A Novel Passive Tag with Asymmetric Wireless Link for RFID and WSN Applications

Majid Baghaei-Nejad, Zhuo Zou, Hannu Tenhunen, Li-Rong Zheng
Department of Electronics, Computer and Software System
Royal Institute of Technology (KTH)
Electrum 229, SE-164 40 Kista-Stockholm, Sweden
Email: majidbn|zhuo|hannu|lrzheng@imit.kth.se

Abstract - In this paper, we present a radio-powered module with asymmetric wireless link utilizing ultra wideband radio system for RFID and wireless sensor applications. Our contribution includes using two different standards in uplink and downlink. Such as conventional RFIDs, incoming RF signal transmitted by reader is used to power the internal circuitry and receive the data. However, in upstream link, an IR-UWB transmitter is utilized. Unlike traditional RFID systems, due to great advantages of UWB communication, this tag is very robust to multi-path fading and collision problem and it is more secure against eavesdropping or jamming. The module consists of a power scavenging unit, a RF receiver, an IR-UWB transmitter, digital baseband controller, and an embedded UWB antenna are designed for integration on Liquid-Crystal Polymer (LCP) substrate, using 0.18um CMOS process technology.

Ultra wideband (UWB) techniques using impulse radio have the possibility to achieve high throughput, long operating range, low power consumption, positioning and ranging capability, secure link, and low cost [3]. It is recognized to be a cost-effective way to be integrated in wireless sensor modules and RFID tags.

In this paper we present a passive CMOS module with asymmetric wireless link integrated in a Liquid-Crystal Polymer (LCP) with an embedded small size UWB antenna. It includes an ultra-low power UWB transmitter, a low power RF receiver, a power scavenging unit and a digital baseband controller. The final module is designed in 0.18um CMOS technology.

I. INTRODUCTION

Nowadays, wireless sensor networks (WSN) and Radio Frequency Identification (RFID) are widely used in supply chain for inventory control, product tracking, asset monitoring, space and environment monitoring [1-2]. It merges a wide range of information technology that spans hardware, software, networking, and programming methodology. Passive tags are more interested than active tags, because of their great advantages. Passive tags operate without on-board power source. They obtain operating power from the received electromagnetic wave transmitted by the reader. Compared with active tags, they offer several advantages such as smaller size, lower cost and longer life cycle. Conventional passive tags are based on half-duplex communication using narrow-band radio frequency. The reader sends a RF carrier to the tag, adding additional data by amplitude modulation. In the reverse link, tags backscatter the data by changing the antenna load. In both directions narrowband RF signal is used. However, this simple implementation holds some drawbacks. It is sensitive to interference, multipath fading, multi user interference and collision problem, and susceptible to passive and active attack [2].

In order to address these problems, many proposals have been made. Most of them are improvements in protocol-level or algorithm-level of the communication link and usually increase the circuit complexity, chip area, implementation cost and power consumption. However, utilizing a different communication link could be another solution for these problems.

II. SYSTEM DESCRIPTION

A. System Architecture

The block diagram of the proposed module can be seen in Fig.1. It consists of a power scavenging unit, a power management block, a narrowband receiver, an IR-UWB transmitter, a digital baseband, an embedded UWB, and a dipole antenna.

As can be seen different standards have been used in uplink and downlink. Such as conventional passive RFIDs, incoming RF signal transmitted by the reader is used to provide power supply and receive the data. However, unlike usual RFIDs which back scatter the data to the reader; our proposed tag uses a low power impulse ultra wideband (IR-UWB) transmitter. UWB communication has several advantages that can improve the performance of the whole system [3]. It offers longer operation range with less power consumption and simple hardware implementation.

The short pulses used in UWB communication, brings more security to the system against jamming or eavesdropping. Thus, unlike normal RFIDs, no complex digital cryptography and coding are necessary. It means more reduction in baseband complexity, chip area, total power consumption and cost.

As can be seen later, high speed UWB communication link decreases the collision probability. Therefore, no more complex circuit is needed for anti-collision protocol. On the other hand, more tags can be read in a short time with lower probability of collision.

