Radar-Communication Integration Based on OFDM Signal

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Abstract: ***As the volume of the electronic platform growing with the increase of their functions. It has great significance to utilize single form of signal to realize multiple functions. Since the multicarrier waveform has been widely used in communication and also show good performances in radar, this paper put forward an integrated radar and communication signal based on the OFDM. How to achieve the transmitter and how to transmit the communication data are discussed afterwards. The ambiguity function of the integrated signal is worked out to analysis the characteristics in detail, especially how the random digital sequence affect the radar performance. Theoretical analysis and simulation results show that the integrated signal can satisfy conventional radar detection and have good communication performance.***

Index Terms—OFDM, ambiguity function, multicarrier, Radar-Communication Integration

I. INTRODUCTION

In order to improve the survival rate and gain more capabilities, battle platform has to equip with more and more electronic equipments. Therefore, the study on the integration of radar and communication not only help to reduce the cost and mutual interference, but also show great importance in raising the overall platform's effectiveness, reliability and maintainability.

As the key problem of the integration, the design of the integrated signal has draw great attention in recent years. The studies focus on two threads: ① First, the radar and communication use respective 各自的 signal to realize their own function, they mix at the transmitter and be separated at the receiver using separating algorithm corresponding to the way how they mix. As in [2], the radar and communication signal multiply before they transmit, using the improved blind source separation algorithm to separate after they are transmitted. Limited by the separating algorithm, however, the integrated signal is sensitive to the Doppler shift ② The other thought is using only one signal to achieve two functions simultaneously, In this method, parameters of the conventional radar signal are modulated by communication sequence, or some concepts in communication or other fields are used for reference. As in [3], the method are similar to the concept of FDM (Frequency Division Multiplexing) which is widely used in the field of communication..

Obviously, we can see the second way has a higher degree of integration. Noticing that the OFDM waveform is not only widely used in communication, but also show great potentials in radar detecting. This paper does some research on the ground of the previous research, designing an integrated radar and communication signal based on multicarrier phase coded waveform. In the design, the deserialized digital sequence is modulated in every subcarrier at the transmitter, the radar and communication system extract their required information respectively at the receiver. 识别

II. THE INTEGRATED SIGNAL

The expression of the OFDM signal :

$$s(t)=\sum_{n=0}^{N-1} w_n u_n(t)\exp(j2\pi f_n t) \tag{1}$$

Here, N is the number of the subcarrier. $u_n(t)$ is envelope of the phase code. $f_n = f_c + (n-1)\Delta f$ is the carrier frequency of the nth carrier. w_n is the weight coefficient.

Modulate digital information into the OFDM, we obtain the integrated signal:

$$s(t)=\sum_{n=0}^{N-1} d(n) w_n(t) u_n(t)\exp(j2\pi f_n t) \tag{2}$$

Here, $d(n)$ is the deserialized digital sequence Modulated in the nth sub-carrier.

The transmitter structure shows in Fig.1. Form it we know, it's a multicarrier direct-sequence spread spectrum system for communication and a multi-carrier phase coded system for radar.

III. AMBIGUITY FUNCTION

Ambiguity function is an important tool for signal analysis and designing, it illustrates the range and Doppler resolution when the transmitting signal is dealt with an optimal match filter.

The ambiguity function of the integrated signal :

