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The Performance Analysis of a Compound Modulation Signal

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Abstract

Step-Frequency signal is widely used in radar systems. However it suffers from the technique challenges that are the imaging moving-targets. In this paper, a new compound modulation signal is analyzed. It combines phased code modulation during the pulse and Step-Frequency modulation between the pulses time, and it is called as phase-coded Step-Frequency signal. Numeric simulation comparison experiments show that PCSF signal can get the same imaging result with less pulse number, which can be used to solve the conflict problem, such as the number of pulse and transmit average power. So this compound modulation signal can be widely used in the application of engineering project. Finally, the processing method of PCSF is simple analyzed, and numerical simulation proves its effectiveness and accuracy.

Keywords: *Signal, Phase-Coded, Step-Frequency, Compound Modulation, Processing Algorithm*

1. Introduction

Step-Frequency (SF) signal can acquire a large bandwidth and high-resolution range-resolution by IFFT processing [1]. But its accumulation period is relatively long and the system data rate is low, even with the same speed of the targets, its Doppler frequency shift of the echo signal are different, which will affect the effect of high resolution one-dimensional range, it is often called Distance—Doppler coupling [2]. In reference [3], based on the time domain and waveform entropy, two effective motion compensation methods are presented, however they have low estimation accuracy and are only effective in high SNR and moving targets with low-speed. In reference [4], based on SF and Pulse Doppler system, an effective algorithm of motion compensation is presented; numerical simulation shows that the method has higher compensation accuracy and better anti-noise performance. However, it will increase the complexity of radar system. In reference [5], it gives a new kind of waveform which can be used to reduce the coupling of Distance—Doppler.

In this paper, according to these references and different signals, an effective compound modulation signal with intra-pulse phase coded and extra-pulse Step-Frequency (PCSF) is analyzed in detail. It can overcome the shortcomings of the phase coded (PC) signal and the Step-Frequency (SF) signal, the numeric simulation results have proved this conclusion.

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2. The Analysis of PCSF Signal Waveform

For the SF signal, if it wants to get a larger bandwidth, the frequency step Δf or the number of synthesis pulse N should be increased. If Δf is increasing, the pulse width T must be decreased, therefore it will affect the average power of the transmitting pulse. In addition, increasing N will reduce the data rate of radar system, which will make the problem of Distance-Doppler coupling worse.

The PCSF signal is an effective compound modulation signal, through the phase modulation with the sub-pulse of the Step-Frequency signal, Δf is changing with T_1 (the phase coding sub-pulse width), and $T = KT_1$, where K is the number of coding bits. Therefore a larger Δf than SF signal can be acquired and a radar system can achieve the same bandwidth with fewer numbers of pulses, and solve the confliction among the transmitting power, the distance, the bandwidth and the data rate.

The analytical expression of the PCSF signal is as follows:

$$u(t) = \frac{1}{\sqrt{N}} \sum_{i=0}^{N-1} \sum_{m=0}^{K-1} c_m u_c(t - mT_1 - iT_r) \exp(j2\pi i \Delta f t) \quad (1)$$

Where, $u_c(t) = \frac{1}{\sqrt{T_1}} rect(\frac{t}{T_1})$, N is the number of pulses, T_r is the period of the stepped sub-pulse, Δf is frequency step, T is stepped sub-pulse width, T_1 is the width of each bit of phase coded sub-pulse, K is code length, and $T = KT_1$, c_m is the phase code sequence, which commonly use Barker code sequence, Frank code sequence, P code sequence and so on in radar systems.

The waveform of the PCSF signal is shown in Figure 1, where T is the frame period of the PCSF signal.

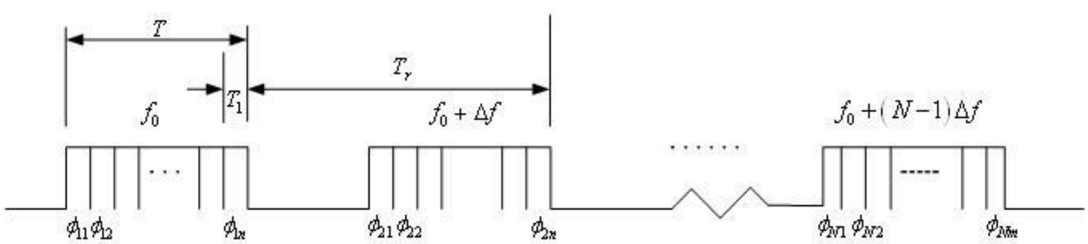


Figure 1. The Waveform Model of the PCSF Signal

2.2. The Frequency Spectrum of PCSF Signal

Barker codes is one of the Binary-phase Coded Signal (BPCS), therefore, in order to derive the frequency spectrum of PCSF signal, suppose the sub-pulse of PCSF is barker codes, and the formula is shown as follows.

