

SYSTEM DESIGN CONSIDERATIONS OF UNIVERSAL UHF RFID READER TRANSCEIVER ICS

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Abstract. *This paper describes the architecture, system analysis and implementation of world-wide regulation compliant UHF RFID reader transceiver for ISO 18000-6 multi-class tags in the ISM band 860 MHz-960 MHz. The presented considerations are based on a system analysis providing evaluation of the transceiver's building blocks parameters in accordance with the required characteristics of a complete RFID reader system, read range, data transmission rate, reading speed and power consumption. The Phase Noise, Noise Figure, Sensitivity, P1dB, Dynamic Range are estimated for the design of a custom 'system-in-package' transceiver, implemented in LTCC-module. Based on the direct-conversion architecture, the reader transceiver integrates RF-blocks, frequency synthesizer, modulation and demodulation functions, low frequency analog baseband. The receiver sensitivity is down to -85 dBm, the transmitter produces output power of +17 dBm.*

Key words: RFID, UHF, LTCC, 'system-in-package', SiGe BiCMOS

1. INTRODUCTION

Radio-Frequency Identification (RFID) UHF band supporting the EPC global Class 1 Generation 2 and ISO 18000-6A/B/C standards have become indispensable in today's distribution industries, purchasing, manufacturing, energy and healthcare services [1]. A UHF RFID system consists of reader(s), tags, and host computer.

A UHF reader is a system with an integrated transceiver module as a core. As shown in Fig.1, RFID reader transceiver consists of a UHF receiver and transmitter front-ends, frequency synthesizer, low frequency analog baseband, analog-to-digital (ADC) and digital-to-analog (DAC) converters, and digital baseband for data processing and control [2], [3]. The UHF front-end of a RFID reader transceiver contains a low noise amplifier (LNA), power amplifier (PA) (required for improving sensitivity of receiver path and output power level in forward link), quadrature RF modulator and demodulator. The low frequency analog baseband of a RFID reader transceiver contains an active bandpass

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filters (BPF) with variable bandwidth, and variable gain amplifiers (VGA). The BPF is required for rejection of noisy signals from DAC and ADC and digital baseband parts.

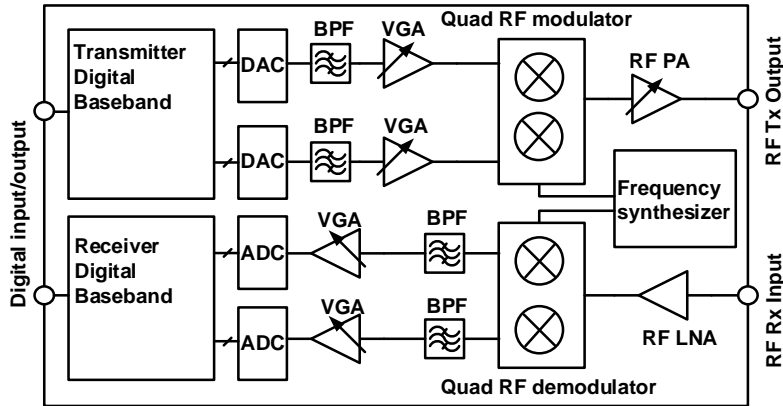


Fig. 1 RFID reader transceiver block diagram

This paper describes issues associated with the system design of UHF RFID reader ICs [4]. The proposed considerations are based on the evaluation of the RF transceiver's building blocks parameters in conjunction with the required characteristics of a complete RFID reader system, i.e. read range, data transmission rate, reading speed, power consumption, etc. The Phase Noise, Noise Figure, Sensitivity, P1dB, Dynamic Range are estimated for the design of a custom 'system-in-package' direct-conversion RFID transceiver that produces output power up to +17dBm and input linearity up to +6 dBm in the ISM band between 860 MHz - 960 MHz and provides a read range more than 1 m without using an external PA.

2. SYSTEM ANALYSIS

2.1. Read range

Typical parameters [1] of a UHF RFID system described in this work are presented in Table 1.

Passive tags have no independent source of electrical power and are widely used in UHF RFID systems because of their cost. The RF carrier signal transmitted by a reader is required for the passive tag to be activated.

