Improved Coded Mark Inversion for the Passive Radio Frequency Transmission System of the Electronic Time Fuze

Dong Xiong, Xiaoping Zeng, and Xiaogang Zhao

ABSTRACT—To fit the limited volume and power consumption of the passive radio frequency transmission system of the electronic time fuze, an improved coded mark inversion (CMI) is proposed in this letter. From the performance analysis, the energy transmission efficiency of this encoding method is at least 50% higher than that of CMI and NRZ. Finally, the experiment results show that by adopting this improved CMI, the change of DC voltage through magnetic coupling is lower than 0.2 V when the accuracy of data transmission is above 99.5%.

Keywords—Passive radio frequency transmission system, energy transmission, data transmission, improved CMI.

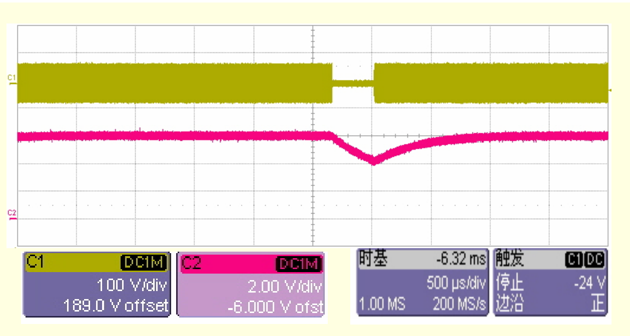

Fig. 1. Antenna voltage and DC voltage of receiver.

I. Introduction

The data and the energy transmission of the passive radio frequency transmission system (PRFTS) is achieved through the magnetic coupling of the oscillating circuits. Its working principle is the same as that of radio frequency identification (RFID) [1], [2]. However, the clock frequency of the microcontroller used in demodulation and decoding should be limited because the volume and power consumption of the electronic fuze are limited, and the crystal oscillator cannot be used in a high overload environment (above 300,000 m/s^2). Thus, the data transmission rate is limited. To ensure the low cost and reliability of the system, the data transmission rate employed in this system is 25 kbps, which is much lower than the 106 kbps rate used in ISO 14443 of RFID [3].

Even though the NRZ and the modified Miller are widely used in ISO 14443 of RFID, they are not appropriate to be used in this system for the following reasons. If the NRZ is employed, the energy sharply decreases or even shortly cuts off when a continuously low level appears in the data transmission as shown in Fig. 1. In this diagram, the transmission data is hexadecimal 00H, channel 1 is the waveform of the receiver antenna voltage, and channel 2 is the waveform of the DC power voltage of the receiver produced by the magnetic coupling. If the improved Miller is employed, it can easily solve the energy problem. However, the extraction of bit timing signals is complicated during the decoding [4], so a specialized decoding circuit is needed. Because of the previously mentioned limitations of traditional methods, a new improved encoding method is proposed in this letter. In light of its similarities to coded mark inversion (CMI), we call the new encoding method improved CMI.

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II. Improved CMI

In the encoding method, bit 1 is represented by a rectangular wave of a certain duty cycle. When the bit is 0, there are two possibilities. When the previous bit is 0, it can be represented by a rectangular wave of a certain duty cycle which differs from the duty cycle when the previous bit is 1. When the previous bit is 1, it can be represented by a high level as shown in Fig. 2.

The low level time of bit 1 is T_{l1}, and that of bit 0 is T_{l0}. The shortest time of the signal that can be recognized by the hardware of the receiver is $T_{d\,min}$. For bits 0 and 1 to be recognized, T_{l1} must not be equal to T_{l0}. If $T_{l0} > T_{l1}$, then the relations among the times in the encoding process are

$$T_b = T_S \geq T_{l0} > T_{l1} \geq T_{d\,min}. \tag{1}$$

Here, T_S represents the time duration of symbols after encoding, and T_b represents the time duration of the symbols of the signal resource. To simplify the calculation, we suppose that $T_{l0}=2T_{l1}$, and $T_{l1}=\alpha T_S$. Here, α is proportional factor, $0<\alpha\leq 0.5$ (when $\alpha=0.5$, it is CMI).

