Parameter Design of ISAR Real-time Imaging System

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Abstract. The article mainly designs the basic parameter of ISAR real-time imaging system, meantime analyses the basic property index of real-time imaging. then, it will obtain favorable high resolution ratio ISAR image through post imaging processing.

1 Introduction

Radar can not only observe object's location and movement parameters, but also obtain images of the target and scene, greatly improving the radar information acquisition ability, especially the battlefield awareness. So imaging as a new function of radar is widely applied at home and abroad. According to the working principle of radar and the different methods of imaging, imaging radar can be divided into synthetic aperture radar (SAR) and inverse synthetic aperture radar (ISAR). Because of ISAR can get moving targets (such as aircraft, ships, missiles, satellites and other target) detailed images, has become a strategic defense system is very important in a target recognition method. Now, the main developed countries have the ISAR technology is widely applied in the actual radar system[1].

Based on the above background, this paper designs the basic parameters of real-time ISAR imaging system, and analyzes the basic performance index of real-time ISAR imaging.

2 Systematic parameter require of imaging

2.1Radar system、work frequency and bandwidth

Long coherent processing of Radar signal can greatly improve the target signal's output signal-to-noise ratio. In high resolution ISAR imaging system, the high resolution of range is achieved by launch large bandwidth directly or indirectly synthesis large signal bandwidth; the high resolution of azimuth is achieved by Long coherent processing of Radar time to obtain the radar's big angle. meanwhile, Combination advantages of active phased array radar target detection and tracking, this system considers to utilize X-band broadband active phased array radar signal 's long coherent processing to single (multi -) target high resolution ISAR imaging.

In the doppler navigation radar, fire control radar and precision tracking radar system, generally adopt the X-band. The X-band radar signal wavelength is centimeter level, relative target radar angle is 3o～5o, which can achieve high resolution in ISAR imaging. The center of the radar signal frequency is approximately 9.5 GHz.

High resolution two-dimensional imaging range resolution is achieved by transmitting a large band width, namely $\rho_r = \frac{c}{2B}$ .In order to achieve better than 0.5 m range resolution, at the same time, considering the system error or to the influence of the main lobe of broadening brought by window function (such as hamming window broadening is 1.47 times), so it can consider to set the distance signal band width is about 400 MHz.

2.2 Imaging signal waveform

Due to the characteristics of large time bandwidth product of LFM signal has been widely used in modern high resolution radar system. In high resolution image, it obtains its high resolution of range by wideband linear frequency modulation signal matched filtering of pulse compression technology. It obtains its broadband by transmitting signals or compositing signals directly. Direct transmitting signal waveform as shown in figure 2.1, the waveform is affected by adjustable frequency, the bandwidth is determined by adjustable frequency and coherent accumulation time, as shown in figure 2.2. Range resolution of wideband linear frequency modulation signal is

$$\rho_r = \frac{c}{2B} \qquad (2.1)$$

In the formula , B is transmitting signal bandwidth , c is the speed of light.