Table 1 UHF RFID System's Parameters

Reader	Tag	Air interface
$P_{TX}=30$ dBm	$P_{TAGMIN}=-15$ dBm	F=865 MHz
$G_{TX}=3$ dBi	$G_{TAG}=-5$ dBi	M = 0,25 (ASK)
$G_{RX}=3$ dBi		M[dB]=20log(0,25)

Minimal RF power level required for the tag activation (sensitivity) is -15-20 dBm for typical UHF RFID systems [2]. Power level at the tag input P_{TAG} and reader receiver input P_{RX} can be calculated using the following equations [3], [4]:

$$P_{TAG}[\text{dBm}] = P_{TX} + G_{TX} + G_{TAG} - LOSS, \quad (1)$$

$$P_{RX}[\text{dBm}] = P_{TX} + 2G_{TX} + 2G_{TAG} - 2LOSS + M, \quad (2)$$

$$LOSS[\text{dB}] = 20 \log\left(\frac{4\pi l}{\lambda}\right), \quad (3)$$

where P_{TX} is power level at transmitter output in dBm; G_{TX} and G_{TAG} are gains of reader and tag antennas correspondingly in dBi; $LOSS$ is loss in the air interface between reader and tag in dB; M is modulation depth of tag backscattering signal in dB; l is the distance between reader and tag (read range) in meters; λ is wavelength of carrier signal in meters.

Dependencies of P_{TAG} and P_{RX} versus distance between reader and tag for typical UHF RFID systems simulated by Eq. (1)-(3), are shown in Fig.2.

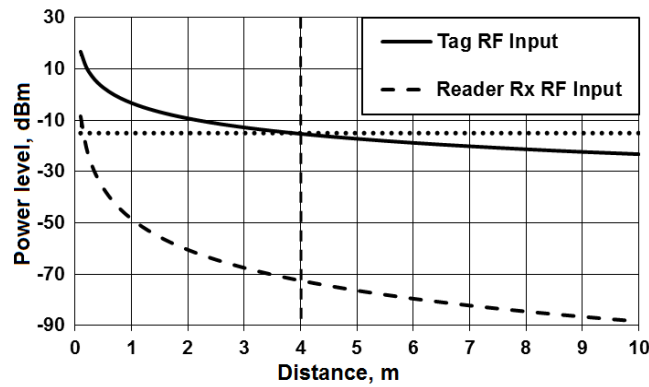


Fig. 2 Power level vs. distance for typical UHF RFID system

According to Fig.2, for a RFID system with $P_{TAG} = -15$ dBm, $l = 4$ m, power level at receiver input should be more than -73 dBm. The semi-active tags (with high sensitivity) or high output power PA should be used to improve the read range. In the last case it may lead to a reader receiver blocking.

2.2. Receiver noise figure

In accordance with EPC global C1 G2 standard [1] RFID reader needs to support Listen Before Talk (LBT) and Talk modes. This means that before a reader can transmit at a given channel, it should make sure the channel is free. Only the reader receiver is active in LBT-mode. In Talk-mode the receiver and transmitter operate in duplex. The amplitude-shift-keying (ASK) is a basic type of modulation for forward (reader-tag) and reverse (tag-reader) link.

To receive the messages reliably a bit error rate (BER) in UHF RFID systems should be less than 10^{-5} [3], which corresponds to the signal-to-noise ratio (SNR) of 12 dB (for ASK).

The UHF reader receiver noise figure (NF_{RX}) can be calculated using the equation [3]:

$$NF_{RX}[\text{dB}] = P_s + 174 - 10\log(BW_N) - SNR, \quad (4)$$

where P_s is the reader receiver sensitivity in dBm, BW_N is receiver bandwidth in Hz. In Talk-mode P_s is equal to -73 dBm and BW_N is 1.28 MHz (for maximum bit-rate of 640 kbit/s) and value of NF_{RX} should be less than 28 dB.

In LBT-mode BW_N is 200 kHz, P_s should be -100 dBm and less and NF_{RX} in accordance with Eq. (4) should be less than 9 dB.

2.3. Receiver input linearity

An example of a multiple reader environment is illustrated in Fig. 3.

