Ambiguity Function Analysis of Radar-Communication Integrated Waveform Based on FDM and TDM Technologies

Hongzhi Men[1,2], Zhiqun Song[2(✉)], and Guisheng Liao[1]

[1] School of Electronics Engineering Xi'an, Xi'an 710126, China
[2] The 54th Research Institute of CECT, Shijiazhuang 050081, Hebei, China
zhiqunsy@163.com

Abstract. In this letter, we propose a novel radar-communication integration signal, which employs the linear frequency modulation (LFM) signal modulated by digital symbols is divided from time and frequency domain to achieve radar detection and data communication. By analyzing its ambiguity function, we confirm its feasibility of applying in radar-communication integration system.

Keywords: Radar-communication integration · LFM · TDM · Ambiguity function

1 Introduction

The more and more complex electronic environment and scenarios require the electronic system smaller size, more function, lower consumption and greater capacity. Hence, the concept of the integrated electronic systems is proposed to meet a variety of applications, especially the integrated radar-communication system. The concept of the radar-communication integration is proposed in recent few decades, whose existing researches mainly focus on the waveform design. Now it is a research hot-spot to employ multiple resources and technologies to form a integrated waveform for high data rate, long distance, reliable communication and high measurement accuracy, high resolution radar detection.

Over the last few decades, several design approaches have been proposed to design integrated radar-communication signal [1]. The key difference between these approaches is how the radar signal and communication data are combined. These methods can be summarized as resource reuse method, waveform multiplexing method and technologies fusion method. The integrated signal design is mainly supported by the spread spectrum (SS) technology [2,3], linear frequency modulation (LFM) [4–6], and the orthogonal frequency division multiplexing (OFDM) [7–9]. In the existing SS-based [2,3] and LFM-based [4–6] design

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schemes, particular technology carriers modulated by digital symbols are used for radar and communication pulses, the envelop of integrated signal and digital symbols presenting radar waveform and information data respectively. However, SS-based and LFM-based approaches cannot meet the demand of transmitting a large number of data, because the SS-technology makes equivalent available bandwidth of radar and communication great decrease under the condition of the same system bandwidth. In recent years, OFDM waveform also has been introduced to design integrated waveforms for higher transmission rate due to its frequency orthogonality and high order number of modulation symbols. While, peak-to-average ratio, frequency deviation and easily broken orthogonality limit its application in the design of integrated signals.

Considering the above issues, this paper proposes a novel design scheme of radar-communication integrated waveform. In the design scheme, the key parameters of LFM carrier are modulated by communication sequences, the time division factor L and frequency selection sequences.

The rest of the manuscript is organized as follows. In Sect. 2, we introduce the basic principles of the LFM signal. In Sect. 3, we first describe the design scheme and mathematical expression of the integrated signal, and then analyze its ambiguity function performance. Section 4 presents the simulation results of the proposed integrated waveform. Finally, Sect. 5 ends up with conclusion.

Notation: $(\cdot)^*$ is the conjugate of a complex number; $|a|$ is the modulus value of the variable a.

2 A Novel Integrated Signal

2.1 Waveform Generation

In the radar-communication integration system, we suppose that the bandwidth, the time period and the pulse width are represented by B, T and T_s, respectively. To describe the design scheme of the integrated signal, we propose two key parameters, time division factor N and frequency division factor L. The signal bandwidth is divided into N sub-bands, and the signal pulse width T_s is divided into L sub-signal periods. Hence, the bandwidth and time period of the sub-signals are $\tilde{B} = B/N$ and $T_t = T_s/L$, respectively.

The proposed integrated waveform is a special sub-signal sequence, i.e.,

$$s(t) = \{s_1(t), s_2(t), \cdots, s_L(t)\} = \sum_{k=0}^{L-1} s_k(t), \tag{1}$$

where the k^{th} sub-signal is

$$\begin{aligned} s_k(t) &= s_k \exp[j2\pi f_k(t - kT_t) + j\pi\mu(t - kT_t)^2]\mathrm{rect}(\frac{t - kT_t}{T_t}) \\ &= P_k \exp[j2\pi(f_k - \mu kT_t)t + j\pi\mu t^2]\mathrm{rect}(\frac{t - kT_t}{T_t}) \end{aligned} \tag{2}$$

where the variable $P_k = s_k \exp[-j2\pi f_k kT_t + j\pi\mu(kT_t)^2]$. In the expression of the sub-signal $s_k(t)$, the function $\mathrm{rect}(x)$ is

$$\mathrm{rect}(x) = \begin{cases} 1, \, 0 \le x \le 1; \\ 0, \, \text{else}. \end{cases} \tag{3}$$

