An UHF RFID Tag with Long Read Range

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Abstract— **In this paper, the design of a long read range UHF RFID tag was presented. The read range is one of the key parameters in RFID systems and is frequently evaluated for RFID system assessment. Conventional tag designs were generally focused in saving power consumption, which results in the degradation of the tag sensitivity and a shorter read range. A battery-assisted passive tag provides a better sensitivity in forward-link and the amplification of backscattering signal provides a longer read range in reverse-link. The minimum threshold power of the designed tag was measured to be -23dBm and the amplification of the backscattering signal by 28 dB provided the twice read range of the conventional passive tag, which was predicted by simulation.**

I. Introduction

UHF RFID (Radio Frequency Identification) system generally consists of a reader and tags that modulates the reader signal by passive switching. A reader interrogates multiple tagged-objects within reading zone and tag generates the backscattering signal using the reflection of the received CW (continuous wave) by time varying impedance according to the internal memory of the tag. Such backscattering results in the modulation of reader signal [1] and the spectrum are located so close due to slow modulation of tag. The reader receives the backscattered signal and identifies tag. The controller or host computer connected to the RFID reader provides various application services such as collecting, storing, processing and tracking tagged objects.

The read range is defined as the distance between a reader and tag that a reader can recognize tag. The read range is one of key parameters in RFID system assessment. The read range can be classified into two read ranges; one is forward-link read range from reader to tag and the other is reverse-link read range from tag to reader. The smaller one is decided to be the read range [2]. The forward-link read range is defined by the distance the reader signal can wake up tag. The reverse-link read range is defined by the distance the reader can detect the backscattered signal of tag. The former can be generally improved by decreased power consumption in tag chip and the latter can be done by better reader's sensitivity.

This paper proposes the improvement of two read ranges; the forward range is improved by battery-assisted tag and the reverse link range is done by the amplification of the backscattering signal. While the received power in tag is generally backscattered using passive modulation in conventional RFID system, the backscattered signal is amplified in the proposed method. This approach results in the improvement of the reverse-link read range. In addition, tag's sensitivity can be also improved by on-board battery in forward-link.

The forward and reverse link budget analysis for the read range in passive RFID system was presented in following section II. Overall operation of the proposed system was described in section III and the measured results were shown in section IV. The conclusion was in Section V.

II. Read Range Analysis

Since a distance of reader to tag is short in passive RFID system, Friis's free-space propagation formula can be used for computing the read range of passive RFID system. [3].

$$P_{RX,tag} = P_{TX,reader} G_{reader} G_{tag} \left(\frac{\lambda}{4\pi r} \right)^2 T_b \quad (1)$$

$$P_{RX,reader} = P_{TX,reader} T_b G_{reader}^2 G_{tag}^2 \left(\frac{\lambda}{4\pi r} \right)^4 \quad (2)$$

where, $P_{RX,tag}$, $P_{TX,reader}$, G_{reader} , G_{tag} , T_b , λ , and $P_{RX,reader}$ represent the received power at tag, the transmitted power from reader, the Tx antenna gain of reader, the Rx antenna gain of tag, backscattered transmission loss, wavelength, and the received power in reader, respectively [4]. The forward-link received power at tag is proportional to $1/r^2$ as in (1). The reverse-link received power at reader, which is transmitted from tag to reader, is proportional to $1/r^4$. This indicates that the improvement in forward-link is less effective than that in reverse-link.

Based on Friis's equation, the powers $P_{RX,tag}$ and $P_{RX,reader}$ are shown in Fig. 1 by black solid line and red dotted line respectively. In the forward-link, a tag generates DC supply voltage with the transmitted power from reader because the conventional passive tag has no on-board battery. The transmitted power strength at tag should be large enough to generate DC power supply to tag (wake-up). The threshold power determines the forward-link read range. Generally, the forward-link read range is defined as the minimum threshold power required from tag. In Fig. 1, the threshold is about -9 dBm for Impinj Monza tag and about -14 dBm in Alien Higgs tag [5]. Thus for a reader of 4 W EIRP, Alien Higgs tag chip can be used below 9 m in LOS (Line of Sight) environment as shown in Fig. 1 and Impinj Monza tag has a shorter range than Alien Higgs.

