Implementation of Radar Signal Models on High Performance DSP Architectures

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Abstract— The radar systems requires high processing capabilities. The signal processing chain applied to the received echo requires high-computing power to extract target information in real time. In order to meet the requirements multiprocessor systems on chip (MPSoC) [1] have become the processing platform of choice. They provide unmatched signal processing at very low power levels for radar and avionics, as well as software defined radios (SDR), imaging and video applications that often accompany radar and avionics. The objective is to implement a radar signal processing chain on multiprocessor heterogeneous tiled System on Chip (SoC) architecture which uses multiple programmable processor tiles with different functionalities that operates concurrently. The multiprocessor system on chip consists DSP blocks such as multiplier/adder and hardware accelerators. The hardware accelerator is a component that works together with the processor and executes key functions much faster than the processor.

Key words: Multiprocessor System on Chip(MPSoC), Radar, Verilog

I. Introduction

The word radar is an abbreviation for Radio Detection And Ranging [2]. In general, radar systems use modulated waveforms and directive antennas to transmit electromagnetic energy into a specific volume in space to search for targets. Objects (targets) within a search volume will reflect portions of this energy (radar returns or echoes) back to the radar. These echoes are then processed by the radar receiver to extract target information such as range, velocity, angular position and other target identifying characteristics. The first use of radar was for military purposes: to locate targets and fire control. In aviation, to warn obstacles in path of aircraft and to give accurate altitude readings. Marine radars are used to measure the bearing and distance of ships. In harbor, vessel traffic service radar systems are used to monitor and regulate ship movements. Meteorologists use radar for weather forecast. Geologist use to map the composition of Earth's crust. Police forces use Radar guns to monitor vehicle speeds on the roads.

The use of multiple digital signal processor tiles is a key technology enabling increasingly sophisticated signal processing to advance the state of the art in waveform intensive applications, such as avionics, radar, sonar, signal intelligence (SIGINT), image and video processing and SDR. Avionics, radar and related applications need multi tile DSPs to meet the advancing requirements of these mission critical applications including higher processing throughput, finer resolution, increased accuracy and the integration of advanced I/O.

We propose an efficient method to implement the radar signal processing chain on tiled MPSoC. Each sequential task in the overall processing chain needs to be efficiently mapped to the DSP architecture. These main sequential tasks are FFT blocks, MTI filter and Doppler processing blocks. These steps are considered as modules for implementation on the MPSoC. The parallel implementation using the multiple tiles on the MPSoC platform can be achieved by letting each tile process a different portion of the blocks. Within each tile, the above mentioned tasks can be implemented accordingly.

II. System Model

A heterogeneous System on Chip (SoC) with different kind of (reconfigurable) processing tiles interconnected by a Network on Chip (NoC) as depicted in Fig.1. The type of processing tiles considered here is Field Programmable Gate Array (FPGA),

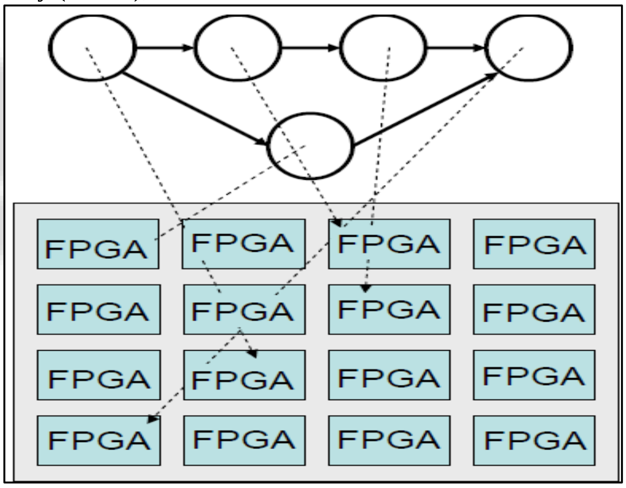


Fig.1: Heterogenous tiled SoC

The Fig.2 shows the tile architecture [3]. This is a single tile and multiple tiles can be replicated similar to this tile.