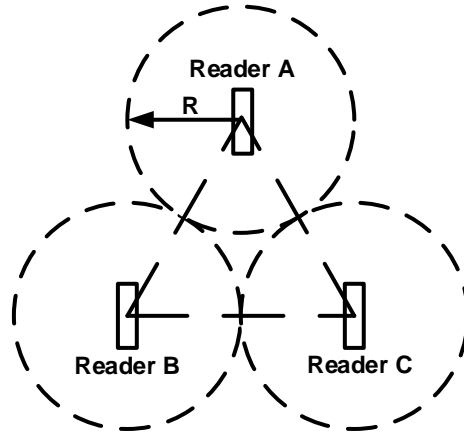


Fig. 3 Interference in multiple reader environment

In the case when readers A and B are operating in Talk-mode reader C is operating in LBT-mode, 1 dB input compression point of receiver $P_{.1dB}$ can be calculated by the following equation [3]:

$$P_{.1dB_LBT}[\text{dBm}] = P_{TX_A} + G_{TX_A} + G_{RX_C} - LOSS_{A-C}, \quad (5)$$

$$LOSS_{A-C}[\text{dB}] = 20\log\left(\frac{4\pi(2R)}{\lambda}\right). \quad (6)$$

In typical RFID system (see Table 1) with the distance between readers $2R = 4$ m $P_{.1dB}$ should be more than -13.3 dBm.

In mono-static configuration a single antenna can be used for both transmission and reception. In bi-static configuration two different antennas are used for transmission and reception. The main disadvantage of the mono-static configuration is insufficient isolation between receiver and transmitter. Typical isolation value is less than 20 - 25 dB. Meanwhile, a mono-static configuration is a good choice for mobile reader with integrated antenna. Typical isolation value between receiver and transmitter for bi-static configuration is 30 - 40 dB.

Examples of mono-static and bi-static reader configurations are shown in Fig.4.

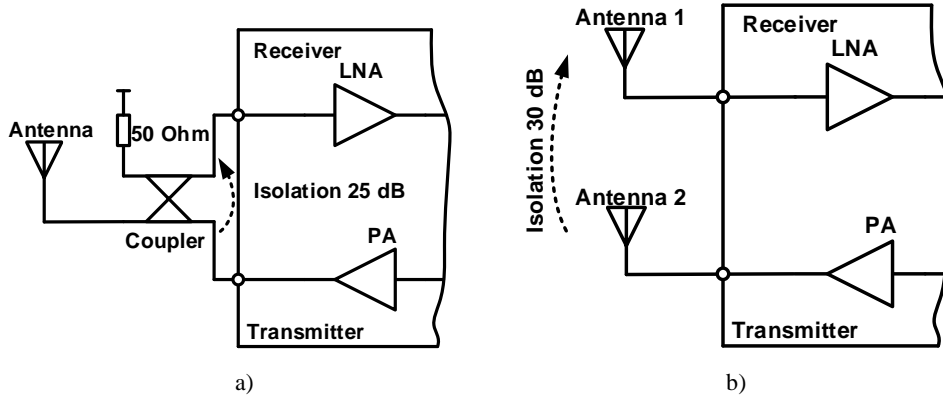


Fig. 4 Reader configurations: (a) mono-static (b) and bi-static

In Talk-mode P_{-1dB} is determined by self-jammer signal in the receiver input as a part of transmitter power P_{TX} and can be calculated by the following equation:

$$P_{-1dB_Talk} [dBm] = P_{TX} - ISO, \tag{7}$$

where ISO is isolation between the reader's transmitter and receiver.

In accordance with Eq. (7) P_{-1dB} for a RFID system (see Table 1) in mono-static (ISO is less than 25 dB) and bi-static configurations (ISO is more than 30 dB) should be more than 5 dBm and 0 dBm, respectively.

2.4. Phase noise

In Talk-mode the main problem is a weak tag signal ($F_{LO}+F_{BLF}$) detection (typical power level is less than -60 dBm) which is limited by a carrier signal from the transmitter output (F_{LO}) and signals from adjacent readers (F_{AC}). The simplified signal spectrum diagrams at receiver RF input and low frequency output are shown in Fig. 5a and Fig. 5b respectively. For these reasons, special requirements to the phase noise level should be determined.

