Broadband Leaking Carrier Cancellation for RFID Systems

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***Abstract*— Reader systems for passive RFID tags suffer from a strong self generated interferer at the receiver, caused by transmitter to receiver leakage. This problem is often addressed by leaking carrier cancelers which compensate the leaking carrier at a single frequency. In this paper, we present measurements of the leakage channel in an RFID system. Based on the obtained results, we evaluate the leakage reduction that can be achieved by a novel analog broadband leakage canceller in the RF domain. Our proposed method allows for suppression of transmitter noise components. Moreover, it facilitates new broadband technologies, such as precision localisation or chipless RFID.**

***Index Terms*— carrier cancellation, channel characterisation, leakage isolation, multipath channel, RF identification (RFID)**

I. Introduction

Radio frequency identification (RFID) is a technology to remotely detect and identify objects, which are carrying a small transponder called tag. While there are RFID systems at several frequencies, this paper focuses on UHF RFID systems. Passive RFID tags do not carry any electrical energy source, instead, their analog and digital circuitry is powered by the electromagnetic field provided by the RFID reader. Furthermore, data transfer from tag to reader is solely achieved by backscatter modulation. Since for both reasons passive tags require the reader to transmit a signal even during tag transmissions, the reader's receiver has to be isolated from the reader's transmitter. This can be accomplished by a monostatic or a dual-antenna (i.e., bistatic) approach. The primer method uses only one antenna at the reader and achieves the isolation by a circulator or a directional coupler. The latter approach requires two physically separated antennas. Since both techniques do not achieve perfect isolation, leakage cancellation techniques were proposed by several authors [1]–[4], respectively, are used in commercial RFID readers. All of these techniques extract a fractional amount of the transmit signal, adjust its amplitude to be equal and its phase to be opposite to the leaking signal, and finally add it to the received signal by means of a directional coupler or a similar device. When properly adjusted, these leaking carrier cancellers (LCCs) significantly increase the transmit to receive isolation at a certain carrier frequency.

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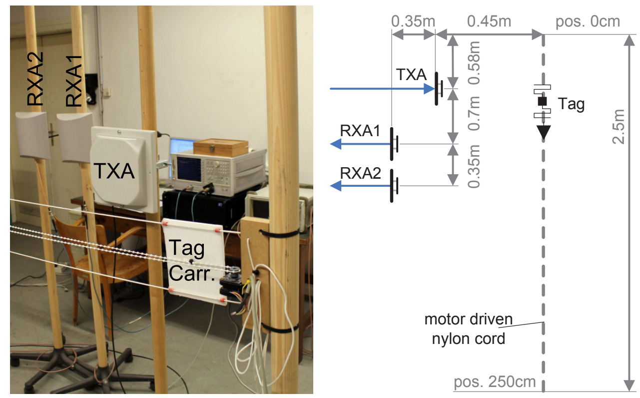

(a) (b)

Fig. 1. Photo (a) and principal drawing (b) of the measurement setup.

According to [4], this narrowband approach is only sufficient for conventional RFID readers, which solely transmit an unmodulated sinusoidal signal with low noise characteristics. Novel RFID technologies, such as chipless RFID [5] or localisation [6] necessitate RFID readers which operate at larger bandwidths. Consequently, those enhanced techniques require LCCs with increased bandwidth. In the following section, we present measurements of the leakage channel for a bistatic scenario. Based on an analysis of the obtained measurement results in time domain, we present a broadband leakage canceller comprising an analog transversal filter. The performance of this novel canceller is then compared to the performance of a conventional LCC.

