by 4 block then feed local oscillator signal into RF I/Q up/down-converter. Frequency synthesizer also oscillates crystal unit or buffers crystal oscillator output so that system clock of 19.2 MHz is transferred to MODEM.

B. Power amplifiers

The UHF RFID power amplifier is fabricated using a $2 \times 20\,\mu m^2$ InGaP/GaAs HBT process. It has an output power of 24 dBm for the wireless communication to the tags within a distance of 1 m. The PA in the module fairly determines the reader's performance because of the nonlinearity characteristics from the active device and high power level. Especially, the PAE is one of the most significant factors because the readers always transmit the CW signal to energize the tags. Also, the ACPR is an important param-

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eter in dense-reader environments for the mobile RFID communication [4]. Therefore, the PA which enables to communicate in the distance of 1 m was designed with the optimized performance of the ACPR and a low current consumption for mobile applications. For the testing, the PA mounted on the quad flat no-lead (QFN) package and it has been measured with the ASK modulation and CW signals. The PA has a gain of 24.4 dB; the rectified total current is 158.5 mA, the PAE is 43.8%, and the second harmonic is −44 dBc at an output power of 24 dBm.

3 Measurements

The fully integrated RFID reader module is implemented within SiP which has an area of 11 mm × 11 mm, as shown in Fig. 2. The reader contains the UHF transceiver in TSMC 0.18 μm Si CMOS, the power amplifier of $2 \times 20\,\mu m^2$ InGaP/GaAs HBT, and other passive components.

The performances of the RFID reader were verified on the evaluation board. The system operates in a half-duplex procedure (HDX) because the transmitter (TX) and the receiver (RX) share a single antenna. To verify these performances, the gain is measured with the ASK modulation under the conditions of pseudo-noise 9 (PN9) data, a modulation depth of 90%, and a symbol rate of 40 kbps. The measurement results show that the gain is 19.2 dB in the case of the ASK modulation with an output power of 23 dBm at 917.1 MHz for wireless communication over a distance of 1–3 m. The 1-dB compression point is at 23.2 dBm with the ASK modulation.

Fig. 3 (a) shows the measured total current of the power amplifier and the transceiver. The total current is 253 mA at the transmitter output power of 23 dBm. The current of the power amplifier and the UHF transceiver are 151 mA and 102 mA at 917.1 MHz, respectively. With the supply voltage controlled with 3.6 V, the power added efficiency (PAE) of the power amplifier is 41.3% with the continuous wave signal (CW) and it represents low

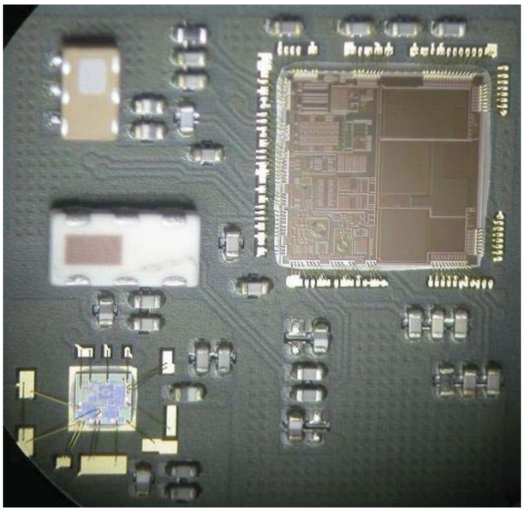

Fig. 2. The photograph of a fully integrated UHF RFID mobile reader using the system-in-package (SIP).

