Hardware and Software Stack for an SDR-based RFID Test Platform

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***Abstract*—This paper describes a software defined radio system for measurements of minimum activation power and backscatter power of UHF RFID tags. We propose a platform for performance testing of tags, which is based on a general purpose universal software radio peripheral (USRP) and optimized for operation in the frequency band from 700 MHz to 1100 MHz at the output power of 2 W ERP. The presented HW and SW stack extends the standard library of USRP with RFID specific functions, an interface to LabVIEW, and by a top level LabVIEW code for automated testing.**

Keywords-RFID; WBX; USRP; LabVIEW

I. Introduction

Up to now, commercially available systems for performance tests are either based on high-end, and thus expensive, vector signal analyzers and generators, on proprietary solutions, or on standard readers with low measurement accuracy [2], [3]. The platform described in the paper is based on a general purpose universal software radio peripheral (USRP) by Ettus Research with top level code created in the LabVIEW environment.

A prototype of a USRP RFID reader is presented in [1], focusing on developing partial reader functionality. In this work, a prototype system was created to address the need for an RFID tag development tool, which allows to quickly measure a UHF RFID tag communication range with high reliability and low cost. Such a system can be utilized by designers of RFID tag antennas, research teams and end users to precisely characterize tag performance. In order to fulfill the requirements on the compactness of the target system, flexibility and configurability at the same time, a commercially available general-purpose modular software-defined radio platform was selected as the core module.

The LabVIEW GUI for RFID tags measurement is a software module which covers advanced algorithms for RFID tag performance measurements using universal software defined radio (SDR) hardware produced by Ettus Research, known as USRP. By considering the specifics of the RFID communication, the software optimizes the use of hardware resources in order to minimize measurement time and to maximize the level of automation. The GUI provides the user with an easy-to-use way to define stimuli, perform tests, supervise results, and control the underlying hardware.

The software performs frequency sweeps in the frequency band from 700 MHz to 1.1 GHz, with the goal to evaluate specific effects of RFID performance, such as detuning. Therefore the band supported by the proposed SDR platform is four times broader than the band specified according to [7] (860 MHz to 960 MHz), which is partly used for UHF RFID worldwide.

II. Hardware

To provide high measurement accuracy, the core module was further extended by developed hardware modules, which have been tailored to UHF RFID tests, maintaining the original concept of the system modularity, and making the final system a complete solution. The prototype covers a design of modified RFID antennas to meet the requirements for system performance in a bistatic setup.

A. Core SDR Platform

A commercially available SDR designed and manufactured by Ettus Research (USRP N200 with WBX daughterboard) had been selected for this project [4]. The most important features are:

- dual 16 bit DAC at 400 MSPS, dual 14 bit ADC at 100 MSPS, TCXO reference,
- Gigabit LAN for control connection and data streaming between USRP and PC,
- frequency synthesis range from 50 MHz to 2.2 GHz, full I/Q modulator and demodulator,
- ready-made FPGA code and drivers for most of the RX/TX operations,
- low cost compared to industrial RFID test systems.

There are two independent synthesizers for RX and TX on the WBX board. These synthesizers are locked to common reference frequency, so the synthesized outputs are coherent. On the other hand, there is an unknown phase shift of $n \cdot \pi/2$ between RX and TX. Moreover, the phase noise of synthesized signals is not correlated [9]. This appeared to be a critical problem for signal demodulation. To overcome the issues, it was necessary to use only one synthesizer for both RX and TX. As a result, the TX synthesizer was disabled in the software and its signal was rewired to the auxiliary output of the RX synthesizer.

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B. Custom Design of the RFID GDB

The required output power of the developed measurement system is 30 dBm in the frequency range from 800 MHz to 1 GHz. The power amplifier on the WBX board is able to deliver only about 20 dBm.

A new RFID grand-daughterboard (GDB) was designed. This GDB includes a power amplifier, a directional coupler and a precise power detector. It is supported by a power supply IC and an EEPROM for GDB identification by USRP. The designed target frequency range is 800-1000 MHz with at least 32 dBm output power and 700-1100 MHz with lower performance.

