The Phase Difference Method for Transmit Diversity in Monostatic RFID Systems

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***Abstract*—For passive backscatter radio frequency identification (RFID) systems, the power incident on the radio frequency (RF) tag can be improved by applying transmit diversity. In this paper, we have demonstrated a new scheme, the *phase difference method*, in which the phase of the forward links of a multi-antenna monostatic backscatter system are aligned at the RF tag by compensating for the phase difference between different channels. It is shown that dynamic application of transmit diversity can increase the power delivered to the RF tag at multiple points, sequentially.**

I. Introduction

Owing to path loss, multipath, shadowing and attachment affects, backscatter RFID systems are range limited due to the power incident on the RF tag [1]. Various approaches have been reported to increase the read range of a passive RF tag including power optimized wave forms [2] and interrogation enhancers [3]. Transmit diversity provides an effective way of increasing the power incident on the RF tag and one possible way to implement transmit diversity is the *phase division method* [4]. In this paper we propose a new approach, the *phase difference method*, to implement transmit diversity for monostatic backscatter RFID systems. In the phase difference method, the phase difference between the backscatter signals received at each reader antenna are used to align the transmitted signal phases with the signal from the reference antenna. The result is constructive interference at the RF tag.

The monostatic phase difference method avoids two implementation difficulties associated with the monostatic phase division method. The first difficulty is that the phase division method requires the transmitter antennas to be time multiplexed to measure the forward link phase. With the phase difference method, each transmitter antenna can operate simultaneously. Second, the phase division method may introduce a phase flip problem and result in less than optimal transmit diversity performance. The phase flip problem is that coherent receivers can only measure wrapped phases – i.e., a phase $\hat{\phi}$ wrapped into the range $-\pi \leq \pi$. The wrapped phase is related to the unwrapped phase by $\hat{\phi} = \phi - 2k\pi$, where k is an unknown positive integer. In the monostatic phase division method, the forward link phase $\hat{\theta}^f$ used to apply transmit diversity is calculated from the measured, wrapped, round-trip phase of the backscatter channel $\hat{\theta}$ as $\hat{\theta}^f = \hat{\theta}/2$. Using the relationship between wrapped and unwrapped phases, the wrapped forward link phase becomes $\hat{\theta}^f = (\theta - 2k\pi)/2 = \theta/2 - k\pi$. Since the unknown integer k may be different for the forward link of each reader antenna, it is possible for the phases of the signals arriving at the RF tag to differ by an integer multiple of π after transmit diversity has been applied. If they differ by an odd multiple of π, the signals will add deconstructively. Since the phase difference method does not divide the wrapped phase by two, signals from each reader antenna will only differ by multiples of 2π after transmit diversity is applied, which ensures constructive interference.

The proposed method is described in Section II, and the measurement setup along with results are reported in Section III, followed by a brief discussion in Section IV.

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II. The Monostatic Phase Difference Method

A monostatic backscatter channel is composed of a forward and a backscatter link [4]. In a system with M reader antennas, the signal received at the i^{th} antenna, while all antennas are transmitting simultaneously, can be described as [5]

$$\tilde{y}_i = \tilde{h}_i^b(\tilde{h}_1^f + \tilde{h}_2^f + \cdots + \tilde{h}_M^f)\tilde{\Gamma}\tilde{x}, \tag{1}$$

where $\tilde{y}_i$ is the complex baseband signal received at the i^{th} antenna; $\tilde{x}$ is the complex baseband signal transmitted from the reader; $\tilde{\Gamma}$ is the complex reflection coefficient at the tag antenna terminals; and $\tilde{h}_i^f$ and $\tilde{h}_i^b$ are the complex, baseband channel impulse responses of the forward and backscatter links, respectively, of the i^{th} antenna. Each antenna is operating in monostatic mode and the baseband backscatter channel is assumed to be static and narrowband.

It can be observed that the phase measured for the i^{th} and $(i+1)^{\mathrm{th}}$ antenna, using equation (1), contains common phase information of the transmit signals of all reader antennas (i.e., $\angle\{[\tilde{h}_1^f + \tilde{h}_2^f + \cdots + \tilde{h}_M^f]\tilde{\Gamma}\tilde{x}\}$). Exploiting the fact that the forward link of a monostatic system is equal to the backscatter link, subtracting the phase measured at the i^{th} antenna from $(i+1)^{\mathrm{th}}$ antenna will cancel the common component and the relative phase shift between the forward channels of the i^{th} and $(i+1)^{\mathrm{th}}$ antennas will be

