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Measurement and Simulation of Crosstalk and Crosstalk Compensation in UHF RFID

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***Abstract*—In this contribution we introduce geometric based modeling of carrier crosstalk between transmitter and receiver of an Ultra High Frequency (UHF) Radio Frequency Identification (RFID) reader. We take two paths into account: a direct static crosstalk path between transmitter and receiver, and a backscatter path between the transmit antenna of the RFID reader, a transponder and the receive antenna of the RFID reader. While the positions of the reader antennas are fixed, the position of the transponder is varied in simulation based on the movement of a transponder on a conveyor belt. Furthermore, also the compensation of this crosstalk is simulated and results are presented. Finally, for dedicated scenarios we compare simulation results with measurements carried out with our multi antenna RFID research environment which incorporates active crosstalk compensation.**

***Keywords*-RFID, UHF, reader, crosstalk, leakage, cancelation, modeling**

I. Introduction

In passive and semi-passive Radio Frequency Identification (RFID) the reader has to provide a continuous carrier signal during the whole communication process between reader and transponder. Passive transponders require this signal for powering their circuitries as well as for the communication based on backscatter modulation. Semi-passive transponders require a carrier signal only for the backscatter communication with the reader. In particular, the backscatter technology requires from the reader to transmit and receive at the same time and within the same frequency band [1]. At the receiver (RX) of the RFID readers this leads to a very strong crosstalk signal from the transmitter (TX) of the reader. The TX-RX isolation is depending upon the reader design and the antenna configuration. A mono-static antenna configuration relies on a circulator or a directional coupler to separate the transmit and receive path. Here the isolation is limited especially with a circulator by the antenna matching and in case of a directional coupler by the directivity of the coupler. In the bi-static antenna configuration with separate antennas for transmitting and receiving the spatial configuration and the radiation pattern of the antennas define the isolation. Typical values for isolation are between 15 dB to 40 dB. Research is going on how to increase the isolation between the transmitter and the receiver of RFID readers. Passive as well as active isolation enhancement techniques are under investigation [2]-[10]. We have investigated in a two path crosstalk model with an additional crosstalk compensation part at the receiver. One part considers the direct crosstalk from the reader which is defined mainly by the configuration of the reader and a second crosstalk part contains the backscattering by the transponder. Based on this simple model we have implemented a crosstalk simulator in Matlab and present first simulation results. Furthermore, we compare crosstalk measurements we have carried out with our RFID research environment with our simulations. The paper is organized as follows. In the next section we explain the crosstalk model and give the main assumptions and equations. In Section III we describe the measurement setup and in Section IV we present first simulation results and show a comparison with measurement data. Finally, in Section V we conclude our paper.

II. Crosstalk Modeling

In Figure 1 we illustrate our proposed crosstalk model for a bi-static RFID reader with one transmit antenna, two receive antennas and one transponder. For meaningful comparison this scenario is identical with the later used measurement setup.

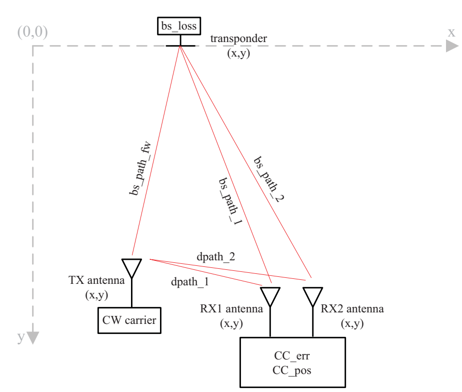

Figure 1. Model scenario with crosstalk paths and parameters.

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The Self-Interference (SI) at the receiver antennas RX1 and RX2 of the reader is the sum of the corresponding direct crosstalk signals from the transmitter to the receivers of the reader and a transponder backscattered component:

$$SI_{\mathrm{RX1,RX2}} = SIDP_{\mathrm{RX1,RX2}} + SIBP_{\mathrm{RX1,RX2}} \quad (1)$$

Whereas $SI_{\mathrm{RX1,RX2}}$ denotes the overall self-interference at a receive antenna and $SIDP_{\mathrm{RX1,RX2}}$ and $SIBP_{\mathrm{RX1,RX2}}$ are the direct path self-interference and the backscatter path self-interference respectively.

