Research on the Integrated Working Mode Based on Positive and Negative Frequency Modulation in Radar Communication Integration

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Abstract. Nowadays, the fast development of the digital circuits results in a more and more high digital level of radar system. Especially, the development of the solid-state active module, the high-speed multi-digital A/D convertor, the direct digital synthesizer (DDS), and universal use of the high-speed digital signal processor provide an outstanding basis of the radar communication integration. Minimum Shift Keying Linear Frequency Modulation (MSK-LFM) is a novel multifunctional radar waveform. For all above, this paper proposes an integrated working mode based on positive and negative frequency modulation in radar communication integration. In the mode, the radar main station transmits positive linear modulation frequency signals, however, the communication affiliated station transmits negative linear modulation frequency signals. Their orthogonality causes less interference. Through the derivation, the method for the orthogonality improvement is obtained. The effectiveness of this working mode is proved by the simulations.

Keywords: Radar communication integration · MSK-LFM · LFM

1 Introduction

Recently, radar communication integration has been a focus point at home and abroad. In the references [1], Chen proposed using linear frequency modulation: LFM signal as the carrier of minimum shift keying (MSK) [2] signal to form a new MSK-LFM signal with both radar detection function and communication function, and theoretically analyzed the signal. It was proved that MSK-LFM is no worse than LFM on the performance of range and velocity acquisition [3, 4, 5]. For integrated waveform, there are difficulties such as large interference in practical applications [6, 7, 8], so the working mode with the same frequency and the same time based on positive and negative frequency modulation is proposed in order to study the system of integrated signal, and its principle of working mode and orthogonality are studied. Through simulation, it is concluded that the orthogonality of radar signal processing is related to modulation data and the time-bandwidth product.

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2 Same-Time and Same-Frequency Working Mode

Same-time and Same-frequency working mode means that the radar waveform and the communication waveform are sent at the same wavelength and at the same time. Its schematic diagram is shown in Fig. 1.

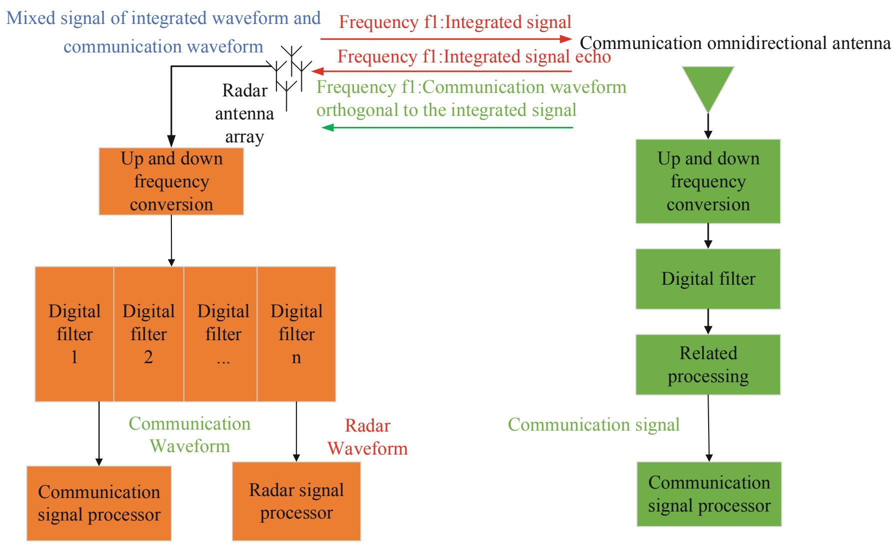

Fig. 1. Same-time and Same-frequency working mode

(1) the MSK-LFM signal waveform with a frequency of f1 sent by the radar main station is used to complete the detection and communication functions simultaneously.

(2) Communication from the station to the radar main station sends a signal of integrated waveform orthogonal to the radar waveform and with a frequency of f1, which is used to complete communication from the station to the radar main station.

(3) When the communication receives the integrated signal from the radar main station from the station, the communication signal is obtained after down-conversion, digital filtering and correlation processing demodulation, then the communication function is completed.

(4) Waveform of communication from communications affiliated stations and radar echo could reach the radar main station at the same time, but the two signals are orthogonal, so they will not produce interference. The two orthogonal signal, after completing down frequency conversion, digital filtering, correlation processing and matching processing, radar echo complete detection function in the radar signal processor, communication signals complete the communication function in communication processor.