Ranging and positioning are other benefits that UWB scheme brings to the system. It can be a powerful candidate for asset monitoring and positioning applications.
Digital like UWB transmitter allows the module to adapt data rate based on the channel and power condition. In short range application, when more incoming power is available high data rate is chosen. On the contrary, in long range situations when the received RF signal is weak, data is transmitted in lower data rate which consumes less power.

B. Communication protocol

Our proposed tag has asymmetric link and therefore needs another protocol for communication than conventional RFIDs. A new pipelined communication protocol has been proposed. A successful reading session contains three modes: power-up mode, command mode, and reading mode.

1. Power-Up Mode: The reader radiates the RF signal with no data for at least 7ms which is the time of full charge of the storage capacitor. The tags capture the power by the power scavenging unit and store it in a relatively big capacitor. After gathering enough power tags go to the receiving mode to receive commands from the reader.

2. Command Mode: The reader broadcasts the WUP (wake up) or REQ (request) command in this mode. Such as conventional RFIDs, the reader sends the data by generating a series of gaps in the RF signal [2]. The gaps (3us and 6us represent 1 and 0 respectively and period of 25us) are short enough to allow continues power supply of the tag, but long enough to comply with bandwidth regulations. The WUP activates all tags in the field, while the REQ performs the activation but does not affect tags in halt state.

3. Reading Mode: After receiving the REQ command all active tags in the reading area send their ID based on a pipelined protocol. It employs Frame Slotted ALOHA algorithm as the anti-collision protocol [4]. Each tag transmits its ID to the reader in a randomly selected slot of a frame and listens for an acknowledgment (ACK) response during the next slot. When the reader receives and identifies an ID without any collision, sends an ACK in the next slot. The identified tags go to the halt state after receiving the ACK, in order to decrease the collision. Collided tags resend their ID in the following frames in a new randomly selected slot, until all tags are identified. Figure 2 shows the data process in two following frames.

Due to the using of high speed UWB transmitter, transmission time is very short, and a frame can contain more time slots (e.g. a 0.125ms slot result 4000 slots in a 500ms frame). Therefore, compared to conventional tags with low speed link, the collision probability is significantly degraded.

III. DESIGNING BUILDING BLOCKS

Circuit implementation issues have been considered in order to achieve the desirable properties of the transceivers as well as to verify the proposed system architecture. The design has been done in ADS environment using 0.18um CMOS technology.

A. Impulse UWB Transmitter

Fig. 4 shows the schematic of the IR-UWB transmitter. The original clock and inverted-delayed version of it are applied to the NOR gate and generates a short pulse. A low power pulse shaping circuit filters the pulse to meet the FCC regulations. Duration and pulse amplitude are tunable and these controls enable the module to compensate the process and temperature variations, packaging effects, and nonlinearity of the antenna. On the other hand, this ability allows the module to control the output power and bandwidth in different pulse repetition rates, data rates, and operation ranges. The parasitic effects of ESD protection, packaging and antenna have been considered during the simulation. [5]

B. Energy Scavenging Unit

Passive tags usually obtain power supply from the incoming RF signal by a voltage multiplier. In this work, in order to increase the efficiency and operation range, a schottky diode voltage multiplier is utilized. [6]
To avoid of high cost process with embedded schottky diodes, surface mounted components have been used. On the other hand, high quality factor of off-chip passives causes more improvement in power efficiency and operation range.

Fig. 5 shows the schematic and the layout of the power scavenging unit. All passive components including blocking capacitors and matching network except output capacitor are integrated in LCP substrate. The storage capacitor is charged during the sleep and receiving mode, when the power consumption is less than 2µA. However, UWB transmitter consumes 64µA which is too high to be provided by the received RF signal. Fortunately, due to the using of high speed UWB transmitter, transmitting time is very short (e.g. less than 0.13ms for transmitting 128bits at 1Mbps at 10MHz pulse repetition). Thus, a relatively big capacitor at the output can provide enough current with acceptable voltage drop (e.g. 0.7V with 13nF capacitor). For such big capacitor, surface mounted component is used.