Moreover, the variables s_k and f_k are respectively on behalf of the transmitted symbol and initial frequency of the LFM carrier, which are decided by the current communication information. The communication information bit-stream is divided into blocks with $\log_2(N) + \log_2(M)$ bits, i.e.,

$$X_k = \{\underbrace{x_1, x_2, \cdots, x_{\log_2(M)}}_{q_k}, \underbrace{y_1, y_2, \cdots, y_{\log_2(N)}}_{p_k}\}. \tag{4}$$

Thereinto, the first $\log_2(M)$ bits are used to select the transmitted symbol s_k from M-ary modulation signal set, i.e., $s_k = A_k \exp(j\theta_{q_k})$. The second $\log_2(N)$ bits are used to select one sub-carrier $f_k = f(p_k)$ from the initial frequency set. L blocks are spliced together to constitute the integrated signal waveform. In Fig. 1, we illustrate the modulator diagram of the integrated waveform for the integrated radar-communication system.

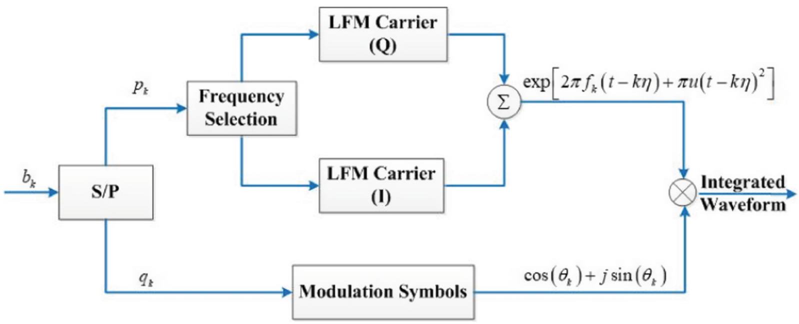

Fig. 1. Modulator

2.2 Spectrum of Waveform

The frequency spectrum of the integrated signal can be calculate as

$$\begin{aligned} &\int_{-\infty}^{+\infty} s(t)\exp(-j2\pi f t)dt \\ &= \sum_{k=0}^{L-1} P_k \int_{kT_t}^{(k+1)T_t} \exp[j2\pi(f_k - f - \mu kT_t)t + j\pi\mu t^2]dt \\ &= \sum_{k=0}^{L-1} P_k \exp\left(-j\pi\mu\xi^2\right) \int_{kT_t}^{(k+1)T_t} \exp\left[j\pi\mu(t+\xi)^2\right] dt, \end{aligned} \tag{5}$$

where the variable $\xi = (f_k - f - k\mu\eta)/\mu$. To acquire an accurate theory result, Fresnel integral can be applied,

$$\begin{aligned}
&\int_{kT_t}^{(k+1)T_t} \exp\left[j\pi\mu(t+\xi)^2\right] dt \\
&= \int_{\sqrt{2\mu}(kT_t+\xi)}^{\sqrt{2\mu}[(k+1)T_t+\xi]} \exp\left(j\frac{\pi x^2}{2}\right) dt \\
&= \int_{\sqrt{2\mu}(kT_t+\xi)}^{\sqrt{2\mu}[(k+1)T_t+\xi]} \cos\left(\frac{\pi x^2}{2}\right) dt + j\int_{\sqrt{2\mu}(kT_t+\xi)}^{\sqrt{2\mu}[(k+1)T_t+\xi]} \sin\left(\frac{\pi x^2}{2}\right) dt \\
&= \left[\mathcal{C}(\nu_1) - \mathcal{C}(\nu_2)\right] + j\left[\mathcal{S}(\nu_1) - \mathcal{S}(\nu_2)\right]
\end{aligned} \tag{6}$$

where the variable $x = \sqrt{2\mu}(t+\xi)$, $\nu_1 = \sqrt{2\mu}[(k+1)T_t+\xi]$ and $\nu_2 = \sqrt{2\mu}(kT_t+\xi)$, and the Fresnel integral function is

$$\mathcal{C}(\nu) = \int_0^{\nu} \cos\left(\frac{\pi x^2}{2}\right) dt, \quad \mathcal{S}(\nu) = \int_0^{\nu} \sin\left(\frac{\pi x^2}{2}\right) dt. \tag{7}$$

3 Ambiguity Function

In this subsection, we analyze the performance of the integrated signal from its ambiguity function.

