Research on MSK Demodulation Method for M-Sequence in IFF System

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Abstract. M-Sequence, short for Maximum Linear Feedback Shift Register Sequence, is widely used in identification friend or foe (IFF) system because of its good equalization and autocorrelation characteristics, and Minimum Shift Keying (MSK) signal has been paid more attention in military communication field because of its excellent signal characteristics. A new demodulation method for MSK modulation signal of M-Sequence is studied. The MSK signal is sampled by A/D converter, and an integration circuit is designed in the FPGA. The same M-Sequence is generated by the same M-Sequence source polynomial as the integrator coefficient. The peak value of the integrated signal is judged to determine the M-Sequence. When the symbol rate is 1 Mbps and the carrier rate is 1 Mbps and M-Sequence is 5 bits, the recognition time of the new method is less than 1 us, which is less than one fifth of the recognition time of the traditional demodulation method. This method simplifies the demodulation process and is easy to implement. It improves the recognition speed of M-Sequence in MSK modulation signal and provides some reference value for the development of IFF system.

1. Introduction
Electronic countermeasure is a very important link in modern warfare, in which the identification of enemy and foe occupies a core position in electronic warfare. Due to the continuous upgrading of IFF system in recent years, its inquiry and response signal has also been upgraded from pulse amplitude modulation (PAM) mode to MSK mode [1]. MSK has a series of advantages, such as phase continuity, constant envelope, strong anti-jamming energy, high spectrum utilization, and is widely used in military communication field [2-3].

Traditional MSK signal demodulation methods mainly include coherent demodulation and incoherent demodulation. Incoherent demodulation plays a dominant role in engineering applications, such as two-bit delay differential demodulation. Some foreign scholars have carried out related studies, for example, the high-power 6-bit digital phase shifter [4], which is used in airborne IFF applications, and the narrowband interference resistance of related receivers with BCO and MSK-BCO modulation types. Some domestic researchers have studied the identification method of MSK signal [5-7], and fast acquisition algorithms of direct sequence spread spectrum used in the engineering applications [8]. All the above methods have been deeply studied about the MSK signal, and these methods can be used to demodulate the modulated MSK signal correctly, but it will take a certain time to identify after demodulation, which is very important for electronic countermeasures in modern warfare.
In order to improve the speed of M-sequence identification after MSK demodulation in IFF system, a new demodulation method is proposed in this paper. M-sequence is used as identification code, and MSK modulation is used to integrate the M-sequence at the receiving end. The integrator coefficients are generated locally using the same M-sequence, and the identity of the friend or foe can be determined by detecting the peak value of the signal after integration. The experimental results show that the proposed method can simplify the process of reconciliation and complete the identification of friend and foe at a very fast speed.

2. New method of MSK demodulation

Signal recognition is to determine the correlation between the two signals. When the correlation of the two signals reaches its maximum, it can be considered that the correlation between the two signals is the strongest, that is, the two signals can be equivalent. The formula for calculating signal coherence is shown in formula (1).

\[ y(t) = s(t) \otimes h(t) = \int_{-\infty}^{\infty} s(\tau)h(t-\tau)d\tau \]  

(1)

From formula (1), it can be concluded that the calculation of signal correlation is transformed into an integral operation, so signal recognition is transformed into an integral operation.

According to the above principle, a new demodulation method (here named integration demodulation method) is designed to identify the signal of M-sequence modulated by MSK, which can help IFF system to complete IFF identification. Figure 1 shows the demodulation process of the new MSK demodulation method proposed in this paper. The MSK signal is sampled into the internal of the FPGA through the analog-to-digital conversion chip, and the sampling frequency is 50 MSPS. The received MSK modulation signal is transmitted to the integrator module. After the signal is integrated, the peak value is judged by the peak decision module, so as to determine the correlation of the signal. When the correlation is the strongest, that is, when the peak value of the signal reaches the maximum, the corresponding M-sequence has been detected.

![Figure 1. Principle block diagram of MSK demodulation](image1)

2.1. Design and simulation of M-sequence generator

The source polynomial of M-sequence generator is selected as \(x^5 + x^2 + 1\). From this polynomial, the circuit of M-sequence generator as shown in Figure 2 is designed. As the input data of MSK modulation, M-sequence needs to generate the same M-sequence at the demodulator. The simulation waveform is shown in Figure 3.

![Figure 2. Circuit diagram of M-sequence generator](image2)
2.2. Design and simulation of integrator
Firstly, the simulation is carried out in MATLAB. M-sequence is modulated by MSK to get MSK modulation signal. The simulated signal data is exported, and then the derived data is stored in the FPGA in advance as these coefficients. In practice, MSK signals are sampled through five shift registers and multiplied with the corresponding coefficients one by one. Finally, the multiplied data are superimposed and output. The maximum value can be obtained when the data in the shift register is the same as its corresponding coefficients. The integral circuit designed for this paper is shown in figure 4.