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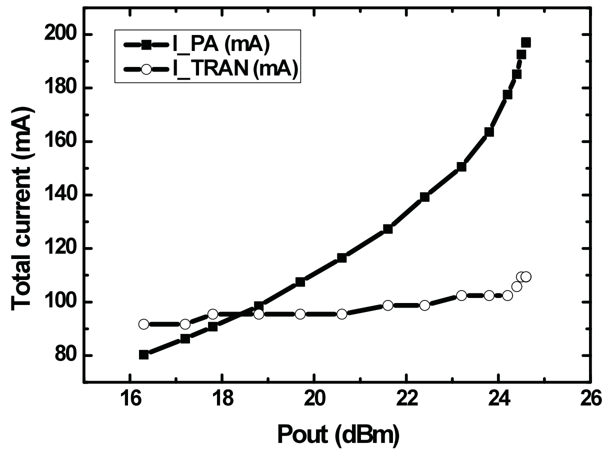
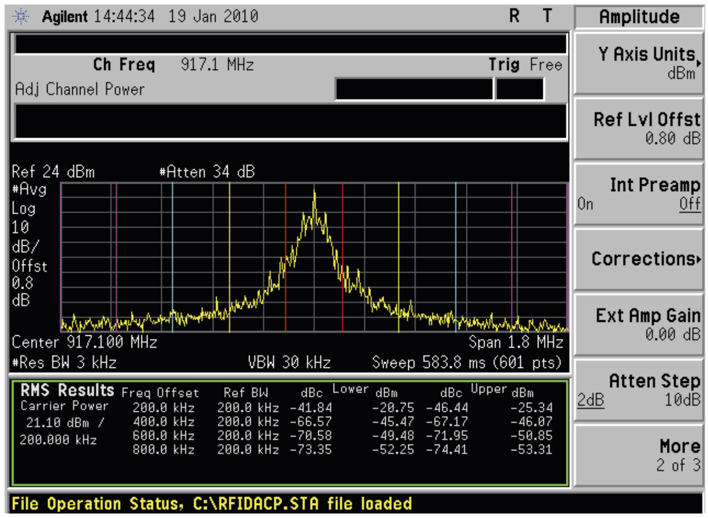
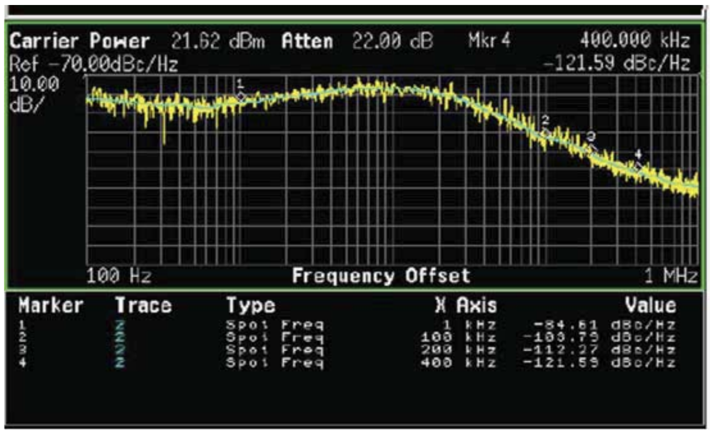


(a)



(b)



(c)

Fig. 3. Measurements for the power amplifier and the transceiver in the SiP UHF RFID mobile reader module, (a) total current, (b) output spectrum, and (c) Tx-Rx leakage (Tx power at RX port with offset frequency).

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consumption of the battery for the energizing working of the tags form the reader. Also, ACPR, ACLR and the second harmonics were measured with the ASK modulation and the CW signal, respectively. The offset frequency of the adjacent channel for ACPR is 200 kHz, and that of the alternate channel for ACLR is set to 400 kHz in UHF RFID systems. For an optimized output power of 23 dBm, the ACPR is −41.84 dBc and the ACLR is −66.57 dBc for the output power of 23 dBm at 917.1 MHz. The performances are sufficient to meet the specification requirements that state that the performance should be at least an ACPR of −20 dBc for multi-reader environments and an ACPR of −30 dBc for dense-reader environments as shown in Fig. 3 (b).

One of the most significant factors related to the UHF RFID reader is the high spurious signal at the second harmonic frequency because this signal may affect the other communication standards for cellular phones (1920–1980 MHz) as interferers. Therefore, the PA was designed with a focus on the optimized performance of the second harmonics by using 2^{nd} harmonic traps (series resonator at 2^{nd} harmonic frequency) at the collector of the amplifier and output matching network using bond wire. So the high performance for the second harmonic is required and measurement result for the second harmonic is −34 dBm with the output power of 23 dBm at 917.1 MHz.

One of the critical problems in the RFID mobile reader module is the TX–RX leakage on the single chip using SIP [3]. The measured phase noise from TX power at the RX port is −84.61 dBc with the offset frequency of 1 KHz and −108.8 dBc with that of 100 KHz at a TX output power of 23 dBm, where this leakage should be reduced by using the RF coupler with high isolation in SIP module and also TX output metal trace on the board is set to be away as much as it can from the RX path in order to prevent the LNA from being desensitized with a high leakage as in Fig. 3 (c).

4 Conclusions

A fully integrated UHF RFID mobile reader using SIP is presented in this paper. The compactly designed RFID reader module has a size of 11 mm × 11 mm using SIP technology. The 24-dBm linear PA was designed with the PAE of 41.3% for low current consumption. So the RFID reader has the total current of 253 mA which is 151 mA for the power amplifier and 102 mA for the transceiver for the case of wireless communication systems with a range of 1–3 m. Also, the performances of ACPR of −41.84 dBc, ACLR of −66.57 dBc and the second harmonic of −34 dBm for the output power of 23 dBm at 917.1 MHz meet the meet the standard RFID global specifications.

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