Research on the Chirp Signal Echo Processing Based on DDS

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Abstract—For the advantage of high range resolution and low power, the radar usually use the linear frequency modulated continuous waveform. With the development of electronic technology, the operating bandwidth of radar is also growing. In broad bandwidth, to realize the linear modulated waveform using VCO is difficult. It requires additional circuits to detect the linearity of VCO, and feed it back to the control system. Then do the correction to the control signal of VCO. Since the digital controllability of DDS, it can provide highly linear modulated waveform without additional correction circuits. In this paper, through studying the broadband chirp source system of radar based on DDS technology and analyzing the error model of the system, a method that selecting the ADC sampling rate accordance with the speed of linear FM frequency agile is proposed. It reduces the system errors caused by the discontinuous chirp signals. Simulation results show that this method can effectively solve the interference problem brought by the discontinuity of DDS chirp signal.

Keywords-Chirp Signal; DDS; radar; echo; sampling

I.   INTRODUCTION

The radar generally uses chirp signal as the transmitted waveform [1-2]. It has the advantage of wide bandwidth, high distance resolution. In practical applications, to achieve the ideal chirp waveform is impossible, it will bring a variety of system errors. Currently, there are two main methods of the chirp waveform generation. One method is using a VCO which input waveform is a sawtooth voltage. Since the input signal of the control voltage is a continuous waveform, it can guarantee that the output frequency of the chirp wave is continuous. However, due to the nonlinear frequency conversion of the VCO, when the system requires a high linearity source, the linearity of the frequency modulation of the VCO needs to be corrected. Another method is using direct digital frequency synthesizer (DDS) to generate the chirp waveform. The DDS has a higher operating frequency. By using a digital accumulator, DDS has a high frequency resolution. By controlling the step size of the accumulator, it is possible to control the output frequency of DDS. So its chirp signal output has the advantages of good linearity and frequency stability.

II.   THE PROCESSING OF RADAR ECHO SIGNAL

For the frequency source based on direct digital frequency synthesis (DDS) technology, its frequency conversion time is very short and has a very high frequency resolution. Principle diagram of direct digital frequency synthesizer is shown in Fig .1.
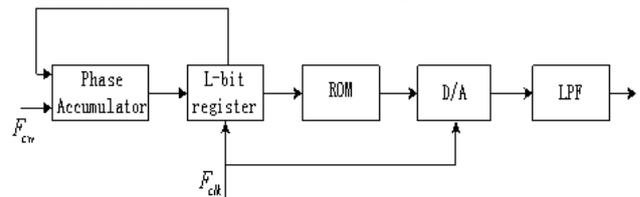

Figure 1. Principle diagram of direct digital frequency synthesizer

We assume the ideal emission waveform in a period of FMCW radar is

$$x_1'(t) = x(t)e^{j\pi\beta t^2/t_0} \qquad (1)$$

Where t_0 is the period of the chirp signal, β is the bandwidth, $x(t) = \begin{cases} 1 & (0 < t < t_0) \\ 0 & else \end{cases}$

After stretching the processed echo signal is as follows:

$$x_r(t) = x(t - t_r)\exp(j\pi\beta t_r(2t - t_r)/t_0 - j\frac{4v\pi}{\lambda}t + 2j\pi ft_r) \quad (2)$$

Where f is the initial frequency, v is the speed of the target, t_r is the arriving time of the echo, λ is the wave length.

When using the piecewise linear frequency modulated signal generated by DDS as the radar transmission signal, the radar echo signals after the stretching process, is not a sine wave, but a modulation signal in the frequency domain .
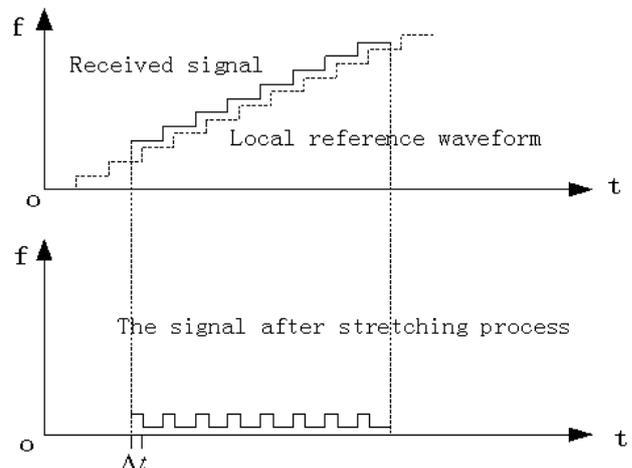

