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A hybrid reader tranceiver design for industrial internet of things

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ABSTRACT

This paper presents an integrated asymmetric UHF/UWB reader transceiver in 90 nm CMOS technology for industrial enterprise IoT applications. The reader uses UHF transmitter to power up and inventory the tags. Instead of backscattering, tag replies the reader using Ultra-wideband (UWB) pulses, allowing high throughput transmission and precise positioning. Therefore, a UWB receiver is deployed in the proposed reader for data reception and Time-of-Arrival (ToA) estimation using energy detection schemes. The transmitter delivers 160 kb/s ASK modulated data by an integrated modulator and a Digital Controlled Oscillator (DCO). The DCO has 11% tuning range ability to cover different UHF signal channels. On the UWB receiver side, the 3–5 GHz energy detection receiver supports maximum 33 Mb/s data rate in both OOK and PPM modulations. The receiver front-end provides 59 dB voltage gain and 8.5 dB noise figure (NF). Measurement results shows that the receiver achieves an input sensitivity of -79 dBm at 10 Mb/s, and the power consumption of transceiver is 21.5 mW.

1. Introduction

Radio frequency Identification (RFID) technology play important role in the industrial enterprise Internet-of-Things (IoTs) applications, such as intelligence logistic, system control, inventory management, machines-to-machines (M2M) communication, and human-to-machines interaction [1–3,31–33]. The related commercial market of RFID systems has been increased to 9.5 billion US dollars in the end of 2015, and will keep 10% increasing rate annually in the further years. According to IDTechEx, the market size will exceed 15 billion US dollars [4].

In the context of the industrial enterprise IoT, all objectives such as tools, materials, machines and people are networked by radio links with not only sensing, processing, communication and control capabilities, but also location information [5–8]. In order to satisfy these requirements, the future RFID systems are expected to provide both reliable identification and high-precision positioning with low power, low cost and low latency. Unfortunately, current passive RFID systems, such as UHF RFIDs can only achieve meters level positioning accuracy within 10 m range. On the other hand, active RFID systems using fully Ultra-wideband (UWB) radio (e.g., Ubisense system) can provide efficient performance, but at the expense of system complexity and high cost (the system consists of 4 readers and 6 tags and cost 1400 US dollars).

To address these problems, an UHF/UWB hybrid system has been proposed. It uses conventional UHF signal to power up and inventory the tag, while the tag responds the reader using an active UWB transmitter. Such solution allows UWB transmissions in a passive RFID system [9]. Based on this architecture, a remote-powered RFID tag with 10Mb/s UWB uplink and -18.5 dBm sensitivity UHF downlink has been developed [10]. Still, an UHF/UWB reader is to be developed to pair the tag.

In this work, an asymmetric UHF/UWB reader transceiver is designed and implemented. It contains a UHF transmitter and an energy detection (ED) IR-UWB receiver. The UHF transmitter with 160 kb/s data rate is implemented by using Amplitude-Shift-Keying (ASK) modulation. The IR-UWB receiver supports On-Off-Keying (OOK) and Pulse Position modulation (PPM) with data rate up to 33 Mb/s. The transceiver is fabricated in 90 nm CMOS technology. The chip area is 1.72 mm^2 with power consumption of 21.5 mW. In the entire signal band from 3–5 GHz, the front-end of the receiver exhibits a noise figure of 8.5 dB and S11 <-9.6 dB is measured. Providing 59 dB voltage gain, the receiver achieves an input sensitivity of -79 dBm with 10^{-3} BER at 10 Mb/s data rate.

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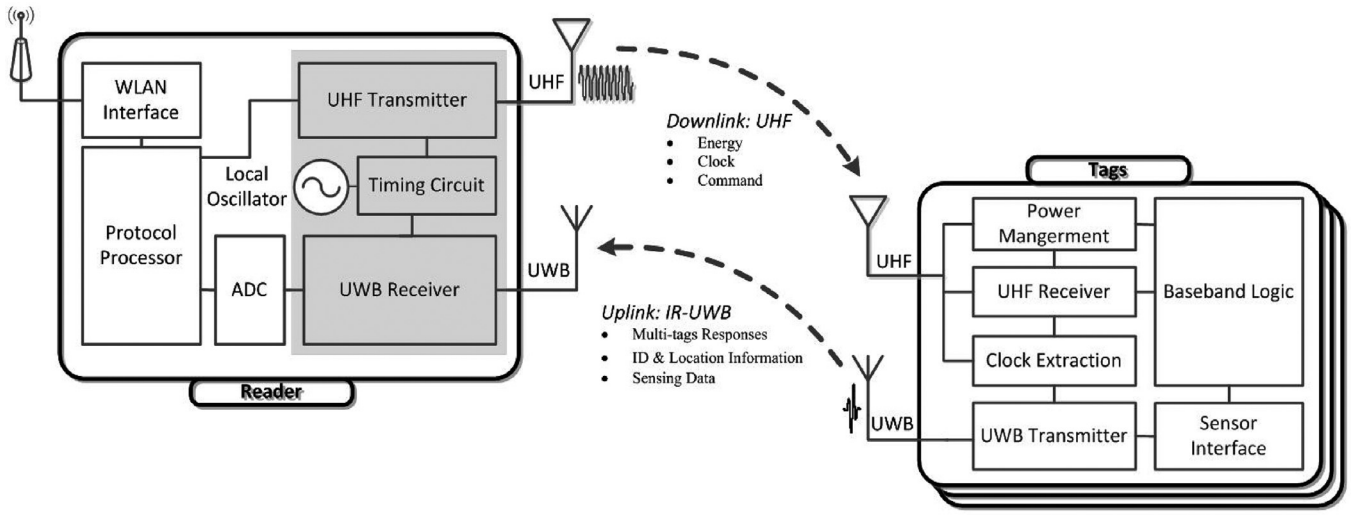

