Implementation of Strip Map Algorithm for Synthetic Aperture RADAR (SAR)

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Abstract:

In this paper we first analyse thecharacteristics of FPGA and puts forward fast pulsecompression architecture. System-level simulation using MATLAB and Verilog for space borne SAR is carried out by the new way ofsystem verification techniques.In anticipation of much potential joint Space-Based-Radar (SBR) missions between the Air Force and NASA inthe future. We propose to develop an FPGA-based (field programmable- gated-array) architecture for on-board processing of radar data. In particular, the hardware is targeted for the high computational load in processing Synthetic aperture-radar (SAR).

Pulse compression plays an important role in design of the radar system. Pulse compression using linear frequency modulation techniques are very popular in modern radar. The linear frequency modulation is done here to resolve two small targets that are located at long range with very small separation between them.Pulse compression technology is defined as a process that radar transmitter emits large pulse frequency modulation signal and the receiver can obtain narrower pulse after matching and compression processing. The method better resolves the contradiction between the restriction of peak pulse power and range resolution in radar.

Pulse compression actually employ matching filter for radar receiving signal. Based on the theory of matching filter, the impulse response of filter is the conjugation of input signal. Similarly Azimuth resolution is carried out by using Azimuth reference function.

The application of this is finding the two different targets located at same place with a very small separation between them. And use of doing pulse compression is use of low power in the RADAR systems.

Keywords: SAR, RADAR,RDA, FPGA, FFT,LFM, PRI, BW,PW.

I. INTRODUCTION

RADAR is an acronym for **R**adio **D**etection **andR**anging. Radar works like a flash camera but at radio frequency. Typical radar system consists of transmitter, switch, and antenna. The switch directed the pulse to antenna and returned echo to receiver. The antenna transmitted the EM pulse towards the area to be imaged and collects returned echoes. The returned signal is converted to digital number by the receiver and the function of the data recorder is to store data values for later processing and display [9].

Airborne radar refers where radar is implemented by mounting, on a moving platform such as an aircraft or spacecraft.A synthetic aperture RADAR is a coherent mostly airborne or space borne side looking radar systemwhich utilizes the flight path of the platform to simulate an extremely large antenna or aperture electronically, and that generates high resolution remote sensing imagery. The signal processing uses magnitude and phase of the received signal over successive pulses from the elements of the synthetic aperture. After a given number of cycle, the stored data is recombined to create a high resolution image. The SAR works similar of phased array, but contrary of a large number of parallel antenna elements of the phased array, SAR uses one antenna in time multiplex. The differentgeometric positions of the antenna element s are the results of the moving platform [8].

Synthetic aperture radar offers dramatically improved image resolution over radar without sophisticated post processing by utilizing the movement of the antenna with respect to the target. Due to diffraction, a smaller aperture, or antenna length, such as the kind that could fit on the side of a plane or on a satellite, will produce a beam that is much wider once it has made its way to earth or to a target at a long distance as shown in Figure.

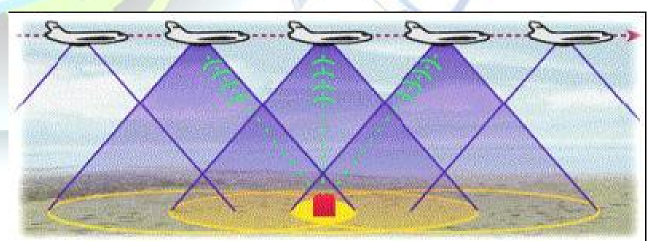

Figure1. Multiple RADAR beams

The wider the beam on the target, the more difficult it is to discern when reflections are coming from the target and thus locates the target. In order to improve the resolution without post processing, a larger antenna would have to be used that would generate a narrower beam pattern on the target and make it easier to distinguish target features. If an antenna platform is moving with respect to the target, many beams can be sent from and received at the antenna as shown in Figure, and when these reflections are analysed together by coherent combination using the range Doppler algorithm (RDA), they can generate an image with the resolution of a much wider “synthetic” aperture [5].

The RDA uses matched filtering to generate an image of the radar illuminated target by correlating the obtained noisy raw SAR signal with template reflections from ideal radar scattering. Christo Ananth et al.[6] discussed about E-plane and H-plane patterns which forms the basis of Microwave Engineering principles.

