Analysis and Simulation of UHF RFID System

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Abstract

This article presents the analysis and simulation of UHF RFID system. The simulation is divided into the transmitter and receiver part using Matlab/Simulink. The architecture of the model is described in details, and is flexible to achieve different modulation and encoding types. Finally, some results of the simulation are presents.

1. Introduction

Radio Frequency Identification (RFID) systems use radio frequency to automatically identify products. The RFID system contains two parts, Reader and Tag. The different transmission frequencies are classified into the four basic ranges, LF (low frequency, e.g. 125KHz), HF (high frequency, e.g. 13.56MHz), UHF (ultra high frequency, e.g. 868MHz or 915MHz) and microwave (e.g. 2.4GHz). For LF and HF RFID, the read range is usually less than 60cm. For microwave RFID, because of the sensitivity to the environment, the maxim reader range is about 1m. For UHF RFID, the read range can generally reach to 5m. Also the RFID system can be classified into active RFID (Tag with battery) and passive RFID (Tag without battery). In this paper, we only discuss the passive UHF RFID system.

In passive RFID, Reader should send out electromagnetic waves first to wake-up Tag, and then transmit the modulated wave to command Tag. A passive tag absorbs power from the field created by the reader and uses it to power the microchip's circuits. Then Reader transmits continuous wave (CW), while Tag backscatters the information.

There are many protocols about UHF RFID, in this paper, the simulation is mainly based on EPC Class 1 and EPC Class 1 Generation 2 UHF RFID (abbreviate as Gen 2) protocols.

2. Modeling and simulation

2.1 The transmitter

The architecture of transmitter shows in Fig.1.

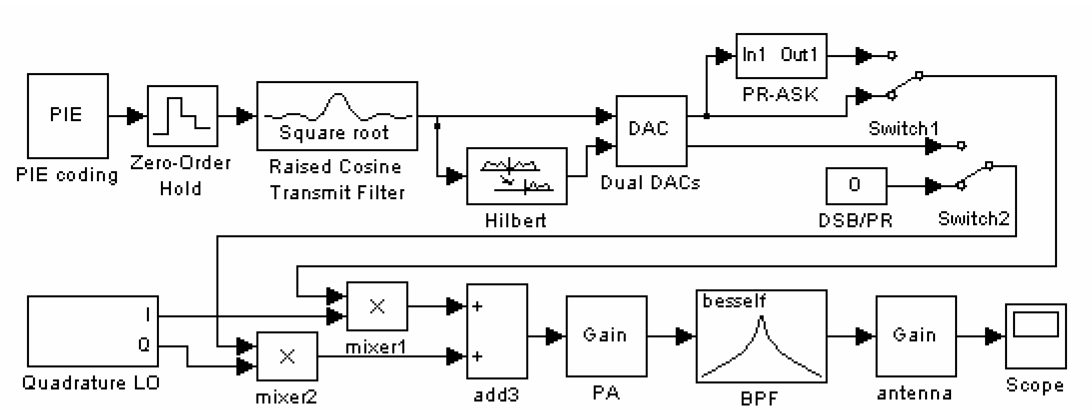

Figure 1. Simulation of Transmitter

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2.1.1 Forward Link Encoding. In both the Class 1 and the Gen 2 protocols, binary data from Reader to Tag is encoded as Pulse-interval encoding (PIE) of the low amplitude pulse. But there are some differences between them and is specified in Fig.2 and Fig.3, where T_0 is the master clock interval.

Fig.2 shows the PIE encoding in Class 1 protocol, where data-0 is encoded by a 1/8 T_0 pulse width modulation, data-1 is encoded by 3/8 T_0 pulse width modulation, and T_0 is defined as 14.25μs (in North America) or 66.67μs (in Europe). So the data rate of forward link is 70.18Kbps (in North America) or 15Kbps (in Europe).