We express the unmodulated transmit signal (the carrier) as follows:

$$s_{\mathrm{TX}} = A\,\cos(\omega\,t - k\,r) \quad (2)$$

Here, ω denotes the angular frequency, t the time, k the angular wavenumber, and r the distance in propagation direction. On the one hand this wave propagates from the transmit antenna via the direct paths $dpath\_1$ and $dpath\_2$ to the receive antennas RX1 and RX2, and on the other hand via the backscatter paths r_{bs1} and r_{bs2} composed of a common forward path from the transmit antenna to the transponder bs_path_fw and a backward path from the transponder to the receive antennas RX1 and RX2, bs_path_1 and bs_path_2. All further equations are given only for receiver RX1. We model the backscattered interference signal at the receive antenna RX1 as follows:

$$SIBP_{\mathrm{RX1}} = A\,\frac{\lambda}{4\,\pi\,r_{\mathrm{bs1}}}\,bs\_loss\,\cos(\omega\,t - k\,r_{bs1}) \quad (3)$$

Additionally to the path loss, losses also occur due to the reflection at the transponder which are taken into account by the factor bs_loss.

The second part of the crosstalk at the receiver results in the direct path signal $SIDP_{\mathrm{RX1}}$ and is formulated in the following equation

$$SIDP_{\mathrm{RX1}} = A\,\frac{\lambda}{4\,\pi\,r_{\mathrm{dp1}}}\,ISO_{\mathrm{TXRX1}}\,\cos(\omega\,t - k\,r_{\mathrm{dp1}}) \quad (4)$$

Aside from the pathloss caused by the propagation distance r_{dp1} between the transmit antenna and the receive antenna an additional factor ISO_{TXRX1} allows us to include the isolation of transmitter and receiver in our model. Especially the antenna radiation patterns in combination with the spatial distribution of the antennas shows great influence on this value. Up to here only the crosstalk of the RFID reader was taken into account, finally we add a crosstalk compensation to our model. Based on Equation 1, we subtract the self-interference compensation signal SIC_{RX1} from the overall crosstalk at the receive antennas:

$$CSI_{\mathrm{RX1}} = SIDP_{\mathrm{RX1}} + SIBP_{\mathrm{RX1}} - CC\_err\,SIC_{\mathrm{RX1}} \quad (5)$$

SIC_{RX1} perfectly compensates the self-interference, but since this is infeasible in practice the parameter CC_err introduces a scalar valued compensation error. In Table I we summarize terms and parameters of the model.

Table I
MODEL TERMS AND PARAMETERS

Parameter	Description
tx_pos	position (x,y) of the TX antenna
rx1_pos	position (x,y) of the RX1 antenna
rx2_pos	position (x,y) of the RX2 antenna
tag_pos	position (x,y) of the transponder
CC_pos	tag position (x,y) for crosstalk compensation
bs_loss	backscatter loss
bs_phase	backscatter phase shift
CC_err	crosstalk compensation error
$\mathrm{ISO}_{\mathrm{TXRX1}}$	TX-RX1 antenna decoupling
$\mathrm{ISO}_{\mathrm{TXRX2}}$	TX-RX2 antenna decoupling
f	frequency
A	amplitude

Based on this model, our simulator enables to choose the positions of transmit and receive antennas and of the transponder autonomously. Several parameter sweeps are implemented e.g. sweep of the transponder position in x and y direction, the compensation error and the compensation position, to identify and analyze their influence on the crosstalk compensation behavior.