The ambiguity function of the integrated signal is

$$\chi(\tau, f_d) = \left| \int_{-\infty}^{\infty} s(t)\left[s(t-\tau)\right]^* \exp\left(j2\pi f_d t\right) dt \right|^2. \tag{8}$$

According to Sect. 2, we can know that the mathematical expression of the integrated waveform can be presented as follows,

$$s(t) = \sum_{k=0}^{L-1} P_k \exp[j2\pi(f_k - \mu kT_t)t + j\pi\mu t^2]\mathrm{rect}(\frac{t-kT_t}{T_t}). \tag{9}$$

To calculate the ambiguity function in (8), we first simply the integral function,

$$s(t-\tau) = \sum_{k=0}^{L-1} P_k Q_k \exp[j2\pi(f_k - \mu kT_t - \mu\tau)t + j\pi\mu t^2] \tag{10}$$

where $Q_k = \exp\left[-j2\pi(f_k - \mu kT_t)\tau + j\pi\mu\tau^2\right]$. Hence, the equation in (8) can be written as

$$\chi(\tau, f_d) = \left| \int_{-\infty}^{\infty} \sum_{k=0}^{L-1}\sum_{l=0}^{L-1} s_k(t)s_l^*(t-\tau)\exp\left(j2\pi f_d t\right) dt \right|^2. \tag{11}$$

In the following, we discuss the values of the delay τ and the Doppler frequency shift f_d to calculate the ambiguity function of integrated waveform.

$$\chi(\tau, f_d) = \begin{cases} \mathbf{C1}, \tau = 0, f_d = 0; \\ \mathbf{C2}, \tau = 0, f_d \neq 0; \\ \mathbf{C3}, \tau \neq 0, f_d = 0; \\ \mathbf{C4}, \tau \neq 0, f_d \neq 0. \end{cases} \tag{12}$$

C1:

$$\chi(\tau, f_d) = \left| \sum_{k=0}^{L-1} \int_{kT_t}^{(k+1)T_t} |s_k|^2 dt \right|^2 = (T_t)^2 \sum_{k=0}^{L-1} |s_k|^2 . \tag{13}$$

C2:

$$\begin{aligned} \chi(\tau, f_d) &= \left| \sum_{k=0}^{L-1} \int_{kT_t}^{(k+1)T_t} \exp\left(j2\pi f_d t\right) dt \right|^2 \\ &= \left| \frac{\sin(\pi f_d T_t)}{\pi f_d} \right|^2 \left| \sum_{k=0}^{L-1} |s_k|^2 \exp\left[j\pi f_d (2k+1) T_t\right] \right|^2 . \end{aligned} \tag{14}$$

C3:

$$\chi(\tau, f_d) = \begin{cases} 0, \quad |\tau| \geq T_s; \\ \mathbf{C_3^1}, -T_s < \tau < 0, |\tau| = KT_t + \Delta t; \\ \mathbf{C_3^2}, 0 < \tau < T_s, |\tau| = KT_t + \Delta t. \end{cases} \tag{15}$$

$\mathbf{C_3^1}$:

$$\chi(\tau, f_d) = \left| \sum_{k=0}^{L-K-1} \int_{kT_t}^{(k+1)T_t - \Delta t} f_1(t) dt + \sum_{k=0}^{L-K-2} \int_{(k+1)T_t - \Delta t}^{(k+1)T_t} f_2(t) dt \right|^2 , \tag{16}$$

where the integral functions $f_1(t)$ and $f_2(t)$ have the following expressions,

$$\begin{aligned} f_1(t) =& s_k(t) \left[s_{k+K+1}(t-\tau)\right]^* , \\ f_2(t) =& s_k(t) \left[s_{k+K+2}(t-\tau)\right]^* . \end{aligned} \tag{17}$$

Thus, we can know that

$$\begin{aligned} &\int_{kT_t}^{(k+1)T_t - \Delta t} f_1(t) dt \\ =& P_k P_{k+K+1}^* Q_{k+K+1}^* \int_{kT_t}^{(k+1)T_t - \Delta t} \exp(j2\pi f_k^1 t) dt \\ =& P_k P_{k+K+1}^* Q_{k+K+1}^* Y_k^1 \sin\left[\pi f_k^1 (T_t - \Delta t)\right] / (\pi f_k^1), \end{aligned} \tag{18}$$

where the variables f_k^1 and Y_k^1 are

$$\begin{aligned} f_k^1 &= f_k - f_{k+K+1} + \mu(K+1)T_t + \mu\tau, \\ Y_k^1 &= \exp\{j\pi f_k^1 [(2k+1)T_t - \Delta t]\}; \end{aligned} \tag{19}$$

and

$$\begin{aligned}&\int_{(k+1)T_t-\Delta t}^{(k+1)T_t} f_2(t)dt\\ =&P_kP^*_{k+K+2}Q^*_{k+K+2}\int_{(k+1)T_t-\Delta t}^{(k+1)T_t}\exp(j2\pi f_k^2 t)dt\\ =&P_kP^*_{k+K+2}Q^*_{k+K+2}Y_k^2\sin(\pi f_k^2\Delta t)/(\pi f_k^2),\end{aligned} \tag{20}$$

where the variables f_k^2 and Y_k^2 are

$$\begin{aligned}f_k^2 &= f_k - f_{k+K+2} + \mu(K+2)T_t + \mu\tau,\\ Y_k^2 &= \exp\{j\pi f_k^2[(2k+2)T_t - \Delta t]\}.\end{aligned} \tag{21}$$