II. Measurement Setup

As shown in Fig. 1(a), the measurement setup consists of three commercial circular polarised patch antennas mounted on wooden supports, set up in a semi-industrial room. Two identical antennas, RXA1 and RXA2, with a nominal gain of $8\,\mathrm{dBi}$ are placed side by side. To increase isolation, a third antenna TXA with a nominal gain of

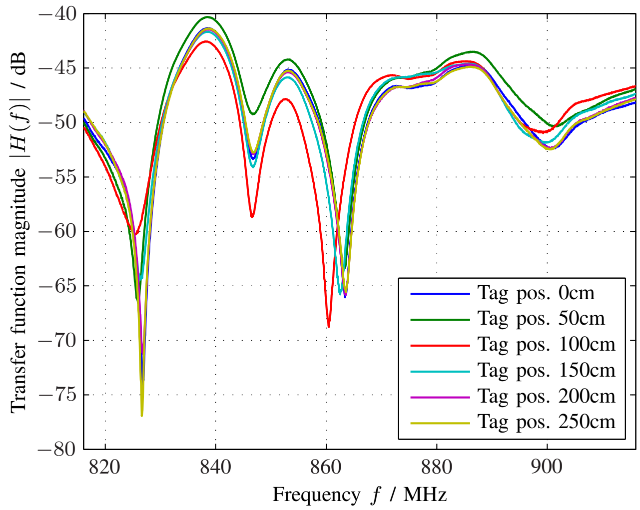

Fig. 2. Transfer function magnitude $|H(f)|$ for different tag positions.

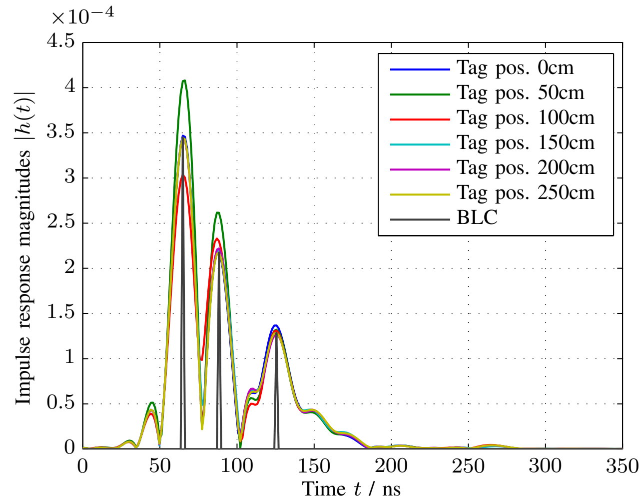

Fig. 3. Impulse responses $h(t)$ and $h_{\mathrm{BLC}}(t)$ for the leakage and the BLC channel.

$9\,\mathrm{dBi}$ is placed $35\,\mathrm{cm}$ in front of the two receive antennas RXA1 and RXA2, as depicted in Fig. 1(b). Additionally, a commercial RFID tag (UPM Raflatac DogBone) is mounted on a dielectric foam carrier. It can be moved along a track parallel to the receive antenna plane by means of a dielectric cord driven by a stepper motor. For the bistatic measurement considered here, the tag track is mounted $45\,\mathrm{cm}$ in front of the transmit antenna TXA, and RXA1 is used as receive antenna. Both, TXA and RXA1 are connected to a vector network analyser (VNA) and 1601 samples between 816 and $916\,\mathrm{MHz}$ are measured. We denote the transfer function between the two antennas by $H(f)$. In Fig. 2, its magnitude $|H(f)|$ is plotted for several different tag positions. Note that here, the RFID tag acts as a passive unmodulated reflector, since it is not addressed by a query command.

III. Broadband Leakage Canceller

Fig. 3 presents the impulse response calculated from the transfer function. First, a Tukey window [7] is applied in frequency domain with coefficient $\alpha = 0.65$ (i.e. the central 35% of the transfer function remain unchanged). Next, the windowed data are zero padded to achieve an interpolation in time. Finally, the inverse discrete Fourier transform is carried out. The resulting impulse response $h(t)$ primarily consists of three peaks at delays $64.9\,\mathrm{ns}$, $88.3\,\mathrm{ns}$, and $125.6\,\mathrm{ns}$, where most of the delay of the first peak is due to the cables connecting the antennas to the VNA, which replaces our standard RFID reader.

