The Performance Analysis of Up and Down LFM Based on Multi-Pulsed Simultaneous Polarimetric Measurement Technique

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Abstract**—: Polarimetric measurement is the base of obtain of radar polarimetric information, and the pattern of polarimetric measurement and the selected waveform have an important influence on it. In this paper, a briefly introduction about the commonly interleaved-pulsed polarimetric measurement technique and the simultaneous-pulsed polarimetric measurement technique is presented. The ambiguity function and the waveform isolation function of up and down LFM signal have been studied based on multi-pulsed simultaneous polarimetric measurement technique in this paper, the theory derivation and the simulation experiment show the ambiguity function of the waveform is determined by the time-band width product and the waveformisolation is the function of the time-band width product, the waveform have a well performance in the doppler toleration.**

Index Terms**—: interleaved-pulsed polarimetric measurement technique, simultaneous-pulsed polarimetric measurement technique, ambiguity function, waveform isolation, Doppler toleration**

I. INTRODUCTION

The polarization is a common property in phasor wave and have been paid a lot of attention in photology, radar and so on. As for the radar, the polarization is used to describe the trace of the electric field vector varied with the time in the cross section of the propagation direction [1]. As a property of the electric waveform, the polarization is an important resource which can be used for obtain information except time, frequency and spatial. The excavation of polarization information fully provide an expansive space for the improvement of the modern radar detection system [1]-[2]. Since the conception of the radar target's polarimetric scatter matrix has been presented by Sinclair in 1946[3], the study of radar polarimetric technology has been go through more than seventy years and the radar polarization has been an important branch in modern radar technology.

The polarimetric measurement and data calibration is the base of obtained the radar polarimetric information, which applied in the surveillance of space target and the feature measurement, spaceborne/airborne SAR, weather observation and so on. It is obviously the selected of polarimetric measurement style and the waveform have an important impact on the result of the measurement. The early way of transmit in single polarization while receive in full polarization can only get the target's polarimetric scatter information partly and it have been can't meet the demand [4]-[5], so the way of transmit in full polarization and receive in full polarization has been developed, in this way, the transmit and receive could fulfill full polarimetric in a coherent processing interval (CPI), and the two mainly fundamental techniques are: interleaved-pulsed polarimetric measurement technique and simultaneous-pulsed polarimetric measurement technique [6]. The stand or fall about the two technique have been discussed in a lot of literature and a briefly introduction about these two techniques will be presented in this paper, the performance such as ambiguity function and isolation about a selected waveform based on simultaneous -pulsed polarimetric measurement technique will be mainly discussed in this paper, which is useful to design a properly measurement waveform and the literature about this is rarely so far.

II. BRIEFLY INTRODUCTION OF TWO POLARIMETRIC MEASUREMENT TECHNIQUE

The interleaved pulsed polarimetric measurement technique transmit different polarization between pulses which usually fulfill by transmit orthogonal polarization interleaved while receive the orthogonal polarization simultaneously and then obtain the scatter matrix of the target, and the waveform sequences of transmit and receive is show as fig.1. Seen from the fig.1, the interleaved-pulsed polarimetric measurement techniqueneed at least two pulses to obtain the polarimetric scatter matrix of the target accurately.

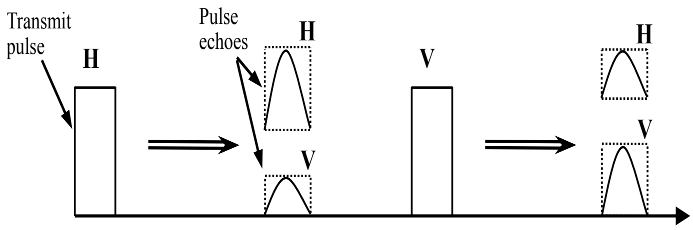

Fig.1The waveform sequences in interleaved-pulsed polarimetric measurement technique

Although the interleaved-pulsed polarimetric measurement technique could obtain more scattering information about the target, there are some inherent drawbacks such as [7]-[8]:

(1) The decoherent effect which is relatively harmful to the measurement result between different pulse echoes will arise in interleaved pulsed polarimetric measurement technique when the target belong to non-stationary target

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which means the scattering character vary quickly with the time caused by the change of the target's motion gesture.