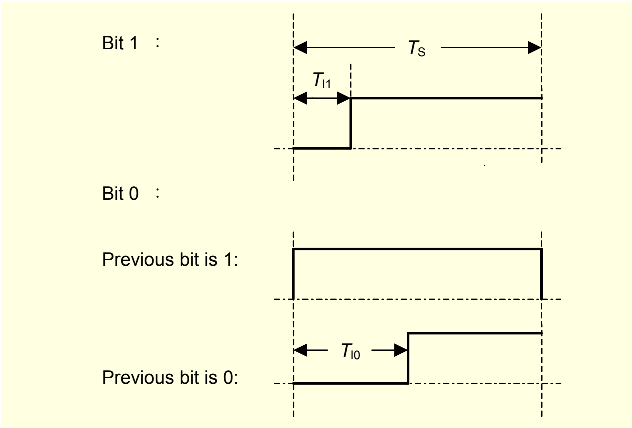

Fig. 2. Encoding method of improved CMI.

III. Performance Analysis

1. Performance Analysis of Energy Transmission

Suppose the high level amplitude is A, the low level amplitude is zero, and the probabilities of 1 and 0 to be output by the information source are equal and independent. Therefore, the probabilities of symbols to be output by improved CMI are $P_1=0.5$, $P_2=0.25$, and $P_3=0.25$.

The average energy E_{avg} of improved CMI can be calculated through the energy formula. That is,

$$\begin{aligned} E_{avg} &= P_1E_1 + P_2E_2 + P_3E_3 \\ &= A^2(T_b - \frac{1}{2}T_{l1} - \frac{1}{4}T_{l0}). \end{aligned} \tag{2}$$

In the same way, the average energy of CMI can be calculated as

$$E_{CMI} = \frac{1}{2}A^2T_b. \tag{3}$$

From (2) and (3), we can get the following relation:

$$\begin{aligned} E_{avg} - E_{CMI} &= A^2(T_b - \frac{1}{2}T_{l1} - \frac{1}{4}T_{l0} - \frac{1}{2}T_b) \\ &= A^2(T_b - \frac{1}{2}\alpha T_b - \frac{1}{4}\times 2\alpha T_b - \frac{1}{2}T_b) \\ &= A^2(\frac{1}{2}T_b - \alpha T_b). \end{aligned} \tag{4}$$

Only if $\alpha<0.5$, then $E_{avg}-E_{CMI} > 0$, that is, $E_{avg} > E_{CMI}$. From this, it is apparent that if improved CMI is adopted, it can improve the transmission energy during data transmission, and the improved ratio λ can be calculated as

$$\lambda = 1 - 2\alpha. \tag{5}$$

In the same way, this relation expression is valid for the NRZ.

2. Analysis of Bit Error Rate

The binary amplitude shift keying non-coherent demodulation method is adopted to demodulate the improved CMI in the added white Gaussian noise (AWGN) channel [5]. The bit error rate (BER) is analyzed as follows.

The probabilities of the high level and the low level are expressed as

$$P_H = (1-\alpha)\;\; P_1 + P_2 + (1-2\alpha)P_3 = 1-\alpha \tag{6}$$

$$P_L = \alpha P_1 + 2\alpha P_3 = \alpha. \tag{7}$$

Therefore, the BER is

$$P_e = (1-\alpha)P_{eH} + \alpha P_{eL}. \tag{8}$$

Here, P_{eH} is the BER when the symbol is the high level, and P_{eL} is the BER when the symbol is the low level. Suppose the optimal threshold level V_T is A/2, then

$$\begin{aligned} P_e &= \frac{1}{2}(1-\alpha)\mathrm{erfc}(\frac{A}{2\sqrt{2}\sigma_n}) + \alpha e^{(-\frac{A^2}{8\sigma_n^2})} \\ &= \frac{1}{2}(1-\alpha)\mathrm{erfc}(\sqrt{\frac{E_b}{4(1-\alpha)n_0}}) + \alpha e^{(-\frac{E_b}{4(1-\alpha)n_0})}. \end{aligned} \tag{9}$$

Their BERs are shown in Fig. 3. As seen in the simulation graph, the increase of α can decrease the BER with the same signal to noise ratio.