Figure 2. The waveform of the echo signal in the frequency domain

Considering the Doppler shift of the echo signal, the waveform of echo radar signal in the frequency domain is shown in Fig .2. After stretching process, the signal is

$$S(t) = x_1(t)\exp(2\pi j \frac{Kd + d(2t-d)\Delta k}{2^L}F_{clk} - j\frac{4v\pi}{\lambda}t) + \quad (3)$$

$$x_2(t)\exp(2\pi j\frac{K(d+1) + \Delta k(d+1)(2t-d-1)}{2^L}F_{clk} - j\frac{4v\pi}{\lambda}t)$$

Where

$$x_1(t) = \begin{cases} 1 & n/F_{clk} < t < n-1/F_{clk} + \Delta t \\ 0 & else \end{cases}$$

$$x_2(t) = \begin{cases} 1 & n-1/F_{clk} + \Delta t < t < n/F_{clk} \\ 0 & else \end{cases}$$

Do Fourier transform to $S(t)$, we obtain:

$$S(\omega) = \frac{2}{(\omega - 4\pi j\frac{d\Delta k}{2^L}F_{clk} + j\frac{4v\pi}{\lambda})}\exp(-j(\omega - 4\pi j\frac{d\Delta k}{2^L}F_{clk}$$

$$+ j\frac{4v\pi}{\lambda})\frac{\Delta t}{2})$$

$$\exp(-j(\omega - 4\pi j\frac{d\Delta k}{2^L}F_{clk} + j\frac{4v\pi}{\lambda})(n-1)T_c/2)$$

$$\frac{\sin(j(\omega - 4\pi j\frac{d\Delta k}{2^L}F_{clk} + j\frac{4v\pi}{\lambda})nT_c/2)}{\sin(j(\omega - 4\pi j\frac{d\Delta k}{2^L}F_{clk} + j\frac{4v\pi}{\lambda})T_c)}$$

$$\sin(\frac{\Delta t}{2}(\omega - 4\pi j\frac{d\Delta k}{2^L}F_{clk} + j\frac{4v\pi}{\lambda}))$$

$$\exp(2\pi j\frac{Kd - d^2\Delta k}{2^L}F_{clk}) +$$

$$\frac{2}{\omega - 4\pi j\frac{\Delta k(d+1)}{2^L}F_{clk} + j\frac{4v\pi}{\lambda}}$$

$$\exp(-j(\omega - 4\pi j\frac{\Delta k(d+1)}{2^L}F_{clk} + j\frac{4v\pi}{\lambda})(n-1)T_c/2)$$

$$\exp(-j(\omega - 4\pi j\frac{\Delta k(d+1)}{2^L}F_{clk} + j\frac{4v\pi}{\lambda})\frac{T_c - \Delta t}{2}) \quad (4)$$

$$\frac{\sin(j(\omega - 4\pi j\frac{\Delta k(d+1)}{2^L}F_{clk} + j\frac{4v\pi}{\lambda})nT_c/2)}{\sin(j(\omega - 4\pi j\frac{\Delta k(d+1)}{2^L}F_{clk} + j\frac{4v\pi}{\lambda})T_c)}$$

$$\sin(\frac{T_c - \Delta t}{2}(\omega - 4\pi j\frac{\Delta k(d+1)}{2^L}F_{clk} + j\frac{4v\pi}{\lambda}))$$

$$\exp(2\pi j\frac{K(d+1) - \Delta k(d+1)^2}{2^L}F_{clk})$$

By (4) we know that, when $\Delta t \neq 0$, after the stretching process the spectrum of echo signal is the sum of the two signals. These two parts respectively at

$$\omega = 4\pi\frac{d\Delta k}{2^L}F_{clk} - \frac{4v\pi}{\lambda} \quad \text{and} \quad \omega = 4\pi\frac{\Delta k(d+1)}{2^L}F_{clk} - \frac{4v\pi}{\lambda}$$

reach their peaks, and the distance between the two peaks is $4\pi\frac{\Delta k}{2^L}F_{clk}$. When n is small, then the spectrum will superimpose, there is only one peak. With the increase of n, the spectrum of the echo signal will have two peaks.