3 Orthogonal Analysis of Radar Performance

Integration of radar echo signals and communication signals may arrive at the main radar station at the same time, only when two waveform quadrature to each other it will not produce interference, so this section will analyze the orthogonality of the radar signal processing. Set the integrated signal frequency of the radar main station to $+\mu$, and the integrated communication signal frequency of the communication affiliated station to $-\mu$. So the two waveform expressions are as follows:

$$s_+(t) = \sum_{k=1}^{N} rect\left(\frac{t-(k-1)T_C}{T_C}\right)\exp\left(j\pi\left(\mu t^2 + p_k q_k \frac{t}{2T_C} + \frac{1-p_k}{2}\right)\right) \tag{1}$$

$$s_-(t) = \sum_{k=1}^{N} rect\left(\frac{t-(k-1)T_C}{T_C}\right)\exp\left(j\pi\left(-\mu t^2 + p_k q_k \frac{t}{2T_C} + \frac{1-p_k}{2}\right)\right) \tag{2}$$

The expression of the integrated signal given in references [4, 9, 10] is:

$$\int_a^b \varphi(l,k,t)dt = \frac{1}{2\sqrt{\mu}}\exp\left(j\pi\left(\mu\tau^2 + \frac{p_l q_l \tau}{2T_C} + \frac{p_l - p_k}{2}\right)\right)\cdot\exp\left(-j2\pi\mu\left(\frac{f_0+f}{2\mu}\right)^2\right) \cdot\left[\begin{array}{c} C\left(2\sqrt{\mu}\left(b+\frac{f_0+f}{2\mu}\right)\right) - C\left(2\sqrt{\mu}\left(a+\frac{f_0+f}{2\mu}\right)\right) + \\ jS\left(2\sqrt{\mu}\left(b+\frac{f_0+f}{2\mu}\right)\right) - jS\left(2\sqrt{\mu}\left(a+\frac{f_0+f}{2\mu}\right)\right) \end{array}\right] \tag{3}$$

We can obtain the correlation coefficient between the integrated waveforms of positive and negative frequencies. The correlation coefficient of integrated waveforms of positive and negative frequency modulation is simulated to analyze how to improve the cross-property. Simulation parameters are set as follows:

In Fig. 2: radar bandwidth is 30 MHz, radar pulse width is 10 µs and modulation data number is 10.

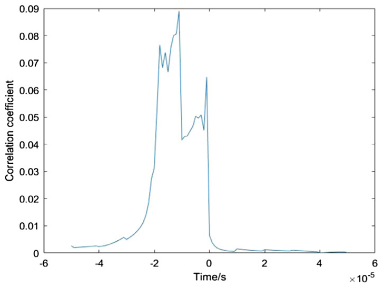

Fig. 2. Simulation of parameter one

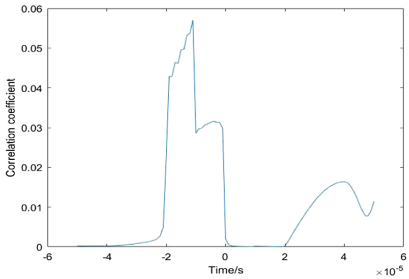

Fig. 3. Simulation of parameter two

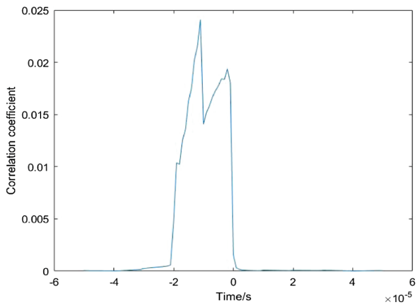

Fig. 4. Simulation of parameter three

In Fig. 3: radar bandwidth is 30 MHz, radar pulse width is 10 μs and modulation data number is 100.

In Fig. 4: radar bandwidth is 500 MHz, radar pulse width is 10 μs and modulation data number is 10.

It can be seen that the orthogonality of integrated waveforms with positive and negative frequencies is affected by the number of modulated data and time-bandwidth product. According to the simulation results, the orthogonality of the integrated waveform with positive and negative frequency modulation will be improved with the increase of time-bandwidth product. But as the number of modulation data increases, the integration of the signal spectrum is increased, so the best way to improve the positive rate of integration waveform orthogonality method is to increase the time-bandwidth product.

4 Orthogonal Analysis of Communication Signal

The upper limit and lower limit of integral can be obtained:

$$\begin{cases} v_1(\tau,f) = 2\sqrt{\mu}\left((k-1)T_C + \tau + \frac{1}{2\mu}\cdot\left(\frac{p_k q_k}{4T_C} - \mu\tau + f\right)\right) \\ v_2(\tau,f) = 2\sqrt{\mu}\left(kT_C + \frac{1}{2\mu}\cdot\left(\frac{p_k q_k}{4T_C} - \mu\tau + f\right)\right) \end{cases} \tag{4}$$