III. MEASUREMENT SETUP

In this section we briefly describe the measurement setup and the spatial antenna configuration of the measurements we have conducted and compared then with our simulation results. Our RFID research and development environment allows in a very flexible way to access system parameters like the crosstalk, which is hardly possible for commercial RFID readers. Our setup is composed of three main building blocks: a digital baseband, analog radio frequency frontends, and reader antennas and transponders. The transponders are automatically moved by means of a motor driven nylon cord. Our UHF frontends support the European UHF RFID frequency band from 865 MHz to 868 MHz and allow for active crosstalk compensation at the receiver of the reader. Figure 2 shows the baseband and analog frontend setup. In the digital baseband, the desired transmit signal is generated and fed via a Digital-to-Analog Converter (DAC) to the input of the analog frontend which main functions are amplification and frequency conversion to the UHF frequency band. Furthermore, the transmitter provides a sample of the transmitted signal which is fed into the active Carrier Compensation Units (CCUs), each of them consisting of a vector modulator and an amplifier. These CCUs enable crosstalk compenstion of the carrier at the receivers of the RFID reader. Finally, the analog receiver frontends perform the frequency down-conversion and the received signals are recorded after the Analog-to-Digital Converters (ADCs) of the baseband section. A detailed description of the measurement environment is given in [11] and [12].

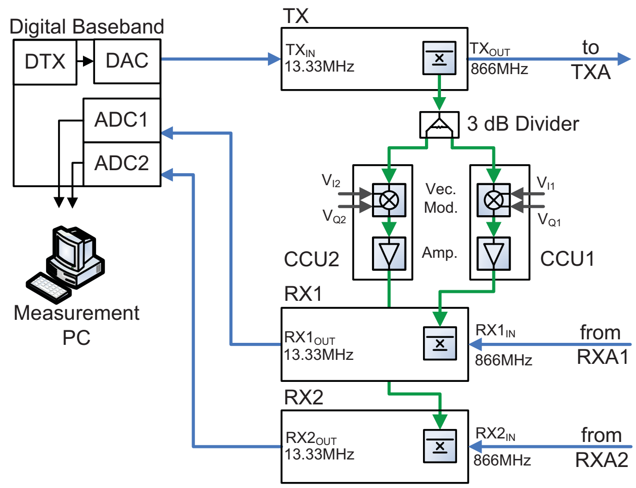

Figure 2. Measurement setup.

The spatial configuration of the transmit antenna (TXA), the transponder and the two receive antennas (RXA1 and RXA2) is given in Figure 3. Several measurements with

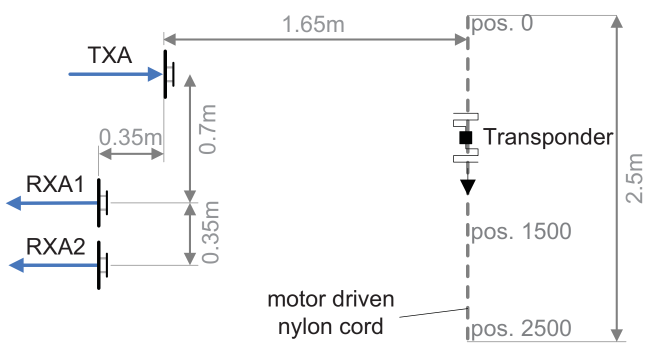

Figure 3. Antenna setup for the measurements.

and without active carrier compensation based on this setup have been carried out [13], [14]. The observed crosstalk behavior will be compared in the next section with the results of our simulations. As a reference we have chosen one measurement without carrier compensation and use this to calculate our SI improvement on each measurement position for measurement where we compensate the crosstalk with the CCUs. As shown in Figure 3 the transponder was moved along a path in front of the reader antennas. Every 100 mm, 25 measurement were taken and the received data were recorded. For measurements with the CCUs the tag was moved to the position pos. 1500, were 1500 denotes the distance in mm from the origin at pos. 0. At this position the CCUs were tuned for crosstalk compensation. This adjustment was used for all tag positions during the measurements.