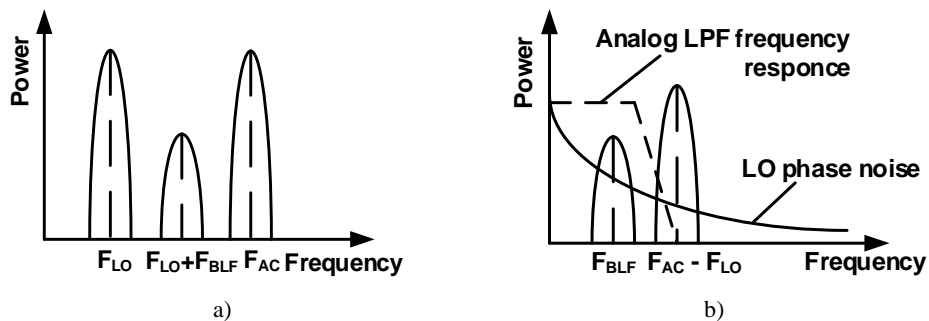


Fig. 5 (a) Signal spectrum diagrams at receiver RF input and (b) receiver low frequency output

Providing that the conversion and proper processing of weak tag information signal is available, the phase noise level can be calculated using the following equation [5, 6]:

$$PN @ BW_N[\text{dBc/Hz}] = P_s + ACRR - SNR - 10\log(BW_N), \quad (8)$$

where BW_N is bandwidth in Hz, $ACRR$ – adjacent channel rejection ratio in dB.

The transceiver's key parameters estimated in accordance with equation (8) are summarized below:

- sensitivity in Talk-mode, determined by Eq.(1) – (3), equals -73 dBm;
- signal to noise ratio (SNR) is 12 dB, which corresponds BER of 10^{-5} (for ASK);
- typical value of ACRR [1] is 40 dB;
- the maximum available phase noise level should be less than -95 dBc/Hz at 100 kHz.

3. TRANSCEIVER IMPLEMENTATION

To verify the proposed system approach to transmitter design a test UHF RFID reader transceiver, shown in Fig.6a, was implemented as 'system-in-package' in low temperature co-fired (LTCC)-module. The simplified cross-section of the LTCC-module which consists of seven layers is shown in Fig.6b.

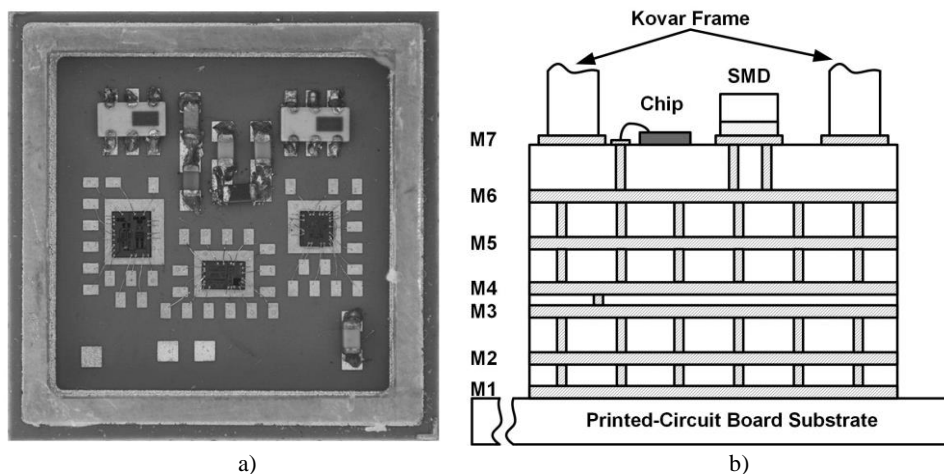


Fig. 6 UHF RFID reader transceiver module: (a) top-view (20×20 mm²) and (b) cross-section

The transceiver LTCC-module (20 mm × 20 mm × 4 mm) with appropriate thermal properties and RF grounding, integrates the RF-receiver, transmitter and frequency synthesizer dies were fabricated on a 0.25 μm SiGe BiCMOS process. DuPont 951 GreenTape ($\epsilon_r=7.8@3\text{GHz}$, $\text{tg}\delta\leq 0.006@3\text{GHz}$) was used as substrate materials with 10...15 μm thick argentineum conductors as low loss interconnection and microstrip lines.