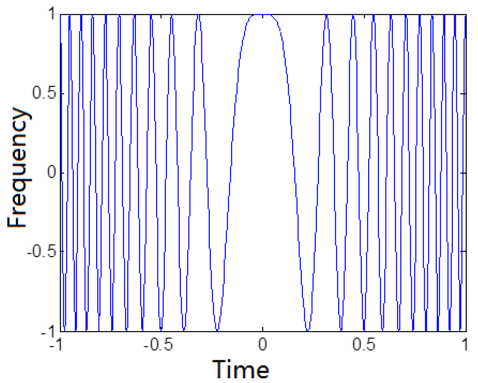

Fig 2.1 Amplitude variation of chirp signal

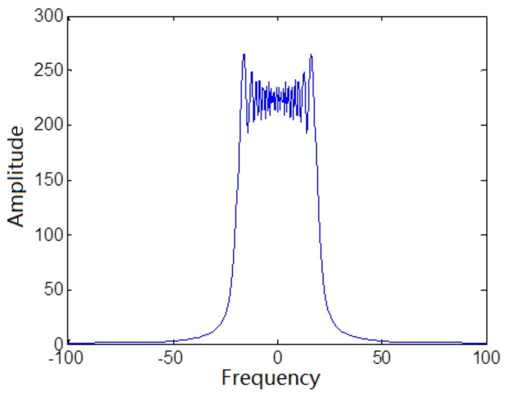

Fig 2.2 Frequency characteristic of chirp signal

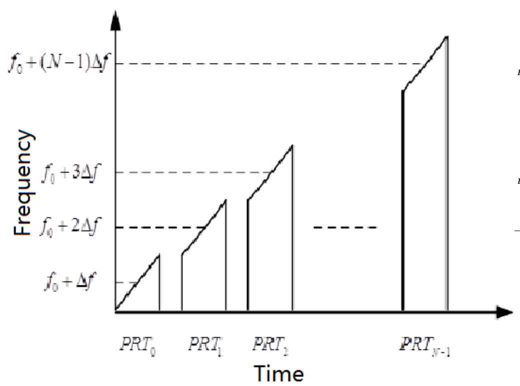

Fig 2.3 transmitting rule of Stepped chirp signal

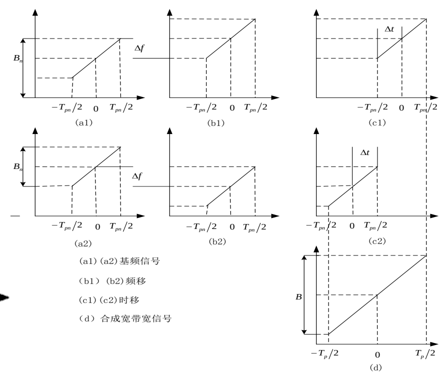

Fig 2.4 band synthesis process

In addition to transiting wide-band linear frequency modulation signal directly, it also obtains high resolution one-dimensional distance by synthesizing frequency of narrow band and wideband, namely transmitting stepped chirp signal, its transmitting regulation diagram as shown in figure 2.3. it transmits linear frequency modulation singnal, which have different carrier but same rate in every pulse repeat period, the carrier frequency step jump at a fixed frequency. Through a series of frequency shift, time shift and the phase compensation, it can put the narrowband signal synthesis a broadband signal as shown in figure 2.4, so as to achieve high resolution target of one dimension. The synthesis of range resolution is

$$\rho_r = \frac{c}{2N\Delta f} \qquad (2.2)$$

In the Formula, N is the synthetic pulse number, Δf is stepped frequency.

2.3 Imaging two dimensional (range and azimuth)resolution

ISAR achieve range high resolution through the pulse compression radar technology[2], synthetic aperture technology is adopted to achieve azimuth high resolution. The size of the signal bandwidth determines ISAR radar range resolution. The specific formula is as follows

$$\rho_r = \kappa \frac{c}{2B} \tag{2.3}$$

In the formula, B is transmitted signal bandwidth, κ is the main lobe coefficient of pulse compression with window .Setting transmitted signal bandwidth is $B = 400\,\text{MHz}$, hamming window after broadening coefficient is $\kappa = 1.47$, the range resolution is $\rho_r = 0.5513\text{m}$.

Lateral high resolution rely mainly on the doppler effect, by Fourier analysis of the target echo sequence transformation to the doppler domain, as long as the doppler resolution is high enough, can the transverse distribution of each unit. Goal the scattering points on the axis of rotation caused the echo phase change, the change of the performance for multiple doppler, with the target of the scattering points on the horizontal position. Horizontal position, the greater the scattering points, the higher the doppler frequency. The lateral resolution

$$\rho_a = \frac{\lambda}{2\Delta\theta} \tag{2.4}$$

In the formula, λ is the signal wavelength, $\Delta\theta$ is the goal the total rotation angle. For lateral resolution, the greater is angle, the higher is resolution. But for centimeter-wave long radar, a smaller angle can achieve high resolution. Set radar work in the x-band, $\lambda = 0.313\,\text{m}$, $\Delta\theta = 0.05\,\text{rad} \approx 3°$,then $\rho_a = 0.313\,\text{m}$.

