Active Carrier Compensation for a Multi-Antenna RFID Reader Frontend

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***Abstract*— In this paper we present our multi-antenna radio frequency identification (RFID) research and development environment. We show measurement results for an ultra high frequency multi-antenna (one transmitter × two receivers) RFID reader setup using active carrier compensation at the receivers. Moreover, we evaluate the signal to self interference ratio (SSIR) and compare these results with a reference measurement performed without active carrier suppression. By adjusting the active carrier compensation circuits at one single transponder position an SSIR improvement of 73 dB at the tuning position is achieved. For other tag positions, without changing the adjustment, a minimum SSIR gain of 23 dB is observed.**

***Index Terms*— cross talk, multi-antenna, reader, RFID, signal-to-interference, frontend**

I. INTRODUCTION

In passive and semi-passive radio frequency identification (RFID) systems the required energy transfer from the reader to the tag in combination with the used backscatter modulation technique leads to a very strong cross talk from the transmitter to the receiver of an RFID reader. Tag response signals are superposed and interfered at the reader with this strong cross talking carrier signal which is required to be sent by the reader during the entire communication process. Furthermore, this interference increases the receiver's linearity requirements of the reader. The superposition of interference and desired signal leads to signal to self interference ratios (SSIR) of -50 dB and worse [1].

In fact the effective SSIR depends on the transmit power of the reader, the antenna configuration at the reader, the backscatter performance of the tag, and the distance between reader and tag. The inherent cross talk at an RFID reader can be decreased substantially using carrier compensation techniques or transmitter–receiver isolation techniques. We distinguish between passive and active techniques. Passive techniques utilize circulators or directional couplers to separate transmit and receive paths in reader designs where one single antenna is used. In scenarios where separate transmit and receive antennas are used, different circularly polarized transmit and receive antennas can be used or the positions of the antennas can be optimized for increased isolation [2], [3].

Active compensation techniques are using a sample of the current transmit signal and add it, after amplitude and phase adjustments, via a directional coupler into the receiver [4]- [6]. This technique can be used in both kinds of reader antenna configurations and can be combined with the passive ones.

We focus on the latter technique and establish it into our ultra high frequency (UHF) multi-antenna RFID research and development environment. We have implemented this environment to enable experimental research on multi-antenna RFID. The introduction of multi-antenna techniques in RFID systems offers new fields of applications and allows further improvement of current RFID systems. In general, multiple antennas can be used either at the tag [7] or at the reader [8], [9] or on both sides of the communication link. We concentrate on multiple antennas at the reader and use a commercially available single-antenna UHF tag.

The rest of the paper is organized as follows: In Section II we describe our multi-antenna RFID reader research and development system we have used to carry out our measurements. In Section III we explain the measurement setup and discuss our measurement results. Finally, in Section IV we conclude our paper.

II. DESCRIPTION OF THE MULTI-ANTENNA RFID RESEARCH AND DEVELOPMENT SYSTEM

To investigate multi-antenna techniques in RFID in the UHF band we have implemented a 2×2 (two transmitters × two receivers) RFID reader environment. Fig. 1 shows a simplified overview. The system is set up in a modular approach and

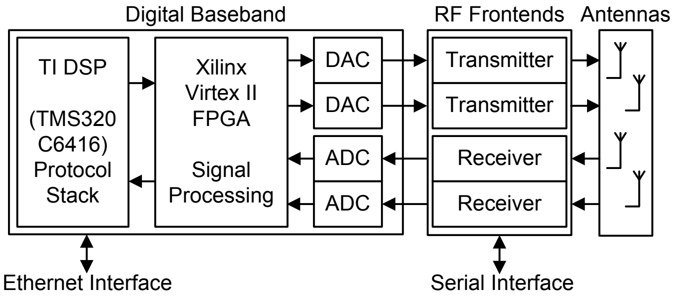

Fig. 1. Research and development RFID reader environment.