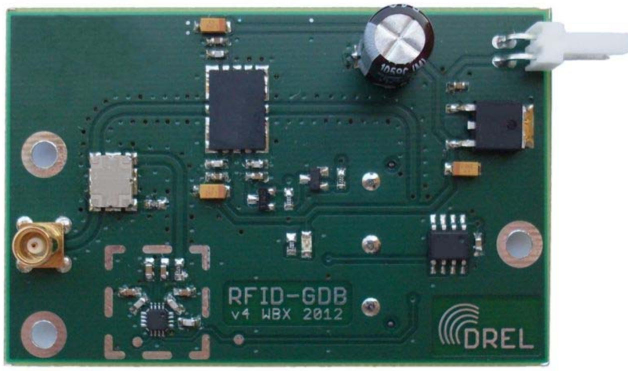

Figure 1. The RFID GDB prototype

A critical issue in performance tests is the achievable accuracy. Commercial readers and general-purpose devices suffer from temperature dependent instability and absolute level uncertainty of the transmit power. Therefore, several designs of the RFID GDB with different components had been tested before the requirement of 0.5 dB measurement precision defined by the performance test standard [10] was met.

C. Antennas

A bistatic antenna setup using two spatially separated antennas with circular polarization was chosen to achieve high isolation between the RX and TX path. The configuration of the antennas and RFID tag during testing in an anechoic chamber is shown in Figure 2.

Both of these antennas have an opposite direction of circular polarization – the RX antenna is right-hand circularly polarized (RHCP), while the TX is left handed (LHCP). This configuration is used for two crucial reasons. Firstly, the isolation between the RX and TX path is higher compared to the setup with linearly polarized antennas. Secondly, special tags with dual-dipole (polarization-diverse) antennas change the direction of circular polarization from RHCP to LHCP and vice versa [6]. Such tags should not be used with circularly polarized monostatic antennas, as well as two bistatic antennas with the same direction of circular polarization.

Figure 2. Measurement setup in an RF chamber

III. Software

The software part of this system can be divided into four layers, as shown in Figure 3. The lowest two layers are provided by Ettus Research and have been updated only for use in the described system.

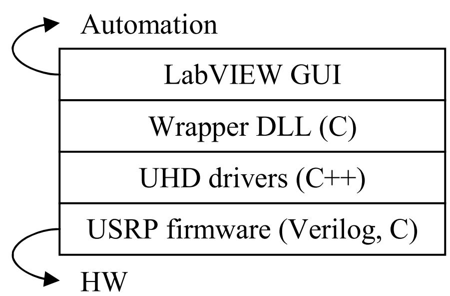

Figure 3. Software layers

Several patches and updates in the universal hardware driver (UHD) were done in order to support the new RFID GDB. The changes were implemented in the UHD host code (main DLL in Windows) and in the soft CPU implemented in USRP FPGA (commonly called ZPU). The FPGA code itself was not altered.

A. USRP Firmware and UHD Drivers Soft Core to increase TX Level Accuracy

RFID tag measurements are done in bursts. To increase accuracy of the result compared to the standard WBX configuration in UHD a new concept of the SDR soft core for the transmitter was implemented. A feedback loop was implemented to measure the power of the transmitted signal. This measurement occurs at a precisely defined time during the transmission. The power is measured with the USRP auxiliary RX ADC, which could not be synchronized in the original UHD driver.

The timed auxiliary ADC conversion was implemented in both ZPU and UHD. Communication is done via unused ZPU firmware registers. When the FPGA clock reaches the target time, several samples are read from ADC, averaged and made available to UHD.

To support communication between the SDR core HW platform and the RFID GDB, an identification of the GDB through the UHD was implemented. During the transmission, the corresponding driver is called. It registers all necessary parameters of the GDB, such as frequency range and available antenna connectors.

B. SDR Library

The purpose of the wrapper DLL is to provide an interface between the C++ based UHD drivers and the high-level SW written in LabVIEW. The driver library covers three main functions.

The signal generator module is responsible for the generation of basic ISO18000-6C RFID protocol signals [7]. It provides 90% ASK and PR-ASK modulations. Tari values of 25 µs, 12.5 µs and 6.25 µs are supported. The actual Tari value error depends on TX resampling capabilities of USRP. Each transmit burst consists of 0.2 ms silence, signal ramp-up, 1.5 ms of CW, optional Select command, Query command, CW signal of adjustable length, signal ramp-down, and several silent samples. The receiving window is defined over the CW part of the signal following the Query command.