3. ISAR imaging of phased array antenna requirements

3.1 The effect of frequency change on beam direction and range imaging scans

Adopting large instantaneous wideband signal tracking, high resolution imaging, and accordingly improving the radar tracking data rate, it can obtain more information [3][4]. However, directing of antenna pattern will change with the change of the signal frequency. If radar signal instantaneous bandwidth is wide enough, it must consider signal frequency changes on the influence of antenna pattern. The phased array antenna array is as shown in figure 3.1, θ is the beam scanning Angle, d is spacing between adjacent array element, L is length of the entire antenna. Antenna beam direction depends on the phase shifter decision "within the matrix phase difference" φ_B and "balance of spatial phase difference" φ_S .When the center frequency radar signal after changing from the initial value to a rotary Angle of beam pointing to the need, to make "within the matrix phase difference" and "phase space". Thus, it deduces the relationship of beam deviation Angle $\Delta\theta$ and the signal bandwidth Δf is

$$\Delta\theta = -\frac{\Delta f}{f_0} \tan\theta \tag{3.1}$$

It is visible that the antenna beam direction will swing in the space with the change of the signal frequency, which is referred to as a dispersion phenomenon of phased array antenna beam in space . The limits of Δf might be called a phased array antenna bandwidth. Combing formula (3.1), it can get the maximum bandwidth should satisfy

$$\Delta f_{\max} \le \frac{\Delta\theta_{1/2} f_0}{4\sin\theta} \Rightarrow \theta \le \arcsin\frac{\Delta\theta_{1/2} f_0}{4\Delta f_{\max}} \tag{3.2}$$

In the formula, $\Delta\theta_{1/2}$ is Formula of lobe in front the half power point width of normal direction. Assumed that the radar system parameters is as follows: $\Delta\theta_{1/2} = 2°$, $f_0 = 9.5\,\text{GHz}$, $\Delta f_{\max} = 400\,\text{MHz}$,the biggest beam direction is $\theta = 0.2088\text{rad} \approx 12°$ 。When radar beam pointing is $\theta = 60°$,the maximum signal bandwidth allowed is $\Delta f_{\max} \approx 96\,\text{MHz}$ .Meanwhile, figure 3.2 shows also the relationship ,which maximum signal bandwidth will change with antenna scanning angle. It is visible that a wide range of scanning Angle of radar will limit the bandwidth of the phased array antenna, in the high resolution imaging process, , it need to compensate broadband signal by other means.

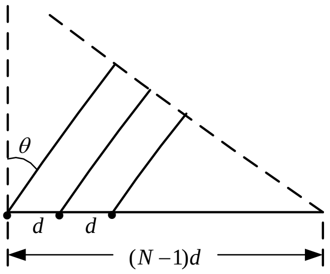

Fig3.1 Phased array antenna array

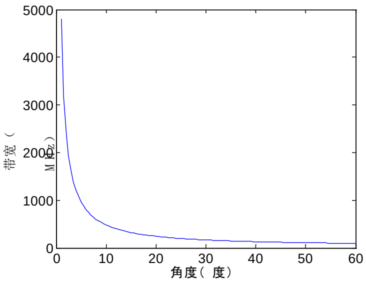

Fig 3.2 Change relationship between scan angle and the signal bandwidth

3.2 The limit of signal instantaneous bandwidth of the antenna aperture transit time

For different arrays element, the phase difference of the antenna unit from phased array antenna phase shifter is different, the last one array unit and delay difference of the first unit is

$$T_A = \frac{L\sin\theta}{c} \tag{3.3}$$

Here, T_A is the array antenna aperture transit time. The receiving array output signal wave after pulse compression can be seen as the antenna unit compressed the signals which are the result of the linear additivity. So the requirements on both ends of the antenna array antenna unit receives the signal after pulse compression time is less than the half power point pulse width after pulse compression, it can obtain signal instantaneous bandwidth Δf limit condition from the antenna aperture transit time

$$\Delta f \le \frac{c}{(N-1)d\sin\theta} = \frac{c}{L\sin\theta} = \frac{1}{T_A} \tag{3.4}$$

