The hardware implementation of real-time SAR signal processor

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Abstract

This paper considers an implement of real-time signal processor for high resolution SAR(Synthetic Aperture Radar) imaging. In many tasks, we need the SAR imaging take in time, so the real-time processor becomes more and more important. On the basic SAR imaging principle, it is well known that the high range resolution depends on the transmitted signal bandwidth, while high azimuth resolution results from space Doppler frequency bandwidth. With the increasing of frequency bandwidth, the rate of sampling increases, so the fast processor is required in high resolution real-time SAR imaging. To address this need, we discussed how the high speed general DSP and special DSP are applied for high resolution real-time imaging, and the good performance is obtained.

Keyword: real-time signal processing, matched filtering, range compression, azimuth compression

Introduction

In recent years, Synthetic Aperture Radar (SAR) images have been used in many different fields of study. To the key part of real-time processor, by means of early computers, was beyond mind not in computation speed, but also in calculating precision. As a result, optical processing way was put into operation, but they are much more complicated in practice, and not facile. Development of modern semiconductor technology makes real-time SAR digital processing possible. However, the processing precision and computation efficiency are the key problem in real-time processor. In general, they lie in many factors, such as chips' selecting, chips' numbers, the program flow and system architecture, etc. The high resolution real-time SAR processor requires the devices with faster processing ability and more reasonable system architecture because of the short computation time and much more large data quantity. The hardware system designed has succeeded in real-time SAR imaging, which reach the resolution 3m× 3m.

The Principle of SAR Imaging

The echo signal from the target illuminated by SAR is expressed as:

$S(r, x)=\iint \delta(x, r)\, h(x'-x, r'-r, x, r)dx\, dr$

Where (x', r') are output azimuth and range coordinates; (x, r) are the corresponding coordinates over the ground, and h(x'-x, r'-r, x, r) is s transfer function depending on the electrical, the cinematical and geometrical parameters of the SAR system.

The transfer function exhibits increasing complexity depending on the approximations of the distance from the platform to the imaged ground point. In its simplest from:

$h(x'-x, r'-r, x, r) \rightarrow h(x'-x, r'-r)$

So that expression (1) reduces to a double convolution:

$s(x, r) = \delta(x, r) \otimes h(x, r)$

The SAR processing is to obtain the information from the echo, which is decided by the microwave back-scattering coefficient. Because it is an inherently two-dimension problem, so that range and azimuth dependency of raw data cannot be factorized if a precision image is desired, the process of SAR imaging can be expressed as:

$$\hat{\delta}(x,r) = s(x,r) \otimes h_s(x,r)$$

Where $h_s(x, r)$ is the system response function which is decided by the radar, the spacecraft and some other factors.

In order to decrease the complexity of computation, if movement compensation has been done, the digital SAR process often resorts to a series of two one-dimension process to produce the two-dimension results from the digitized input data, i, e. range compression (4) can be rewritten as

$$\hat{\delta}(x,r) = s(x,r) \otimes h_r^{-1}(x,r) \otimes h_a^{-1}(x,r)$$

If the amplitude is assumed to be unity, the time-domain expression of the range reference function $h_r^{-1}(x, r)$

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and the azimuth reference function $h_a^{-1}(x, r)$ is

$h_r^{-1}(x, r)=\exp(j2\pi(f_0\, t-1/2\alpha\, t^2))$

$h_a^{-1}(x, r)= \exp(j2\pi(t-1/2 f_{DR}\, t^2))$

Where f_0 is the carrier frequency, α is chirp rate, f_{DC} is Doppler centroid and f_{DR} is Doppler frequency rate.

System Parameters and Devices Selecting

1. System parameters.

The basic parameters are listed in table 1.

(1). Resolution	3m×3m
(2). Antenna azimuth size	1.5m
(3). Modulation bandwidth	70MHz
(4). PRF	700Hz

Table 1. System parameters

2. Devices selecting

Judging from above parameters, high-speed special DSP must be selected for real-time digital SAR processing. By comparing some kinds of special DSP, LH9124 is selected due to its excellent performance. The performances are compared in table 2.

The System Structure of Signal Processor

In the real-time SAR imaging procedure, range compressing, azimuth compressing, estimating of azimuth compression are the main stages. In the case of airborne SAR, two-dimension signal processing of convolution can be described as two independent one-dimension convolutions

When the Radar echo signal comes back from targets, it is sampled by A/D and sent to range compressing. That means, raw data FFT, multiply echo frequency domain signal with frequency domain reference function, and IFFT. Then, the signal is transposed in RAM, and sent to azimuth compressing. During azimuth compression, the azimuth reference function is obtained by analyzing platform information from GPS/INS. Just as range compression, azimuth compression is also accomplished by the same method in frequency domain, which will decrease the quantity of computing. The processing steps are described in the system block of figure 1.