Thus, the ambiguity function under the above conditions in $\mathbf{C_3^1}$ is

$$\begin{aligned}&\chi(\tau, f_d)\\ =&|\sum_{k=0}^{L-K-1} P_kP^*_{k+K+1}Q^*_{k+K+1}Y_k\sin[\pi f_k^1(T_t-\Delta t)]/(\pi f_k^1)\\ &+\sum_{k=0}^{L-K-2} P_kP^*_{k+K+2}Q^*_{k+K+2}Z_k\sin(\pi f_k^2\Delta t)/(\pi f_k^2)|^2.\end{aligned} \tag{22}$$

$\mathbf{C_3^2}$:

$$\chi(\tau, f_d) = \left|\sum_{k=0}^{L-K-1}\int_{kT_t}^{(k+1)T_t-\Delta t} f_3(t)dt + \sum_{k=0}^{L-K-2}\int_{(k+1)T_t-\Delta t}^{(k+1)T_t} f_4(t)dt\right|^2 \tag{23}$$

where the integral functions $f_3(t)$ and $f_4(t)$ have the following expressions,

$$\begin{aligned}f_3(t) =& s_{k+K+1}(t)\left[s_k(t-\tau)\right]^*,\\ f_4(t) =& s_{k+K+2}(t)\left[s_k(t-\tau)\right]^*.\end{aligned} \tag{24}$$

Thus, we can know that

$$\begin{aligned}&\int_{kT_t}^{(k+1)T_t-\Delta t} f_3(t)dt\\ =&P_{k+K+1}P_k^*Q_k^*\int_{kT_t}^{(k+1)T_t-\Delta t}\exp(j2\pi f_k^3 t)dt\\ =&P_{k+K+1}P_k^*Q_k^*Y_k^3\sin[\pi f_k^3(T_t-\Delta t)]/(\pi f_k^3),\end{aligned} \tag{25}$$

where the variables f_k^3 and Y_k^3 are

$$\begin{aligned}f_k^3 &= f_{k+K+1} - f_k - \mu(K+1)T_t - \mu\tau,\\ Y_k^3 &= \exp\{j\pi f_k^3[(2k+1)T_t - \Delta t]\};\end{aligned} \tag{26}$$

and

$$\begin{aligned}&\int_{(k+1)T_t-\Delta t}^{(k+1)T_t} f_4(t)dt\\ =&P_{k+K+2}P_k^*Q_k^*\int_{kT_t}^{(k+2)T_t-\Delta t}\exp(j2\pi f_k^4 t)dt\\ =&P_{k+K+2}P_k^*Q_k^*Y_k^4\sin\left[\pi f_k^4(T_t-\Delta t)\right]/(\pi f_k^4),\end{aligned} \tag{27}$$

where the variables f_k^4 and Y_k^4 are

$$\begin{aligned}f_k^4 &= f_{k+K+2}-f_k-\mu(K+2)T_t-\mu\tau,\\ Y_k^4 &= \exp\{j\pi f_k^4[(2k+2)T_t-\Delta t]\};\end{aligned} \tag{28}$$

Thus, the ambiguity function under the above conditions in $\mathbf{C_3^2}$ is

$$\begin{aligned}&\chi(\tau,f_d)\\ =&|\sum_{k=0}^{L-K-1}P_kP_{k+K+1}^*Q_{k+K+1}^*Y_k^3\sin\left[\pi f_k^3(T_t-\Delta t)\right]/(\pi f_k^3)\\ +&\sum_{k=0}^{L-K-2}P_kP_{k+K+2}^*Q_{k+K+2}^*Y_k^4\sin(\pi f_k^4\Delta t)/(\pi f_k^4)|^2.\end{aligned} \tag{29}$$

C4:

$$\chi(\tau,f_d)=\begin{cases}0, & |\tau|\geq T_s;\\ \mathbf{C_4^1}, -T_s<\tau<0, |\tau|=KT_t+\Delta t;\\ \mathbf{C_4^2}, 0<\tau<T_s, |\tau|=KT_t+\Delta t.\end{cases} \tag{30}$$