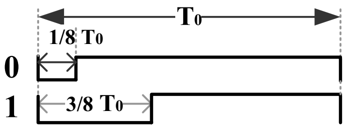

Figure 2. Class 1 Forward link PIE encoding

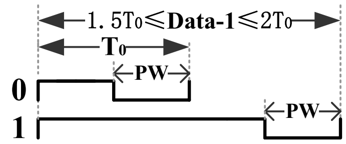

Figure 3. Gen 2 Forward link PIE encoding

Fig.3 shows the Gen 2 protocol PIE encoding, where the duration of data-0 is T_0, the duration of data-1 is between 1.5 T_0 and 2 T_0, the value of Pulse Width (PW) is from $0.265T_0$ to $0.525T_0$. The value of T_0 is between 6.25μs and 25μs. So the data rate of forward link is between 26.7Kbps and 128Kbps.

2.1.2 Modulation. In Class 1 protocol, the reader shall communicate with the tag by Amplitude Shift Keying (ASK) modulation, and the modulation depth is from 30% to 100%. In Gen 2 protocol, the reader shall use double-sideband amplitude shift keying (DSB-ASK), single-sideband amplitude shift keying (SSB-ASK) or phase-reversal amplitude shift keying (PR-ASK), and the modulation depth is from 80% to 100%. By the architecture in Fig. 2 of the simulation, it can implement all these modulation types.

Assuming that the input signal is f(t), which is the binary data passed through raised cosine filter, DAC and filter etc. Local oscillation uses dual orthogonal signals to generate the SSB-ASK modulated wave, denote as sin ω t(I branch) and cos ω t(Q branch). For other modulation types, it should adjust the input of Q-branch to 0. The modulation depth is only depending on the proportion of AC offset and DC offset. PR-ASK modulation inverts the phase at every symbol binary. For example, if the first symbol is positive, then the next symbol must be negative. This modulation can be implemented by changing the code type.

2.2 The receiver

The architecture of Reader receiver in simulation using Matlab/Simulink is shows in Fig.4.

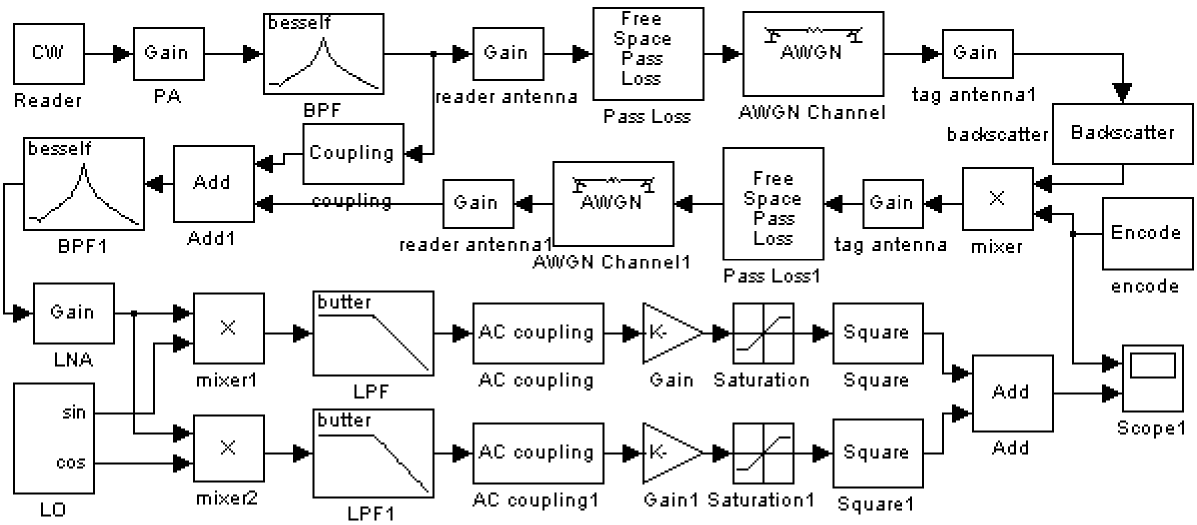

Figure 4. Receiver simulation

2.2.1 Return Link Encoding. In Class 1 protocol, Tags reply to Reader commands with backscatter modulation with the encode form shown in Fig.5, where two transitions are observed for a binary zero and four transitions are observed for a binary one during one Bit Cell. And the data rate of return link is 140.35Kbps (in North America) or 30Kbps (in Europe).

