ISSN: 2688-8645

A Novel Integrated Navigation Radar and Communication Waveform based on OFDM

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Abstract

In order to solve the integration problem of radar communication system, an implementation method of radar communication integration signal based on orthogonal frequency division multiplexing (OFDM) is proposed in this paper. This method combines OFDM and QAM (quadrature amplitude modulation), loads the communication data onto the subcarrier through QAM modulation technology for parallel transmission, deduces the ambiguity function of the integrated signal, and finally carries out simulation. The simulation results show that the radar ambiguity diagram of the integrated signal presents an ideal "pushpin shape", which represents the radar detection ability of the signal, And it has good communication transmission function.

Keywords

Intergrated nevagation radar and communication; OFDM; QAM.

1. Introduction

With the continuous development of science and technology and maritime traffic, the application scope of marine radar is gradually expanded, and the navigation situation is becoming more and more complex. Modern navigation has higher and higher requirements for radar technology. The pulse magnetron radar, which is most widely used in traditional marine radar, has been unable to meet the requirements of modern navigation. The traditional marine radar has large transmission power and is easy to interfere with mobile communication. Therefore, the new OFDM marine radar has become a new choice [1]. Marine radar is one of the important navigation instruments to ensure navigation safety. However, when marine radar is used in bad weather conditions, the detection effect of marine radar will be seriously affected. When using marine radar to detect and identify the target in the sea background, because the electromagnetic wave emitted by marine radar also irradiates the sea background, the received echo includes the scattered echo of sea background and target information. In this case, the radar echo from the sea surface will have a serious impact on target detection, which is called sea clutter. Sea clutter may mask the echo of the target ship, so it may not detect whether there is a target in the detection area. With the development of science and technology, there are more and more similarities between communication system and marine radar. In terms of hardware, marine radar and communication have transmitters, antennas, receivers, signal processors and so on. The spectrum resources of communication and navigation radar are getting closer and closer. Under this background, the research on communication integration of navigation radar has sufficient theoretical basis [2].

For the research of radar communication integration, scholars at home and abroad have done a lot of related research. As early as the early 1960s, the concept of radar communication integration was put forward abroad. Randall proposed to modulate communication information to the pulse position of radar pulse waveform in 1963, but this scheme can only carry 1 bit of data at one pulse position, so it can not be applied to the communication requirements with large amount of information. At the same time, in the 1970s, researchers of the U.S. Navy verified the feasibility of using radar system to realize communication data transmission through experiments.

The navigation radar communication integration system based on OFDM in this paper realizes the communication information data transmission while realizing the detection of surrounding targets by navigation radar, so as to realize the communication between ships, and then indirectly solve the interference of sea clutter on the detection targets of navigation radar, reduce the collision accidents between ships, ensure the navigation safety of ships, and provide reference for intelligent ships Make a contribution to intelligent navigation. To sum up, the navigation radar communication integrated system based on OFDM plays a good role in promoting navigation safety, efficient utilization of spectrum resources, cost control and other aspects, and system integration, informatization and intelligence are the development trend in the future. Therefore, the integrated system has research value.

This paper mainly includes the following aspects: firstly, the OFDM signal is analyzed, the navigation radar communication integrated signal is analyzed, and its fuzzy function is analyzed. Finally, the fuzzy function and bit error rate of the integrated signal are simulated and analyzed.

2. OFDM

Orthogonal frequency division multiplexing (OFDM) technology is first used in the field of communication because it can make full use of spectrum resources and realize high-speed transmission in wireless environment. At the same time, it has the advantages of strong anti fading and anti-interference ability, high spectrum efficiency and easy system implementation.

2.1. Analyzing OFDM Signal

OFDM is a spread spectrum transmission technology. Its signal contains multiple subcarrier components. There are frequency intervals between subcarriers and they are orthogonal to each other. The orthogonal subcarrier structure also requires that the signal period T is the reciprocal of the carrier interval. Therefore, the OFDM signal can be expressed as the sum of multiple subcarrier components:

$$s(t) = \sum_{i=1}^{N} a(i) exp\{j2\pi f_i t\}, \qquad 0 \le t < T \tag{1}$$

Where N is the number of subcarriers, $a(i)$is the modulated symbol sequence, and$f_i = i\Delta f$ is the subcarrier frequency and$T$is the signal period.