SAR systems installed on small aircrafts suffer from trajectory deviations and instabilities of antenna orientation. These kinds of motion errors lead to significant geometric distortions in SAR images. In the paper, we describe a time-domain multi- look strip map SAR processing algorithm with built -in correction of geometric distortions. In the algorithm, the azimuth reference functions and range migration curves are specially designed to produce SAR images directly on a correct rectangular grid on the ground plane.

In the subsequent sections, we willdiscuss the integrated and systematic approach undertaken todesign a real time high-performance and fault-tolerant FPGA-based hardware architecture for SAR processing.

IISynthetic Aperture Concept

Synthetic Aperture is when a narrow pulse in range is created (or synthesized). To create such pulse, signal is frequency-modulated. Therefore, the signal frequency changes in time. This is also called chirp signal and depending on whether frequency increases or decreases in time,Signal is up-chirp or down- chirp. This radar is capable of automatic searching, single- target tracking, and real-beam ground mapping. Wesee that pulsed radar consists of four basic functional elements transmitter, receiver, time-shared antenna, and display.

In optic sensors, when sensor is closer to target, more details are revealed. But in SAR systems the azimuth bandwidth is independent of range (or distance from target). The exposure time is proportional to range and azimuth FM rate is inversely proportional to range, therefore the signal bandwidth which is product of azimuth FM rate and exposure time remains independent of range [5].

Modes of SAR operation

There are a few different methods of operation for SAR systems.

1).Strip map SAR
2).Scan SAR:
3).Spotlight SAR Inverse SAR
4).Biostatic SAR

Here we have considered Strip Map mode of operation

In this mode, the antenna the antenna pointing direction is fixed. The beam sweeps along the earth surface with a constant rate and a contiguous image is formed. It provides a strip image
of the ground. The length of image depends on the distance sensor travels. In this case the length of antenna defines the azimuth resolution, and the range resolution or pulse compression.The two resolution methods are explained as below.

1).**Range resolution\Pulse compression.**

2).Azimuth resolutions.

1).Range Resolution\Pulse compression-Using Range Doppler Algorithm

The SAR signal processing in a simple and easy way using MATLAB can be explained.The signal processing of the SAR data is very important for generating various data products for different applications and analysis of land features. The SAR raw data for signal processing is a two dimensional array which contains sampled echoes in a complex form, the range reference signal is (LFM) Linear Frequency Modulated Signal. Pulse compression techniques are used to compress energy of echoes and thereby increasing the resolution of SAR.

Range Doppler algorithm is the most common algorithm for SAR processing as shown in block diagram [4].

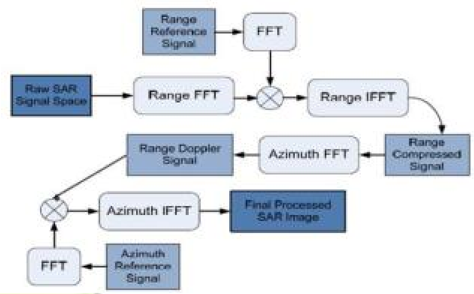

Figure2. Block Diagram of Range Doppler Algorithm.

The raw signal space SAR input is the two-dimensional signal which also a LFM signal. The two-dimensional signal is first analysed as a series range time signals for each azimuth bin. Each range time signal undergoes matched filtering in the range frequency/azimuth time domain through range FFTs applied to the range time signals. After each signal is transformed back into the range time/azimuth time domain, the result is the range compressed signal as the matched filtering was performed in the range frequency domain. In order to obtain azimuth compression, azimuth matched filtering must be performed. Each azimuth signal is Fourier transformed via an azimuth FFT and RCMC is performed before azimuth matched filtering in the range-Doppler domain[7].

Flow of Range Doppler Algorithm

The main steps in the version of the range -Doppler algorithm used in A SAR are shown in the block diagram below, and are described in the following sections. The range Doppler algorithm (RDA) was developed in 1976-1978 for processing SEASAT SAR data. Later it was used to digitally process space borne SAR image in 1978 and it is still the most widely used algorithm today.