(2) A phase discrepancy between adjacent pulse echoes caused by the doppler effect of the target will affect the accuracy of the measurement.

(3) The interleaved-pulsed polarimetric measurement technique need to switch between different polarizations, there is an adversely impact on the measurement results because of the cross polarimetric interference due to the isolation of the device is limited.

(4) The range ambiguities will impact the receipt of pulse echoes and then degrade the accuracy of the polarimetric measurement.

The simultaneous pulsed polarimetric measurement technique transmit simultaneously and receive simultaneously two orthogonal coded signal via orthogonal polarization channels. If the target's motion can be ignored and the signal to noise ratio (SNR) is high enough, the fully polarimetric scatter matrix can be obtained in a PRI, the waveform sequences of transmit and receive based on simultaneous -pulsed polarimetric measurement techniqueis show as fig.2.

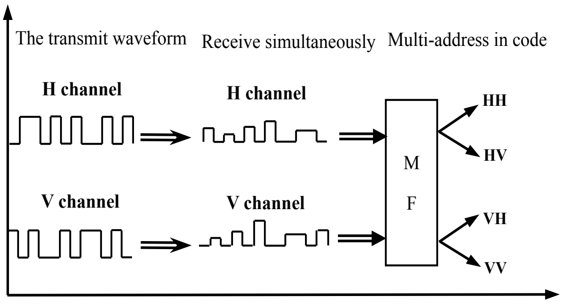


Fig.2The waveform sequences in simultaneous -pulsed polarimetric measurement technique

However, the simultaneous pulsed polarimetric measurement technique still have some drawbacks such as [6]:

(1) Because the coded sequences are not orthogonal fully, there are coupling influences between coded channels inevitably, so there are coupling influences between the measurement results.

(2) The almost coded sequences' auto-correlation and cross-correlation are constrained each other and couldn't reach a perfect state simultaneously especially when the number of transmit polarization is big, in this case, it is difficult to find the coded sequences meet the acquirement.

III. THE MODEL OF MULTI-PULSES SIMULTANEOUS-PULSED POLARIMETRIC MEASUREMENT TECHNIQUE

In the fact measurement case, there is a relatively motion between the radar and target, so, the doppler effects should be taken into consideration. Besides, in the case such as the target's RCS is small or the transmit power is limited, we need to improve the target's SNR bymulti-pulses accumulation. So the general multi-pulses simultaneous-pulsed polarimetric measurement technique is considered, the transmit measurement waveform sequences is showed as fig.3:

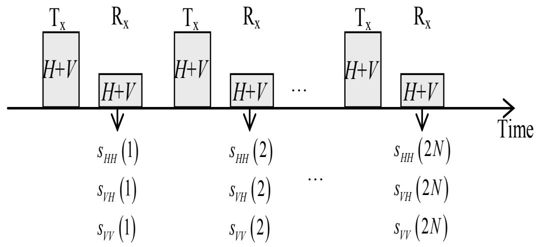


Fig.3The waveform sequences in multi-pulses simultaneous-pulsed polarimetric measurement technique

When the radar worked in the pulsemode, we will get the sample of the target's time-varied polarimetric scatter matrix in slow time and fast time (in this paper, the nrepresent then-th pulse, the t represent the fast time, the sample in fast time after pulse compressed is used to product high resolution range profile, the sample in slow time is processed in every range cell is mainly used to pulse doppler accumulation processing for moving target). We assume the radar's pulse repeat interval (PRI) is Tp, there are 2N measurement data within the measurement time Ω_T , then the sample sequences of the target's polarimetric matrix are:

$$\mathbf{S}(n)=\begin{bmatrix} s_{HH}(n) & s_{HV}(n) \\ s_{VH}(n) & s_{VV}(n) \end{bmatrix},\quad n=0,\cdots,2N-1 \tag{1}$$