The financial support by the Federal Ministry of Economy, Family and Youth and the National Foundation for Research, Technology and Development is gratefully acknowledged.

can be divided into three main building blocks: the digital baseband, the analog frontend, and the antennas.

- As digital baseband we use a rapid prototyping board (SmartSim) [10]. It consists mainly of digitally reconfigurable parts like digital signal processors (DSPs), field programable gate arrays (FPGAs), microprocessors, and memories. Additionally, it supports two 16 bit digital-to-analog converters (DACs) and two 14 bit analog-to-digital converters (ADCs).
- We have designed the RF frontends in a modular approach. Transmitters and receivers are independent devices and support the European UHF frequency band from 865 MHz to 868 MHz. Moreover, they are based on a double heterodyne linear transponder concept. Variable attenuators and variable amplifiers offer a gain adjustment range of around 55 dB at the transmitters as well as at the receivers. Additionally, we have designed carrier compensation units (CCUs) based on vector modulators to increase the SSIR at the receivers [11], [12].
- The overall system concept with independent RF frontend modules allows for different antenna configurations which strongly influence the reader cross talk property. In contrast to a reader with integrated circulator or directional coupler this also allows to use different antennas at the transmitters and the receivers.

III. EXPERIMENTAL SETUP AND RESULTS

In this section we describe firstly the basic 1×2 measurement setup which is divided into the baseband and RF frontend setup on the one hand and into the antennas–tag configuration on the other hand. Furthermore, we describe and discuss our measurement results on SSIR and SNR. The measurements were carried out in a static environment at different tag positions.

A. *Measurement setup*

For our measurements we placed our baseband and frontend hardware as well as our antennas and the tag in separate rooms. Fig. 2 shows the setup of the digital baseband and the RF frontends. The digital baseband is configured with one transmitter (DTX) which periodically generates the following sequence: a time period of a continues wave carrier to power the tag, a QUERY command to start a communication round with the tag, followed again by a time period of pure carrier signal in which the tag should answer with its random number, and finally an idle time period to reset the tag. Via the DAC the baseband hardware is interfaced at 13.33 MHz with the RF transmitter TX. The chosen backscatter link frequency is 640 kHz for all measurements. At the receiver side the baseband hardware is interfaced to the two receivers RX1 and RX2 via ADC1 and ADC2 respectively, again at 13.33 MHz. The ADC samples are directly transferred to a measurement PC and processed off-line in Matlab.

The UHF frontend is also configured with one transmitter and two receivers and with two carrier compensation units. The transmitter is set to an output frequency of 866 MHz and a transmit output power of 30 dBm. The output power is measured directly after the output port of the transmitter with a power meter. Finally, the output is connected to the transmit antenna TXA1. The resulting equivalent radiated power (ERP) concerning cable losses and antenna gain is 33 dBm ERP. Using a directional coupler directly before the transmitter output (at 30 dBm power level) a sample of the transmit signal is extracted which is used for the carrier compensation units. Furthermore, two receivers, RX1 and RX2 are connected to the two receive antennas, RXA1 and RXA2. Before the first active components in the receivers the carrier compensation signals are added via directional couplers into the receive paths. The gain of the receivers is adjusted so that measurements with and without CCUs are possible without reconfiguring the receivers. The CCUs consist mainly of a vector modulator and an amplifier each and can be adjusted separately via the control voltages V_{I1} and V_{Q1} and V_{I2} and V_{Q2} respectively. The amplitude adjustment range is 50 dB and the phase can be adjusted in a full 360° range. For all measurements presented in this paper the CCUs were adjusted manually.