In order to make subcarriers orthogonal to each other and avoid mutual interference, the following conditions must be met:

$$f_i = i\Delta f = i/T \qquad i = 1,2, \dots, N \tag{2}$$

The basic idea of OFDM is to convert one channel of serial data into N channels of parallel data [4], modulate the n-bit data information onto n mutually orthogonal subcarriers, add the n-channel modulated signals and transmit them through the antenna. After reaching the receiving end, the receiving end uses the orthogonal relationship between the frequencies of each subcarrier to separate the n-channel signals, so as to realize demodulation [5]. Obtain the data information carried by the subcarrier, and obtain the echo distance, speed information and communication information, so as to realize the functions of radar and communication [6]. The spectrum diagram and time domain diagram of OFDM signal are shown in the figure.

ISSN: 2688-8645

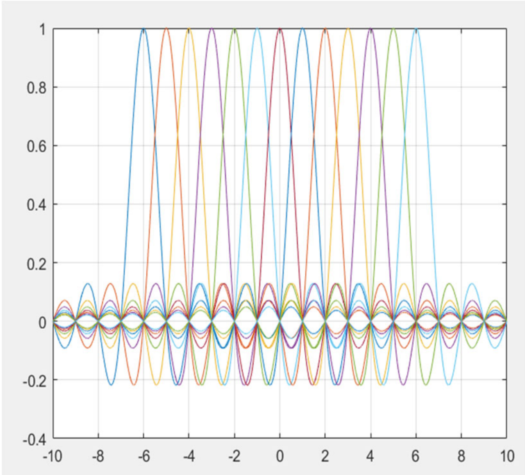

Figure 1. Spectrum

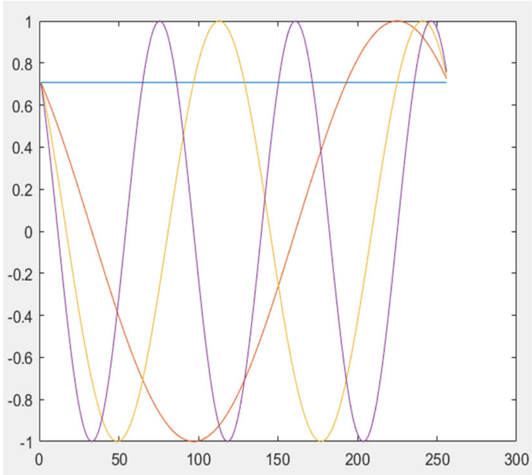

Figure 2. Time domain

In the figure, the OFDM signal is composed of 12 subcarriers equally spaced in frequency. At the maximum frequency of each subcarrier, the spectrum value of other subcarrier signals is zero. Therefore, it is easy to separate each subcarrier at the receiving end by using the orthogonality between subcarriers.

2.2. OFDM Modulation and Demodulation

Traditional OFDM modulation uses sinusoidal generator to generate each subcarrier, but when the number of subcarriers is large, discrete Fourier transform (DFT) and discrete Fourier transform (IDFT) can be more convenient to realize the modulation and demodulation of OFDM signal[7].

Sampling the first symbol of each subcarrier in the OFDM signal represented by equation (1), and the sampling rate is N/T, that is, let t=$\frac{kT_s}{N}$ $(k = 0,1,2 \ldots N-1)$we can obtain:

$$s_k = s_{OFDM}\left(\frac{kT_s}{N}\right) = \sum_{n=1}^{N} d_n \exp(j2\pi f_n \frac{kT_s}{N}) \tag{3}$$

Will $f_n = n/T_s$into the equation, and we get

$$s_k = \sum_{n=1}^{N} d_n \exp(j2\pi \frac{kn}{N}) \tag{4}$$

Equation 3 shows that s_k is exactly IDFT of d_n, and at the receiving end, in order to demodulate the communication information of the sending end, $s_k$performs DFT transformation, and the transformation formula is as follows:

$$d_k = \sum_{n=1}^{N} s_k \exp\left(-j2\pi \frac{kn}{N}\right) \quad (0 \le k \le N-1) \tag{5}$$

Because the amount of operation of IDFT is very large, for example, the multiplication operation required for IDFT transformation of N points is N^2. Therefore, IFFT algorithm is proposed. IFFT is a fast algorithm belonging to IDFT.