$\mathbf{C_4^1}$**:**

$$\chi(\tau,f_d)=\left|\sum_{k=0}^{L-K-1}\int_{kT_t}^{(k+1)T_t-\Delta t}h_1(t)dt+\sum_{k=0}^{L-K-2}\int_{(k+1)T_t-\Delta t}^{(k+1)T_t}h_2(t)dt\right|^2$$

where the integral functions $h_1(t)$ and $h_2(t)$ have the following expressions,

$$\begin{aligned}h_1(t)=&s_k(t)\left[s_{k+K+1}(t-\tau)\right]^*\exp(j2\pi f_d t),\\ h_2(t)=&s_k(t)\left[s_{k+K+2}(t-\tau)\right]^*\exp(j2\pi f_d t).\end{aligned} \tag{31}$$

Thus, we can know that

$$\begin{aligned}&\int_{kT_t}^{(k+1)T_t-\Delta t}h_1(t)dt\\ =&P_kP_{k+K+1}^*Q_{k+K+1}^*\int_{kT_t}^{(k+1)T_t-\Delta t}\exp(j2\pi\tilde{f}_k^1 t)dt\\ =&P_kP_{k+K+1}^*Q_{k+K+1}^*Z_k^1\sin\left[\pi\tilde{f}_k^1(T_t-\Delta t)\right]/(\pi\tilde{f}_k^1),\end{aligned} \tag{32}$$

where the variables $\tilde{f}_k^1$ and Z_k^1 are

$$\begin{aligned}\tilde{f}_k^1 &= f_k - f_{k+K+1} + \mu(K+1)T_t + \mu\tau + f_d,\\ Z_k^1 &= \exp\{j\pi\tilde{f}_k^1[(2k+1)T_t - \Delta t]\};\end{aligned} \tag{33}$$

and

$$\begin{aligned}&\int_{(k+1)T_t-\Delta t}^{(k+1)T_t} h_2(t)dt\\ =&P_kP_{k+K+2}^*Q_{k+K+2}^*\int_{(k+1)T_t-\Delta t}^{(k+1)T_t}\exp(j2\pi\tilde{f}_k^2 t)dt\\ =&P_kP_{k+K+2}^*Q_{k+K+2}^*Z_k^2\sin(\pi\tilde{f}_k^2\Delta t)/(\pi\tilde{f}_k^2),\end{aligned} \tag{34}$$

where the variables $\tilde{f}_k^2$ and Z_k^2 are

$$\begin{aligned}\tilde{f}_k^2 &= f_k - f_{k+K+2} + \mu(K+2)T_t + \mu\tau + f_d,\\ Z_k^2 &= \exp\{j\pi\tilde{f}_k^2[(2k+2)T_t - \Delta t]\}.\end{aligned} \tag{35}$$

Thus, the ambiguity function under the above conditions in $\mathbf{C_4^1}$ is

$$\begin{aligned}&\chi(\tau, f_d)\\ =&|\sum_{k=0}^{L-K-1}P_kP_{k+K+1}^*Q_{k+K+1}^*Z_k^1\sin[\pi\tilde{f}_k^1(T_t-\Delta t)]/(\pi\tilde{f}_k^1)\\ +&\sum_{k=0}^{L-K-2}P_kP_{k+K+2}^*Q_{k+K+2}^*Z_k^2\sin(\pi\tilde{f}_k^2\Delta t)/(\pi\tilde{f}_k^2)|^2.\end{aligned} \tag{36}$$

$\mathbf{C_4^2}$:

$$\chi(\tau, f_d) = \left|\sum_{k=0}^{L-K-1}\int_{kT_t}^{(k+1)T_t-\Delta t}h_3(t)dt + \sum_{k=0}^{L-K-2}\int_{(k+1)T_t-\Delta t}^{(k+1)T_t}h_4(t)dt\right|^2 \tag{37}$$

where the integral functions $h_3(t)$ and $h_4(t)$ have the following expressions,

$$\begin{aligned}h_3(t) =&s_{k+K+1}(t)\left[s_k(t-\tau)\right]^*\exp(j2\pi f_d t),\\ h_4(t) =&s_{k+K+2}(t)\left[s_k(t-\tau)\right]^*\exp(j2\pi f_d t).\end{aligned} \tag{38}$$