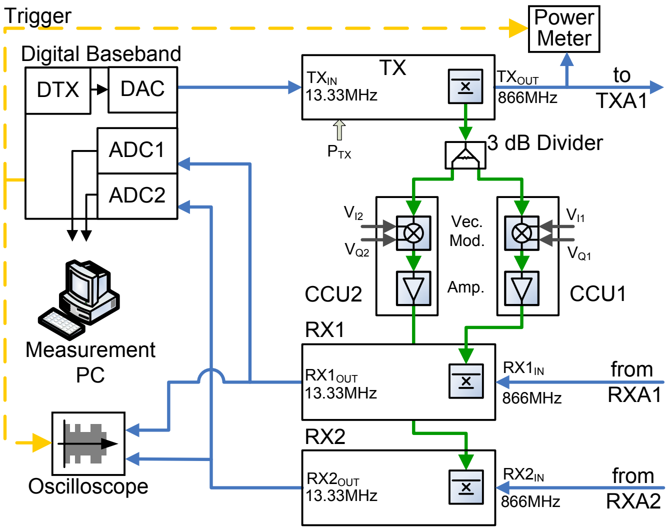

Fig. 2. Baseband and RF frontend measurement setup

The used spatial configuration for the reader antennas and the tag is illustrated in Fig. 3. Transmit and receive antennas are commercially available right hand circularly polarized patch antennas. The transmit antenna TXA1 has a gain of 9 dBi and the gain of the receive antennas RX1 and RX2 is 8 dBi.

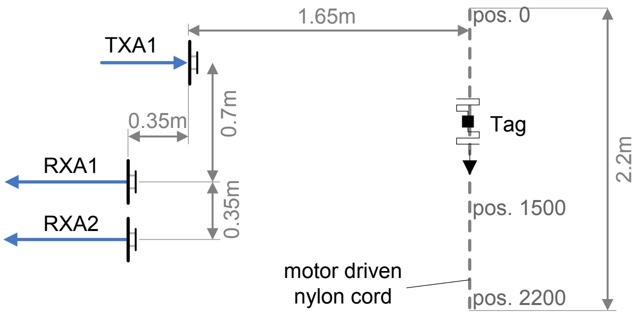

Fig. 3. Bird's eye view of the antenna–tag configuration.

The positions of the antennas are chosen for a good decoupling of around 40 dB between transmitter and receivers. We have used a commercially available tag which was mounted on a motor driven nylon cord. With this nylon cord the position of the tag was changed automatically and reproducibly.

B. Measurement results

First we performed a measurement without the CCUs which serves as reference for the following measurements with CCUs. All other parameters of the setup are unchanged. The measurement procedure starts with the tag at pos. 0. In 100 mm steps the tag is moved by the motor driven nylon cord to position pos. 2200. The position numbers give the distance to pos. 0 in millimeters. At each position the ADC samples of 25 communication cycles were recorded.

In Fig. 4 the resulting SSIRs and the SNRs in terms of E_b/N_0 are shown for both receivers over the measured positions. The E_b/N_0 varies over the positions and the two receivers from 12 dB to 33 dB and the SSIR varies between −61 dB and −37.5 dB. This means that the self interference due to the carrier cross talk is up to 1 million times stronger than the tag response even for a chosen spatial antenna configuration with good TX-RX isolation. Tendentiously, the response quality becomes better when the tag moves to positions closer to the receive antennas. The variations in SSIR and E_b/N_0 are due to multi path propagation and the distance and angle variations between reader antennas and tag during the different positions. For each receiver the variation behavior of SSIR and E_b/N_0 is identical. Assuming a dominant and constant direct cross talk signal at the reader and the variations of the signal strength of the received tag answer, this conformity implies a strong correlation between the direct cross talk and the noise floor at the receivers.

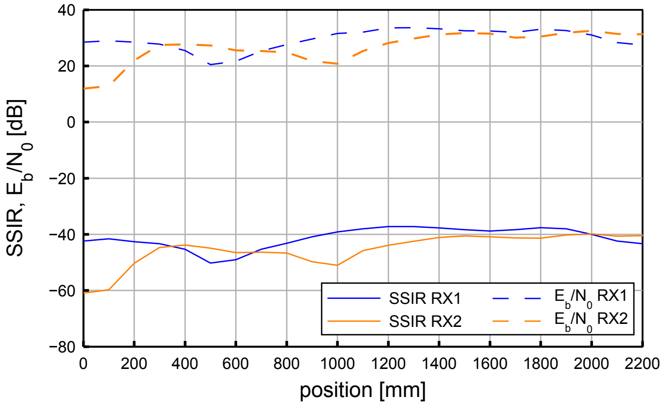

Fig. 4. Reference measurement of SSIR and E_b/N_0 without use of the active carrier compensation circuitry.