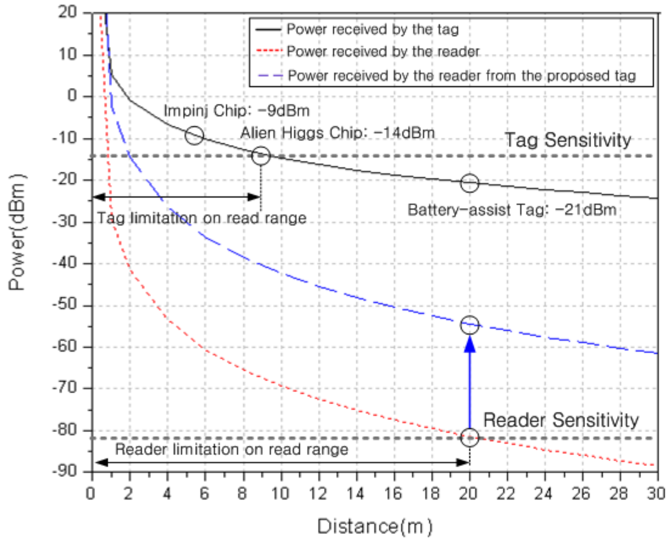


Fig. 1 Forward and reverse link budget for a passive tag

The reverse link range can be also found using Fig. 1. For a tag with a minimum threshold of ≤-21 dBm (so the forward link read range is -21 dBm) and placed at 20 m distance, a backscattered signal to a reader is found to be ≤-80dBm which is shown by the red dotted line from the equation (2) in Fig. 1.Thus the reader should have the sensitivity of≤-80dBm to recognize such tag. However, it is difficult to design a reader with the sensitivity of below -80 dBm due to communication environments. The spectrums of the transmitted and received signals are too close in passive RFID system. The transmitter and receiver signals in reader are generally isolated by circulator. The transmitted signal in reader leaks into the receiver in reader due to the imperfect isolation of circulator. The leakage power results in the degradation of the sensitivity and make difficult to detect small tag's backscattered signal. Commercial readers show the sensitivity of -50 to -60 dBm. This is one of disadvantages in passive modulation. The reverse-link read-range consequently becomes shorter and many researchers have been studying to overcome the leakage of transmitted power [6].

III. Long Range RFID Tag

As analysed in Section II, the commercial passive RFID tag in UHF band has the read range of less than 10m. In this paper, two concepts were introduced to extend the read range to 20m and more. The battery-assisted passive tag was applied to increase the forward-link read range. The reverse-link read range was achieved for the amplification of backscattered signal, which is possible due to on-board battery.

A. Battery Assisted Passive Tag(BAP)

Generally, a conventional passive RFID tag has no battery because the tag power is generated with the transmitted power from a reader. The battery generated by Tx power is dominantly used for DC supply for passive tag, and negligible power consumption for communication. The passive tag consists of analog / digital circuits and memory as shown in Fig. 2, and most part of battery is used to drive these circuits.

The activation command from reader controlling tag's status prevents continuous power consumption in BAP. Initially BAP stays into hibernate mode (or sleep mode) and, once it receives activation command, it is in active mode and talks to reader. Backscattering modulation is also used in this status. The backscattering modulation is achieved simply by switching the impedance connected to tag antenna and results in smaller power consumption. Fig. 2 shows the structure of such BAP.

So the on-board battery is effective to solve short distance problem in forward-link read range. With on-board battery, the passive tag without amplification, the forward-link read range can be easily improved by 20~30m.

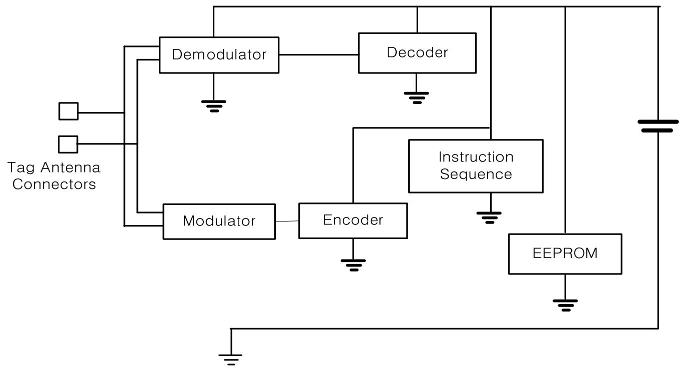


Fig. 2 The structure of battery assisted passive tag (BAP)

B. Backscattered Signal Amplification

Fig. 3 shows the proposed backscattered signal amplification. As shown in Fig. 3, the transmitted electromagnetic wave (S) from reader comes into port 1 of circulator through tag antenna. The tag impedance is changed by a switching circuit and the reflected power at port 2 is directed to port 3 of the circulator. The reflected signal is amplified and then radiated by antenna. Consequently the reader receives a stronger backscattered signal. The received power at reader by the amplified backscattering signal is shown in Fig. 1. The amplification is about 28 dB. The reader located at 20 m from tag and its sensitivity about -50 to -60 dBm is found to be enough to detect the backscattered signal. As described in Section II, the reader sensitivity below -80dBm is required for 20m reverse-link read range. However, with the proposed method, the reverse-link read range can be increased without reader improvement.