Thus, we can know that

$$\begin{aligned}&\int_{kT_t}^{(k+1)T_t-\Delta t}h_3(t)dt\\ =&P_{k+K+1}P_k^*Q_k^*\int_{kT_t}^{(k+1)T_t-\Delta t}\exp(j2\pi\tilde{f}_k^3 t)dt\\ =&P_{k+K+1}P_k^*Q_k^*Z_k^3\sin[\pi\tilde{f}_k^3(T_t-\Delta t)]/(\pi\tilde{f}_k^3),\end{aligned} \tag{39}$$

where the variables $\tilde{f}_k^3$ and Z_k^3 are

$$\begin{aligned} \tilde{f}_k^3 &= f_{k+K+1} - f_k - \mu(K+1)T_t - \mu\tau + f_d, \\ Z_k^3 &= \exp\{j\pi\tilde{f}_k^3[(2k+1)T_t - \Delta t]\}; \end{aligned} \tag{40}$$

and

$$\begin{aligned} &\int_{(k+1)T_t-\Delta t}^{(k+1)T_t} h_4(t)dt \\ =&P_{k+K+2}P_k^* Q_k^* \int_{kT_t}^{(k+2)T_t-\Delta t} \exp(j2\pi\tilde{f}_k^4 t)dt \\ =&P_{k+K+2}P_k^* Q_k^* Z_k^4 \sin[\pi\tilde{f}_k^4(T_t - \Delta t)]/(\pi\tilde{f}_k^4), \end{aligned} \tag{41}$$

where the variables $\tilde{f}_k^4$ and Z_k^4 are

$$\begin{aligned} \tilde{f}_k^4 &= f_{k+K+2} - f_k - \mu(K+2)T_t - \mu\tau + f_d, \\ Z_k^4 &= \exp\{j\pi\tilde{f}_k^4[(2k+2)T_t - \Delta t]\}; \end{aligned} \tag{42}$$

Thus, the ambiguity function under the above conditions in $\mathbf{C_4^2}$ is

$$\begin{aligned} &\chi(\tau, f_d) \\ =&|\sum_{k=0}^{L-K-1} P_k P_{k+K+1}^* Q_{k+K+1}^* Z_k^3 \sin[\pi\tilde{f}_k^3(T_t - \Delta t)]/(\pi\tilde{f}_k^3) \\ +&\sum_{k=0}^{L-K-2} P_k P_{k+K+2}^* Q_{k+K+2}^* Z_k^4 \sin(\pi\tilde{f}_k^4 \Delta t)/(\pi\tilde{f}_k^4)|^2. \end{aligned} \tag{43}$$

4 Simulation Results and Performance Analysis

In the simulations, we set the key parameters of the proposed integrated signal as pulse period $T = 100\,\mu\text{s}$, pulse width $T_s = 10\,\mu\text{s}$, the initial frequency $f_0 = 0\,\text{MHz}$, frequency division factor $N = 64$, and the sampling rate $f_s = 4B\,\text{MHz}$.

From Figs. 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11, we can know that

1. The ambiguity function of the proposed integrated signal must have the best performance, when the appropriate time division factor L is used in the simulations;
2. The proposed integrated-signal with orthogonal f_k sequence has better ambiguity function compare to the integrated-signal with no orthogonal f_k sequence;
3. The proposed integrated-signal with orthogonal f_k sequence requires larger bandwidth compared with the integrated-signal with no orthogonal f_k sequence.

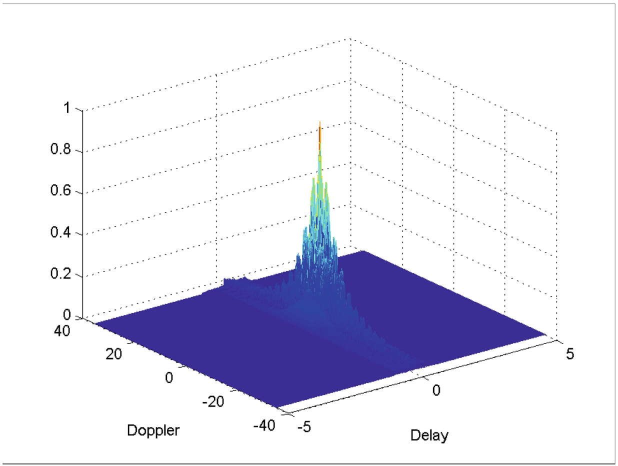

Fig. 2. Ambiguity function of integrated signal with orthogonal f_k sequence time division factor $L = 5$

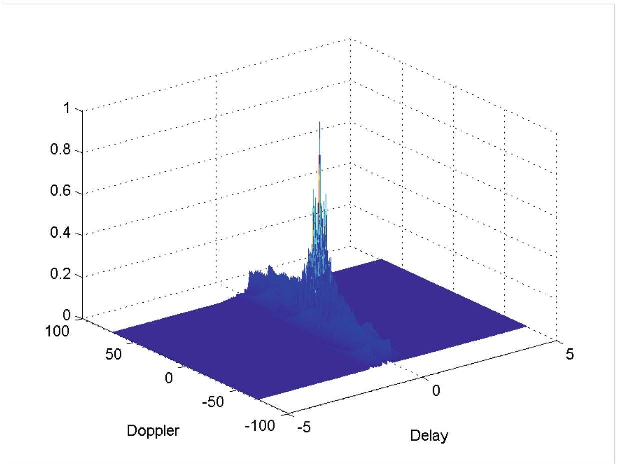

Fig. 3. Ambiguity function of integrated signal with orthogonal f_k sequence time division factor $L = 10$