III. THE SAMPLING RATE SELECTION

Generally, the operating frequency of DDS is much greater than the sampling frequency of A / D. After the stretching process, the two frequencies of the echo signal will alternately appear in the time domain which periods are all $1/F_{clk}$. Therefore, if the operating frequency F_{clk} of the DDS is the integer multiple of the frequency of the receiver A / D sampling rate, the signal will have only one frequency component.
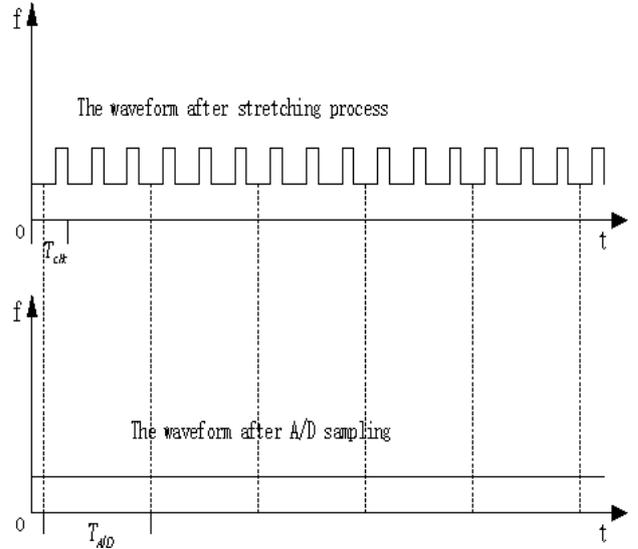

Figure 3. Waveform of echo signal sampling in frequency-domain

As shown in Fig .3, DDS operating frequency is three times of the ADC sampling frequency. The sampling point falls on one frequency in the time domain; this will change the two frequency signals caused by the discontinuity of DDS frequency step into one frequency signal.

$$S(t) = x_1(t)\exp(2\pi j\frac{Kd + d(2t-d)\Delta k}{2^L}F_{clk} - j\frac{4v\pi}{\lambda}t) + \quad (5)$$

$$x_2(t)\exp(2\pi j\frac{K(d+1) + \Delta k(d+1)(2t-d-1)}{2^L}F_{clk} - j\frac{4v\pi}{\lambda}t)$$

For (5), when the sampling start time is $\Delta t'$ （$0 < \Delta t' < \Delta t$）, the sampling interval is $T_{A/D}$ (for an integer multiple of T_{clk}), the sampling sequence can be written as:

$$S(n)_{A/D} = \exp(2\pi j \frac{Kd + d(2(\Delta t' + nT_{A/D}) - d)\Delta k}{2^L} F_{clk} \tag{6}$$
$$- j\frac{4v\pi}{\lambda}(\Delta t' + nT_{A/D}))$$

Its discrete Fourier transform is:

$$S(k)_{A/D} = \exp(2\pi j \frac{Kd + d(2\Delta t' - d)\Delta k}{2^L} F_{clk} - j\frac{4v\pi}{\lambda}\Delta t' + \tag{7}$$
$$(N-1)(2\pi j \frac{d2T_{A/D}\Delta k}{2^L} F_{clk} - j\frac{4v\pi}{\lambda} T_{A/D} - j\frac{2\pi}{N}k))$$
$$\frac{\sin(\dfrac{2\pi j \dfrac{d2T_{A/D}\Delta k}{2^L} NF_{clk} - j\dfrac{4v\pi}{\lambda} NT_{A/D} - j2\pi k}{2})}{\sin(\dfrac{2\pi j \dfrac{d2T_{A/D}\Delta k}{2^L} F_{clk} - j\dfrac{4v\pi}{\lambda} T_{A/D} - j\dfrac{2\pi}{N}k}{2})}$$