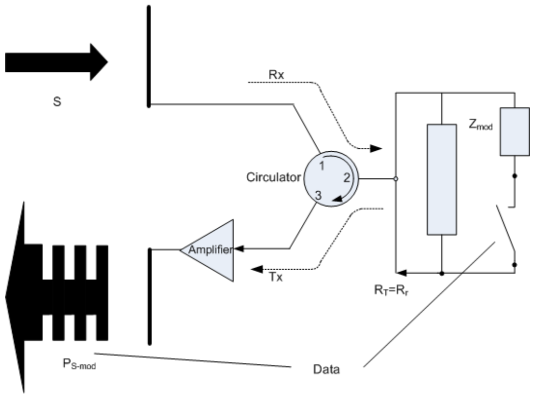


Fig. 3. Proposed structure for amplification on backscattering signal

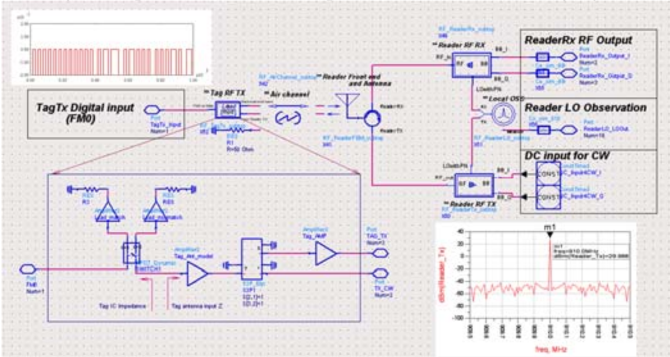
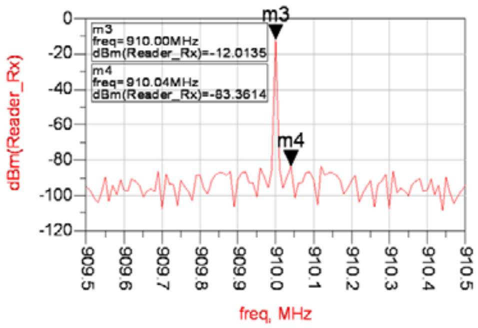
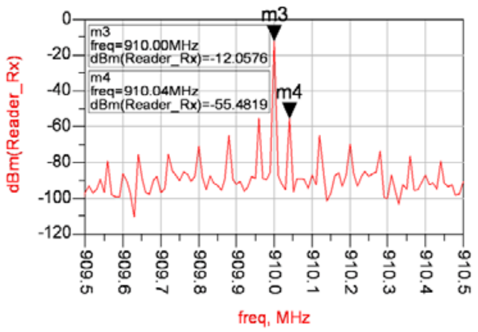


Fig. 4 ADS simulation environment to improve reverse-link read range



(a) Passive Tag backscattering signal spectrum



(b) The proposed tag backscattering signal spectrum

Fig. 5 Simulation results of backscattered signal spectrums in reverse-link

The simulation using ADS is shown in Fig. 4. The reader EIRP was set to 4W on UHF band. Friis's equations are used to model the propagation loss. After wake-up tag by CW reader signal, the reader transmits its information with FM0 encoding at 40kbps. Tag's information is then transmitted to reader with back-scattering modulation. Figure 5 shows the simulation results. The received power at reader is shown in Fig. 5(a). The power of -12dBm represent CW power with no information and the power -83dBm above the frequency is the tag's backscattered power. The reader is away from tag by 20 m. Figure 5(b) shows the received power at reader for the proposed tag shown in Fig. 3. The tag's backscattered power is observed to be stronger. The amplification of backscattered signal was 28dB. Considering the conventional reader sensitivity about -55dBm, the proposed BAP is concluded to be in reading zone of 20m and more.

IV. Fabrication and Measurement

The proposed BAP was fabricated as Fig. 6. The board size was 5.3cm by 5.3cm. Fig. 6(a) shows the top view of the fabricated tag which consists of analog circuit, digital circuit, and battery. Fig. 6(b) shows antenna of the tag which located on the back panel. The circulator on analog circuit has specification as following:

- Frequency: 908 ~ 915MHz
- Insertion loss: 0.6dB
- Isolation: 28dB

The amplifier with a gain of maximum 30dB was used on the path of backscattering signal. The tag uses two separate antennas and was designed with two orthogonal linear polarizations to improve the isolation.

a) Front panel (b) Back panel

Fig. 6 Photograph of the fabricated tag

Figure 7 shows the experimental setup to measure the performance of the designed BAP. Reader emulation board radiates 1W CW(continuous wave) and, after tag receives reader's power, it sends the encoded data of FM0 40kbps with backscattering modulation. To implement 40dB transmission/reception isolation in reader, the backscattered signal is combined with local oscillator signal and the resulting transmission leakage power was -10dBm.