A minimal via diameter of 100 μm is available within the LTCC-process that makes this technology suitable for realizing packages with ground plane inductance low enough [7]. The metal layers coming from top to bottom are as follows: top metal layer

(M7) is for SMD-component, chip and kovar frame mounting, two microstrip lines interconnect layers (M6-M5), two layers (M4-M3) are for passive elements (RF capacitors, inductors, baluns, etc.) [7-10], layer M2 and M1 are for shield ground planes. The bottom shield ground plane layer is used for mounting LTCC-module on a printed-circuit board (PCB) by conventional soldering technique.

4. SIMULATION AND EXPERIMENTAL RESULTS

The transceiver performance (Dynamic Range, Noise Figure, Sensitivity, P1dB, Phase Noise, etc.) was simulated based on the proposed system design considerations in conjunction with the required characteristics of a complete RFID reader system, i.e. read range, data transmission rate, reading speed, power consumption, etc.

Measurements were performed using a special PCB test-fixture and specialized microwave test system (MwTS), based on Cascade Summit 12000B microwave probe station, Agilent N5230A vector network analyzer, N9020A signal analyzer [10, 11], shown in Fig.7. MwTS is successfully used with complex radiation test facilities for experimental studies and theoretical analysis of radiation effects in wide range complex multifunctional Very-Large-Scale mixed and digital ICs [12-14].



Fig.7 Specialized microwave test system

Simulated and measured receiver conversion loss in Talk-Mode is in good agreement, as shown in Fig. 8. Measured frequency synthesizer carrier phase noise response is shown in Fig. 9. Simulated and measured transmitter output power characteristics in Talk-Mode are shown in Fig.10. Measured transmitter output spectrum for single-sideband modulation and carrier frequency of 865MHz, IF bandwidth of 1 MHz is shown in Fig. 11. The obtained RF output power is more than +17 dBm for a frequency range 860 to 960 MHz.