$$u(t) = b(t) \otimes w(t) \quad (2)$$

$$b(t)=\frac{1}{\sqrt{T_1}}\sum_{k=0}^{P-1}c_k rect\left(\frac{t-kT_1-T_1/2}{T_1}\right),\quad w(t)=\frac{1}{\sqrt{N}}\sum_{k=0}^{N-1}\delta(t-iT_r)\exp(-j2\pi i\Delta ft)$$

Where, the frequency spectrum of Barker code signal is

$$U(f)=\sqrt{\frac{T_1}{P}}\sin c(fT_1)\exp(-j\pi fT_1)\sum_{k=0}^{P-1}c_k\exp(-j2\pi fkT_1) \tag{3}$$

, and the frequency spectrum of SF signal is

$$W(f)=\frac{1}{\sqrt{N}}\sum_{i=0}^{N-1}\exp(-j2\pi(f-i\Delta f)iT_r) \tag{4}$$

According to the rule of Fourier self-deconvolution, the frequency spectrum of PCSF signal can be calculated, which is shown as follows.

$$\begin{aligned}X(f)&=U(f)W(f)\\&=\sum_{i=0}^{N-1}\sqrt{\frac{T_1}{P}}\sin c((f-i\Delta f)T_1)\exp(-j\pi(f-i\Delta f)T_1)\\&*\sum_{k=0}^{P-1}c_k\exp(-j2\pi(f-i\Delta f)kT_1)\frac{1}{\sqrt{N}}\sum_{i=0}^{N-1}\exp(-j2\pi(f-i\Delta f)iT_r)\\&=\sqrt{\frac{T_1}{NP}}\sum_{i=0}^{N-1}\sqrt{\frac{T_1}{P}}\sin c((f-i\Delta f)T_1)\exp(-j\pi(f-i\Delta f)T_1)\\&*\exp(-j2\pi(f-i\Delta f)iT_r)\sum_{k=0}^{P-1}c_k\exp(-j2\pi(f-i\Delta f)kT_1)\end{aligned} \tag{5}$$

According to formula (4), the frequency spectrum of PCSF signal is expanded.

2.3. The Ambiguity Function of PCSF Signal

Signal's ambiguity function is an effective tool for the analysis of signal and the design of waveform, it describes as launching a certain waveform under the condition of optimal signal processing, the performances of resolution measurement accuracy and clutter suppression for radar system. The classic definition of the ambiguity function is shown as follows:

$$\chi_{PCSF}(\tau,v)=\int_{-\infty}^{+\infty}x(t)x^*(t+\tau)\exp(j2\pi vt)dt \tag{6}$$

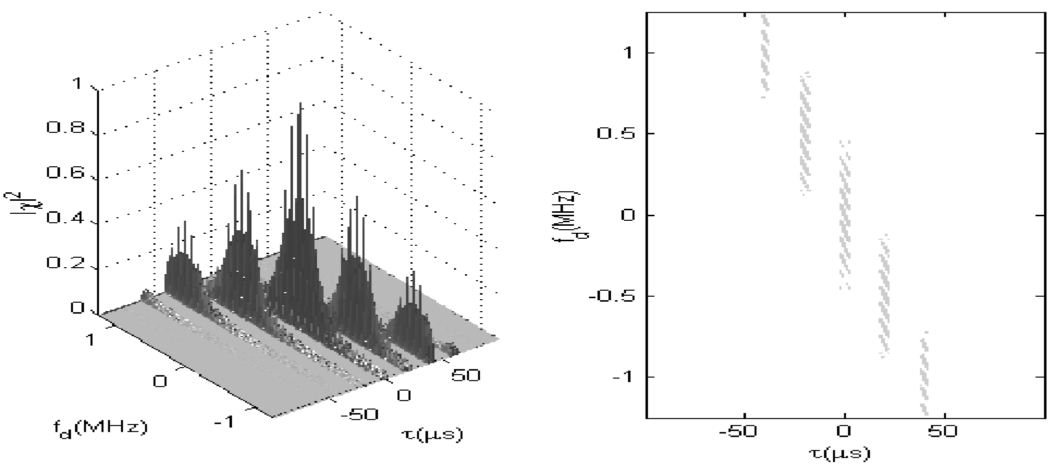
Substituting formula (1) into (6), the ambiguity function of PCSF can be gotten.

$$\begin{aligned}\chi_{PCSF}(\tau,v)&=\int_{-\infty}^{+\infty}x(t)x^*(t+\tau)\exp(j2\pi vt)dt\\&=\frac{1}{N}\sum_{n=0}^{N-1}\sum_{m=0}^{N-1}\int_{-\infty}^{+\infty}u(t-nT_r)\exp(j2\pi n\Delta ft)\\&\times u^*(t+\tau-mT_r)\exp(-j2\pi m\Delta f(t+\tau))\exp(j2\pi vt)dt\end{aligned} \tag{7}$$