3. Integrated Signal Design of OFDM navigation Radar Communication

According to the previous analysis, OFDM signal has many advantages, such as high frequency spectrum utilization, high anti-interference ability and anti- multipath fading, and is widely used in communication systems. OFDM is a signal with large time bandwidth and wide product. It has good range resolution. It can better solve the problem of detection range and range resolution of marine radar. It is suitable for marine radar. Next, this paper mainly analyzes the integrated signal design of OFDM marine radar communication.

3.1. Integrated Signal

According to the above OFDM signal form, the signal waveform of OFDM navigation radar communication integration can be deduced as follows:

$$s_n(t) = e^{j2\pi f_c t} \sum_{m=1}^{N_s} a_n c_{n,m} e^{j2\pi n\Delta f(t-mT_s)} rect((t-T_s)/T_s) \tag{6}$$

$$s(t) = \sum_{n=1}^{N_c} s_n(t) \tag{7}$$

Where, $s_n(t)$ is the transmission signal of the nth subchannel (subcarrier); $f_c$is the subcarrier center frequency of the signal; $N_s$is the number of OFDM symbols; a_n is the complex weight value of the nth subcarrier, which is set to 1 in this paper; $c_{n,m}$ is the communication information modulated by the nth subcarrier and the m-th OFDM symbol, and the transmitted communication information is modulated to each subcarrier using QAM technology; Δf=1/T, T is the duration of each OFDM symbol; T_s is the time interval for completing each OFDM symbol, $T_s = T_g + T$, where T_g is the duration of each cyclic prefix; $rect(.)$is a rectangular window function; N_c is the number of OFDM shared signal subcarriers.

The integrated system block diagram is as follows:

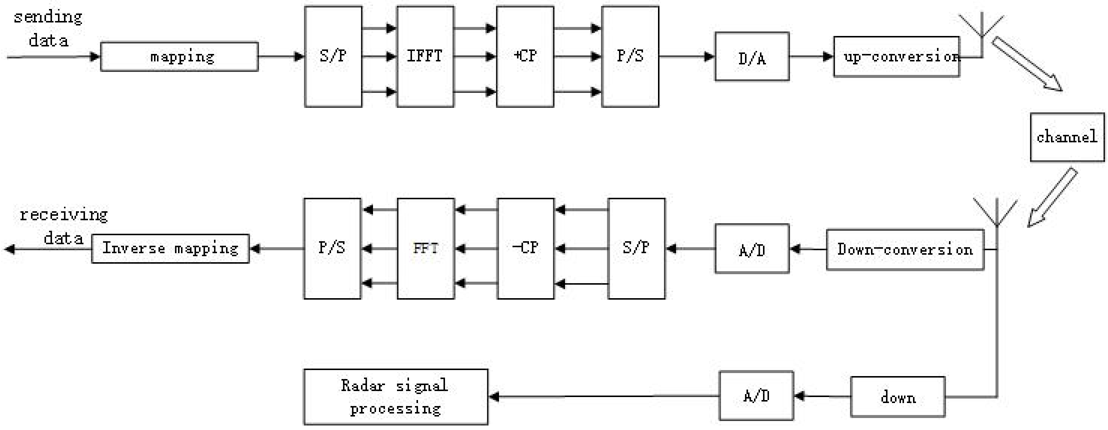

Figure 3. The integrated system block diagram

The specific work flow of the system is as follows: at the receiving end, first input the transmission data, map the constellation of the transmission data, send it to the serial parallel conversion module to obtain multi-channel sub data stream, then perform IFFT conversion, insert CP (cyclic prefix), and then convert the multi-channel parallel data into one channel of serial data through parallel serial conversion, and then conduct D/A conversion (digital to analog conversion), Finally, the signal is processed by the transmitter and transmitted through the antenna [8]. At the receiving end, corresponding demodulation processing is required to obtain the initial data.

