An Arbitrary Waveform Generator for SAR
Test-Bench Application

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Abstract: Function and performance simulation is an effective method for the development and verification of modern radar modes. Gathering radar raw data during flight trials is an essential but expensive way. In order to minimize such costs, synthetic radar raw data at an early system design stage will be adopted widely. In this paper, an arbitrary waveform generator for Synthetic Aperture Radar (SAR) test-bench application is presented. This waveform generator uses high speed multi-DSPs to accelerate the processing to obtain a near real-time baseband echo signal of SAR, and a DDS based frequency synthesizer is used to shift the signal to the operating band. By this way, a lot of system parameters and different target features will be simulated and verified. Some result waveforms gained with data created for certain test scenarios by this generator are presented.

Keywords: waveform generator; Synthetic Aperture Radar (SAR); Direct Digital Synthesizer (DDS)

1. Introduction

Synthetic Aperture Radar (SAR) can provide high quality images in all weather and all time conditions for civil and military applications. Design and develop a real SAR system is a cost and time consuming work, especially for spaceborne SAR system. To meet the demand of SAR system development, a SAR test-bench has been developed in the early stage of radar design.

The arbitrary waveform generator is one basic part of the hardware-in-the-loop test-bench for SAR evaluating and testing [1]. The synthetic aperture radar raw data, such as, SAR single point target, different background clutter maps and moving target, calculated by multi-chip DSP board. The I/Q modulator converts the baseband signal to IF band. The DDS based frequency synthesizer shift the IF signal to wanted carrier frequency.

The model of SAR received signals [²] and its waveform generation is described. This paper can help to evaluate SAR image formation algorithms and contribute towards optimizing SAR system parameters. In order to offer the highest possible degree on flexibility, the multiple DSPs calculating and memory readout technique are adopted together. The digital waveform samples are converted by Digital-to-Analog Converter (DAC) and subsequently filtered to generate the desired analogue output signal. Waveform samples update is programmable. Some results gained with data created for certain test scenarios by the arbitrary waveform generator are given in the paper.

2. Signal model

The arbitrary waveform generator has the ability to change its amplitude and phase according to the requirements of users. The arbitrary signal \( f(t) \) can be expressed as:

\[
 f(t) = A(t) \exp[j\phi(t)] 
\]

where \( A(t) \) is the signal amplitude, \( \phi(t) \) is the signal phase. They are both programmable.

The Linear Frequency Modulated (LFM) signal is widely adopted by SAR designer, and the radiating pulse sequences with strong coherence from radar can be represented as [²]

\[
 f(t) = \sum_{n} p(t - nT_p) 
\]

1.2
\begin{align*}
\sum_{n} rect(t-nT_p) \exp \left \{ j \left [ 2\pi f_c (t-nT_p) + \pi K (t-nT_p)^2 \right ] \right \}
\end{align*}

where \( rect(\cdot) \) is a rectangular function, \( f_c \) is the carrier frequency, \( K \) is the coefficient of quadratic phase term (frequency rate).

The received echoes of SAR \( s(t) \) can be calculated by:

\begin{equation}
\begin{aligned}
s(t) &= \sigma_s G_s \left[ t - \frac{R(t)}{c} \right] \frac{2}{c} \left( t - \frac{2R(t)}{c} \right) \\
&= \sigma_s G_s \left[ t - \frac{R(t)}{c} \right] f(t - \frac{2R(t)}{c})
\end{aligned}
\end{equation}

where \( \sigma_s \) is the equivalent backscattering coefficient of the target, \( c \) is the velocity of light, \( G_s \) is antenna gain pattern.

Two dimensional SAR image is the function of range \( r \) and cross range \( x \), so the received signal is:

\begin{equation}
\begin{aligned}
s(x, r) &= \int \int \sigma_s(x, r) w_s(x-x')w_s(r-r') \left[ t - \frac{R(t)}{c} \right] f(t - \frac{2R(t)}{c}) \\
&= \int \int \exp \left \{ \frac{4\pi}{\lambda} (r-R(x)) + \frac{4\pi}{c} (r-R(x))^2 \right \} dx \, dr
\end{aligned}
\end{equation}

Equation (1.4) is a two-dimensional convolution of the function of target backscatter coefficient and 2-D impulse response:

\begin{equation}
\begin{aligned}
S(x, r) &= \sigma(x, r) \otimes h(x, r)
\end{aligned}
\end{equation}

where

\begin{equation}
\begin{aligned}
h(x, r) &= h_x(x, r) \otimes h_x(x, r)
\end{aligned}
\end{equation}

\begin{equation}
\begin{aligned}
h_x(x, r) &= w_x(x) \exp \left \{ \frac{4\pi}{\lambda} R(x) \right \} \delta (r - R(x))
\end{aligned}
\end{equation}

\begin{equation}
\begin{aligned}
h_x(t, r) &= \left[ \frac{2r}{c} \right] w_r(r) \exp \left \{ \frac{4\pi\alpha}{c^2} r^2 \right \} \delta (x)
\end{aligned}
\end{equation}

3. Waveform generator architecture

The waveform generator used to generate SAR echoes is one basic part of SAR test-bench. The block diagram of the waveform generator is shown in Fig. 1 and Fig. 2. It consists of two basic modules: synthetic aperture radar raw data calculating module and raw data to RF echoes waveform converting module. By the use of a high speed DSP board configured with multiple DSPs, the raw data are generated quite flexible in terms of changing parameters. Figure 1 and Figure 2 show the waveform generator which contains the SAR raw data calculating module, two digital to analog converter, quadrature modulator, DDS frequency synthesizer and up-converting mixer. Operating frequency bands are achieved by frequency translating to the desired frequency band from the IF band.

4. Experimental results

Several waveforms are generated by the arbitrary waveform generator, which shown in Figure 3-5. There are two components of I and Q of signal in
the diagram. Fig. 3 is a waveform of a LFM signal which IF bandwidth is 250MHz. Fig. 4 is a waveform of a Gaussian noise. Fig. 5 is a waveform of a scene echo signal of SAR.

5. Summary
The arbitrary waveform generator described above is used to generate general waveforms include radar echo waveforms. Changing the parameters of the waveform is very flexible. It can be readily adapted to test and evaluate different radar systems and sub-systems.

6. References