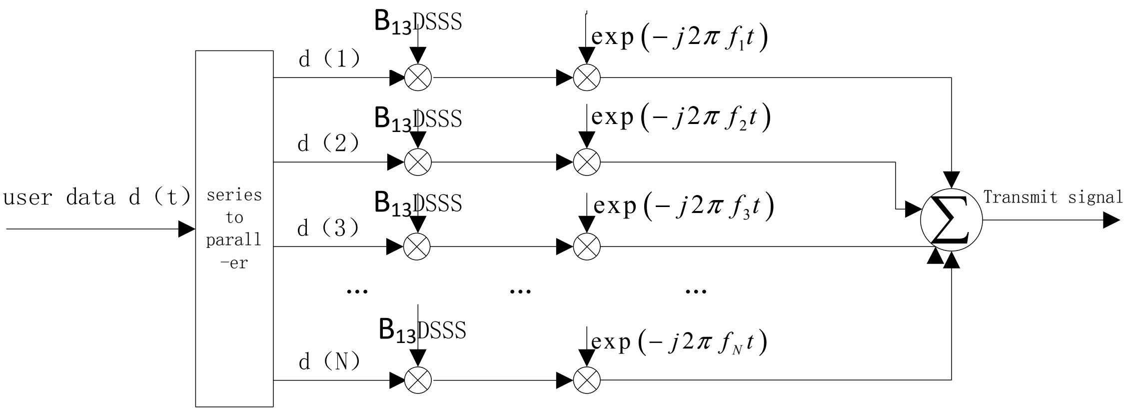

Fig. 1. transmitter design of the integrated signal

$S(t)=\sum_{n=0}^{N-1} d(n) W_n(t) U_n(t) \exp(j2\pi f_n t)$

$$\begin{aligned}\chi(\tau,f_d) &= \int_{-\infty}^{+\infty} s(t)s^*(t+\tau)\exp(j2\pi f_d t)dt \\ &= \sum_{p=0}^{P-1}\sum_{l=0}^{P-1} w_p w_l^* d(p)d(l)\exp[-j2\pi l\Delta f\tau] \\ &\int_{-\infty}^{+\infty} u_p(t)u_l^*(t+\tau) \\ &\bullet\exp\left[j2\pi(p-l)\Delta ft + j2\pi f_d t\right]dt \\ &= \chi_{auto}(\tau,f_d)+\chi_{cross}(\tau,(p-l)\Delta f+f_d)\end{aligned} \tag{3}$$

Here, χ_{auto} is the main part of the ambiguity function, obtain in the situation $p=l$, χ_{cross} is the mutual interference, acquire when $p\neq l$. After calculation, we get the expression below:

$$\chi_{auto}(\tau,f_d)=\sum_{p=0}^{P-1} w_p^2\exp[-j2\pi p\Delta f\tau]\chi_p(\tau,f_d) \tag{4}$$

$$\chi_{auto}(\tau,f_d)=\sum_{p=0}^{P-1} w_p^2\exp[-j2\pi p\Delta f\tau]\bullet\chi_p(\tau,f_d) \tag{5}$$

Here, $\chi_p(\tau,f_d)$ is auto ambiguity function of $u_p(t)$, $\chi_{p,l}(\tau,f_d)$ is the cross ambiguity function of $u_p(t)$ and $u_l(t)$.

Let's ignore the computation process and give the expression of the auto ambiguity and cross ambiguity function directly:

$$\begin{aligned}\chi_{auto}(\tau,f_d) &= \sum_{p=0}^{P-1} w_p^2\exp(-j2\pi p\Delta f\tau) \\ &\bullet\sum_{q=-(M-1)}^{(M-1)}\chi_u(\tau-qt_b,fd)\chi_a(qt_b,fd)\end{aligned} \tag{6}$$

?

$$\begin{aligned}\chi_{cross}(\tau,f_d) &= \sum_{p=0}^{P-1}\sum_{l=0,p\neq l}^{P-1} w_p w_l^* d(p)d(l)\exp(j2\pi l\Delta f\tau) \\ &\bullet\sum_{m=0}^{M-1}\sum_{n=0}^{M-1} a_{p,m}a_{l,n}^*\chi_u\left[\tau-(n-m)t_b,(p-l)\Delta f+f_d\right] \\ &\bullet\exp\left(j2\pi((p-l)\Delta f+f_d)mt_b\right)\end{aligned} \tag{7}$$

From (6) and (7), we know χ_{auto} doesn't have a digital sequence factor $d(n)$ in it, but when turn about χ_{cross}, there are digital factors. In other words, digital sequence does influence on the cross ambiguity function but does no influence on the main ambiguity function.

Plus these two parts, we get the final expression of total ambiguity function:

$$\begin{aligned}\chi(\tau,f_d) &= \chi_{auto}(\tau,f_d)+\chi_{cross}(\tau,f_d) \\ &= \sum_{p=0}^{P-1} w_p^2\exp(-j2\pi p\Delta f\tau) \\ &\bullet\sum_{q=-(M-1)}^{(M-1)}\chi_u(\tau-qt_b,fd)\chi_a(qt_b,fd) \\ &+\sum_{p=0}^{P-1}\sum_{l=0,p\neq l}^{P-1} w_p w_l^* d(p)d(l)\exp(j2\pi l\Delta f\tau) \\ &\bullet\sum_{m=0}^{M-1}\sum_{n=0}^{M-1} a_{p,m}a_{l,n}^*\chi_u\left[\tau-(n-m)t_b,(p-l)\Delta f+f_d\right] \\ &\bullet\exp\left(j2\pi((p-l)\Delta f+f_d)mt_b\right)\end{aligned} \tag{8}$$

So from the result we can see, the main ambiguity function of the integrated signal which isn't affected by communication process is origin from some variations of the single carrier phase-coded signals. At the same time, diffident sub-carriers lead to a mutual interference which is affected by random digital sequence. How it act and what the influence lead to will be analyzed in the next chapter.

IV. PERFORMANCE MEASURES

A. Analysis of Ambiguity Function

The integrated signal consist of two parts as we explored before: $\chi_{auto}(\tau, f_d)$ gather most of the energy of the ambiguity function. $\chi_{auto}(\tau, f_d)$ is the part we hope to suppress which show mutual interference among different sub-carriers. The analysis in the former chapter shows that the random digital sequence has no influence in the main ambiguity function, but affects the performance of the interference part. The simulation will help you to see it more visualize. Chose a baker code with a length of 13 as the phase shift keying sequence, Suppose the pulse width $T = 1.3\mu s$, then the chip width $t_b = T/M = 0.1\mu s$, the interval frequency of adjacent sub-carrier $\Delta f = 1/t_b = 10MHz$. Using MATLAB to produce a random digital sequence, simulate the ambiguity function when the sub-carrier is 16 and 64 with no weight coefficients multiplied. The results show in Fig.2 and Fig.3, we see that the signal shows a good resolution both in range and Doppler dimensions, when the number of sub-carrier increase, the resolution get even better.