![Figure 4. Circuit diagram of integrator](image)

This paper uses Altera IP core, fir_compiler_ii, to complete signal integration. The type of IP core is Single Rate, the working clock and the sampling clock are both 50MHz, the coefficient bit width is set to 12 bits, and the tap coefficient is calculated by MATLAB before. Finally, it runs in EP4CE15F23C8 of Altera's FPGA Cyclone IV E series and gets the waveform as shown in figure 5 sampled by Signal Tap II. It can be seen that the integrated waveform has obvious peaks and troughs. When the detected peak value is greater than or equal to the sum of squares of 5 bit M-sequence, it can be determined that the received sequence is consistent with the locally generated sequence.

![Figure 5. Waveform after integration](image)

3. Traditional method of MSK demodulation
In order to illustrate the advantages of the proposed method, a traditional MSK demodulation method, i.e. two-qubit delay differential demodulation method, is realized on FPGA to compare with the proposed demodulation method.
3.1. Two-qubit delay differential demodulation method

![Diagram of two-qubit delay differential demodulation method](image)

Figure 6. Diagram of two-qubit delay differential demodulation method

Figure 6 shows the diagram of two-qubit delay differential demodulation method, which is one of incoherent demodulation methods of MSK signal. The analog signal is received by ADI AD9226, which has a resolution of 12 bits and a sampling frequency of 50 MSPS. After analog-to-digital conversion, the digital signal enters the internal of the FPGA. After delaying two code element periods, it multiplies the original signal. After passing through the low-pass filter, the demodulated data is output by sampling decision and bit synchronization module. The signal passing through multiplier and low pass filter (LPF) is:

$$y_L(t) = \frac{1}{2} \cos \left[ \frac{\pi (a_n-a_{n-2})}{2T_s} t + \Delta \varphi (2T_b) \right]$$

Here,

$$\Delta \varphi (2T_s) = \varphi (t) - \varphi (t - 2T_s)$$

When the sampling time $t = nT_s (n = 3, 4, ...)$, formula (4) can be obtained:

$$y_L(nT_s) = \frac{1}{2} \cos \left[ \frac{\pi}{2} (a_n + a_{n-1}) \right]$$

Define differential coding:

$$b_n \equiv \begin{cases} b_{n-1}a_n, & n \geq 2 \\ a_n, & n = 1 \end{cases}$$

If $b_n$ occurs, a sampling decision is made at the receiving end, and the result is obtained:

$$y_L(nT_s) = -\frac{1}{2} b_n b_{n-1} = -\frac{1}{2} a_n, (n = 3, 4, ...)$$

3.2. Implementation of demodulation on FPGA

According to this demodulation principle, the demodulation circuit is implemented inside the FPGA. Signal Tap II shows the demodulation waveform of MSK based on the FPGA as shown in Figure 7. The signal “ADC_CH1” is the data waveform collected by AD9226, the signal “ast_source_data” is the waveform after low-pass filter, and the signal “DOUT” is the final demodulated waveform.

![MSK modulation waveform](image)

Figure 7. MSK modulation waveform

4. Measurement and analysis

The method proposed in this paper is tested using the experimental device as shown in figure 8. Two FPGA development boards are selected to complete modulation and demodulation respectively. Alinx AX515 is chosen as the development board of the FPGA, AN9767 is used as the digital-analog conversion module, and AN9226 is used as the analog-digital conversion module, which completes data conversion and sampling at 50MHz respectively. SMA radio frequency line is used to complete the transmission of analog signals. The data are modulated by MSK and respectively demodulated by the traditional method and proposed one in this paper. Demodulation signal is displayed by signal Tap
II grabbing package and oscilloscope. Through experiments, it is found that both demodulation methods can recognize M-Sequence. When the symbol rate is 1 Mbps and the carrier rate is 1 Mbps and M-Sequence is 5 bits, the recognition time by the new method is less than 1 us, which is less than one fifth of the recognition time by the traditional method.

![MSK modulation and demodulation experimental device](image)

Figure 8. MSK modulation and demodulation experimental device

5. Conclusion
The experimental results show that the traditional two-qubit delay differential demodulation method can correctly demodulate the original signal, but the demodulation process is complex. In order to match the M-sequence of the sender, it is necessary to match the demodulated single-bit data. The new demodulation method proposed in this paper takes less time and can correctly identify the matched M-sequence.

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