A power management block including a voltage-control Schmitt trigger switch and a low dropout (LDO) regulator is included in the power scavenging unit. Voltage control switch senses the DC output voltage of the power converter and turns on a power switch when the DC voltage is more than 2.5V and turns it off when the voltage is less than 1.8V. When the power switch is on, LDO regulator is activated to produce a constant voltage of 1.8V from the energy stored in the output capacitor. [7]

C. RF Receiver

In order to detect the gaps in the incoming RF signal, an ultra-low power envelope detector and a comparator have been designed. The envelop detector uses the same off-chip voltage multiplier topology than DC power supply, but with smaller capacitors and only 2 stages. A low power discriminator circuit has been designed which decides whether a pulse is long or short and extracts the data. Fig. 6 shows the envelop detector and the comparator, utilized in RF receiver.

D. Integrated UWB Antenna

In order to design the circuit in the presence of the antenna a knight’s helm shape antenna has been considered as the load of the transmitter. It is a double-slotted small size antenna, which shows stable characterizations over the UWB frequency band [8]. Fig. 7 shows the geometry and simulation result of the antenna in LCP substrate. It shows return loss better than -10dB and conversion gain larger than 1.8dB in UWB band.

IV. RESULTS AND DISCUSSION

Fig. 8 shows the simulation results of the power converter circuit. It can provide 2.5V and 2µA output current with minimum -16.6dBm input power. With new regulation in U.S. which allows 4W EIRP emission, it corresponds to 10.7 meter operation range. Considering free space propagation loss and assuming 0dB receiving antenna. This is a huge improvement compared with usual passive tags with operation range of around 1 meter [2], and still a significant improvement compared with [6,9,10].

Simulation results of the RF receiver show the maximum power consumption of 234nA at -17dB received RF input and 40Kbps data rate. This is a great advantage for a self powered module, when the operation range is strongly related to the power consumption. On the other hand, this circuit can be also a powerful candidate for battery powered module with long lifetime. Fig. 9 shows the simulation results of the RF receiver.

Fig. 10 shows the output voltage of the UWB transmitter and normalized radiated power spectral density of the antenna at 10 MHz pulse repetition rate. Results show the maximum power consumption of 64µA and standby power consumption of 1.83nA. This is a great reduction in power consumption. Simulation results show that low data rate UWB communication can be a promising solution for low power applications such RFID and wireless sensor networks. A comparison between this work and some other published works can be seen in Table 1.
V. CONCLUSIONS

In this paper, we have presented a passive CMOS tag with asymmetric link for RFID and wireless sensor applications. It includes a power scavenging unit, an UWB transmitter, a RF receiver, a baseband controller, and an embedded UWB antenna. As conventional RFIDs, the incoming RF signal transmitted by the reader is used to power up the module and receive the data. However, instead of backscatter modulation, a low power impulse UWB radio is utilized to send the data to the reader.

UWB communication brings several improvements to the system. Such as low power consumption, long operation range, higher security, low complexity, low collision probability, positioning capability, and adaptive data rate. A pipelined communication protocol has been proposed which causes lower collision probability and higher throughputs.

Circuit implementation and simulation have been studied in order to verify the system concepts. The UWB transmitter in our proposed tag consumes 64uA at 1Mbps with 10MHz pulse repetition rate. An embedded small size UWB antenna was designed in LCP substrate. It exhibits very stable characteristics with a return loss less than -10dB and conversion gain better than 1.8dB in the UWB frequency range. For RF receiver, the power consumption is less than 234nA at 40Kbps while the input received RF signal is -17dBm.

A power scavenging unit has been design which can provide 2.5V@2uA DC supply at minimum -16.6dBm input power. It corresponds to 10.7m operating range, with 4W EIRP emission.

A power scavenging unit has been design which can provide 2.5V@2uA DC supply at minimum -16.6dBm input power. It corresponds to 10.7m operating range, with 4W EIRP emission.

Our research has revealed that impulse-based UWB is a promising technology for RFID and WSN applications and LCP based System-on-Package technology is a capable technology for complete tag integration including integrated UWB antenna.

Future works will be oriented to implement a matched dipole antenna in the LCP substrate, implementation of the baseband controller for various standards and applications, design a fully integrated module, and implementation aspects of the final module.

REFERENCES