Fig. 1. Asymmetric UHF/UWB wireless link architecture for RFID and WSN.

The paper is organized as follows. Section 2 describes the system characteristics, proposed link architecture and reader operation principles. Circuit-level transceiver architecture and critical blocks of the prototype are explained and analyzed in Section 3. Section 4 summarizes the experimental measurement results which includes the link test with asymmetric RFID tag. Finally, conclusion is given in Section 5.

2. UHF/UWB hybrid RFID

2.1. System characteristic of passive RFID

Different from peer to peer network, the tag-based passive RFID system exhibits a number of inherent features which should be considered in the system level. First, compared with the number of the reader, large amounts of tags are deployed in a reading zone simultaneously. As a consequence, a large system capacity is needed in the massive tags environment. Second, traffic loads between the uplink and downlink are also lopsided. In the downlink, the reader only needs to send and broadcast small amount of data to tags (e.g., synchronization, control command). But, in the uplink, large loaded sensor data on tags should be transmitted back to the reader. If considering the multi-access conditions, even higher communication data rate (tens of Mb/s) is required. Finally, on the hardware perspective, the tags are strictly constrained by cost and power. Thus, tags have very limited resource such as power supply, memory, computational ability and circuitry complexity, while a reader can be a more powerful device.

2.2. Asymmetric UHF/UWB wireless link

The tag-based passive RFID system shows asymmetric characteristic in terms of the system capacity, the traffic load and the hardware complexity. On the other hand, IR-UWB also exhibits an asymmetry: the receiver needs relatively complex hardware implementation, but the transmitter can be extremely low power and low complexity. On the bias of the consideration above, we have proposed an asymmetric UHF/UWB wireless link architecture illustrated in Fig. 1 [9]. Instead of full-UWB or full-UHF wireless link, IR-UWB is introduced for uplink communication from reader to tags, while conventional UHF is applied to power up and correspond the tags for downlink communication.

In the downlink, the reader powers-up the tags using UHF continuous wave (CW) signal. This signal can be also used as a carrier to send commands and clock to the tags, as conventional passive UHF RFIDs. Since the communication is dominated by the uplink, there is no need to apply a high data rate UWB in downlink. Moreover, due to the regulatory constraints, the UWB is aggressively duty-cycled with less than 0 dBm power radiated [11]. It is infeasible to remotely power up the tag at significant distance. Besides, the power consumption and complexity of UWB receiver is too high to implement in passive tags. As a result, a low data rate narrowband radio like UHF is preferred for the downlink communication.

In the uplink, the IR-UWB transmitter uses the scavenged energy to send data for a short time at high data rate. Compared with backscattering UHF RFIDs, ultra-short UWB pulses provide a higher positioning accuracy and wider signal band with high throughput. Baseband-like architecture and low duty-cycled signal promises extremely low power and low complexity transmitter, allowing UWB transmissions in a passive RFID systems. By adapting this approach, tags take full benefits of the UWB technology avoiding complex UWB receiver, but shifts the burden to the reader side, which will be addressed in next section. Table 1 summarizes the characteristic of UHF downlink and UWB uplink.

3. Reader design

The primary task of an RFID reader is to perform identification and positioning, including energy transmission, command dispatch and data reception. As shown in Fig. 2, the asymmetric reader transceiver consists of an UHF transmitter and an IR-UWB receiver. The UHF transmitter includes a fractional-N frequency synthesizer and a modulator which mix the baseband signal to the carrier frequency. The IR-UWB receiver is implemented using energy detectors (ED) for low power and low complexity. Following are some design considerations for the UHF/UWB hybrid reader.

3.1. UHF energy and data transmission

The reader radiates RF energy to power up tags for data receiving and responding. The operation distance usually depends on the energy link, which is limited by reader output power and tags sensitivity. A tunable external power amplifier is preferred to provide flexible and reconfigurable solutions for different standards [12]. For example, 4 W Equivalent Isotropic Radiated Power (EIRP) is allowed to be transmitted in North America regulations, hence the