Set the parameters of the target as aforementioned, in the n-th pulse, the target's middle frequency echo signal in horizontal polarization channel (H) is

$$\begin{aligned} r_H(n,t) &= \frac{K}{4\pi\left[r(n)\right]^2}\exp\left[-\mathrm{j}4\pi f_c\frac{\left(r_0+nv_0T_p\right)}{c}\right] \\ &\exp\left(\mathrm{j}2\pi f_d t\right)\cdot\left\{\begin{matrix} s_{HH}(n)e_H\left[t-\dfrac{2\left(r_0+nv_0T_p\right)}{c}\right]+ \\ s_{HV}(n)e_V\left[t-\dfrac{2\left(r_0+nv_0T_p\right)}{c}\right] \end{matrix}\right\} \end{aligned} \tag{2}$$

And the vertical polarization channel (V) can be described in the same way.

Where, the K in equation (2) is the gain factor which decided by the radar transmit power, the gain of the antenna and so on.

According the target's echo signal in two channel as equation (2), we designed two middle frequency matched filter to filtering the echo signals one by one and obtained four output signals. We take the peak value of the output signals as the n-th measurement result of the polarimetric scatter matrix. If the absolutely amplitude could be ignored, the peak value of four output signals can expressed in matrix as:

$$\begin{aligned} \mathbf{V}(n) &= \begin{bmatrix} v_{HH}(n) & v_{HV}(n) \\ v_{VH}(n) & v_{VV}(n) \end{bmatrix} = \exp\left[-\mathrm{j}4\pi f_c\frac{\left(r_0+nv_0T_p\right)}{c}\right]\cdot \\ &\begin{bmatrix} s_{HH}(n) & s_{HV}(n) \\ s_{VH}(n) & s_{VV}(n) \end{bmatrix}\cdot\begin{bmatrix} A_{HH}\left(\varsigma(n),\xi\right) & A_{VH}\left(\varsigma(n),\xi\right) \\ A_{HV}\left(\varsigma(n),\xi\right) & A_{VV}\left(\varsigma(n),\xi\right) \end{bmatrix} \end{aligned} \tag{3}$$

Where, the matrix $\begin{bmatrix} A_{HH}(\cdot,\cdot) & A_{VH}(\cdot,\cdot) \\ A_{HV}(\cdot,\cdot) & A_{VV}(\cdot,\cdot) \end{bmatrix}$ is the ambiguity function matrix which decided by the transmit waveform. However, the time width and band width are usually limited, so, the really radar signals don't meet the ideally condition, in the narrow-band measurement condition, almost targets usually occupy only one range resolution cell, so we usually ignored the side-lobe influence caused byauto-correlation ambiguity function or cross-correlation ambiguity function and only analysis the measure error caused by the non-ideal factor of the two channel's transmit waveform's isolation.

The waveform isolation factor could be defined as:

$$I_w(\varsigma,\xi) = 20\lg\left[\frac{|A_{pq}(\varsigma,\xi)|}{|A_{qq}(\varsigma,\xi)|}\right] \tag{4}$$

Where, $p,q \in \{H,V\}$, and $p \neq q$.

IV. THE PERFORMANCE ANALYSIS OF UP AND DOWN LFM WAVEFORM

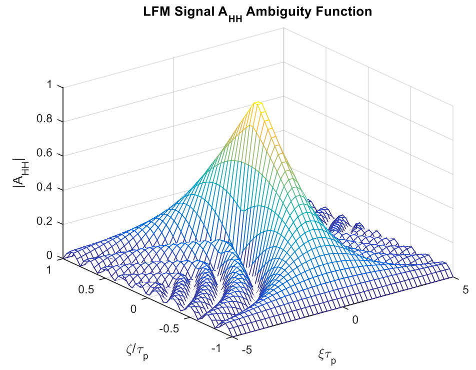
The up and down LFM waveform transmit two LFM signals with the same center frequency while adversely chirp modulation rate via orthogonal polarization channel. Without loss of generality, we assume the H polarimetric channel transmit up LFM waveform while the V polarimetric channel transmit down LFM waveform