It is visible that signal instantaneous bandwidth Δf will decrease with the increasing of the antenna aperture length and scanning Angle. Assumed that antenna beam width is $\Delta\theta_{1/2} = 2°$, center frequency of signal is $f_0 = 9.5\text{GHz}$, the scanning Angle is $\theta = 60°$, the length of the antenna aperture is $L = 0.8592\,\text{m}$, aperture transit time is $T_A \approx 2.58\times10^{-9}\,\text{s}$, maximum signal frequency band width is $\Delta\theta_{1/2} = 2°$ .So, in order to realize the band width is greater than $400\,\text{MHz}$ broadband signal, it need aperture transit time $T_A \le 2.5\times10^{-9}\,\text{s}$.

3.3 The limit of array antenna for LFM signal frequency modulation rate

Linear frequency modulation (LFM) signal is a commonly used signal form in phased array radar. Reference is shown in figure 3.1, assumed that the zeroth array unit signal is represented as $s_0(t) = e^{j[\omega_0 t + xt^2]}$, among $\omega_0 = 2\pi f_0$, $x = \pi k = \pi\Delta f_{\max}/T$, f_0 is the initial frequency of signal , T is the signal rate, T is the signal pulse width. unit signal of i is expressed as

$$s_i(t) = e^{j[\omega_0(t-i\Delta\tau) + x(t-i\Delta\tau)^2]} \tag{3.5}$$

In the formula, $\Delta\tau = d\sin\theta/c$ is the lag of the adjacent unit received signal. Through the phase shifter linear phase compensation, the square phase difference is

$$\Delta\varphi = xi^2\Delta\tau^2 = (\pi\Delta f_{\max}/T)(i\Delta\tau)^2 \tag{3.6}$$

Formula (3.6), the import of the square phase error will produce beam pointing in the direction of migration and make lobe shape become asymmetric. Considering the influence of the antenna to send and receive, if square phase error does not produce waveform change, it is demands that it should be less than or equal to $\pi/16$,

$$\Delta\varphi \le \pi/16 \Rightarrow T \ge 16\Delta f_{\max} T_A^2 \tag{3.7}$$

Visible, linear frequency modulation signal is limited by a frequency modulation rate, the minimum pulse width is limited by formula (3.7). Assumed that antenna beam width is $\Delta\theta_{1/2} = 2°$, Center frequency signal is $f_0 = 9.5\text{GHz}$, scanning angle is $\theta = 60°$,The length of the antenna aperture is $L = 0.8592\text{m}$,Aperture transit time is $T_A \approx 2.58\times10^{-9}\text{s}$,if it want to achieve signal bandwidth $\Delta f_{max} = 400\text{MHz}$,then $T_{min} \approx 0.043\mu\text{s}$.

4. Parameters requirements of wideband imaging signal

4.1 signal form

ISAR is a kind of all-weather high resolution imaging radar, through pulse compression technique of broadband signal to improve range resolution. One of the common methods of improving the signal bandwidth is done by FM, namely the linear frequency modulation pulse signal.

The launch of the linear frequency modulation radar signal can be expressed as

$$s(t) = p(t)\exp(j2\pi f_c t + j\pi\gamma t^2) \quad (4.1)$$

In the formula , f_c is carrier frequency, γ is adjustable frequency, envelope $p(t)$ is

$$p(t) = \begin{cases} p(t) = 1, t \in (nT_r - \frac{T_p}{2}, nT_r + \frac{T_p}{2}) \\ 0, \quad \text{others} \end{cases} \quad (4.2)$$

Among the above formula, T_r is pulse interval.