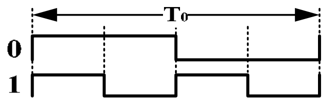

Figure 5. Class 1 return link encoding

In Gen 2 protocol, Tags shall encode the backscattered data as either FM0 baseband or Miller modulation of a subcarrier at the data rate. The Reader selects the encoding type. Fig.6 shows basis functions for generating FM0 (bi-phase space) encoding, the data-0 or data-1 should be encoded like the form in the Fig.6. FM0 inverts the phase at every symbol boundary; a data-0 has an additional mid-symbol phase inversion.

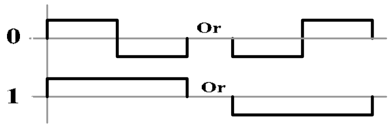

Figure 6. Gen 2 return link FM0 encoding

Fig.7 shows basis functions for generating Miller encoding. Baseband Miller inverts its phase between two data-0s, a data-1 has an additional mid-symbol phase inversion. The Miller subcarrier waveform is the baseband waveform multiplied by a square-wave at M times the symbol rate, and the value of M can be 2, 4 or 8(selected by the Reader).

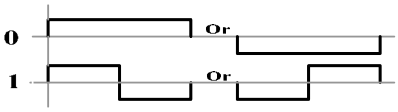

Figure 7. Gen 2 Miller baseband encoding

2.2.2 Free Pass Loss. The formula of the free space pass loss is

$$Ls(dB) = 32.45 + 20\lg f(MHz) + 20\lg d(Km) \quad (1)$$

where f is the carrier frequency, d is the distance between Reader and Tag.

2.2.3 Backscatter. In the return link, Tag communicates with the Reader by backscatter modulation. During backscatter Reader transmits an un-modulated continuous wave (CW) signal, then Tag modulates its reflection of the CW signal. In Class 1 protocol, Tag modulates the amplitude of the carrier (ASK). In Gen 2 protocol, Tag modulates the amplitude and/or phase of the carrier (ASK and/or PSK).

Modulation of the backscattered wave is achieved by changing the tag IC's input impedance between two different states

$Z_1 = R_1 + jX_1$ and $Z_2 = R_2 + jX_2$

For ASK, it is achieved by a change in the real part of the impedance and of the reflection coefficient. And PSK is achieved by changing the imaginary part of the input impedance and of the reflection coefficient. In this paper, it will only discuss the ASK case.

2.2.4 Tag Reflection Power. In backscatter, the reflection coefficient is defined as:

$$\rho_{1,2} = \frac{Z_{1,2} - Z_{ant}^*}{Z_{1,2} + Z_{ant}} \quad (2)$$

where $Z_{ant} = R_{ant} + jX_{ant}$ is the input impendence of antenna, $Z_{ant}^* = R_{ant} - jX_{ant}$ is the complex conjugate of the antenna impedance. If the antenna and IC are optimum matched, then $Z_{1,2} = Z_{ant}$.

Assuming the available power received by Tag is P, and the two states of IC are active an equal amount of time, then the reflect power is:

$$P_{back} = \frac{P}{4L_{ant}} |\rho_1 - \rho_2|^2 \quad (3)$$

where L_{ant} is antenna loss factor. If antenna and IC is optimum matched in one state, $\rho_1 = 0$, and totally un-matched in the other state, $\rho_2 = 1$, and if there is no antenna loses $L_{ant} = 1$, then reflect power is 25% of the available received power.

2.2.5 Demodulation. As analysis above, the Tag reflection power is much weaker than the Reader transmit power, and Reader transmits CW signal and receives the backscatter signal at the same time. So the key problem of Reader is the receiving. The method to solve this is using the Zero-IF receiver, namely the frequency of local oscillator is the same as carrier frequency.