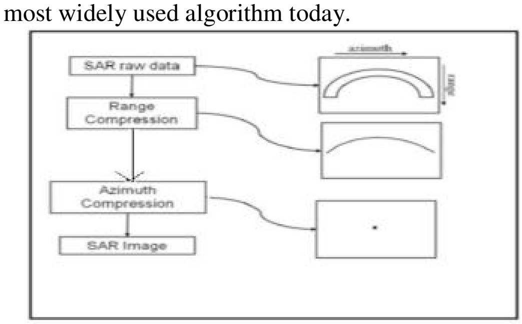

Figure3. Range compression flow graph Or steps.

Range Doppler algorithm is the most common algorithm for SAR processing which provides reasonably good accuracy of result. As described in the theory of this algorithm, RDA follows three main steps:

1. **Range Compression**
2. **Azimuth Compression.**

But when it comes to implementing the code for this algorithm this is what exactly it takes.

Range Compression: In collecting the SAR data, a long-duration linear FM pulse is transmitted. This allows the pulse energy to be transmitted with a lower peak power. The linear FM pulse has the property that, when filtered with a matched filter, the result is a narrow pulse in which all the pulse energy has been collected to the peak value. Thus, when a matched filter is applied to the received echo, it is as if a narrow pulse were transmitted, with its corresponding range resolution and signal-to-noise ratio.

This matched filtering of the received echo is called range compression. Range compression is performed on each range line of SAR data, and can be done efficiently by the use of the Fast Fourier Transform (FFT).

Azimuth Compression: An FFT is performed in the azimuth direction on each range gate to transform the data into the range Doppler domain. The FFTs are performed on blocks of data overlapped by the azimuth matched filter length. The range compressed data is stored in range line order. A group FFT algorithm is used which allows azimuth FFTs to be performed while still accessing the data in range line order[7].

III Linear frequency modulation

In modern pulsed Radar, range resolution (ΔR) isproportional to the pulse duration (τ). Therefore improvedrange resolution necessitates shorter pulse duration. Similarlythe energy (E) content of the signal is also proportional topulse duration (τ) and the detection probability depends it.Therefore to improve the detection, the pulse duration isrequired to be longer. To overcome this two conflictingrequirements, pulse compression method is used. The pulse compression usually done through FrequencyModulation and Phase Modulation are very popular in radars[1].

Frequency modulation can be classified as Linear Frequency Modulation (LFM) and Nonlinear Frequency Modulation (NLFM). LFM is the most popular radar waveform due to good range resolution and Doppler sensitivity. LFM waveform generation schemes are classified in analog and digital techniques.

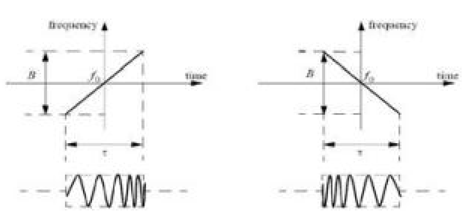

Figure4. LFM Up chirp and Down chirp signal

In this case, the frequency is swept linearly across the pulse width, either upward (up-chirp) or downward (down-chirp). The matched filter bandwidth is proportional to the sweep bandwidth, and is independent of the pulse width. Fig. shows a typical example of an LFM waveform. The pulse width is , and the bandwidth is B.

The LFM up-chirp instantaneous phase can be expressed by

() =2 � 0 + + � � �, − /2 ≤ ≥ /2

Where f0 is the radar centre frequency, and is the LFM coefficient given by

Thus, the normalized complex signal is given by,

By substituting the value of phase equation becomes as follows

() = exp(2 � + + � � ^2�) , − /2 ≤ ≥ /2

Pulse compression technology is defined as a process that radar transmitter emits large pulse frequency modulation signal and the receiver can obtain narrower pulse after matching and compression processing[3].

SAR radar returns: After pulse compression SAR returns again put for the azimuth compression. This is done by using themain requation as, 1( ) = ( )exp (1)

Where phase is given by 1( ) = ������ 1( )

Where 1( ) is Range which is varying at every different point as shown in the figure1 aircraft will be moving for different intervals of time. Range is given by the Pythagoras theorem as,

1( ) = { ������� + ( )�},

Where R is the maximum range at the centre point from the aircraft to the object, SAL is the synthetic aperture length which is varying in the horizontal direction.

In the Azimuth resolution reference signal is different from the input, and it is given by the equation,

= exp(2 � �) + /

Where v is the velocity to calculate the pulse repetition frequency[2].

IV Correlation processing of chirp signals

Because of the recent advances in digital computer development, the correlation processor is often performed digitally using the FFT. This digital implementation is called Fast Convolution Processing (FCP) and can be implemented at base-band. The fast convolution process is illustrated in Fig.