Suppose, $p = m - n$, then

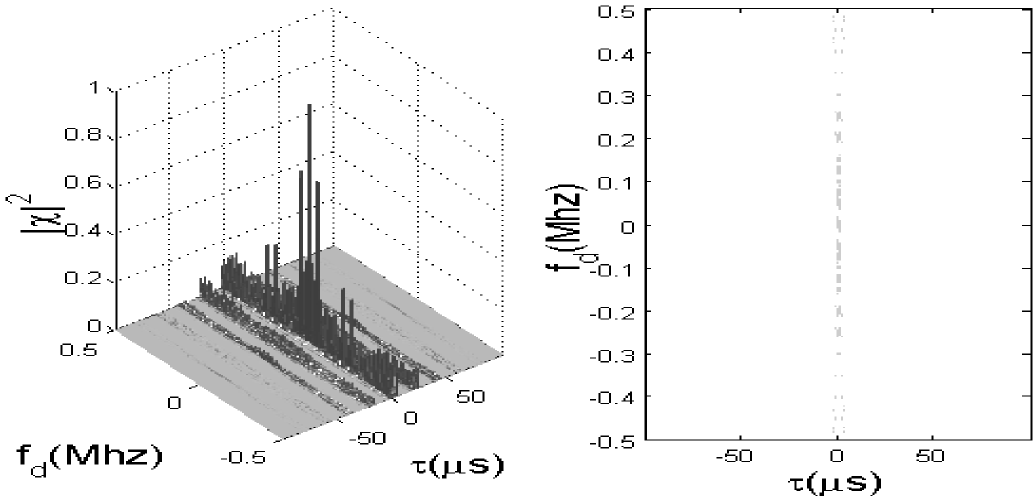
$$\begin{aligned}
\chi_{PCSF}(\tau, v) &= \frac{1}{N}\sum_{n=0}^{N-1}\sum_{m=0}^{N-1}\exp(-j2\pi m\Delta f\tau)\exp\left(j2\pi\left(v-(m-n)\Delta f\right)nT_r\right) \\
&\times\int_{-\infty}^{+\infty}u(t)u^*\left(t+\tau-(m-n)T_r\right)\exp\left(j2\pi\left(v-(m-n)\Delta ft\right)\right)dt \\
&= \frac{1}{N}\sum_{p=0}^{N-1}\exp(-j2\pi p\Delta f\tau)\sum_{n=0}^{N-1-p}\exp\left(j2\pi\left((v-p\Delta f)T_r-\Delta f\tau\right)n\right)\times\chi_{pc}(\tau-pT_r, v-p\Delta f) \\
&+ \frac{1}{N}\sum_{p=-(N-1)}^{-1}\exp\left(-j2\pi(v-p\Delta f)\tau\right)\sum_{n=0}^{N-1+p}\exp\left(j2\pi\left((v-p\Delta f)T_r-\Delta f\tau\right)n\right)
\end{aligned} \tag{8}$$

In this paper, carrier frequency $f_0 = 94\,\text{GHz}$, frequency step $\Delta f = 40\,\text{MHz}$, the width of sub-pulse $T_1 = 0.13\,\text{us}$, Step-Frequency sub-pulse use Barker code sequence with $K = 13$, pulse repetition period $T_r = 20\,\text{us}$, pulse number $N = 13$, the simulation result is shown in Figure 2. Meantime, the ambiguity function of Step-Frequency signal and Phase-Coded signal are shown in Figure 3 and Figure 4.



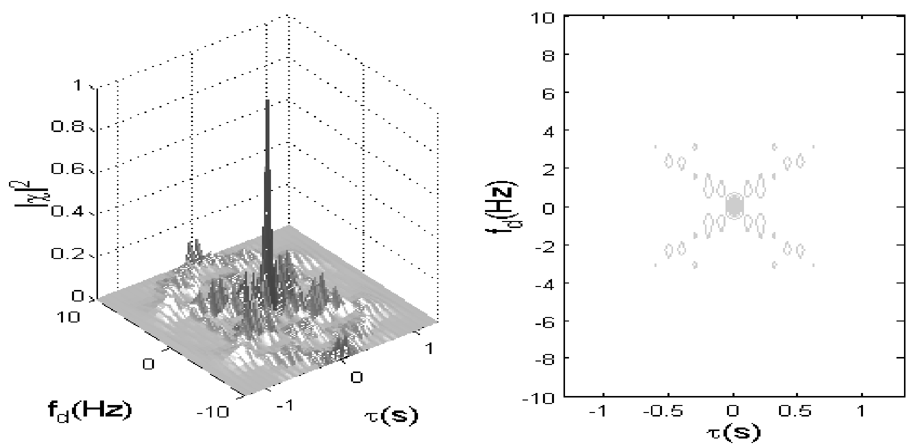
a) 3-D View of Ambiguity Function   b) Contour Plot of Ambiguity Function