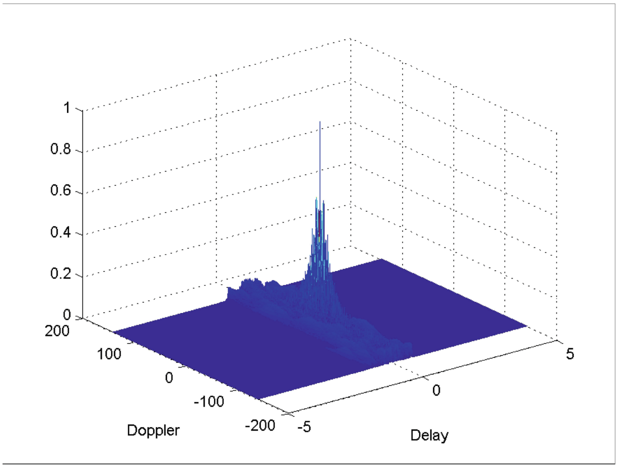

Fig. 4. Ambiguity function of integrated signal with orthogonal f_k sequence time division factor $L = 20$

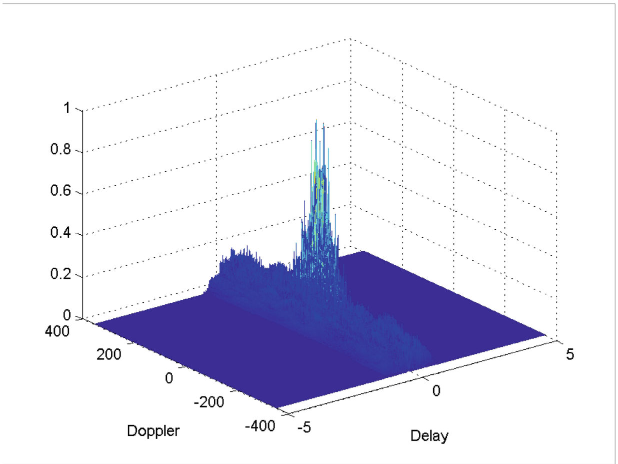

Fig. 5. Ambiguity function of integrated signal with orthogonal f_k sequence time division factor $L = 50$

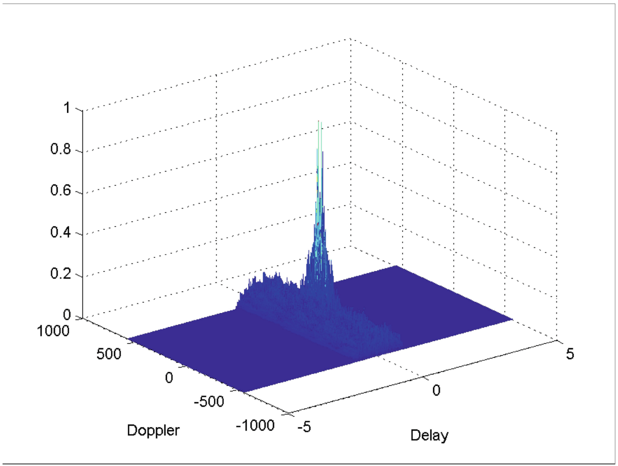

Fig. 6. Ambiguity function of integrated signal with orthogonal f_k sequence time division factor $L = 80$

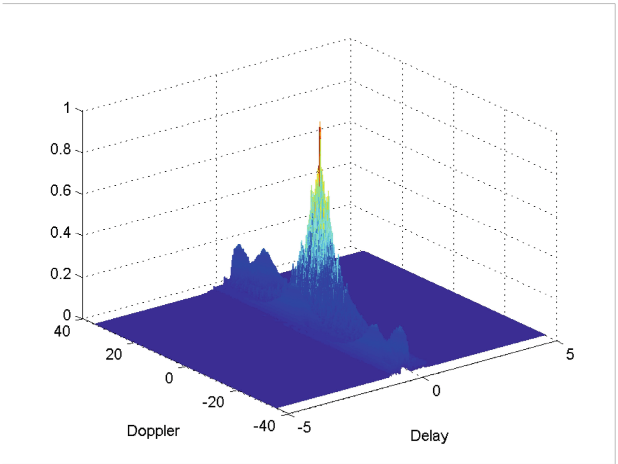

Fig. 7. Ambiguity function of integrated signal with no orthogonal f_k sequence time division factor $L = 5$

