Analysis of the Influence of High-Power Microwave Short Pulse on IFM Performance

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Abstract—In the working scenario of instantaneous frequency measurement (IFM) system, when the high-power short pulse enters the receiver of IFM system as an interference signal, it will have a certain impact on the receiver's normal processing of the counter radar signal. This paper discussed the influence a receiver gets while doing frequency measurement, when short pulses are in different part of the received radar signal in time domain and frequency domain.

1. INTRODUCTION

High-power microwave short pulse is a type of electromagnetic radiation with high peak power, wide spectrum range, and very short pulse duration. The general peak power is above 100MW, and the frequency covers 1~300GHz [1]. With the development of high-power microwave application technology, high-power microwave systems have become a reality, which is usually on operation with the detection radar [2]. Therefore, the corresponding radar receiver will be receiving both HPM short pulses emitted by the high-power microwave system and the wide pulses emitted by the detection radar system at the same time, which will affect the IFM performance of the receiver. This paper is to discuss the impact that the HPM short pulse signal has on the IFM performance as an interference signal.

Compared to other frequency measurement algorithms, mono-bit frequency measurement algorithm quantizes input data into ±1, so that there are only addition and subtraction computation in its DFT, which makes this algorithm processing signals in real time [3].

The instantaneous phase frequency measurement algorithm is a method that analyzes subtle features of radar signals based on time-frequency analysis. The instantaneous phase frequency measurement method firstly needs to calculate the instantaneous phase of the signal at each sampling point after performing the I-Q dual-channel orthogonal sampling of the radar signal [6][8], then figures out the instantaneous frequency of the signal from the relationship between its instantaneous phase and instantaneous frequency [7][10].

When HPM short pulses are put into use as a new method of interference, it is necessary to analyze their impact and regularity on the normal operation of IFM system. This paper briefly analyzes the frequency measurement performance of the IFM system using mono-bit frequency measurement algorithm and the instantaneous phase frequency measurement algorithm, and draws preliminary conclusions.
2. MODELING OF HPM SHORT PULSE AND CHIRP SIGNAL

By analyzing short pulse signal generated by the actual high-power microwave source, it is known that this type of signal is a non-stationary signal with a multi-peak envelope, and the signal phase has a large jitter. In this paper, we choose to use multi-peak Gaussian pulse signal as HPM short pulse signal [1] which can be derived as:

\[ g(t) = P \cdot e^{jQ} \]  
\[ P = \sum_{k=1}^{K} a_k e^{-\frac{(t-b)^2}{c^2}} \]  
\[ Q = \phi(t) \]  

The radar signal in this paper is a chirp signal which can be derived as:

\[ s_{LFM}(t) = A \cdot \text{rect} \left( \frac{t}{T} \right) \cdot \exp \left( j2\pi \left( f_0 t + \frac{1}{2} Kt^2 \right) \right) \]

Where \( j = \sqrt{-1} \), \( A \) is the signal amplitude, \( f_0 \) is the carrier frequency of the chirp signal, \( T \) is the pulse width, and \( K \) is the chirp rate, so, the signal bandwidth is \( B = TK \), here we default the initial phase to zero.

For the time-domain positional relationship between the HPM short pulse signal and the chirp signal, several cases in Fig. 1 are mainly considered.

Where the signal with lower amplitude refers to chirp signal, while the others refer to short pulse signals in different cases:

![Fig. 1 Time-domain positional relationship between HPM short pulse signal and chirp signal.](image.png)

3. THE PRINCIPLE AND SIMULATION OF MONO-BIT QUANTIZATION FREQUENCY MEASUREMENT

Mono-bit quantization process is to compare the sampling voltage to a certain threshold voltage. When the sampling voltage is smaller than the threshold voltage, the sampling voltage is quantized as "-1", otherwise, it is quantized as "+1". These two signal states can be represented by 0 and 1, and the number of quantization bits is only 1 [5][6][9]. The advantages of this are: Firstly, it greatly reduces the data storage pressure brought by high-speed sampling; secondly, it greatly improves the computation efficiency with only simple addition and subtraction needed when performing DFT. Therefore, in cases with high real-time requirements, mono-bit quantization frequency measurement has great advantages [3].