The base band transmitted modulation signals via two orthogonal channel expressed as:

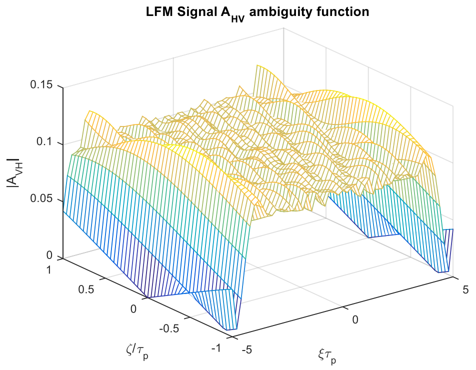
$$\begin{cases} e_H(t) = \dfrac{1}{\sqrt{\tau_p}}\exp\left(\mathrm{j}\pi\gamma t^2\right)\mathrm{rect}\left(\dfrac{t}{\tau_p}\right) \\ e_V(t) = \dfrac{1}{\sqrt{\tau_p}}\exp\left(-\mathrm{j}\pi\gamma t^2\right)\mathrm{rect}\left(\dfrac{t}{\tau_p}\right) \end{cases} \tag{5}$$

Where, the γ means the frequency modulation slope, τ_p represent the width of the pulse, then the band width is $B = \gamma\tau_p$.

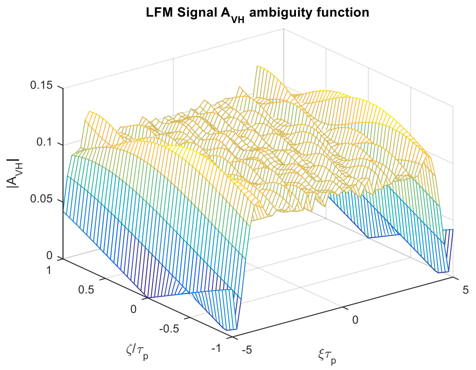
According to the theory of radar signals, the ambiguity function of LFM signal is mainly decided by the time-band width production (BT), when BT=50, the signal's ambiguity function matrix is showed as fig 4. Seen from the fig 4, the up and down LFM signals can't eliminate the interference between different waveforms completely even if in the case $\varsigma = 0\mu\mathrm{s}$ and $\xi = 0\mathrm{Hz}$, in this case, the value of auto-correlation ambiguity function is 1, however, the value of cross-correlation ambiguity function is bigger than 0, so the interference between different waveforms still exist.



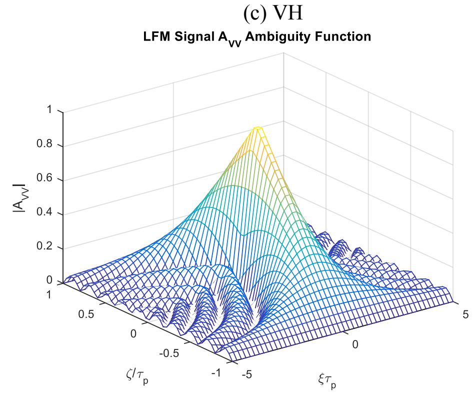
(a) HH



(b) HV



(c) VH



(d) VV

Fig 4The ambiguity function of up and down LFM

According to the equation (3) and equation (4), the waveform isolation of up and down LFM signal is:

$$I(\varsigma,\xi)=20\lg\left\{\frac{|A_{VH}(\varsigma,\xi)|}{|A_{HH}(\varsigma,\xi)|}\right\}=20\lg\left\{\frac{|A_{HV}(\varsigma,\xi)|}{|A_{HH}(\varsigma,\xi)|}\right\} \tag{6}$$