The correlation processor is often performed digitally using the FFT. This digital implementation is called Fast Convolution Processing and can be implemented at base-band. The fast convolution process is illustrated in Fig Since the matched filter is a linear time invariant system, its output can bedescribed mathematically by the convolution between its input and its impulseresponse, and this is implemented for both pulse and the azimuth resolution.

Where s (t) is the input signal h(t) is the matched filter impulse response (replica), and the operator symbolically represents convolution. From the Fourier transform properties, $FFT\{s(t) * h(t)\} = S(f) .H(f)$

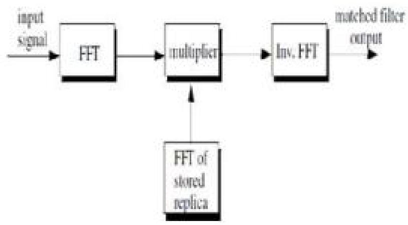

Figure5. Computing the matched filter output using FFT.

$Y= FFT{-1} \{S *H\}$

Where $FFT{-1}$ is the inverse FFT. When using pulse compression, it is desirable to use modulation schemes that can accomplish a maximum pulse compression ratio, and can significantly reduce the side lobe levels of the compressed waveform.

Input and Out Specifications: **For pulse compression**: For LFM signal are as,Band width (W) = 10Mega Hz,Pulse width (λ) =2micro secondSampling frequency (fs) =10Mega Hz.The derived parameters are as shown in the table below.

Derived Parameter Name & denotation	**Formula**
Sampling time (dt)	➢ 1/fs
Centre frequency (f0)	➢ -BW/2
Chirp rate (µ)	➢ BW\PW

TableNo1. Derived in put parameters for Range compression**.**

For Azimuth resolution- The input Signal specification is as follows, Frequency (f) =10Giga Hz, Speed of light (c) =3*10^8 meter per sec,Range (R) =10000, Azimuth resolution(delta1)=3meter, Pulse Repetition Interval=100µs, Velocity=100meter per second.

The derived parameters for the Azimuth resolution are as shown in the below table.

Derived Parameter Name & denotation	**Formula**
Wavelength (λ)	➢ c/f
Distance (ds)	➢ PRI*v

TableNo2. Derived parameters for Azimuth Resolution**.**

The generated input signal, range signal and reference signal is as shown in the fig.

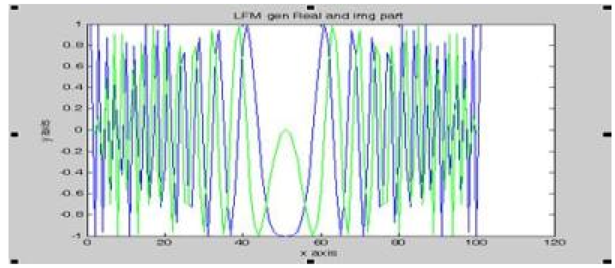

Figure6. Input LFM signal (SAR raw data)

The reference signal is similar to the SAR raw signal with different phase.

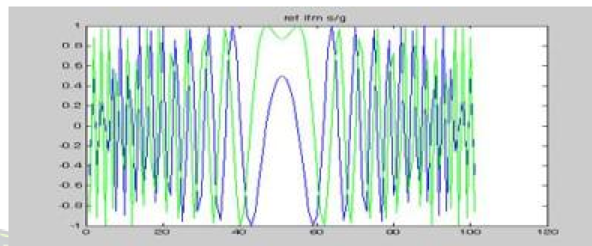

Figure7. Genereted Reference signal

`The output generated using a MATLAB software is same as that like pulse compressed signal with difference in the signal phase which allows us to use reduced transmitter power and still achieves the desired range resolution.

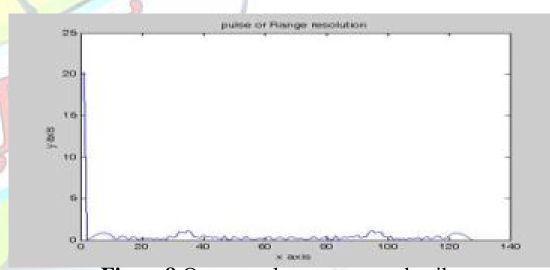

Figure8. Output pulse compressed spike

Thedesired output signal will be a single pulse compressed single spike.

