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Design of Signal-sharing for Radar and Communication

雷达通信一体化共享信号的设计

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***Abstract*—This paper firstly introduces the radar and communication integration system and discusses its working process based on linear frequency modulated (LFM) signal. Then some opportunities created by LFM signal for radar and communication at the same time are discussed to prove the feasibility of adopting a system for radar detection and communication data transmission. The simulation results show that the Chirp signals of opposite slopes can achieve the function of good data transmission and radar detection.**

***Keywords*—radar; communication; integration; signal-sharing**

I. INTRODUCTION

In recent years, radar and communication are strictly distinguished because of their object of study. However, with the technology development of communication, electronics and network, radar and communication have some similarities such as ① operation principle 工作原理, ② system structure 系统结构 and ③ operating frequency 工作频率. Then the integrated design for radar and communication and sharing hardware resources are feasible.

To achieve the function of radar and communication simultaneously, LFM signals of opposite slopes for the communication and radar have been proposed in [1], [2]. The work in [3], [4] has put forward the theoretical basis of signal-sharing for radar and communication. The radar and communication signals must be orthogonal. However, the linear frequency modulated signal with limited time length isn't satisfy this requirement. The quasi-orthogonality of opposite slope LFM signals is being exploited to allow for simultaneous communication and radar operation. We can approximately meet the orthogonal condition by maximizing the ratio of the side lobe levels of the autocorrelation output to the output of the cross-correlation function.

This paper is structured as follows. ① In Section II the system structure diagram of the radar and communication system is presented and briefly describes its working process. ② Section III provides the description of the LFM signal. ③ The theoretical performance and simulation results are described in section IV. ④ Conclusions are presented in section V.

II. SYSTEM STRUCTURE

The radar and communication system referred in this paper is that can generate, send and receive the radar and communication integration signal. The system can not only realize the function of the radar itself, that is to realize the detection, location and tracking enemy radar platform or the operational objectives, but also realize the function of the real-time transmission of intelligence information. Fig. 1 shows the structure diagram of the radar and communication integration system. ① In the transmitter, the communication data need to be sent is coded and modulated with the radio frequency waveform. Then the modulated communication signal which is passed through a LFM filter is added with linear frequency modulated radar signal. The linear frequency modulated radar signal is the radio frequency waveform which passed through a chirp filter. The radar and communication integrated signal is the radar chirp signal added with the communication chirp signal. Then the integrated signal is up-converted and power amplified. And the integrated signal is transmitted by radar transmitter through additive white Gaussian noise channel (AWGN). ② In the receiver, the integrated signal is received by an ideal antenna and the received signal is amplified and down-converted to baseband signal. Then the signal is passed through a communication matched filter, demodulator and decoder where the communication data can be got. While on the other receiving end, the receive signal is passed through radar matched filter and threshold detector. The result out of the threshold is passed through the radar signal processor and the information of the object is got after the radar signal processor. The matched filter 1 is the matched filter of the Chirp filter 1 and the matched filter 2 is the matched filter of the Chirp filter 2. Thus the radar and communication signals will be optimal reception.

In this system, to achieve a practical data rate and avoid phase synchronization problems in the communications receiver, the $\pi/4-DQPSK$ modulation and demodulation are used to encode the digital communications data stream. And $\pi/4-DQPSK$ is a quadrature phase shift keying. It combines the advantages of QPSK and OQPSK. The envelope fluctuation of $\pi/4-DQPSK$ is smaller than that of QPSK and

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the spectrum utilization of is higher than that of GMSK. In the case of multipath extension and fading, the performance of is better than OQPSK. The non-coherent modulation which greatly simplifies the structure of the receiver is adopted to realize $\pi/4-DQPSK$ modulation. Meanwhile, the $\pi/4-DQPSK$ modulation can overcome the problem of phase synchronization.