The working principle of a conventional LCC is to adjust phase and amplitude of a transmit signal sample, and to add the resulting signal in the RFID reader to the signal received from the receive antenna. This corresponds to a flat transfer function $H_{\mathrm{LCC}}(f) = -H(f_0)$, where f_0 denotes the frequency for which the LCC was adjusted. The corresponding impulse response is $h_{\mathrm{LCC}}(t) = -H(f_0) \cdot \delta(t)$, where $\delta(t)$ denotes the Dirac delta distribution. In [4], the authors demonstrate that an additional delay in the compensation path significantly improves broadband suppression, if $h(t)$ approximately consists of a single peak, and accordingly $H(f)$ is flat. This is not the case for our measured scenario, not even for the small bandwidth of the European RFID band ranging form 865 to $868\,\mathrm{MHz}$.

The three distinct pulses in the impulse response $h(t)$ motivate the extension of the conventional LCC to a broadband leaking canceller (BLC) by introducing additional delay paths. More precisely, the BLC extracts a fractional amount of the transmit signal, splits it up, and separately feeds it into three delay lines, each followed by an LCC. Finally, these three LCC output signals are summed up together with the received signal. The impulse response $h_{\mathrm{BLC}}(t)$ of this canceller is plotted in Fig. 3. It is obtained by isolating the three most dominant samples (i.e., the samples with highest magnitudes) in each of the three major peaks of $-h(t)$, which resulted from the measurements with the tag positioned at $250\,\mathrm{cm}$. This tag position is chosen, since in this case, the influence of the tag to the measurements is negligible. Note that the negative sign in $-h(t)$ is introduced since the BLC is desired to cancel out the leakage signal.

When converted to the frequency domain, $H_{\mathrm{BLC}}(f)$ follows the leakage channel $H(f)$, as indicated in Fig. 4. This figure compares the original transfer function $H(f)$, the windowed version which was used to calculate $h(t)$, the transfer function of the proposed BLC, and finally, the transfer function $H_{\mathrm{LCC}}(f)$ for the conventional leaking carrier canceller. The improvement from the LCC to the BLC is evident. This improvement is paid by tripling the hardware complexity of the canceller. Other scenarios,

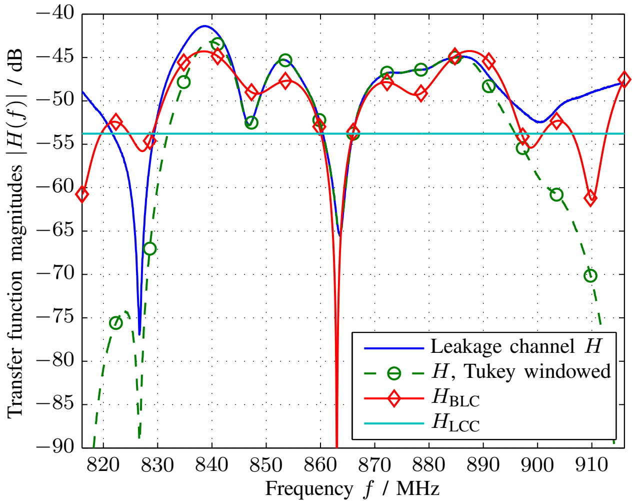

Fig. 4. Magnitudes of the transfer functions of the leakage channel $H(f)$, the Tukey windowed $H(f)$, $H_{\mathrm{BLC}}(f)$, and $H_{\mathrm{LCC}}(f)$.