Figure. 2. The Fuzzy Graph and Time-Frequency Distribution Image of SF Signal



a) 3-D View of Ambiguity Function b) Contour Plot of Ambiguity Function

Figure 3. The Fuzzy Graph and Time-Frequency Distribution Image of PCSF Signal



a) 3-D View of Ambiguity Function b) Contour Plot of Ambiguity Function

Figure 4. The Fuzzy Graph and Time-Frequency Distribution Image of PC Signal

Compared Figure 2 with Figure 3, there are some conclusions which are shown as follows:

(1) The 3-D View of Ambiguity Function of the SF and PCSF signal are both composed by non-overlapping fuzzy band, which exist some blank stripes. But the fuzzy graph of the PCSF signal has a higher Distance-Doppler resolution.

(2) From the contour plot of ambiguity function, SF and PCSF signal both have the characteristic of time frequency coupling, so the motion between target and radar will affect the signal processing. However, under the same effective width, pulse repetition period and work width, the effect of time frequency coupling of PCSF signal is much

smaller than that of SF signal. So, PCSF signal has a low sensitivity to Distance-Doppler.

(3) SF and PCSF signal both have the ambiguity side lobe of distance and Doppler. However, because PCSF signal adopts compound modulation method, which will make the side lobe of distance and Doppler, ambiguity decaying much faster, so, PCSF signal has a better ability of clutter suppression.

3. Conclusion

In this paper, a new compound modulation signal which is called as PCSF signal is presented. It associates an intra-pulse phase coded signal with extra-pulse Step-Frequency signal. The waveform, math model, parameter, ambiguity function and Doppler performance are dentally analyzed. PCSF signal adopts intra-pulse and extra-pulse compound modulation method, therefore it can be used to get a higher Step-Frequency than that of SF signal. Meantime, it can realize the same equivalent bandwidth with less pulse number, and solve the problem of conflicting among the pulse. So this new signal can be used in the application of radar system. But if the target has a very large radial velocity, the speed estimation algorithm should be further studied.

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References

[1] L. Yun, S. Xicai and Z. Zhen, "Study on Signal Performance of High Range Resolution LPI Radar", AVIONICS TECHNOLOGY, vol. 39, no. 3, **(2009)**, pp. 29-33.

[2] S. Ji, X. Jin-wu and Q. Zai-kang, "Study of Influence of Target's Motion on Target Identification for Step-Frequency MMW Radar", ACTA ELECTRONICA SINICA, vol. 31, no. 3, **(2003)**, pp. 45-348.

[3] Z. Bin, L. Chang-yu, Q. Tai-fan and *etc.*, "Phase-coded Step-Frequency signal analysis for high moving targets", Systems Engineering and Electronics, vol. 27, no. 2, **(2005)**, pp. 284-287.

[4] L. Jing, L. Xing-guo and L. Yue-Hua, "Motion Compensation For one-dimensional Range Profile Of Moving Target In MMW Costas Frequency Hopped Radar", Journal of Infrared and Millimeter Waves, vol. 24, no. 5, **(2005)**, pp. 344-347.

[5] L. Yun and S. Xicai, "Study Of A Modified Step-Frequency Signal and Its Performance", Journal of Astronautics, vol. 31, no. 10, **(2010)**, pp. 2381-2387.

[6] L. Teng, "Doppler performance analysis of frequency stepped radar signal", Modern Radar, vol. 2, **(1996)**, pp. 31-37.

[7] L. Jing, L. Xing-guo and W. Wen, "Application of waveform entropy method for motion compensation of MMW Costas frequency hopped radar", Journal of Infrared and Millimeter Waves, vol. 22, no. 4, **(2003)**, pp. 303-306.

[8] W. Gui and L. Xing-guo, "Compound Approach Of Measuring Speed Based On Step-Frequency and Pulse Doppler System", Journal of Infrared and Millimeter Waves, vol. 27, no. 3, **(2008)**, pp. 191-194.

[9] F. Berizzi, M. Martorella, A. Cacciamano and A. Capria, "A Contrast-Based Algorithm For Synthetic Range-Profile Motion Compensation", IEEE TRANSACTI ON GEOSCIENCE AND REMOTE SENSING, vol. 46, no. 10, **(2008)**, pp. 3053-3062.

[10] G.-F. Xia, H.-Y. Su and P.-K. Huang, "Motion compensation methods for LPRF modulated frequency stepped-frequency (MFSF)radar", Journal of Systems Engineering and Electronics, vol. 21, no. 5, **(2010)**, pp. 746-75.