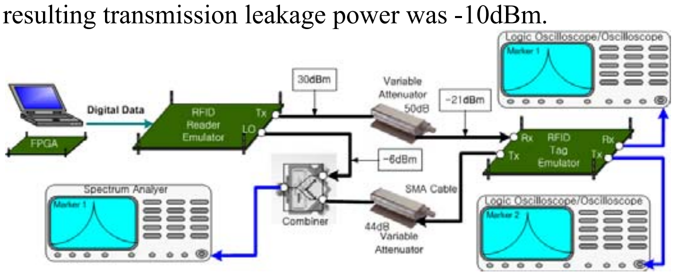


Fig. 7 Measurement setup with reader emulator and proposed BAP

Fig. 8 shows the measured power spectrum of backscattered signal at reader and the distance of 20m is implemented with variable attenuator. Tag's backscattered signal in reader is about -83dBm in case of a general tag and -55dBm in case of the proposed BAP.

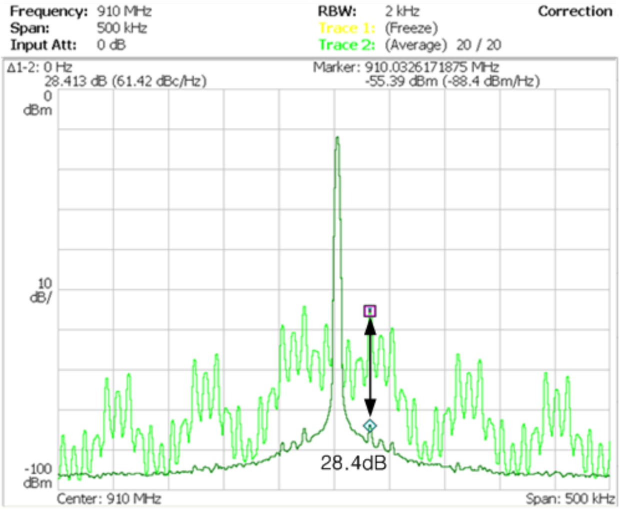


Fig. 8 Backscattered spectrum measured in reader on setup in Fig. 7.

Compared with an experiment using reader emulator in Fig. 7, commercial reader (SAMsys reader) was used in Fig. 9. SAMsys reader [7] can radiate a power with maximum 1W and the frequency hops in 902~928MHz. Variable attenuator was controlled so the received power at BAP to be -21dBm. The backscattered power from BAP was measured at reader is shown in Fig. 10. The backscattered power is amplified by about 28dB in the tag. The reader sensitivity was required about -55dBm in the measurement. The employed reader sensitivity showed about -60 ~ -70dBm, the proposed BAP can successfully talk with them on 20m read range.

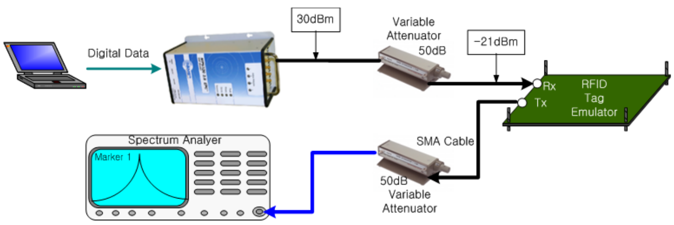


Fig. 9 Measurement setup with commercial reader and proposed BAP

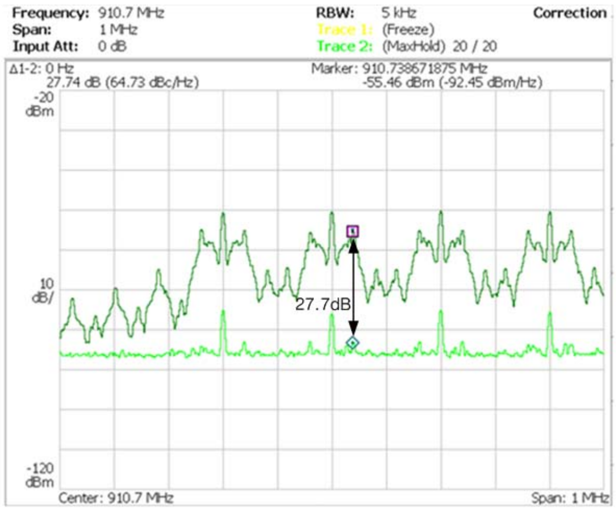


Fig. 10 Backscattered power measured in reader on setup in Fig. 9.

V. CONCLUSIONS

The new method to improve the read range of passive RFID system in UHF band was proposed in this paper. While the commercial reader and tag for passive UHF RFID system shows the read range of 9m and less, the proposed BAP has 20m read range with commercial reader.

ACKNOWLEDGMENT

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