When $-T_C \leq \tau \leq 0$, the lower and upper limits are:

$$\begin{cases} v_1(\tau,f) = 2\sqrt{\mu}\left((k-1)T_C + \frac{1}{2\mu}\cdot\left(\frac{p_k q_k}{4T_C} - \mu\tau + f\right)\right) \\ v_2(\tau,f) = 2\sqrt{\mu}\left(kT_C + \tau + \frac{1}{2\mu}\cdot\left(\frac{p_k q_k}{4T_C} - \mu\tau + f\right)\right) \end{cases} \tag{5}$$

By substituting equation, the interrelationship number expression can be obtained:

$$\rho(\tau) = \frac{1}{2\sqrt{\mu}T_C}\sqrt{\left(C(v_2(\tau,0)) - C(v_1(\tau,0))\right)^2 + \left(S(v_2(\tau,0)) - S(v_1(\tau,0))\right)^2} \quad (6)$$

The correlation coefficient was simulated. Parameters are set as follows:

In Fig. 5: radar bandwidth is 200 MHz, symbol time is 10 μs and modulation data is 500.

In Fig. 6: radar bandwidth is 200 MHz, symbol time is 10 μs, modulation data is 500 and k is respectively set at 4, 30, 50.

In Fig. 7: radar bandwidth is 200 MHz, symbol time is 10 μs, modulation data is 500, $k = 1 \sim 200$.

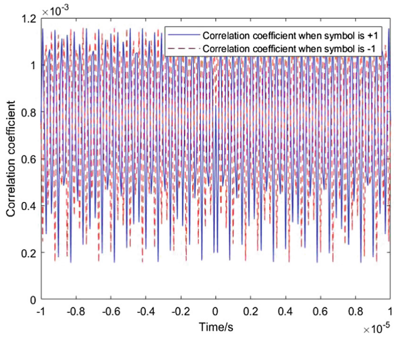

Fig. 5. The correlation coefficient different position of symbol

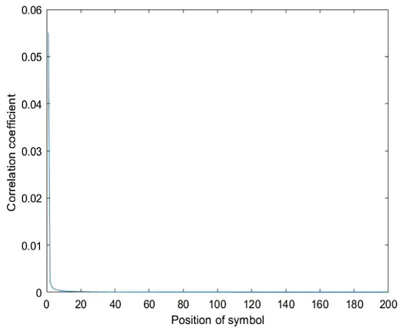

Fig. 6. The correlation coefficient under between symbol is +1 and −1

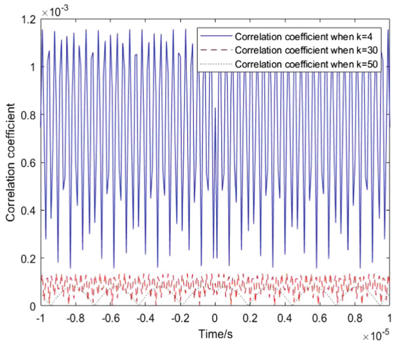

Fig. 7. The correlation coefficient under different k values

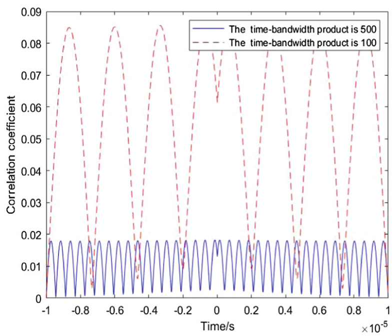

Fig. 8. The correlation coefficient of the different product of time and bandwidth

In Fig. 8: radar bandwidth is 50 MHz and 10 MHz, symbol time is 10 μs and modulation data is 200.

By analyzing the simulation results, it can be seen from Fig. 5 that the correlation coefficient when the symbol is +1 and −1 is basically the same. In other words, the symbol is +1, or −1, which has no effect on orthogonality. As can be seen from Figs. 6 and 7, with the increase of *k* value, the correlation coefficient between the reference signals of radar echo and communication matched filtering decreases, and the orthogonality performance improves. Moreover, the correlation coefficient changes greatly for different *k* values, which means that the later symbol is affected by the radar echo, resulting in a smaller probability of error. Figure 8 shows that as the time-bandwidth product of the symbol increases, the correlation coefficient decreases and the orthogonality becomes better.

5 Conclusion

In the working mode of integrated signal in the same frequency synchronous, radar main station transmits the positive linear modulation frequency integrated signals, and the communication affiliated station uses the negative modulation frequency integrated signals. The less interference results from their orthogonality. Through simulation, it is concluded that the orthogonality of radar signal processing is related to modulation data and the time-bandwidth product. However, the larger the modulation number is, the more serious the spectrum expansion is. Therefore, the method of increasing the time-bandwidth product can be adopted to improve the orthogonality of the two signals. Finally, the correlation coefficient is analyzed, which is independent of the code element polarity, and will decrease with the increase of the time-bandwidth product. And the further the position is, the better the orthogonal performance is.

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