$\chi_{\cos}(\tau, f_d)$ is the mutual interference part and sensitive to the digital sequence. To see the digital sequence's influence on the ambiguity function more clearly, consider the situation when the subcarrier number is 16 and an ideal weight coefficient is given [7], so the signal may present an observable cross ambiguity function. Figure.3 and Figure.4 shows the simulation results with and without a random digital sequence modulation normalized by the amplitude peak of the total ambiguity function. We can see the adjacent interference cause a weak fluctuation in the cross ambiguity function, but not always leading to a worse result.

B. Performance of Communication System

Let's measure a system with 64 sub-carriers, every sub-carrier carries 1 bit of information, therefore, there have a total of 64 bits in every pulse during time. Suppose the duty cycle of the integrated signal is 0.3, then the bit rate can be expressed as:

$\boxed{\frac{64bit}{1.3\mu s \div 0.3}}$

$$64bit / 1.3\mu s \times 0.3 = 14.8Mbit/s \tag{9}$$

The bandwidth of the signal $B = N * \Delta f = 640MHz$, so the spectrum effectiveness is $0.0231 bit/(s*Hz)$, the low efficiency of the spectrum is decided by the wide band of the radar system.

Properly designed, the system could reach a similar bit error rate with a regular OFDM communication system, so we can draw a conclusion that the integrated signal can satisfy the communication requests in some degree [9].

V. CONCLUSIONS

In this paper, we carry out a feasibility study of the phase-coded OFDM signal to conduct the radar-communication integration. First the expression of the signal is given, then some analysis is done with the help of ambiguity function. Theoretical analysis and simulation results show that the integrated signal satisfy the commands for radar and communication system. However, since the study on the integration of radar and communication have just been paid attention, more technological problems still leave to be solved.

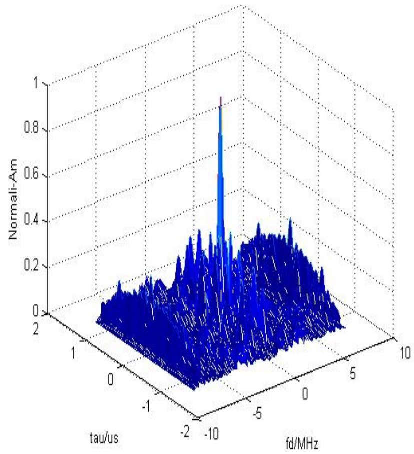

Fig. 2. ambiguity function of the integrated signal.(N=16)

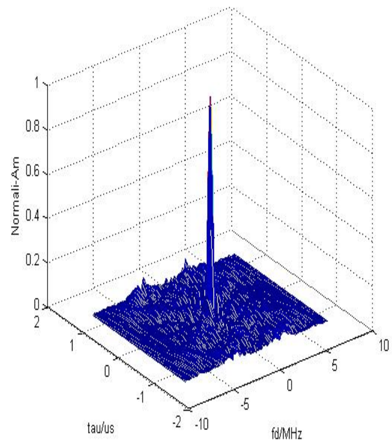

Fig. 3. ambiguity function of the integrated signal.(N=64)

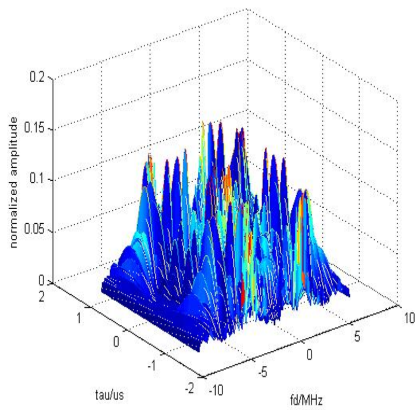

Fig. 4. adjacent channel interference with no digital sequence

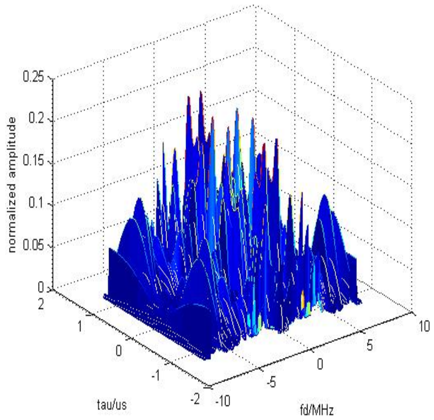

Fig. 5. adjacent channel interference with digital sequence

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