Type / Parameter	TMC2310	A44102	PDSP16510	A66110/a6611	LH9124Y50
Data width	16	16,20,24	16	16	8,16
Timer rate	20MHz	—	40 MHz	33/40 MHz	50 MHz
1K complex FFT	574μs	430μs	96μs	132μs	67.6μs
Radix	r-2	r-2	r-4	r-2、r-4、mixed	r-2、r-4、r-16、mixed
Maximal points	1K	64K	1K	64K	1M
Cascade	No	No	No	Yes	yes

Table 2. Devices performance

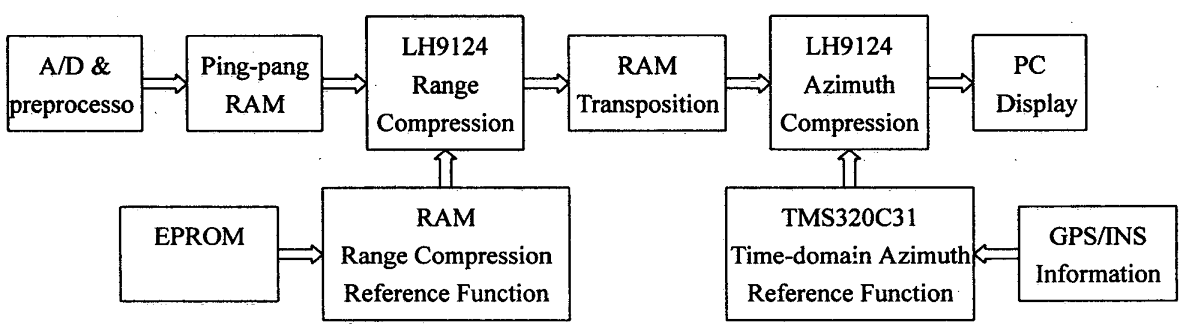


Fig 1. System structure

With the piped-line structure of LH9124, ping-pang RAM, A/D converter, pre-process, range compression and azimuth compression can be processed simultaneously. So the system processing speed and data passing rate are promoted dramatically.

For decreasing quantities of calculating, convolution in time domain is replaced by multiply in frequency domain. In the procedure of transferring time domain to frequency domain, if input data is conjugated, then the answer of FFT is conjugated, the FFT is equivalent to IFFT. As the LH9124 supports input conjugation and output conjugation, it's very convenient to accomplish FFT and IFFT with one device.

As range reference function only depends on signal bandwidth, we can store the frequency domain range reference function in EPROM that has been calculated by PC in advance. For the azimuth reference function, as it depending on platform attitude, must be calculated in time with two steps. (1) The TMS320C31 calculates the time domain reference function depending on the platform information which come from GPS/INS. (2) The LH9124, divided in time, turns it into frequency domain. So the azimuth compression board has two tasks, azimuth compressing and calculating the azimuth reference function, as shown in figure 2.

The central circuit of compression is figured out in figure 3.

The compressing procedure includes (1) reading the raw data from port Q. (2) FFT/IFFT between port A and port B. (3) multiplying the frequency domain raw data with frequency domain reference function. (4) sending the result to port Q. With different number of processing points and different processing time, we can choose r-2, r-4, r-16 and mixed radix, all are supported by LH9124.