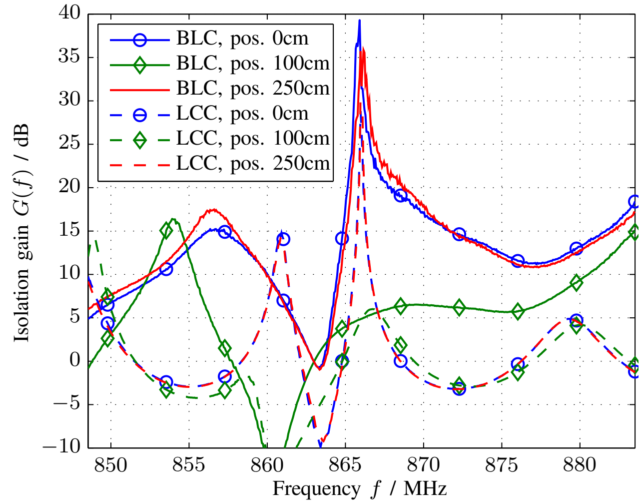

Fig. 5. Isolation gain $G(f) = \frac{|H(f)|}{|H_{\mathrm{RL}}(f)|}$ for BLC and LCC.

especially monostatic configurations, lead to impulse responses with a higher number of significant peaks, but still, a BLC with only three taps adapted to the three highest peaks, produces better results than a conventional LCC.

To quantify the results, we define the isolation gain

$$G(f) = \frac{|H(f)|}{|H_{\mathrm{RL}}(f)|},$$

where $H_{\mathrm{RL}}(f) = H(f) + H_{\mathrm{BLC}}(f)$ is the resulting leakage path from transmitter to receiver after applying the BLC. A comparison of the isolation gains for BLC and LCC is plotted in Fig. 5. Here, both cancellers are adjusted at the tag position $250\,\mathrm{cm}$, and then kept constant to investigate the performance of static adjustment. It is observed from Fig. 3 that for other tag positions, a dynamic adaption of the BLC will only require changes of the phase and amplitude components, since the peak delays stay constant.

For the adjustment tag position at $250\,\mathrm{cm}$, the isolation gains at the center frequency $f_0 = 866\,\mathrm{MHz}$ are extremely large for both cancellers. However, while the LCC shows an isolation gain higher than $15\,\mathrm{dB}$ only on a $600\,\mathrm{kHz}$ wide frequency band, the isolation gain of the BLC remains above $15\,\mathrm{dB}$ over a $6.7\,\mathrm{MHz}$ wide frequency range. For larger bandwidths, the gain of the LCC becomes negative, so it actually degrades the original leakage transfer function in these regimes. In the whole observed frequency range ranging from 848.5 to $883.5\,\mathrm{MHz}$, which is equal to the range of $H(f)$ untouched by windowing, the gain of the BLC does not become negative, with the exception of a $-1\,\mathrm{dB}$ dent at $863.4\,\mathrm{MHz}$. At this frequency, $H(f)$ has a strong intrinsic minimum ($-66\,\mathrm{dB}$) which is difficult to capture with the BLC. Keeping this in mind, a slight degradation of this very high isolation point can be accepted. For the worst case tag position $100\,\mathrm{cm}$ which was also plotted in Fig. 5, the isolation gain still is positive, and just the region of very good intrinsic isolation between 857 to $863\,\mathrm{MHz}$ is flattend out by the misadjusted BLC.

IV. Conclusion

In this contribution, we present an enhanced method to address the leakage problem in broadband RFID systems. Our proposed broadband leaking canceller contains multiple delay paths of adequate delay with separate phase and amplitude control. Based on the measurement of a bistatic RFID scenario, feasibility for a three tap BLC was demonstrated. In our perspective, the additional hardware complexity necessary to extend a conventional leaking carrier canceller into a BLC, is well justified by the significant increase in $15\,\mathrm{dB}$ suppression bandwidth by a factor of 11. Even without adaption to a nearby RFID tag, the BLC leads to a flattened leakage transfer function and a minimum isolation of $52\,\mathrm{dB}$ over a bandwith of $35\,\mathrm{MHz}$.

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