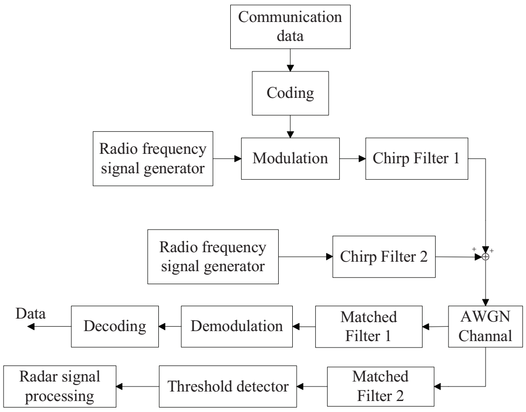

Fig. 1. Structure diagram of the radar and communication integration system

III. DESCRIPTION OF THE SIGNAL

The communications and radar signals can be expressed as follows:

$$S_{comms}(t) = rect(t/T)\exp(j2\pi f_0 t - \mu\pi t^2) \tag{1}$$

$$S_{comms}(t) = rect(t/T)\exp(j2\pi f_0 t + \mu\pi t^2) \tag{2}$$

Where T is the pulsewidth, f_0 is the center frequency of operation, μ is the modulation rate, and we assume $\mu > 0$. $rect(t/T)$ is the rectangular window of duration T and unit amplitude. The chirp bandwidth B is defined as the total range of the instantaneous frequency.

$$B = \mu T \tag{3}$$

To avoid mutual interference, the processing gain should be as large as possible and the radar and communications signals should be orthogonal. In fact, any two-chirp signals that span non-overlapping frequency regions are mutually orthogonal. However, the practical linear frequency modulation signals of (1) and (2) with finite length aren't orthogonal. We can maximize the ratio of the side lobe levels of the autocorrelation output to the output of the cross-correlation function to regard the signals to be orthogonal. And using two opposite polar Chirp signals will completely separate the two signals in the frequency space. This can achieve the fact that the ratio of the side lobe levels of the autocorrelation output to the output of the cross-correlation function can be as large as possible.

IV. SIMULATIONS AND RESULTS

To better understand the simultaneous operation of the communications and radar systems, an analysis and simulation is performed on the communications and radar receivers. And the ambiguity function is shown to prove the feasibility of the signal.

The chirp radar signal, the chirp communication signal and the integrated signal of radar and communication are shown in Fig. 2. The pulse duration is 2us, the frequency modulation width is 80MHz, the linear rates are 40MHz/us and -40MHz/us. From the simulation results, the integrated signal is the addition of radar and communication signals.

Ambiguity function is widely used in radar signal design and it can determine the range resolution and Doppler resolution. While the radar and communication signals are orthogonal, we can derivate the integration signal ambiguity. Then the ambiguity function of the integrated signal will be

$$\chi(\tau; f_d) = \chi_C(\tau; f_d) + \chi_R(\tau; f_d) \tag{4}$$

Where $\chi_C(\tau; f_d)$ is the ambiguity function of the communication chirp signal, $\chi_R(\tau; f_d)$ is the ambiguity function of the radar chirp signal.

$$\left|\chi_C(\tau; f_d)\right|$$

$$= \left|\frac{1}{N}\sum_{q=-(N-1)}^{N-1}\left|\chi_1(\tau - qt; f_d)\right|\left|\frac{\sin[\pi f_d(N-1-|q|T)]}{\sin \pi f_d T}\right|\right| \tag{5}$$

Where

$$\left|\chi_1(\tau; f_d)\right|$$

$$= \left|(1-\frac{|\tau|}{\tau^2})\frac{\sin[\pi\tau(k\tau + f_d)(1-\frac{|\tau|}{\tau})]}{\pi\tau(k\tau + f_d)(1-\frac{|\tau|}{\tau})}\right| \tag{6}$$

Consequently

$$\left|\chi_R(\tau; f_d)\right|$$

$$= \left|(1-\frac{|\tau|}{\tau^2})\frac{\sin[\pi\tau(k\tau - f_d)(1-\frac{|\tau|}{\tau})]}{\pi\tau(k\tau - f_d)(1-\frac{|\tau|}{\tau})}\right| \tag{7}$$