3. Choice of the Parameter

In this design, the system demands accuracy above 99.5% to

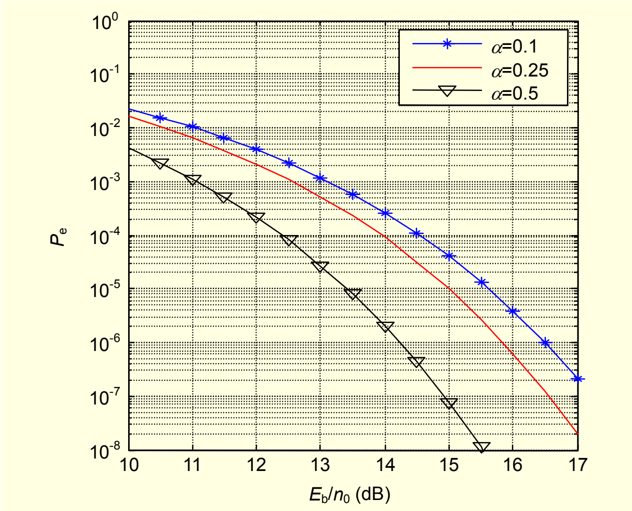

Fig. 3. BER of 2ASK non-coherent demodulation.

transmit 4 bytes when the signal-to-noise ratio is 15 dB, that is, when the BER is below 8.83×10^{-5}. As shown in Fig. 3, as long as α is greater than 0.1, it can meet these demands. To ensure there is a margin, α=0.25 is chosen in this system. The improved efficiency is λ=50%.

4. Decoding of the Improved CMI

In the encoding method of improved CMI, each falling edge is the beginning moment of a symbol. The microcontroller in this system has the function of activating the interruption program through the falling edge on chip's pin; therefore, it can capture the symbol easily and quickly.

The clock in the system comes from the resistance and capacitance oscillator, which has weak stability, so the signals provided by the microcontroller's timer during the demodulating process have some errors. If the errors accumulate, they can cause demodulating and decoding default. However, if the proposed method is adopted, the starting moments of symbols can be captured more frequently; therefore, the accumulation of errors will not happen.

IV. Experiment Verification

MSP430 is adopted in the PRFTS of electronic time fuze as the microcontroller of the receiver. It can only work steadily if the power voltage is greater than 1.8 V. When the transmission data is hexadecimal 00H, the actual measured waveform of the DC voltage fulfilled by magnetic coupling is shown in Fig. 4. From the diagram, it can be seen that if the improved CMI is adopted, it can greatly improve the transmission energy during data transmission. After the verification of the experiment, when the clock frequency is 1 MHz, it can decode correctly,

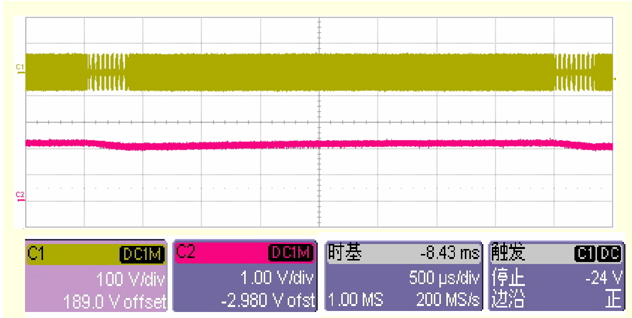

Fig. 4. Improved antenna voltage and DC voltage.

and the decode time is less than 0.1 ms.

V. Conclusion

According to our analysis, the proportional factor α of the improved CMI is the key factor to determine the encoding performance. It influences both the efficiency of energy transmission and the BER of the system. When α=0.25, it can ensure accuracy above 99.5% to transmit 4 bytes. The efficiency of energy transmission is 50% higher than for NRZ and CMI. At the same time, improved CMI can locate symbols easily and eliminate the accumulation of timer errors.

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