The transceiver subsystem module is responsible for data transmission from and to the USRP. It implements the UHD call for frequency tuning, calls for adjusting TX power and RX gain, and disables slow DC offset correction in FPGA. The main part is devoted to the transmission of the burst and the reception of the tag reply. All operations are precisely synchronized. Modulation is scheduled typ. 10–20 ms after the beginning of the frame, power detector measurement takes place 1 ms after transmission start, reception is scheduled according to the receive signal window. Once the burst transmission is finished, this function checks all results for errors, computes the real power levels in dBm from the sampled ADC value, and returns the captured I/Q data.

The main code module exports the DLL functions for LabVIEW. Callings of DLL functions are logged into the log file, which can be analyzed for debugging purposes.

C. Software for Measurement Automation

The top-level software of the presented SDR platform was implemented in a high-level programming language LabVIEW to provide two main functions – to control the HW and to automate the measurement and display the progress and resulting values to the user. The graphical user interface (GUI) of this application is shown in Figure 4.

The automated process contains hardware initialization and cleanup, control of frequency and power sweeping in required steps, and the minimum tag power measurement. This power is further recalculated according to the distances between the antennas and the tag. The received signal power is evaluated from tag responses at the current power step.

A power spectrum of the received signal is computed, the DC component is removed, and backscatter modulated response is separated. The power of this response has to be higher than a user-defined value above ambient noise.

There are two ways how to sweep the tag power at current frequency. The first approach is based on a gradual reduction of radio output power, followed by testing of tag answer presence. If the tag is not detected, the searching is stopped and the power level from the last step is saved as the measured value. This way of traditional power sweeping is rather slow because a significant amount of test points has to be executed.

The second way of the tag turn-on power measurement uses the bisection method, i.e. binary search algorithm. It repeatedly bisects the interval of the minimum and maximum power level, between which the tag turn-on threshold is expected. The convergence to the result is significantly faster than in the case of the linear sweep. This method requires precise setting of the transmit power. However, an absolute power level setting, which would satisfy the requirement of 0.1 dB resolution, is typically not available on general purpose SDR devices. Furthermore, the output power depends on several factors, such as frequency, antenna SWR, temperature, and cable losses. Therefore, the utilized SDR HW was extended by additional HW components, which enable precise detection of the true transmitted power, and allow the setting of the output power with 0.1 dB resolution using a feedback-loop algorithm. A coarse attenuator (1 dB step) and fine setting by multiplication of transmission I/Q data were used to achieve this goal.

The following parameters can be adjusted in the application user interface:

- minimum and maximum measurement frequency (limited to 700 MHz – 1.1 GHz range),
- maximum output power (limited to 32 dBm),
- minimum frequency step and power step (100 kHz and 0.1 dB, respectively),
- parameters of Query command according to ISO18000-6C standard; several choices of parameters (Tari, RTcal, TRcal, DR, Miller coding, TRext) for common backscatter link frequency (BLF; 40 – 640 kHz) are prepared,
- parameters of optional Select command (mask length and bit values).

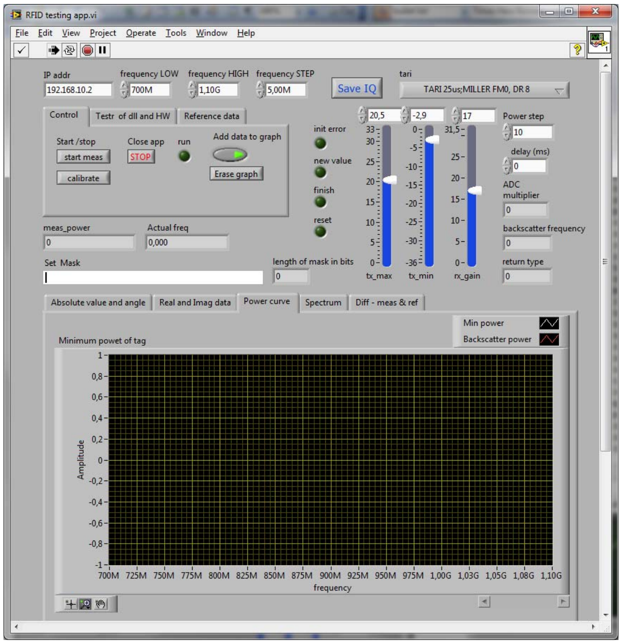

Figure 4. Testing application – GUI

IV. Measured Data of Reference Tags

A test of this system was performed in an RF anechoic chamber with the following parameters:

- frequency range 800 MHz – 1 GHz with 5 MHz step,
- maximum output power 32 dBm,
- both bisecting and linear algorithms for power sweeps with minimum step size 0.1 dB,
- Tari = 12.5 µs, Miller 4, BLF = 320 kHz.