For the next measurements we connected the CCUs to the receivers. Firstly, we performed a measurement adjusting the CCUs for minimum carrier cross talk at a single position (pos. 1500) before conducting the measurement without further changes to the CCUs. Then we performed a second measurement adjusting the CCUs at each position. Fig. 5 shows the SSIR results of both measurements with CCUs and of the reference measurement. In the first case (RXi pos. 1500) were we have adjusted the CCUs only at pos. 1500 we see an SSIR for receiver RX1 of −1.5 dB and for RX2 of 33 dB . Furthermore, at all other positions of this measurement the SSIRs are always better than those of the reference measurement (RXi ref.). The worst SSIR value at pos. 0 is −27.5 dB compared to −61 dB of the reference measurement. The second measurement (RXi all pos.), were we had adjusted the CCUs at each position, shows a significant SSIR improvement over all positions as expected. The strong variations of the achieved SSIR improvement is mainly due to the manual adjustment of the CCUs. Fig. 6 directly gives the improvements for SSIR of both receivers and both measurements compared to the reference measurements. Here we observe that for the measurement were we had adjusted the CCU just at position pos. 1500 the minimum SSIR improvement is 22 dB. For the second measurement we see a minimum improvement of 43 dB. The maximum achieved SSIR improvement is 73 dB.

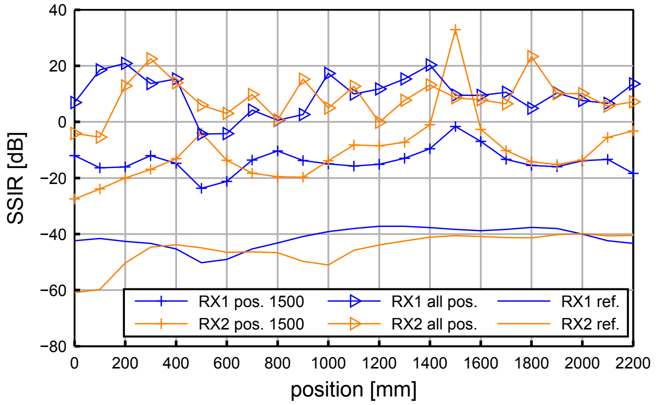

Fig. 5. Comparison of SSIR with and without use of the active carrier compensation circuitry.

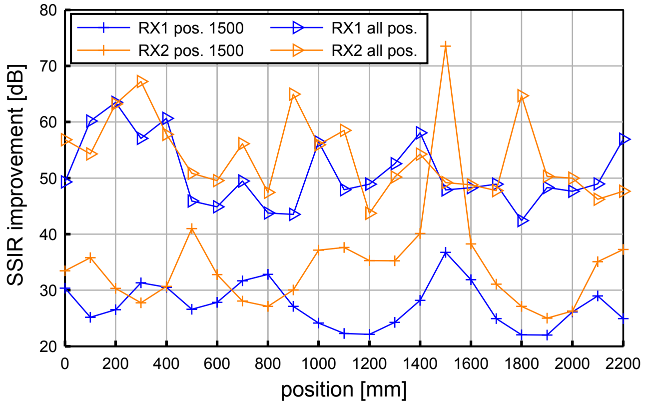

Fig. 6. SSIR improvement of RX1 and RX2 with single and multi position tuned CCUs compared to the reference measurement without CCUs at the receivers.