The key factor affecting the accuracy of single-bit quantitative frequency measurement results is the selection of spectrum threshold value. The threshold selection scheme proposed in [4] is adopted here. Firstly, FFT transformation is performed on the quantized signal to search for the maximum point of the spectrum. Secondly, one-tenth of the sum of the maximum point and the four surrounding points are
selected as the threshold. Finally, the counting of numbers of spectrum points that continuously exceed the threshold starts from the first point above the threshold, and end at the first point below the threshold.

The start point is \( k_1 \), and the number of points above the threshold is \( k_2 \). There we can derive that the estimation carrier frequency is \( f_c = k_2 f_c / N \) and the bandwidth is \( \beta = k_2 f_c / N \). Then, the chirp rate, \( K = \beta / T_1 \), can be calculated, where \( T_1 \) is the pulse width of the collected signal.

To verify the performance of Mono-bit quantization frequency measurement algorithm through simulation, the simulation parameters of the chirp signal were set as follows: \( A = 2 \), \( f_c = 200\text{MHz} \), \( T = 10\mu\text{s} \), \( K = 2.5 \times 10^{12} \text{Hz/s} \), and \( B = 25\text{MHz} \). Under the condition of SNR of 5dB to 25dB, 500 Monte Carlo simulations were performed at 1dB intervals.

![Fig. 2 Performance of Monobit quantization algorithm](image1)

In Fig. 2, (a) shows the estimated chirp rate and (b) shows the estimated carrier frequency. The results show that the chirp rate and the carrier frequency can be better estimated.

Then to set the short pulse carrier frequency to 50MHz, 150MHz, 200MHz, 250MHz, 300MHz, and 500MHz in sequence, the SNR is 20dB, with Gaussian white noise added to signal. We can get the simulation result as below:

![Fig. 3 Estimation of Chirp rate](image2)

In Fig. 3, (a) is the estimated result of chirp rate, and (b) is the estimated RMSE. After the HPM short pulse is added, the mono-bit quantization frequency measurement algorithm's estimation result of the chirp rate remains about \( 2.46 \times 10^{12} \text{Hz/s} \). The estimated RMSE does not exceed \( 4.37 \times 10^{10} \text{Hz/s} \).
In Fig. 4, (a) is the estimated result of carrier frequency, and (b) is the estimated RMSE. For the estimation of the carrier frequency, the estimated value is around 200.2MHz-200.3MHz, and the maximum error is 261.7 KHz, which is within the required range.

The pulse width of the HPM short is less than 100ns. After mono-bit quantization, the amplitude component of the high power is suppressed. Therefore, we can find that short pulse will not cause strong interference to the frequency measurement performance of the IFM system. Therefore, in the process of mono-bit quantization frequency measurement, the change of the position of the short pulse in the time domain and the frequency domain does not greatly affect the estimation of the parameters of the chirp signal.

4. THE PRINCIPLE AND SIMULATION OF INSTANTANEOUS PHASE FREQUENCY MEASUREMENT

To perform Orthogonal two-channel mixing on the signal \( s(t) \) received by the receiver [6][8].

The mixing output can be derived as equation (5):

\[
\begin{align*}
S_f(t) &= A \cos(2\pi f_s t + K \pi t^2) \\
S_Q(t) &= A \sin(2\pi f_s t + K \pi t^2)
\end{align*}
\]  

(5)

The analytical form can be derived as:

\[
S(t) = S_f(t) + j S_Q(t)
\]  

(6)

Derived in discrete form as:

\[
S(n) = S_f(n) + j S_Q(n)
\]  

(7)

Get the instantaneous phase by arc tangent [6][7][9]:

\[
\phi(n) = \arctan\left[ \frac{S_Q(n)}{S_f(n)} \right]
\]  

(8)