Make $\varsigma=\alpha\tau_p$, $\xi=\beta/\tau_p$, then the equation (6) could be expressed as a function with parameter BT as the followed:

$$I(\varsigma,\xi)=20\lg\left\{\begin{array}{l}\frac{1}{2\sqrt{\mathrm{BT}}}\sqrt{|C(u_1)+C(u_2)|^2+|S(u_1)+S(u_2)|^2}\\ \cdot\frac{\pi(\beta+\alpha\mathrm{BT})}{\sin[\pi(\beta+\alpha\mathrm{BT})(1-|\alpha|)]}\end{array}\right\} \tag{7}$$

Especially, when $\varsigma=0\mu\mathrm{s}$ and $\xi=0\mathrm{Hz}$, then the waveform isolation will be the parameter BT's function:

$$I(0)=20\lg\left\{\frac{1}{\sqrt{\mathrm{BT}}}\sqrt{\left|C(\sqrt{\mathrm{BT}})\right|^2+\left|S(\sqrt{\mathrm{BT}})\right|^2}\right\} \tag{8}$$

Seen from equation (8), with the increase of the BT, the value of the waveform isolation decrease, when BT=10, the value of $I(0)$ is about -14 dB, and when BT=10, the value of $I(0)$ is about -26 dB.

When $\varsigma=0\mu\mathrm{s}$, the waveform isolation is:

$$I(\xi)=20\lg\left\{\begin{array}{l}\frac{1}{2\sqrt{\mathrm{BT}}}\sqrt{|C(u_1)+C(u_2)|^2+|S(u_1)+S(u_2)|^2}\\ \cdot\frac{\pi\beta}{\sin(\pi\beta)}\end{array}\right\} \tag{9}$$

Where $u_1=\sqrt{\mathrm{BT}}(1+\beta/\mathrm{BT})$, $u_2=\sqrt{\mathrm{BT}}(1-\beta/\mathrm{BT})$.

When the value of BT is 10,100 and 200, the three curve in fig 5 described the waveform isolation of up and down LFM signal in boundary condition corresponding. Where the fig 5 is the relation curve between $I(\xi)$ and $\xi\tau_p$ when $\varsigma=0\mu\mathrm{s}$. It can be seen from the fig 6, the up and down LFM signal have a preferable doppler toleration which means when ξ increase within the scope, the waveform isolation change little. For example, when BT=200, if the $\xi\tau_p$ increase from -0.5 to 0.5, the value of I vary between -22dB and-26dB.

V. CONCLUSION

In this paper, some properties about the ambiguity function and waveform isolation of up and down LFM signal based on multi-pulses simultaneous-pulsed polarimetric measurement technique have been studied, the theory analysis and simulation experiments showed the ambiguity function of up and down LFM signal was mainly decided by the time width and band width production (BTP) and the interferences between different waveforms can't be eliminated completely; the up and down LFM signal's waveform isolation is the function the BTP, and the signal have a preferable doppler toleration. These conclusions may useful to design waveforms based on multi-pulses simultaneous-pulsed polarimetric measurement technique.

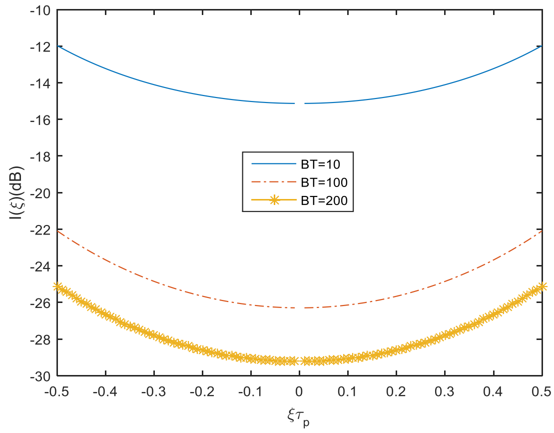


Fig.5 The performance of the waveform isolation when $\varsigma=0\mu\mathrm{s}$

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