Its spectral amplitude is:

$$|S(k)_{A/D}| = \frac{\sin(\dfrac{2\pi j \dfrac{d2T_{A/D}\Delta k}{2^L} NF_{clk} - j\dfrac{4v\pi}{\lambda} NT_{A/D} - j2\pi k}{2})}{\sin(\dfrac{2\pi j \dfrac{d2T_{A/D}\Delta k}{2^L} F_{clk} - j\dfrac{4v\pi}{\lambda} T_{A/D} - j\dfrac{2\pi}{N}k}{2})} \tag{8}$$

As can be seen from (8), only at $k = [\dfrac{d2T_{A/D}\Delta k}{2^L} NF_{clk} - \dfrac{2v}{\lambda} NT_{A/D}]$,the signal spectrum obtains the maximum value.

IV. ALGORITHM SIMULATION ANALYSIS

We assume sweeping clock of the DDS chirp waveform is 250MHz, the sweeping frequency bandwidth of the transmitted signal is 150MHz, emission time is 10us, then the sweeping step of DDS is 60kHz. When the delay of the target echo is 0.401us and no Doppler shift, the echo signal after stretching processing is the sum of 6MHz and 6.06MHz signals which are modulated by the square wave. By using the matlab ,the simulation model is shown below:
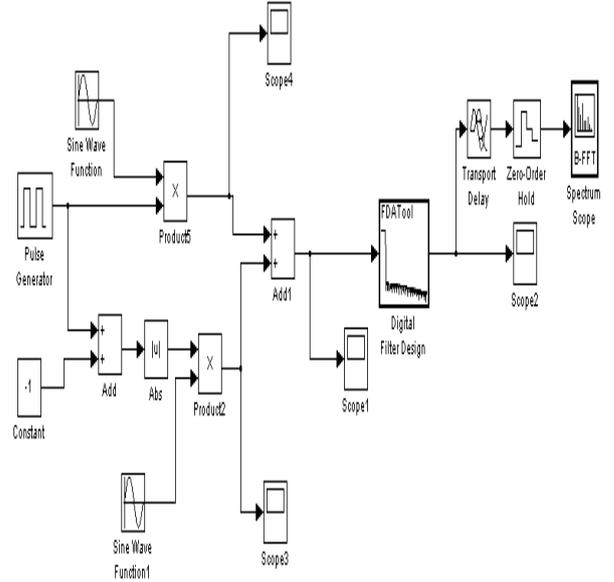

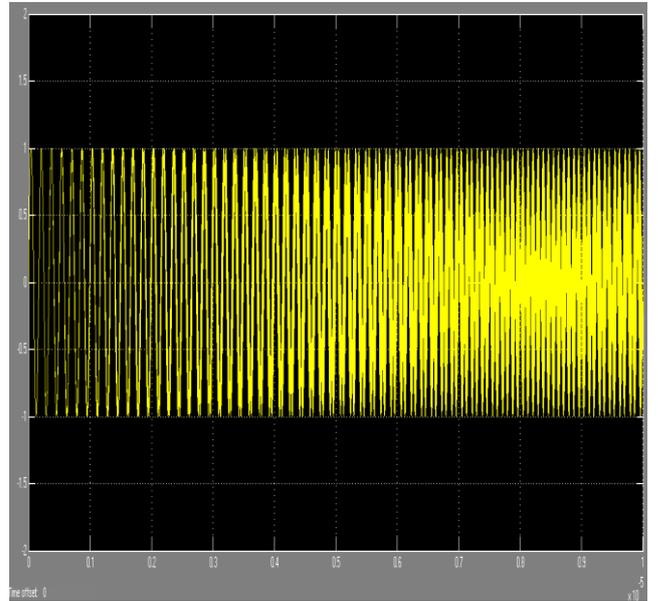Figure 4. Simulation model of the echo signal