The Azimuth Resolution generated output signal should be a signal similar to the range signal. The generated input phase signal for Azimuth resolution is as given below in figure.

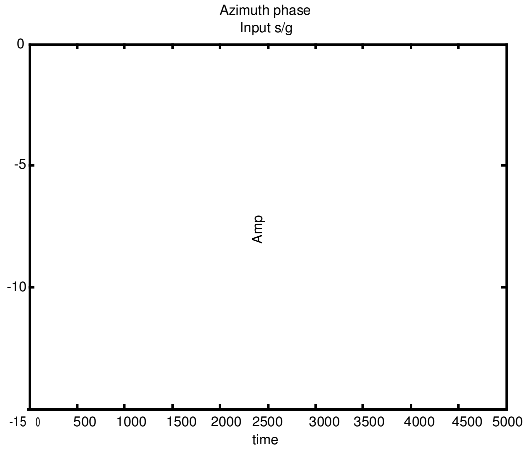

Figure9. Azimuth input signal

The output is generated using MATLAB software. Final step that is Azimuth Resolution is done by multiplying the Azimuth reference function with the range compressed data and then Azimuth ifft is carried out to transfer the data back to the time domain.

Finally we get an image where each pixel represents the energy from a single point target on the ground surface. The Azimuth output signal along with the horizontal direction derived is as in below figure.

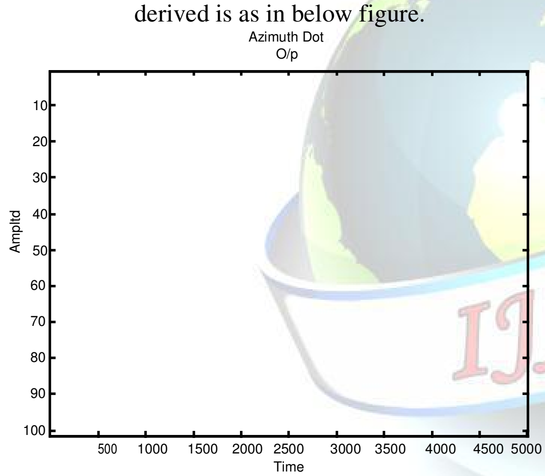

Figure9. Azimuth output signal point target signal.

The final SAR image is generated from the two dimensional simulation of the single point target.

V CONCLUSION

The simulation of LFM waveform is carried out for different specifications. The LFM signal is generated and correlated with the complex conjugate of same and the matched filter response is simulated.The strip map algorithm which includes Range compression or pulse compression and Azimuth resolution is implemented on FPGA and the resolution can be improved in the RADAR target images.

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REFERENCES

[1] Rinki Deo, Ankit jamod, "Mat lab based SAR signal processor for educational use", Center of studies and resources Engineering, Dept of electrical engineering Bombay, India. IEEE 2012.

[2] Shalini Gangele, J.G Vachanni, "Linear Frequency Modulation Waveform Synthesis", Space application center (SAC) ISRO, IEEE Students' Conference on Electrical, Electronics and Computer Science 2012.

[3] Pan Ruo-yu, "Research on Pulse Compression Technology of Linear Frequency Modulation signal",International Conference on Industrial Control and Electronics Engineering, 2012.

[4] Liujin, ChenLiang, "Design of space borne SAR imaging and fast verification based on FPGA", Radar Research Lab Beijing Institute of technology, Beijing 10008, P.R China.

[5] Henning F. Harmuth, "synthetic aperture RADAR based pulse compression", member IEEE, VOL. EMC-21, NO. 1, FEBRUARY 1979.

[6] Christo Ananth, S.Esakki Rajavel, S.Allwin Devaraj, M.Suresh Chinnathampy. "RF and Microwave Engineering (Microwave Engineering)." (2014): 300.

[7] Wang Zong Bo, Javier Carretero Moya, "Range Doppler image processing in linear FMCV Radar and FPGA based real time implementation", Apr. 2009, Volume 6, No.4 (Serial No.53).

[8] GEORGE W. STIMSON, "Introduction to AIRBORNE RADAR", second edition.

[9]Merrill I.Skolnik, "Introduction to RADAR systems", second edition. New York: McGraw-Hill, 1980, pp. 371–373