IV. Simulation and Measurement Results

Figure 4 shows the simulated relative self-interference improvement for a transponder which moves parallel to the reader antennas (see Figure 1). The relative SI improvement is the ratio of the compensated SI signal to the original uncompensated SI signal. The positions of

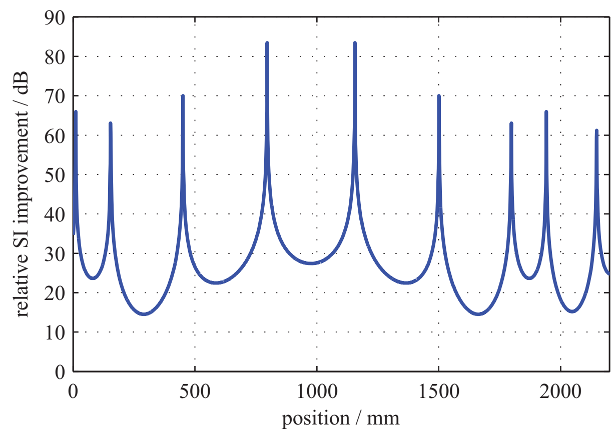

Figure 4. Relative self-interference improvement for a single position (at pos. 1500) CCU adjustment.

the antennas and the transponder are chosen to meet the measurement antenna configuration shown in Figure 3. The compensation signal is acquired at the transponder position pos. 1500 and than used as a static compensation signal for all positions from pos. 0 to pos. 2200 as described for the measurements. The compensation error at the adjustment position is $CC\_err = 3 \cdot 10^{-4}$ which corresponds to the SI improvement of 70 dB at this position. The intrinsic TXA-RXA1 antenna isolation is assumed to be 45 dB which is based on the measurements we have conducted. In Figure 4 we see that by moving the tag on this parallel line we find several local maxima and minima. This represents that, due to the change of the backscatter path length the phase conditions at the compensation point at the receive antenna changes periodically. Furthermore, keeping in mind that the compensation at at the fixed compensation position is not perfect, the maximum improvement has not to be at the adjustment position. Finally, the improvement does not drop below some threshold for the chosen simulation parameters so we observe a minimum improvement of approx. 14 dB. This threshold is depending on the direct path decoupling of the reader antennas and on the backscatter loss caused by the transponder. Figure 5 shows the backscatter path length over the transponder position. The shape of this curve defines how often maxima and minima where reached when the transponder was moved. The moving path of the transponder relative to the reader antennas determines this behavior in path length change for the communication between reader and transponder. Using this information allows us to position

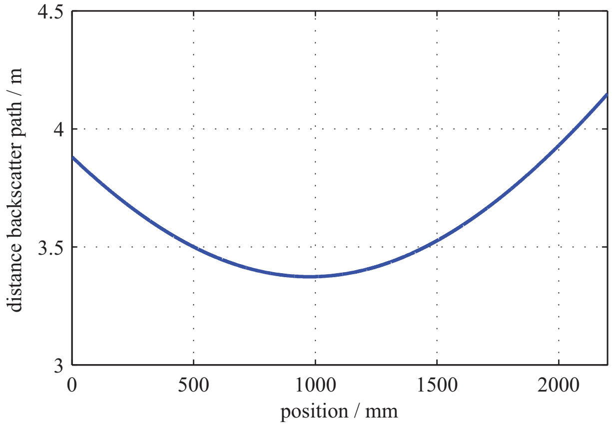

Figure 5. Backscatter path distance based on the reader antenna configuration and the transponder position.

the reader antennas to e.g. a conveyor belt in an optimized way by means of the crosstalk compensation.

Figure 6 shows a comparison of the simulation with measurement results for the antenna RXA1 of the measurement setup. The step width in x direction is now 100 mm, for the simulations as well as for the measurements. For this mea-

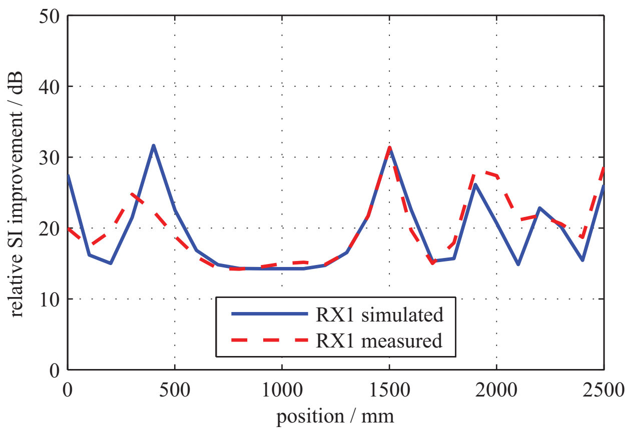

Figure 6. Comparison of measured data with simulations.