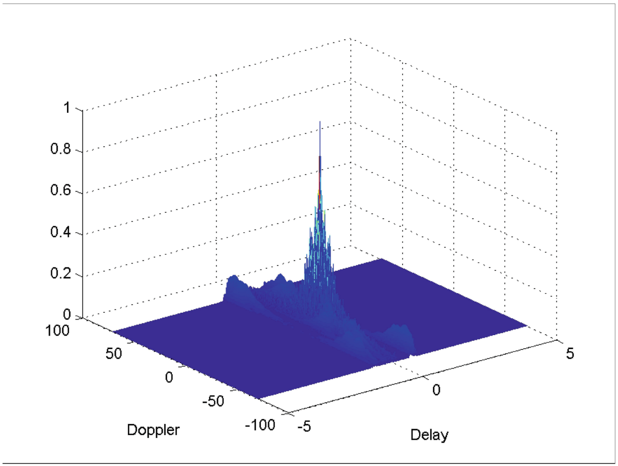

Fig. 8. Ambiguity function of integrated signal with no orthogonal f_k sequence time division factor $L = 10$

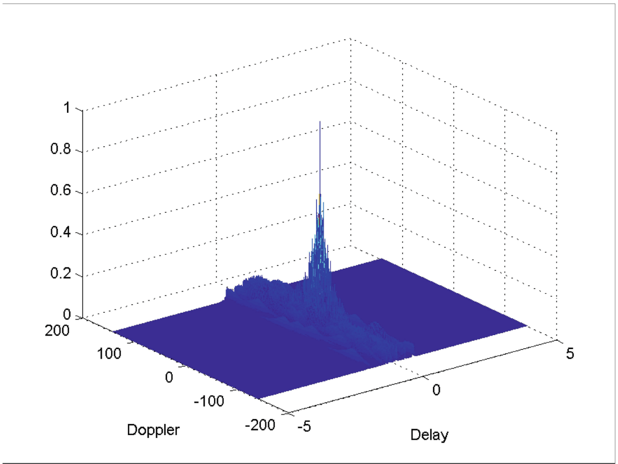

Fig. 9. Ambiguity function of integrated signal with no orthogonal f_k sequence time division factor $L = 20$

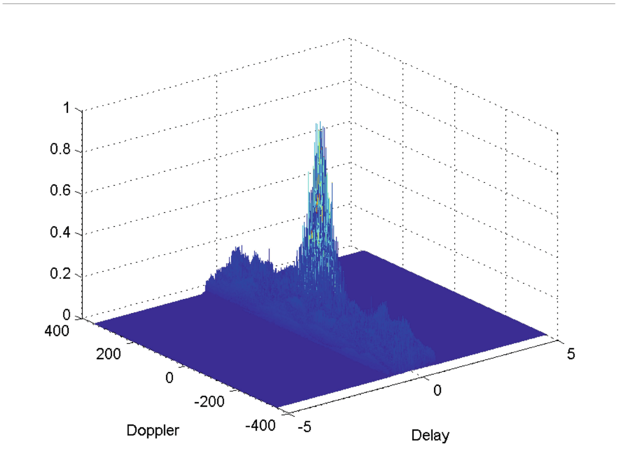

Fig. 10. Ambiguity function of integrated signal with no orthogonal f_k sequence time division factor $L = 50$

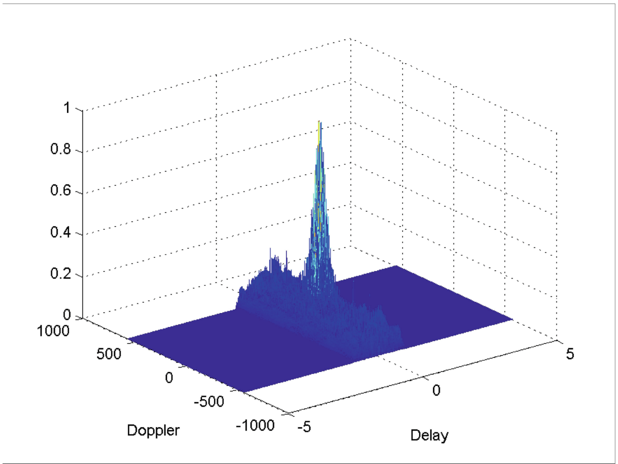

Fig. 11. Ambiguity function of integrated signal with no orthogonal f_k sequence time division factor $L = 80$

5 Summary

In this paper, we first extrapolate the key characteristics of LFM signal when it is employed in the radar system. Then a novel radar-communication integration waveform is proposed to realize the detection and communication at the same time. Moreover, its important performance, ambiguity function, is derived, which shows its feasibility of application in the radar-communication integrated system. Given the length of this journal, other important performance, including detection performance and bits error rate, will not be described in this paper.

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