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A UHF Passive RFID System with Frequency Diversity

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1. Introduction

The half-duplex reader (or Interrogator) and tag (or transponder) communication has been adopted in a variety of UHF passive RFID specifications [1, 2]. A compliant UHF passive tag listens to a reader command in the reader-to-tag (R=>T) link, and then replies its response in the tag-to-reader (T=>R) link by reflecting the continuous wave (CW) with MBSs. It is noteworthy that the reflection is effective for all incident CWs in the tag operation bandwidth. Using this property, frequency diverse MBSs can be produced by illuminating a tag with frequency-different CWs simultaneously. The created frequency diversity in the T=>R link can be used to mitigate the fading channel problem in a UHF passive RFID system [3]. In this work, a UHF passive RFID system with frequency diversity in the T=>R link is proposed and experimental results are presented.

2. The proposed system

As illustrated in Figure1, the proposed system consists of multiple CW emitters (can be more than two), a transmitter, and a receiver. The CW emitters deployed at the proximity of RFID tags not only serve as power sources of the tags but also provide the carriers to the tag MBSs. Unlike an ordinary integrated RFID reader, whose transmitter not only sends reader commands to a tag but also emits CW to provide the power and the backscatter carrier to the tag, the transmitter in the proposed system only sends reader commands. The receiver in the proposed system is designed to receive signals in all frequencies corresponding to the CW emitters and derive the MBS using frequency combining technologies.

In order to simultaneously illuminate a tag with frequency-different CWs, the center frequencies of neighboring CW emitters are mutually exclusively assigned. The frequency separation Δf_{CW} between each CW emitter is assigned as $\Delta f_{CW} > 2R_{MBS}$ to prevent MBS aliasing, where R_{MBS} denotes the MBS data rate. In addition, to prevent the RF envelope fluctuation of reader commands, the operating frequency of the transmitter is separate with all CW carriers in the proposed system.

It is noteworthy that the power of the MBS in the proposed system is mainly determined by the tag radar cross section (RCS) σ as expressed in (1).

$$\sigma = \frac{\lambda^2}{4\pi} G(\theta_i, \phi_i) G(\theta_r, \phi_r) |\Delta\Gamma|^2, \tag{1}$$

where λ is the wavelength of the incident CW, $|\Delta\Gamma|$ is the magnitude of the change in reflection coefficient from the non-modulating state to the modulating state, and $G(\theta, \phi)$ is the tag antenna power gain in the direction with the elevation angle θ and the azimuthal angle ϕ. As depicted in Figure 1, the subscript i and r specify the directions associated with the incident CW and the reflective RF signal respectively. Because the tag antenna gain $G(\theta_i, \phi_i)$ varies according to different θ_i and ϕ_i for a non-isotropic tag, the power of MBS varies as a function of the angle of

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arrival (AOA) of the incident CW. Consequently the RCS should be considered as an essential factor of the channel attenuation in the T=>R link, which can greatly affect the backscattering power of MBS in the corresponding carrier.

Because the CW emitters are deployed closed to tags, the free space loss in the R=>T link is usually much less than that of a distant integrated reader. The multiple CW emitters not only can produce multiple-frequency MBS, but also can act as redundant power sources of an illuminated tag. For instance, when there is a large propagation loss between a CW emitter and a tag, the tag can obtain its power from other CW emitters, and use them to send its responses. In practice, the CW emitters can be leaky cables or small dipole antennas on warehouse racks.

A simplified system operation scenario is illustrated in Figure 2. The transmitter sends a turn-on command to CW emitters first. When a CW emitter receives the turn-on command, it replies an acknowledgement (ACK) signal to the transmitter. In the mean time, the CW emitter starts to illuminate tags in its coverage. The CW emission continues until the CW emitter receives a turn-off command. Following a regular half-duplex reader and tag communication, the transmitter sends a reader command after receiving the ACK signal, and then the receiver demodulates the frequency diverse MBSs in the T=>R link. Because the proposed system does not involve any change in the tag design, it is compatible with present UHF passive tags.

3. Experiment results

The proposed system is validated by taking a Texas Instruments Gen 2 Inlay [4] tag as the unit under test. The constitution of the proposed system is described as follows: As illustrated in Figure 1, two CW emitters, emulated using two identical horn antennas with equal emission power, are symmetrically placed in both sides of the tag boresight axis. The carrier frequencies of the two CW emitters are 905MHz and 915MHz, respectively. The 10MHz separation results in two uncorrelated channels, which agrees with measurement results in [5]. The transmitter operating in 918MHz is emulated using an Agilent E4438C vector signal generator. The receiver is emulated by a dipole antenna connected with an Agilent E4445A spectrum analyzer. Both transmitter and receiver are placed closed to the tag boresight axis. In the experiment, the transmitter sends a properly pre-programmed Gen2 Query command in the proposed system [6], and the tag replies a 16-bit (RN16) MBS after receiving the command as in [1]. The received signals are captured using Agilent 89601 VSA software.

The experiment results are presented by two captured snapshots of the same MBS in the two CW emitters operating frequencies as shown in Figure 3 and Figure 4 respectively. Comparing the two snapshots, the MBS quality in 905MHz clearly outperforms that in 915MHz. In this experiment, the averaged received signal-to-noise ratio (SNR) of MBSs in 905MHz is 4dB higher than that in 915MHz. The experimental results vary with different environmental configurations. However, the frequency diversity gain effectively improves the receiver SNR when the channels are uncorrelated.

4. Conclusions

Frequency diverse tag responses are created using the proposed system. The frequency diversity gain can be used to mitigate the fading channel problem in a UHF passive RFID system. Moreover, the outage problem of a UHF passive tag can be alleviated using the proposed system.