Figure 5. Simulation result of the echo signal

As it can be seen from Fig .5, after superimposing the two signals which are modulated by the square-wave, because their frequency is close to each other, at the beginning, the phase jump is not obvious. However, as time increases, the sum of the two signals will produce a growing phase transition.When the sampling frequency of receiver is 40MHz, $T_{A/D}$ is not an integer multiple of T_{clk} , the simulation result of the signal spectrum is as follows:
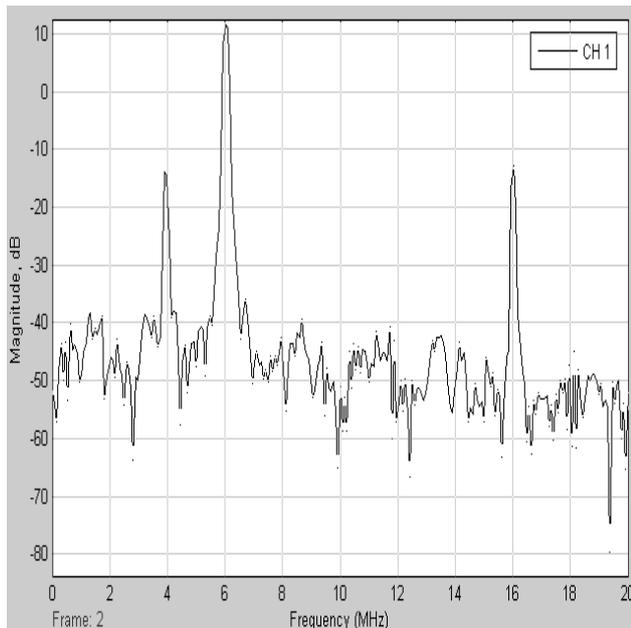
Figure 6. The spectrum of the echo signal with 40MHz sampling rate

As shown in Fig .6, when the interval $T_{A/D}$ of the sampling time is not an integer multiple of T_{clk}, by the sinusoidal modulation influence of the echo signal, it produces a large spurious signals and it will generate large interference on the judgment of target. When the sampling frequency of receiver is 40MHz, the interval $T_{A/D}$ of the sampling time is five times of T_{clk}. When $\Delta t' = 0.5ns$, the simulation result is as follows:
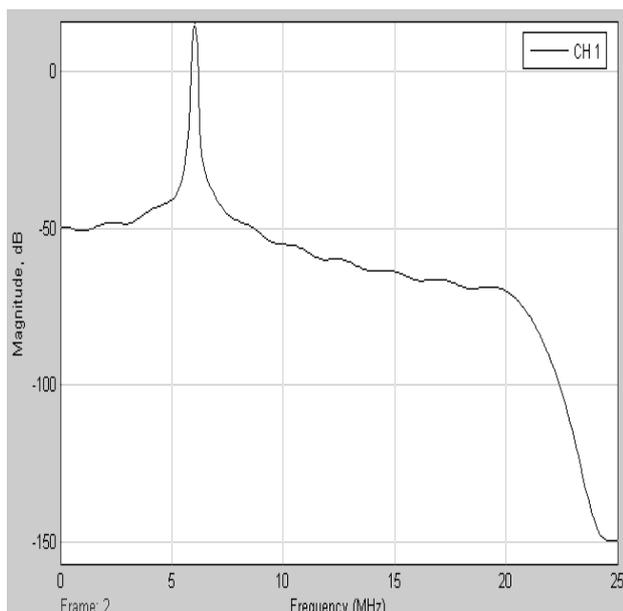

Figure 7. The spectrum of the echo signal with 50MHz sampling rate

As shown in Fig .7, the spectrum of the echo signal is very pure, without the interference of spurs and it verify the results of the above analysis.

V. CONCLUSION

In this paper, the error model of broadband chirp source based on DDS technology is studied. The method selecting A / D sampling rate accordance to the frequency agile rate of the chirp signal is proposed. It reduces system error caused by discontinuities of chirp signal. Then the algorithm is simulated by using the MATLAB. The simulation results show that the algorithm can effectively solve the interference problem brought by the discontinuity of DDS chirp.

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