A typical tag response is displayed in Figure 5.

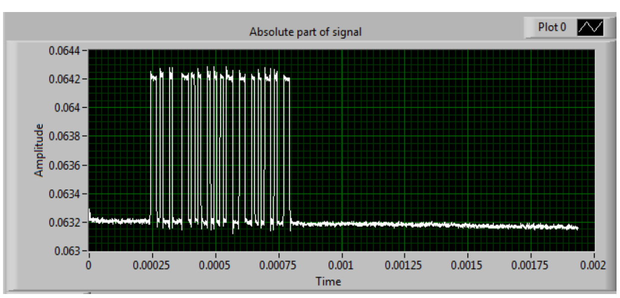

Figure 5. Magnitude of the tag answer to the Query command (Tari = 25 µs, FM0, DR = 8, BLF = 40 kHz)

The measured tag performance values and reference data are shown in Figure 6 and Figure 7. Each tag is characterized by two curves. One of them shows results using a commercially available high-end RFID test system [8]. The other curve shows results using the developed SDR-based test platform. The achieved precision of the tag turn-on power measurement and backscatter power measurement is 0.5 dB and 1 dB, respectively.

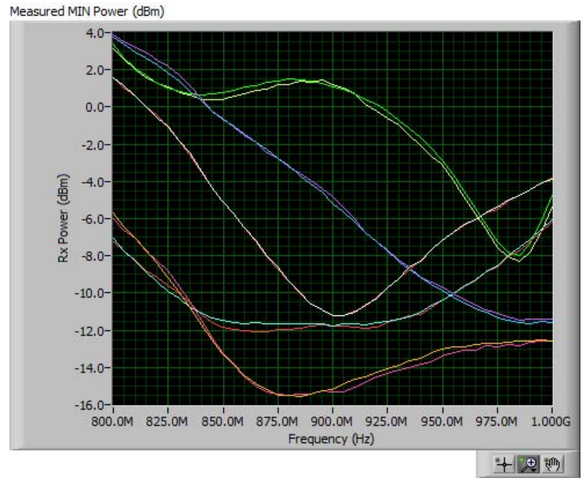

Figure 6. Minimum power measurement of reference tags

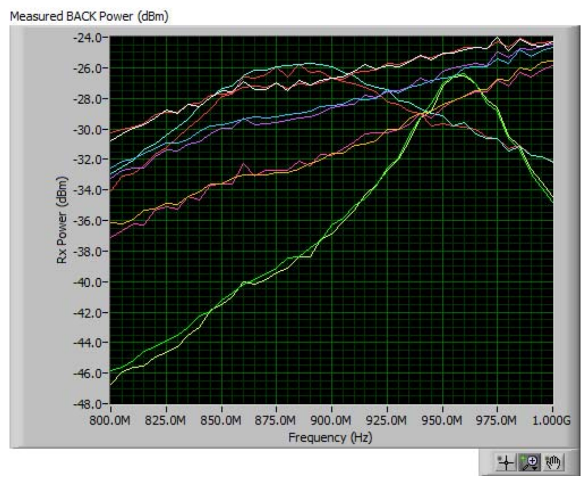

Figure 7. Backscatter power measurements of reference tags

V. Conclusion

This article presents a way of using a general-purpose software defined radio as an RFID test system. An overview of the developed SW architecture and of necessary RFID-specific hardware modules has been provided. The measurement results are comparable with commercial devices. The achieved accuracy of the tag turn-on power measurement is 0.5 dB. The accuracy of backscatter power of the RFID tag is 1 dB. The measurement time of each test step is approximately 60–70 ms while using a typical PC (Intel Core 2 CPU running at 2.66 GHz, 2 GB RAM, Win7 32 bit).

The developed system is suitable for measurements of passive and semi-passive RFID tags by antenna designers, test labs, and academia. It is also possible to use the system for pre-certification testing.

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