Acknowledgments

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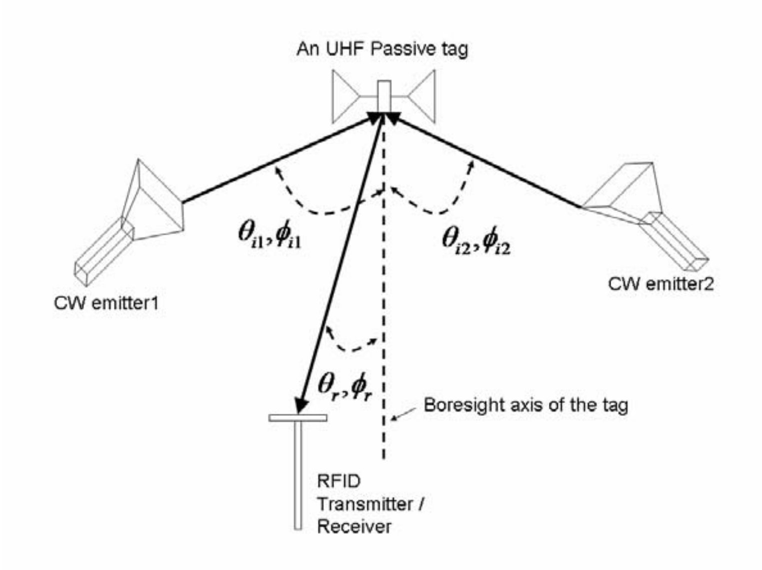

Figure 1: Diagram of the proposed system, where θ_i is the elevation angle of an incident CW, ϕ_i is the azimuthal angle of an incident CW, θ_r is the elevation angle of a reflective CW with MBS toward the receiver, and ϕ_r is the azimuthal angle of a reflective CW with MBS toward the receiver

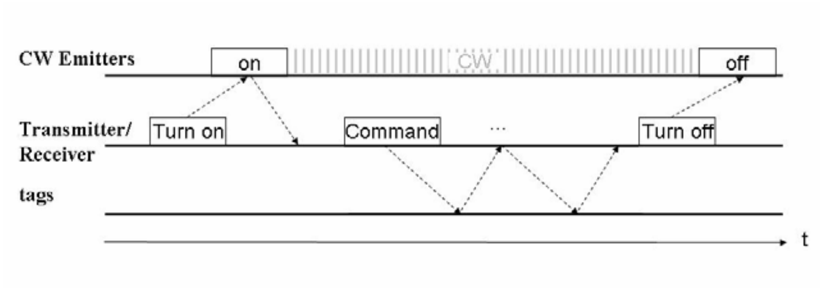

Figure 2: Simplified operation scenario of the proposed system

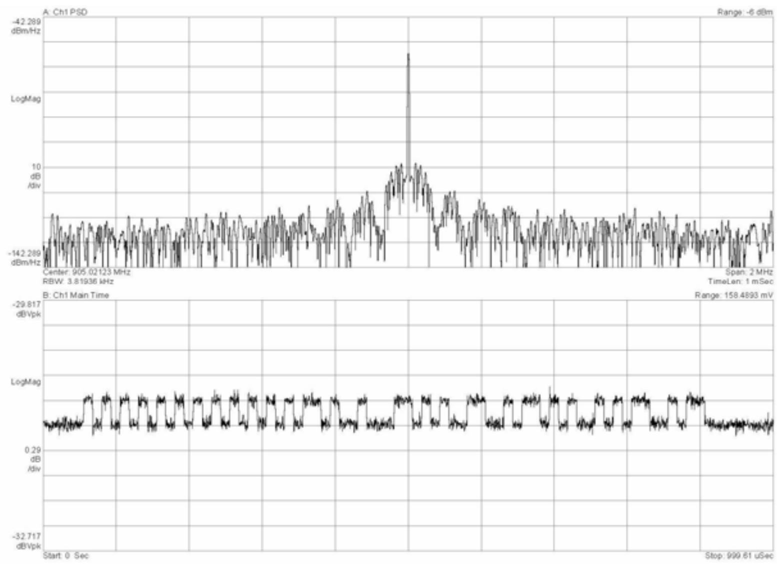

Figure 3: Snapshot of received MBS in 905MHz

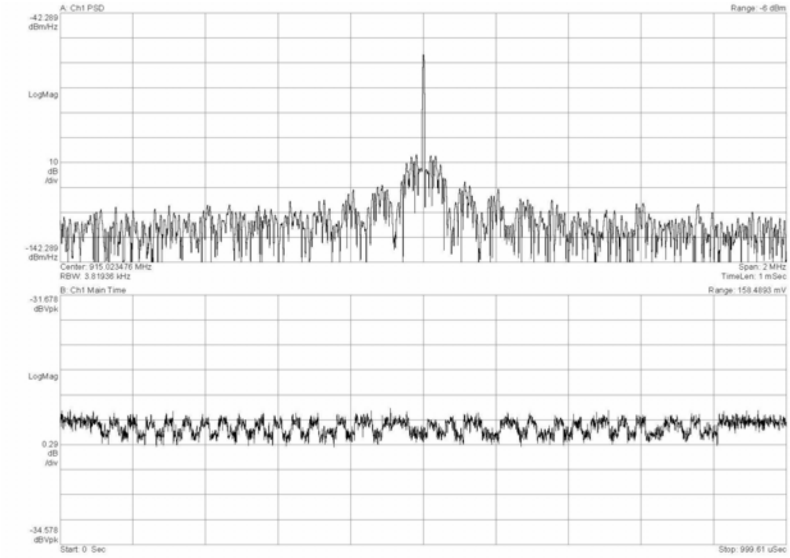

Figure 4: Snapshot of received MBS in 915MHz

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