Because Reader transmits CW signal and receives the backscatter signal simultaneously, so there may be part of the CW signal leak into the receive circuit, denotes as: $A\sin\omega t$

For Tag backscatter signal, Tag modulates its data on this CW signal, and it may have a random phase, so it denotes as: $f(t)\sin(\omega t+\vartheta)$

To solve the phase problem, the receive circuit uses dual orthogonal local oscillation signals: $2B\sin\omega t$ and $2B\cos\omega t$ (multiple of 2 is for convenience)

In I-branch:

$$\begin{aligned}&[A\sin\omega t+f(t)\sin(\omega t+\theta)]*2B\sin\omega t\\&=-[AB*\cos(2\omega t)-AB*\cos(0)]\\&\quad -Bf(t)*[\cos(2\omega t+\theta)-\cos\theta] \qquad (4)\\&=-AB\cos(2\omega t)+Bf(t)\cos\theta\\&\quad +AB-Bf(t)\cos(2\omega t+\theta)\end{aligned}$$

After passing a low-pass filter and wiping off the DC offset, then the I-branch signal will be: $Bf(t)\cos\theta$

In Q-branch:

$$\begin{aligned}&[A\sin\omega t+f(t)\sin(\omega t+\theta)]*2B\cos\omega t\\&=AB*\sin(2\omega t)+AB\sin(0)\\&\quad +Bf(t)[\sin(2\omega t+\theta)+\sin\theta] \qquad (5)\\&=AB\sin(2\omega t)+Bf(t)\sin(2\omega t)+Bf(t)\sin\theta\end{aligned}$$

After passing a low-pass filter and wiping off the DC offset, then the I-branch signal will be $Bf(t)\sin\theta$

As analyzed above, using the Zero-IF receiver can solve the leaked CW problem. And along with the changing of the random phase θ, every branch signal may be positive, negative or zero. And because of the orthogonality, dual branches will not be zero simultaneously. Then square the two branches and add them up, the result is $B^2f^2(t)$. This will solve the phase problem. As the ASK signal is unipolar, so the square operation will not affect the signal shape, but only alter the signal amplitude, thus we can demodulate the Tag signal $f(t)$.

3. Simulation results

3.1 Simulation results of transmitter

In this part, several simulation results are presented by changing the modulation and encoding types.

Fig.8 shows the modulation results using PIE encoding according to the Class 1 protocol. And the modulation depth is 100%(above) and 30%(below).

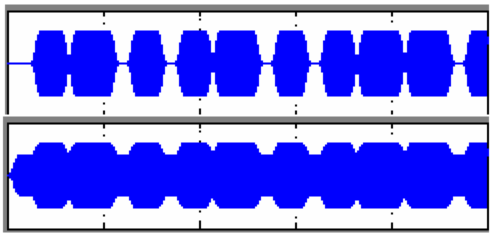

Figure 8. Class 1 PIE Modulation

Fig.9 shows the modulation results using PIE encoding according to the Gen 2 protocol using DSB-ASK modulation. And the modulation depth is 100% (above) and 80% (below).

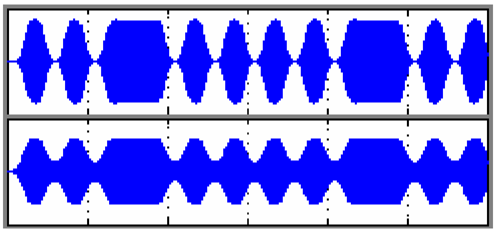

Figure 9. Gen 2 DSB modulation

Fig.10 shows the modulation results using PIE encoding according to the Gen 2 protocol using SSB-ASK modulation. And the modulation depth is 100% (above) and 80% (below).