surement we observed a reduction of the self-interference due to the use of our analog compensation circuitry of approx. 31 dB at the CCU tuning position pos. 1500. This value was also used as simulation parameter to adjust the compensation error at this position. In the simulation the parameters backscatter loss, antenna decoupling and the precise positions of the transmit and the receive antenna where tuned to fit the measurement best. We observe that, the simulation and the measurement match very well. We have carried out a second measurement run with the same setup but only the carrier compensation circuitry was tuned for better compensation of about 43 dB. Also in the corresponding simulation setup, only the compensation error parameter was adjusted to the new measured value, all other parameters remained unchanged. The comparison of simulation and measurement is given in Figure 7. Again,

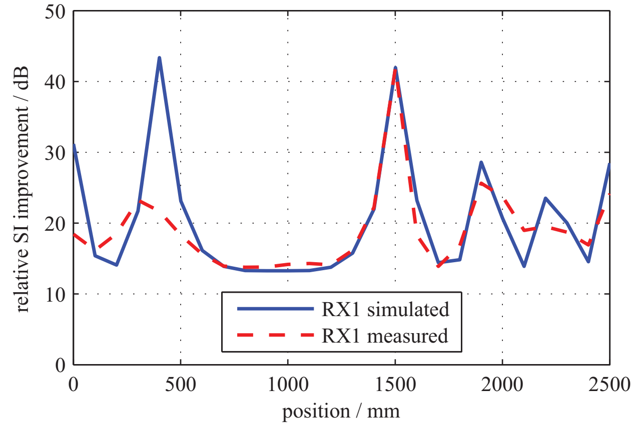

Figure 7. Comparison of measured data with better crosstalk compensation with simulations.

the simulation and the measurement fit very well. The higher deviation at positions between 0 mm and 500 mm has increased visibility compared to the results in Figure 6. This deviations are caused by the simulation assumption that the backscatter loss is constant during the whole movement path of the tag. We found that this is not correct and compensate this with a position dependent backscatter loss. We linearly decreased the backscatter loss until the tag reaches the position of 1500 mm to a minimum value and after this position we again linearly increase the backscatter loss. Figure 8 gives the resulting comparison for the second measurement(Figure 7) with the higher compensation gain. We see, that now using the position depending backscatter

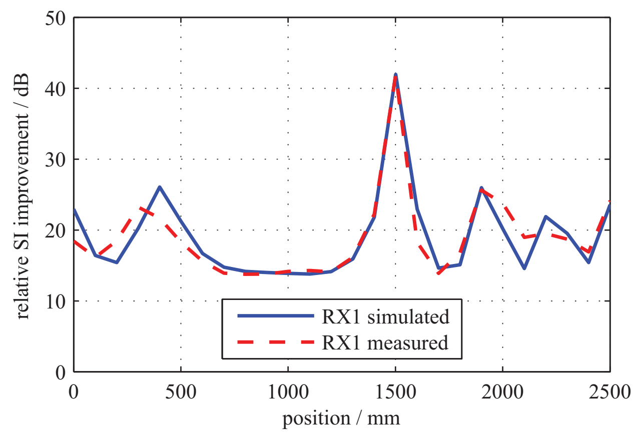

Figure 8. Comparison of measured data with position depending backscatter loss with simulations.

loss, the simulation results and the measurement results fit much better in the region between 0 mm and 500 mm.

V. Conclusion

In this paper we presented a model for crosstalk in UHF RFID systems. The model is based on a two component crosstalk, a direct or transponder independent part and a part which is caused by the backscattering of a transponder. Furthermore, we have added a crosstalk compensation with adjustable compensation error which represents realistic compensation behavior. The presented simulation results give insight into the complex compensation scenario. Moreover, the implemented simulator based on the presented model allows to further analyze different scenarios with different system parameters. In combination with our UHF RFID research environment we were able to validate and cross check simulation results versus measurements and vice versa as demonstrated by comparisons of simulations with measurements.

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