3.2. Integrated Signal Ambiguity Function

The radar ambiguity function describes the influence of Doppler frequency shift caused by target motion on the matched filter output of radar receiver. When the matched filter is completely matched with the target echo signal, The fuzzy function value at point (τ, f_d) is equal to the output of the matched filter [9]. In other words, the reflected echo of the target is located at the origin of the ambiguity function. Therefore, the fuzzy function is non-zero τ and f_d The value at d represents the echo of the target at a certain range and Doppler different from the nominal target.

Ambiguity function is an effective mathematical tool for studying and analyzing radar signals and waveform design. It can accurately describe the resolution characteristics of radar. Different waveforms correspond to different ambiguity functions. There are four kinds of fuzzy function diagrams: inclined blade shape, nail plate shape, pushpin shape and blade shape. Among them, the pushpin shape fuzzy function diagram is the most ideal fuzzy function. The pushpin shape fuzzy function diagram has a high peak only at the origin in the time delay frequency plane, and the amplitude in other places is zero[10].

The range resolution unit of OFDM signal is small, which is a large time broadband wide product signal and does not meet the condition of BT<<c/(2v). Therefore, the commonly used Woodward narrowband ambiguity function can not accurately reflect the output signal characteristics of radar receiver [9]. Therefore, this paper uses another analysis tool - Broadband ambiguity function.

$$\chi(\tau, f_d)=\int_{-\infty}^{\infty} \tilde{x}(t)\, \tilde{y}^*(t)dt=\sqrt{\gamma}\int_{-\infty}^{\infty} \tilde{x}(t)\tilde{x}^*\big(\gamma(t-\tau)\big)\, dt \tag{8}$$

Where $\tilde{x}(t)$ Is the complex analytic signal of $x(t)$, $y(t)=\sqrt{\gamma}x\big(\gamma(t-\tau)\big)$ Is the echo signal of the target, τ Represents time delay, f_d represents Doppler frequency shift, $*$represents conjugate, $\chi(\tau, f_d)$determines the resolution. The larger the value, the higher the resolution [10].

4. Integrated Signal Performance Simulation

4.1. Radar Performance - Ambiguity Function Simulation

It can be seen from the figure that the navigation radar communication integrated signal based on OFDM presents an obvious pushpin type, with good range resolution and velocity resolution.