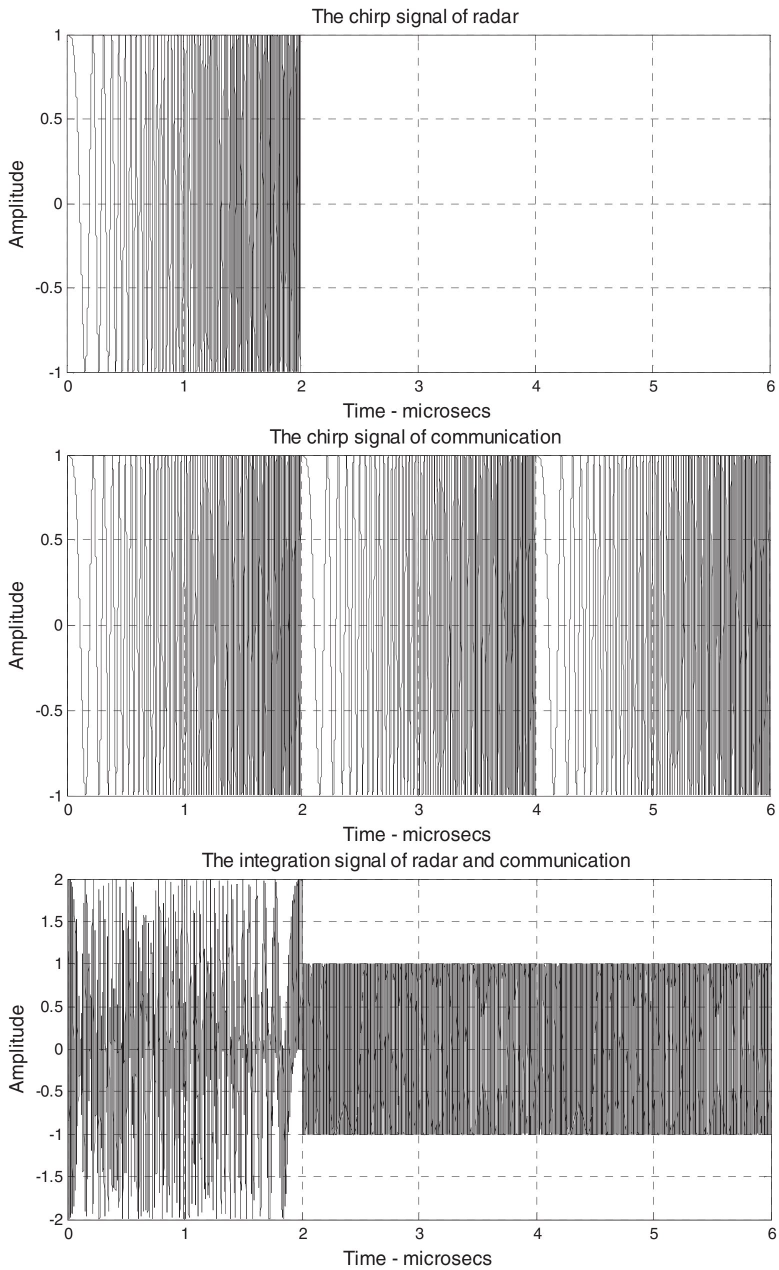

Fig. 2. The integrated signal of radar and communication

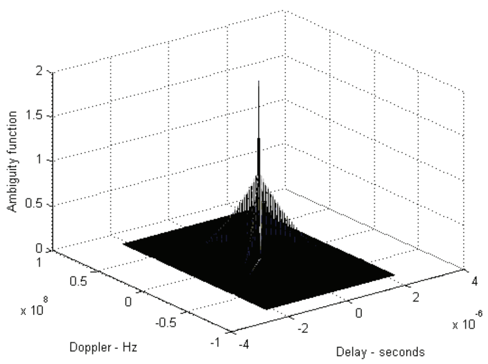

Fig. 3. The ambiguity function of the integrated signal

The ambiguity function of the integrated signal of radar and communication is shown in Fig. 3. Compared with the radar ambiguity function, the ambiguity function of the integrated signal shows more side lobes and the value at zero is smaller than the former one. These side lobes will have some effects on the resolution of the radar. However, the value at zero is still a maximum value of absolute advantage. From the analysis of the integrated signal ambiguity function, the signal has little impact on the performance of radar which states the feasibility of the signal design based on chirp signals.

V. CONCLUSION

In this paper, an integrated system for radar and communication is put forward and expound its working principle. And the modulation system the advantages of the modulation system are proposed. Then a waveform for communication and radar simultaneously has been proposed to demonstrate the feasibility of radar and communication integration.

However, some improvements should be paid more attention. For example, the signal designed in this paper is only referred to chirp signal, some other radar signal can be used to realize the design of radar and communication which will extend the application scope of radar and communication integration. And the channel noise is assumed to be additive white Gaussian noise, while the actual noise is more complex.

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