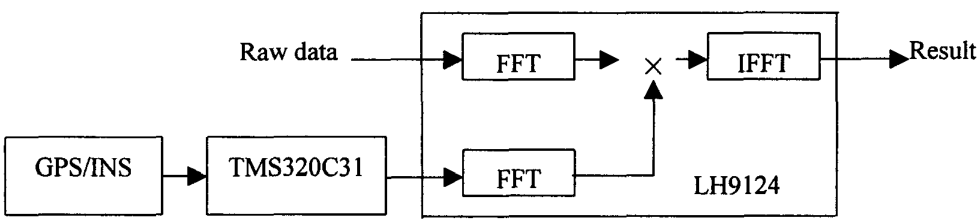


Fig 2. Azimuth compression

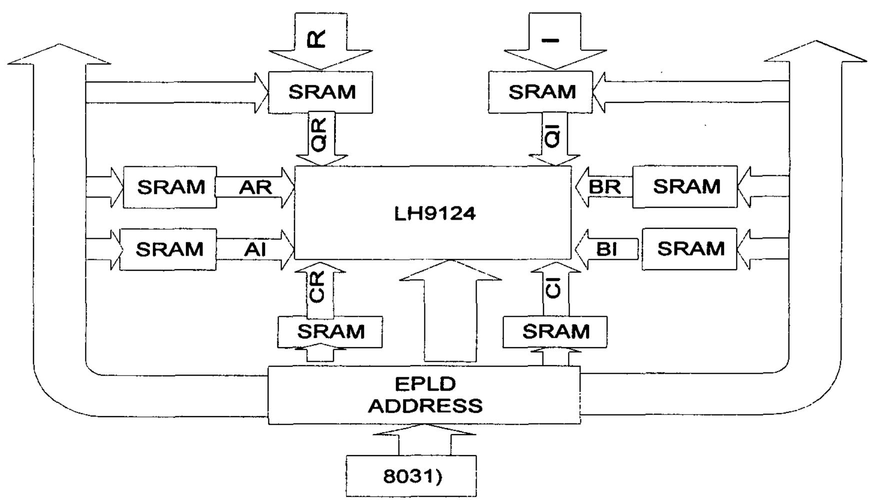


Fig 3. Compression circuit

The main controller (8031), mainly fulfils self-check, alarm, and provides some start and control signals for address-producer of FLEX6016 (Altera corporation). Moreover, it gets a data commute path of PC.

Address producer produces each pass address and LH9124 function signals. It is more popular to produce address with auxiliary chip LH9320. This system we use programmable chip EPF6016 of Altera corporation, which reduces the hardware complication, size, cost and increases system dexterity.

Actual steps are listed below:

1, According length of data, radix of first pass, produces a reversed address.

2, Following, the second pass address is circular shifted, one by one.

At the same time, address of twiddled factor also produced by address-producer. As it is symmetric, can previous be stored 1/4 of it in RAM, the address producer produce a nonlinear address to address.

Analysis of System and performance

1. analysis of real-time performance

Many factors, such as the selected algorithm, selected chips, software programming and hardware design, will affect on the real performance of processor. The system designed achieves the tasks of real-time SAR signal processing. The approach of frequency domain transformation is used during both range compression and azimuth compression, which helps to simple computation and is suit for DSP. This system takes advantage of super-speed chips made in the company of SHARP, and external devises with high speed. Many improve steps have been taken during system design, which makes system computation speeded up. Shown in table 3

It is well known that the more the data are to be processed, the more time is spent. Therefore cascaded way can be employed during processing large points, that is, each chip is just responsible for a certain operation.

2. Analysis of resolution

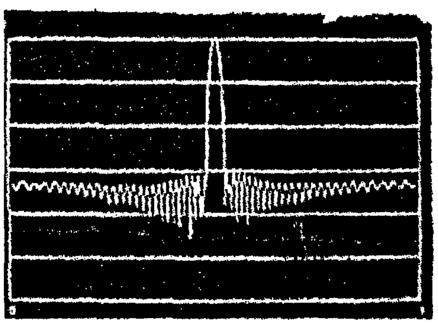
To prevent data overflow, all incoming data is processed through input and /or efficient rounders/shifts, and the LH9124 supports block floating-point scaling, which insures that the input data, output data results are complex data with 24bit precision, thus these are all content to SAR imaging. The testing result of compression is shown in figure 4.

Conclusion

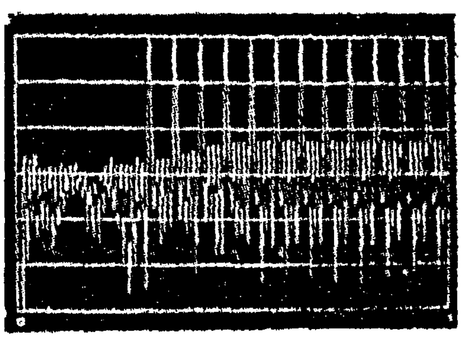
The real-time airborne SAR digital system chose special DSP chips with the fastest speed. What's more, measures are taken to obtain high precision, real-time, less power consumption, small size and some other advantages.

Complex data quantity	Radix	Superposition numbers	Theory time(ms)	Test time(ms)
256	16,16	2	0.0162	0.0175
1024	4,16,16	3	0.0807	0.0831
4096	16,16,16	3	0.3123	0.3147
8192	2,16,16,16	4	0.8248	0.8285
16384	4,16,16,16	4	1.6440	1.6569
65536	16,16,16,16	4	6.5604	6.5703

Table 3



One target



more target

Fig. 4 The result of testing

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