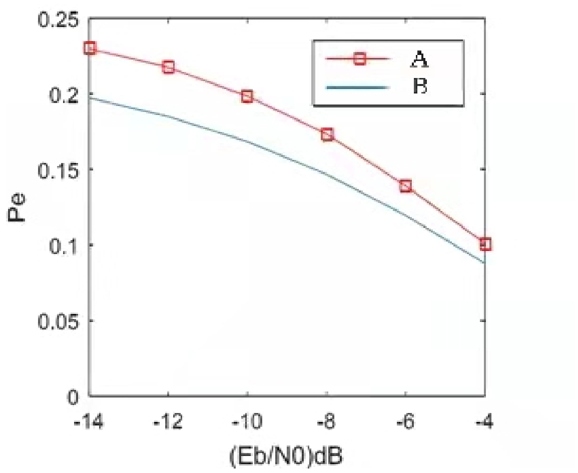

Figure 4. Ambiguity Function

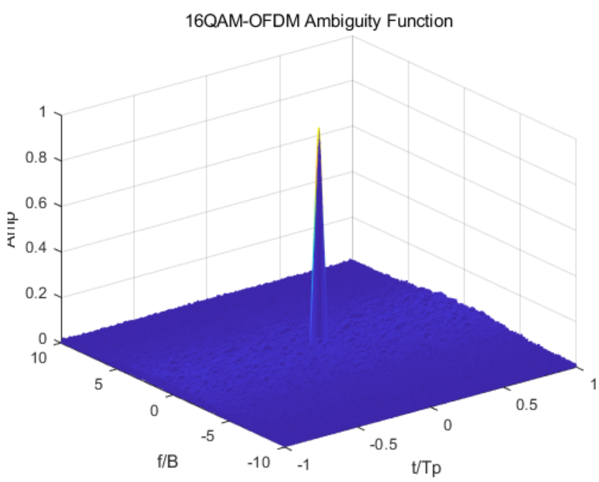

Figure 5. Bit error rate

ISSN: 2688-8645

4.2. Communication Performance Bit Error Rate Simulation

In the communication system, the bit error rate of the symbol is one of the most concerned signal performance, so the following mainly analyzes the general performance of each signal based on the bit error rate.

Theoretically, if the bit error rate of transmission is controlled within 0.5%, the communication with good quality can be guaranteed. According to the above simulation, the communication quality of 16QAM signal has decreased under - 10dB Gaussian white noise, but it can also better realize the transmission of communication information.

5. Conclusion

This paper introduces the principle of OFDM, starts with the structure of OFDM system, expounds the modulation and demodulation process of OFDM in detail, analyzes the form of OFDM signal, analyzes the integrated ambiguity function, and simulates and analyzes the ambiguity function and bit error rate with MATLAB. The simulation results show that the integrated signal has better detection performance of marine radar, The marine radar integrated signal based on OFDM is suitable for the integrated system and can meet the requirements of radar detecting targets and transmitting communication information at the same time, but the bit error rate is high. It needs to be further studied to reduce the bit error rate and better realize communication data transmission.

References

[1] G. C. Tavik et al., "The advanced multifunction RF concept," in IEEE Transactions on Microwave Theory and Techniques, vol. 53, no. 3, p. 1009-1020.

[2] Z. Liu, W. Zhang and S. Xu, "Implementation on the integrated waveform of radar and communication," 2013 International Conference on Communications, Circuits and Systems (ICCCAS), Chengdu, China, 2013, p. 200-204.

[3] Q. Li, Y. Zhang, C. Pan and J. Song, "Waveform design for high speed radar-communication integration," 2016 CIE International Conference on Radar (RADAR), Guangzhou, 2016, p. 1-4.

[4] B. J. Donnet and I. D. Longstaff, "Combining MIMO Radar with OFDM Communications," 2006 European Radar Conference, Manchester, UK, 2006, p. 37-40.

[5] Wenkang Zhang and Zhipeng Liu, "Design and implementation of modulator of a novel rader waveform compatible with communication," 2013 International Workshop on Microwave and Millimeter Wave Circuits and System Technology, Chengdu, China, 2013, p. 357-360.

[6] Y. Chen, X. Yang, Z. Ma, Q. Zhang and G. Wang, "A novel measurement matrix optimization method for radar sparse imaging with OFDM-LFM signals," 2015 IEEE 5th Asia-Pacific Conference on Synthetic Aperture Radar (APSAR), Singapore, 2015, p. 409-412.

[7] X. Chen, X. Wang, S. Xu and J. Zhang, "A novel radar waveform compatible with communication," 2011 International Conference on Computational Problem-Solving (ICCP), Chengdu, China, 2011, p. 177-181.

[8] D. Garmatyuk, J. Schuerger and K. Kauffman, "Multifunctional Software-Defined Radar Sensor and Data Communication System," in IEEE Sensors Journal, vol. 11, no. 1, p. 99-106.

[9] D. Gaglione, C. Clemente, C. V. Ilioudis, A. R. Persico, I. K. Proudler and J. J. Soraghan, "Fractional fourier based waveform for a joint radar-communication system," 2016 IEEE Radar Conference (RadarConf), Philadelphia, PA, USA, 2016, p. 1-6.

[10] C. Sturm and W. Wiesbeck, "Waveform Design and Signal Processing Aspects for Fusion of Wireless Communications and Radar Sensing," in Proceedings of the IEEE, vol. 99, no. 7, p. 1236-1259.