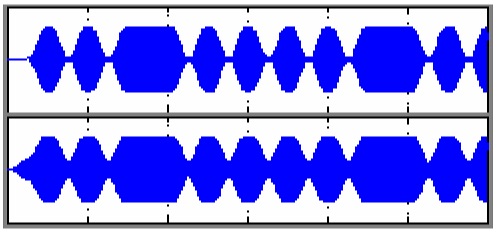

Figure 10. Gen 2 SSB modulation

Fig.11 shows the modulation results using PIE encoding according to the Gen 2 protocol using PR-ASK modulation. And the modulation depth is 100%.

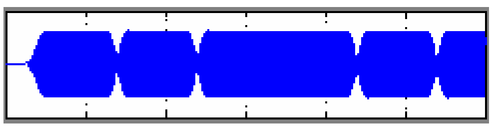

Figure 11. Gen 2 PIE coding PR-ASK

Fig.12 shows the detail between two symbols, the phase reversal between symbols can be seen clearly.

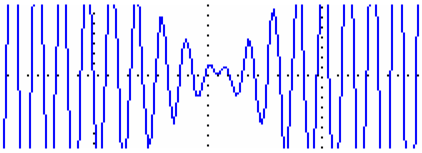

Figure 12. Phase reversal between symbols modulation

3.2 Simulation results of receiver

In the simulation, the transmit power is designed to be 36dBm (EIRP), the gain of antenna is set to be 6dB. Fig.13 shows the demodulated signal. And the distance between reader and tag is 1m (above) and 5m (below).

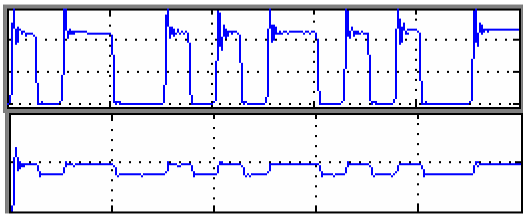

Figure 13. Receive Signal

The simulation results below are the compare of Tag encoding data and Reader demodulated data in different encoding types, Tag encoding sequence are all “0110010011” in three pictures. The distance between Reader and Tag is 1m. And the received signal is rectified by amplifier and limiter.

Fig.14 shows the demodulation results using the encoding according to Class 1 protocol. The above signal is Tag baseband data, and the below signal is the Reader demodulated signal.

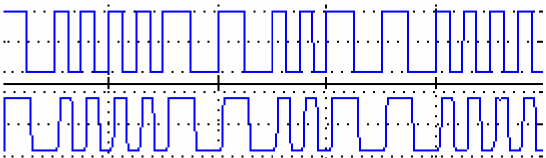

Figure 14. Class 1 encoding demodulation

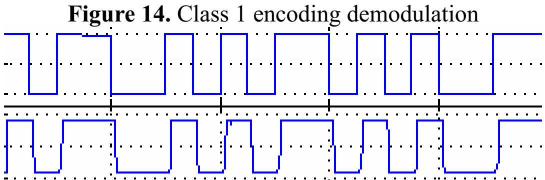

Figure 15. Gen 2 FM0 encoding demodulation

Fig. 15 shows the demodulation results using FM0 encoding according to Gen 2 protocol. The above signal is Tag baseband data, and the below signal is the Reader demodulated signal.

Fig. 16 shows the demodulation results using Miller subcarrier according to Gen 2 protocol, where the value of M is 2. The above signal is Tag baseband data, and the below signal is the Reader demodulated signal.

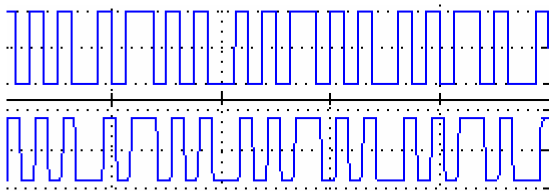

Figure 16. Gen 2 Miller subcarrier demodulation

4. Conclusion

In this paper, a RFID system is modeling and simulated based on two protocols. In the simulation, different encoding and modulation types are used. The architecture of the receiver is designed to solve the CW leak problem and the random phase problem. From the simulation results of receiver, Tag backscatter information can be entirety demodulated.

References

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