Additionally to the SSIR we have evaluated the impact of the active carrier compensation on E_b/N_0 in relation to the reference measurement. Fig 7 shows E_b/N_0 for the two measurements with CCUs and the reference measurement. First we can observe that the E_b/N_0 characteristic of the different positions is not influenced by the carrier compensation. Nevertheless, we observe a slight E_b/N_0 degradation for the measurements with CCUs. The two different measurements show no significant difference. Finally, Fig. 8 directly gives the E_b/N_0 alteration for both measurements with CCUs and both receivers in relation to the reference measurement. Here we observe that the E_b/N_0 degradation by the carrier compensation is between 0 dB and 4.5 dB. This degradation can be explained due to the fact that the compensation signal of the CCU also injects uncorrelated noise into the receive path.

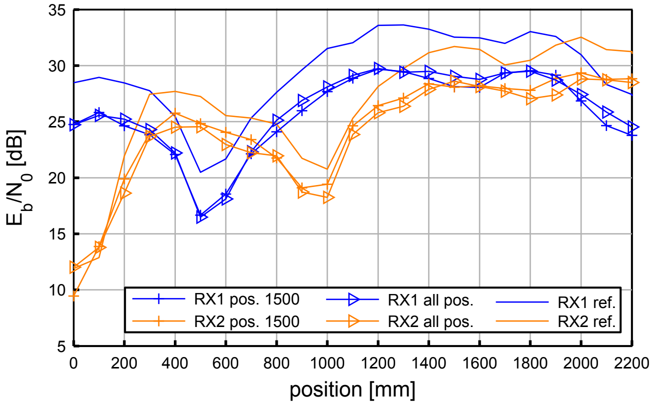

Fig. 7. Comparison of E_b/N_0 with and without use of the active carrier compensation circuitry.

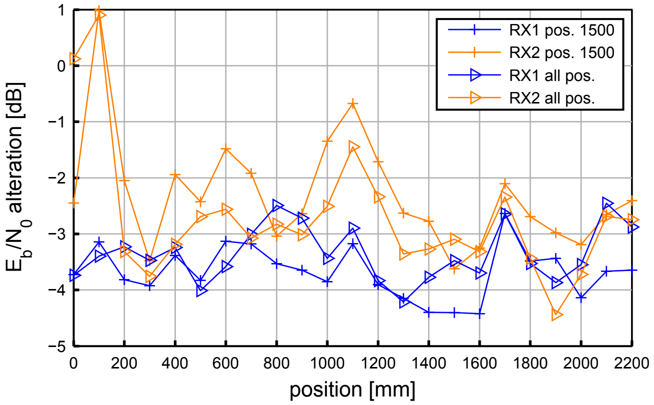

Fig. 8. E_b/N_0 alteration at RX1 and RX2 with single and multi position adjusted CCUs compared to the reference measurement without CCUs at the receivers.

IV. CONCLUSION

We have introduced an active carrier compensation technique, for multi-antenna RFID readers, based on vector modulators to our RFID research and development environment. Using a 1×2 setup at the reader and a commercially available tag we have performed measurements with and without the active carrier compensation units at different tag positions. Two different strategies for adapting the carrier compensation were used. In fact we achieved a maximum SSIR improvement for a single tag position of 73 dB. Furthermore, in a scenario where we had adjusted the carrier compensation just at one single tag position, we observed a minimum SSIR improvement of 23 dB over all tag positions compared with a reference measurement without active carrier compensation. Adjusting the compensation units at each position leads to a better minimum SSIR improvement of 43 dB. Finally, we evaluated the SNR performance in terms of E_b/N_0 when using the active carrier compensation and found a slight degradation of less than 4.5 dB compared to our reference measurement. In fact an adaptive adjustment of an active carrier suppression features an outstanding SSIR improvement by slight costs of SNR performance.

ACKNOWLEDGEMENT

We would like to thank our industrial partner Infineon Technologies for enabling this work and supporting us with many advices and discussions. In addition, we would like to thank Austrian Institute of Technology (previous Austrian Research Centers), who supported us with the SmartSim rapid prototyping board.

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