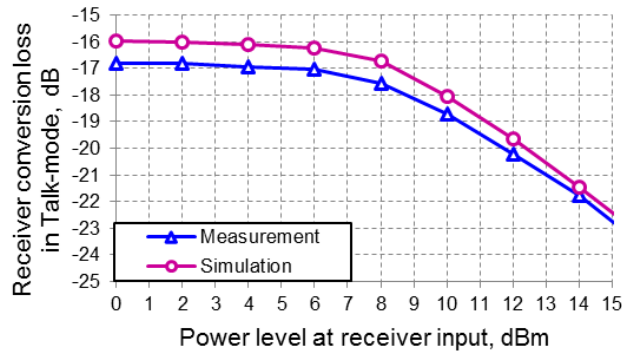


Fig. 8 Simulated and measured receiver conversion loss in Talk-Mode

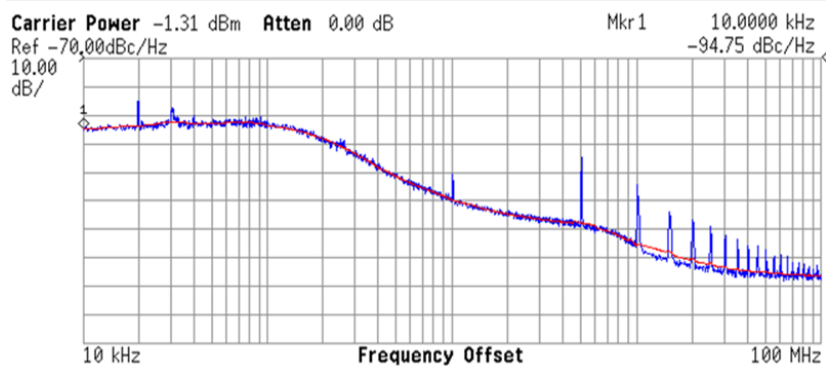


Fig. 9 Measured frequency synthesizer carrier phase noise

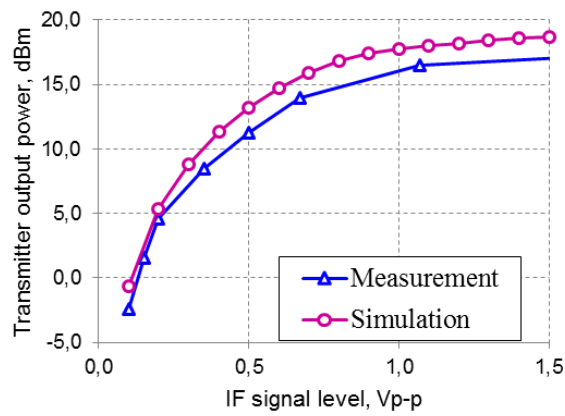


Fig. 10 Transmitter output power characteristics

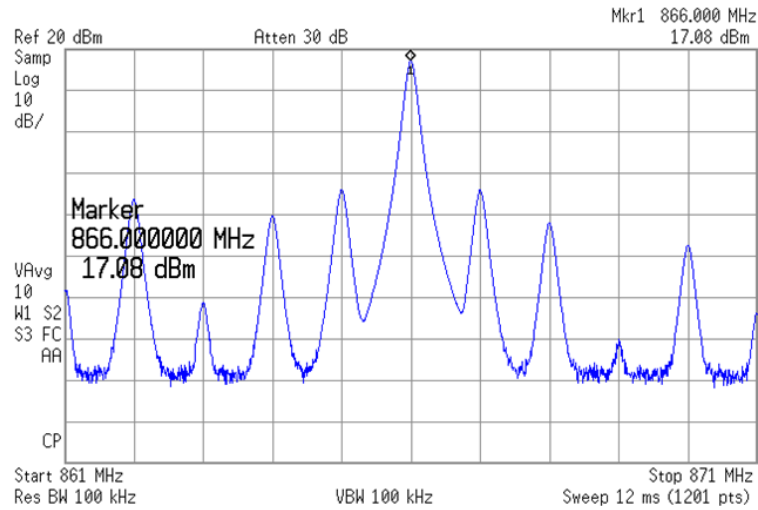


Fig. 11 Measured transmitter output spectrum

Simulated and measured parameters of the UHF RFID reader transceiver presented in this paper are summarized in Table 2 and compared with other published work.

The measured parameters of the UHF transceiver are in good agreement with the modeling results and fulfill the RFID system requirements. Some illegible difference between measured and simulated receiver conversion loss and transmitter output power are probably caused by insertion loss in test PCB microstrip lines.

Table 2 UHF RFID System's Parameters

Parameter	This work		[3]
	RFID system requirements	Measurements	
Frequency, MHz	860...960	860...960	835...930
Technology process	–	SiGe BiCMOS 0.25 μm	CMOS 0.18 μm
Package	–	LTCC, 44 leads, 20 \times 20 mm^2	LQFP64A 10 \times 10 mm^2 (die area is 4 \times 4 mm^2)
P_{-1dB} , dBm	≥ 0 (Talk) ≥ -13 (LBT)	+6 -23	-3 –
NF_{RX} , dB	≤ 28 (Talk) ≤ 9 (LBT)	27 9	35 –
PN , dBc/Hz @ 100kHz	≤ -95	-95	-90
P_{TX} , dBm	–	≥ 17	10
Power supply, V	–	+5	+3.3
Power consumption, W	–	1.1	0.4
Estimated read range, m	≥ 0.5	0.9	0.4

4. CONCLUSION

Architecture, system analysis and implementation of world-wide regulation compliant UHF RFID reader transceiver for ISO 18000-6 multi-class tags in the ISM band 860 MHz - 960 MHz have been presented. The described system design considerations have been verified in the design process of the reader transceiver that integrates a UHF receiver, transmitter and frequency synthesizer, and covers the entire 860 MHz to 960 MHz frequency range. The reader transceiver parameters (input linearity, noise figure, phase noise, output power) have been optimized following the proposed approach provided the required characteristics of complete RFID reader system (read range, reading speed, multiply reader environment-mode, etc.). Fabricated on a 0.25 μm SiGe BiCMOS process, the transceiver was implemented as 'system-in-package' in LTCC-module and measured. Simulated and measured parameters of the UHF RFID reader transceiver are in good agreement and fulfill the RFID system requirements.

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