The instantaneous phase of the signal can be calculated by the following equation [7][8]:

\[
\cdots
\]
To use Eq. (10) (11) to make further adjustments to make the phase continuous:

\[
\phi(n) = \begin{cases} 
0, & n = 0 \\
p(n-1) - 1, & \varphi(n) - \varphi(n-1) > \pi \\
p(n-1) + 1, & \varphi(n) - \varphi(n-1) > \pi \\
p(n-1), & \text{else.}
\end{cases}
\]  

(10)

The relationship between the instantaneous phase of the signal and the instantaneous frequency is:

\[
f(t) = \frac{1}{2\pi} \frac{d\varphi(t)}{dt}
\]

(12)

Derived as a differential form as:

\[
f(t) = \lim_{\delta t \to 0} \frac{1}{4\pi \delta t} [\varphi(t + \delta t) - \varphi(t - \delta t)]
\]

(13)

Then, the instantaneous frequency of the discrete signal \( S_{LFM}(n) \) can be derived as:

\[
f(n) = \frac{f_c}{4\pi} [\varphi(n+1) - \varphi(n-1)]
\]

(14)

Where \( f_c \) is defined as the discrete sampling frequency of the signal.

Through Eq. (14), the instantaneous frequency of each point of the received radar signal can be obtained, and the time-frequency relationship can be obtained by least square fitting. The slope of the time-frequency relationship is the estimated value of the chirp rate of the radar signal \( \tilde{K} \), the intercept of the time-frequency relationship is the estimated value of the carrier frequency \( \tilde{f}_c \).

To verify the performance of the algorithm through simulation analysis:

![Figure 5. Performance of Instantaneous Phase algorithm](image)

Using the instantaneous phase frequency measurement algorithm, under the condition of SNR of 5dB to 25dB, 500 Monte Carlo simulation experiments were carried out at 1dB intervals. The results
show that the chirp rate and carrier frequency of the chirp signal can be better estimated. When SNR is larger than 8dB, the estimated performance tends to be stable.

To set the short pulse carrier frequency to 50MHz, 150MHz, 200MHz, 250MHz, 300MHz, and 500MHz in sequence, and the SNR is 20dB, with Gaussian white noise added to signal. The results of simulation show in Fig. 6 and Fig.7.

When the relative position in time domain is unchanged, the greater the carrier frequency of the short pulse differs from the center frequency of the chirp signal, the greater the deviation of the estimated value of the Chirp rate will be. In the case that carrier frequency of short pulse is fixed, the more the time domain position of short pulse deviates from the center position of chirp signal, the greater the deviation of the estimated value of the Chirp rate will be.

While the amplitude of the HPM short pulse signal is much larger than the chirp signal, it will cause an error when the instantaneous phase of the signal is obtained by the arctangent. When the time domain position of the short pulse deviates from the center of the time domain of the chirp signal, this error will be reflected on the least squares fitting, which makes the erroneous estimation of the parameters of the chirp signal.

![Figure 6. Estimation of Chirp rate](image)

(a) \hspace{1cm} (b)

Figure 6. Estimation of Chirp rate

![Figure 7. Estimation of carrier frequency](image)

(a) \hspace{1cm} (b)

Figure 7. Estimation of carrier frequency

The estimation error also exists when estimating carrier frequency. In time domain, the closer the position of the short pulse is to the center of the chirp signal, the closer the estimated carrier frequency is to the true value. When the short pulse is located on the left of the chirp signal, the influence on the carrier frequency estimation is greater than in other positions.
5. CONCLUSION
This paper briefly analyzes the principles of mono-bit quantization frequency measurement and instantaneous phase frequency measurement, and compares the performance of the two algorithms in estimating the parameters of chirp signals. Under the condition of Gaussian white noise, both can estimate the signal parameters effectively, and the latter algorithm is better than the former one. Under the affect of HPM short pulses, mono-bit quantization frequency measurement has better stability and no significant change in performance.

As to the instantaneous phase frequency measurement algorithm, both the carrier frequency change of the short pulse and the time domain position change will affect the estimation result.

The conclusion of this paper has certain reference significance in analyzing the influence of HPM short pulse on the detection of parameters of chirp signal.

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