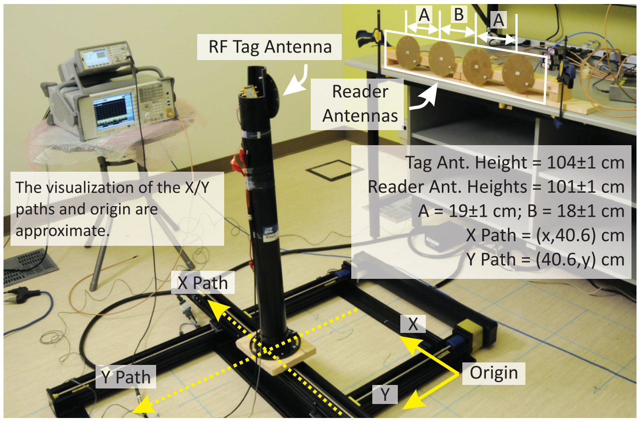

Fig. 1. The experimental setup showing the tag antenna mounted on a plastic support and the 2D linear positioner, the reader antenna array, and the test and measurement equipment.

$$\tilde{\Delta}_{i+1} = \angle\tilde{y}_{i+1} - \angle\tilde{y}_i = \angle\tilde{h}^f_{i+1} - \angle\tilde{h}^f_i. \quad (2)$$

Selecting the i^{th} antenna as the reference, a phase shift of $-\tilde{\Delta}_{i+1}$ applied to the signal transmitted from the $(i+1)^{\text{th}}$ antenna will phase align the transmitted signals of both the channels, creating constructive interference at the RF tag. Using the same method, the remaining antennas of the monostatic backscatter system can also be aligned to the reference signal at the RF tag to maximize the power incident at the tag.

III. Measurements and Results

The phase difference method for monostatic systems was verified through measurements. A photo of the measurement setup is shown in Figure 1. The equipment is identical to the setup described in Section III of [4], except that the one-dimensional positioner has been replaced with a two-dimensional positioner from Velmex.

The first part of the measurement campaign was phase measurement. A CW signal at 5.8 GHz was transmitted from all channels simultaneously and the phase was measured at one reader antenna while moving the tag over the measurement path. This process was repeated for all antennas. With this channel phase information, Δ_i was computed and a phase shift of $-\Delta_i$ was applied to all but the reference antenna. Finally, the incident power on the RF tag was measured at each location using a spectrum analyzer and the tag antenna.

Dynamic application of transmit diversity – i.e., applying transmit diversity at multiple points sequentially – will smooth power nulls caused by the interference pattern of the four antennas, maximize power incident on the RF tag, and demonstrate the ability to create constructive interference as the tag is moved. For experimental demonstration, transmit diversity was applied at every point (with spacing ≈ 1 cm $< \lambda/4$) in the X and Y dimensions. The normalized power distribution with dynamic application of transmit diversity is shown in comparison to the power distribution without transmit diversity in Figure 2. It can be observed that the dynamic application of transmit diversity results in better incident power at almost every point across the 1D grid, with a gain ranging from 0.5 dB

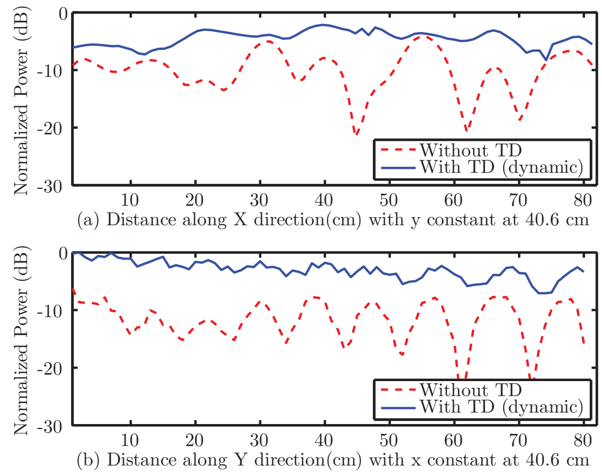

Fig. 2. The power, normalized to the maximum measured power, with and without transmit diversity as the RF tag is moved along (a) the X direction, and (b) the Y direction.

to 21.9 dB, depending upon the fading level before applying transmit diversity.

The maximum error in the phase measurement of the complete backscatter system was estimated to be less than 35^o. The IQ modulators were characterized to be accurate in inducing the phase shift within a tolerance of 4^o. The results suggest that this method is not very sensitive to the accuracy of the phase measurement.

IV. Discussion and Future Work

The phase difference method yields results comparable to the phase division method while overcoming the two implementation difficulties of the phase division method: the phase flip problem and time multiplexing of the transmitter antennas when measuring the phase. The measurements show that transmit diversity can remove spatial nulls in the transmitted power caused by the interference pattern of the reader antennas in a strong line of sight. Future work will investigate the performance of transmit diversity in channels with varying levels of multipath and compare with backscatter systems using single antennas or phased arrays.

References

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