4.2 The signal bandwidth and sampling frequency

The range resolution of ISAR determined by the transmitting signal bandwidth is

$$\rho_r = \frac{c}{2B}$$

(4.3)

In the formula, B is the signal bandwidth, c is the speed of light. In the condition of the required distance resolution, signal bandwidth obtained by transformation is

$$B = \frac{c}{2\rho_r} \quad (4.4)$$

In the actual system, in order to avoid the frequency aliasing, such as with the method of direct sampling, the selection of sampling frequency is generally not less than 1.2 times the signal bandwidth. Therefore, the sampling frequency can be selected as commonly

$$f_s = 1.2B \quad (4.5)$$

In order to achieve better 0.3m range resolution, considering the lower picture after pulse compression disc hamming window is often used to spread the main lobe is 1.2 times, the signal bandwidth and sampling frequency is need as shown in table 4.1.

Table 4.1Range resolution and signal bandwidth and sampling frequency selection

Range resolution	Signal bandwidth	Sampling frequency
0.4m	450MHz	540MHz
0.45m	400MHz	480MHz
0.5m	360MHz	432MHz

4.3 Pulse repetition frequency and duty ratio

By the preceding formula (2.4), the pulse repetition frequency can be selected to 1000Hz, in order to guarantee a five percent duty cycle, requirement is pulse width $50\mu\text{s}$.So, according to table 4.1 combined with the formula B/T_p , it can get the adjustable frequency of transmitting linear frequency modulation signal as shown in table 4.2.

Table 4.2 the selection of transmitting signal adjustable frequency

Range	Signal	Adjustable
0.4 m	450 MHz	9×10^{12} Hz/s
0.45 m	400 MHz	8×10^{12} Hz/s
0.5 m	360 MHz	7.2×10^{12} Hz/s

4.4 FM linearity requirements

When using the solution line frequency modulation way to receive the echo signal, FM linearity of transmitting signal and the reference signal has certain requirements, it is expressed as

$$E = n\left[TB\sin\left(\frac{n\pi W_s}{Tc}\right)\right]^{-1} 10^{-A/20} \quad (4.6)$$

In the formula, T is time width of signal, B is the bandwidth of signal, W_s is the observation distance, c is the speed of light, n is Harmonic frequency of Fourier series expanded from the change of the instantaneous frequency deviates from the straight line, A is range sidelobe caused by FM linearity range sidelobe caused by value.

For X band, T=50 μs , B=400MHz，Ws=50m，n=1；The requirement of FM linearity is as shown in table 4.3.

Table4.3 Requirement of FM linearity

Imaging sidelobe	10dB	20dB	30dB	40dB	50dB
FM linearity	1.50×10^{-3}	4.77×10^{-4}	1.51×10^{-4}	4.77×10^{-5}	1.51×10^{-5}

4.5 Requirement of frequency stability

Echo phase is $\varphi_R = \frac{4\pi Rf}{C}$, the phase difference caused by frequency deviation can be expressed as the following formula $\Delta\varphi_R = \frac{4\pi R(f-f_0)}{C} = \frac{4\pi R\Delta f}{C}$ .if $\Delta\varphi_R$ is known, the frequency deviation is $\Delta f = \frac{\Delta\varphi_R C}{4\pi R}$ .If = 30 °, range R = 100 km, frequency deviation is within the 125 Hz. Frequency stability is $Z = \frac{\Delta f}{f} = \frac{\Delta\varphi_R C}{4\pi Rf}$ .For X band, range R = 100 km, center frequency is f = 10 GHz, Z=1.25×10-8.

5 Conclusion

This paper systematically introduces the design methods, including waveform signal form, antenna parameters, radar range and imaging parameters, etc. Thus, it is finished system design in ISAR imaging radar. Through the late imaging processing, it can obtain good quality high resolution ISAR image.

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