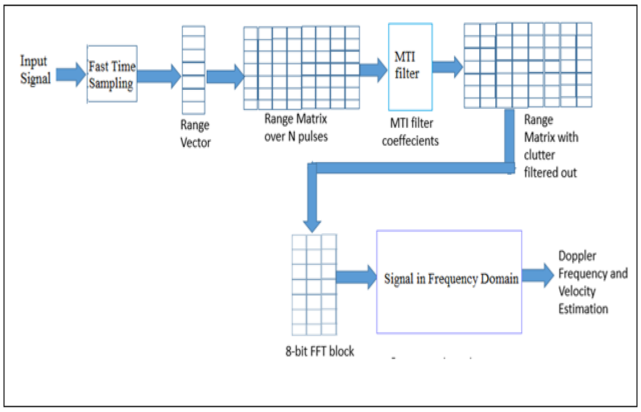


Fig. 2: System architecture

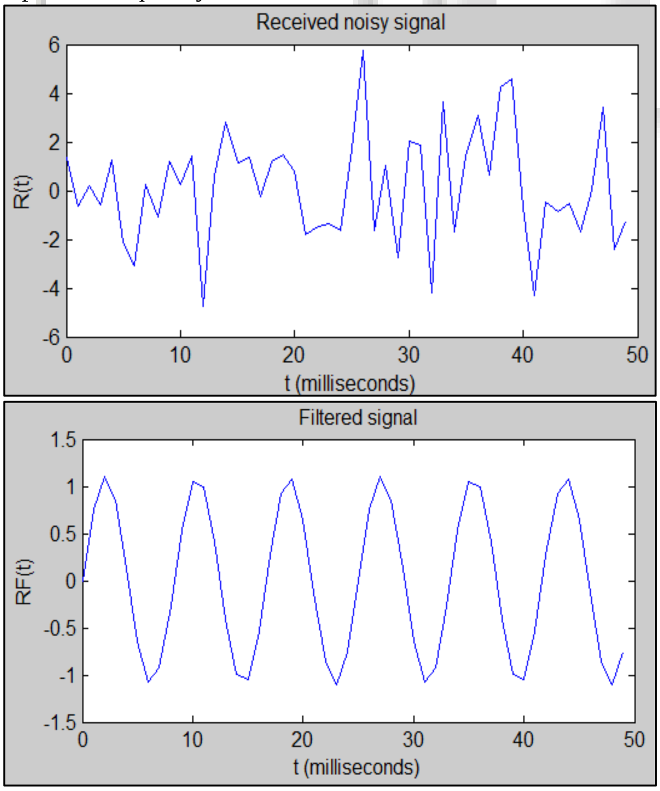
Range and azimuth compression were done to compress the received pulse along the range direction to concentrate the main energy into a narrower duration. It is performed with a fast convolution between the raw data and a reference signal in the frequency (range) – time (azimuth) domain. Therefore, FFT along the range direction is first performed. This generates the range vector. The range matrix was calculated for N number of pulses.

The special class of filter that can distinguish between slowly moving or stationary targets and fast moving ones is known as the Moving Target Indicator (MTI). Clutter is an unwanted noise with spectrum concentrated at DC. The purpose of an MTI filter is to suppress target-like returns produced by clutter, and allow returns from moving targets to pass through with little or no degradation.

The next step is the estimation of velocity and range of target which is the primary purpose of radar. The Doppler frequency shift is used to detect the presence of target.

A. *Detection*

The primary purpose of radar is detection of target. The received signal is a noisy signal. The signal is converted into frequency domain. The FFT operation is performed and noise is filtered out. The single sided spectrum is calculated. The energy concentration is higher if the target is present. This confirms the presence of target. The Fig.3a shows the received signal, Fig.3b shows the filtered out signal and Fig.3c shows the energy vs PRF. Where PRF is pulse repletion frequency.



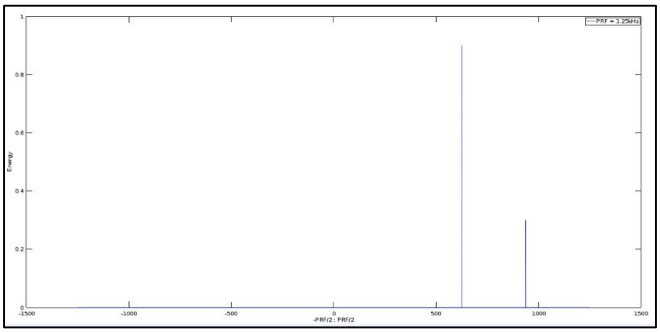


Fig. 3: a, 3b and 3c: Detection of target

B. *Target's location*

The location of target has to be calculated in any one of coordinate system. We used Cartesian coordinate system. The radar's use phased array antennas. There antenna contains N number of array elements and each individual array element acts as an antenna. The Fig.4 shows two beams A and B echo returns. The target is at the center axis which is called boresight axis.

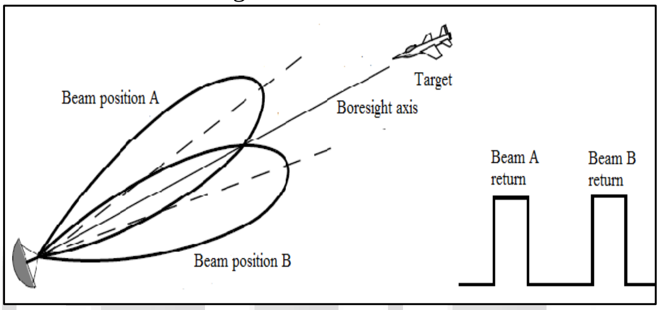


Fig 4: Beam positions

The gain difference and the angle corresponding to that gain difference is calculated. The location for a particular angle is calculated using the relation ax = R*Cos(angle) and ay = R*Sin(angle). Where R is the range. This gives target's position in Cartesian coordinate system.
Fig.5a shows the gain difference between two beams. The difference is zero at the center. Fig.5b shows the target's position assuming that the radar is placed at (0, 0).

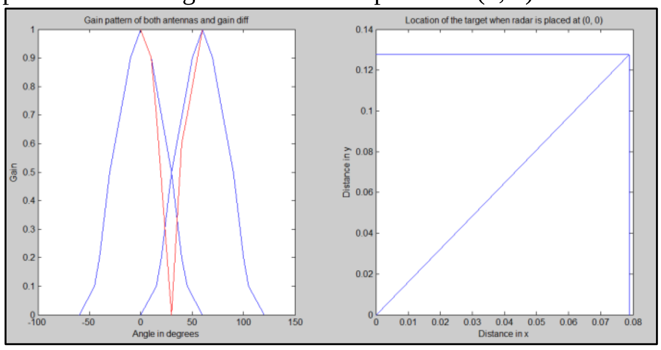


Fig. 5: Target coordinates

C. *MTI*

MTI stands for Moving Target Detection. This is a special type of filter that can distinguish between stationary targets such as hills or buildings and fast moving ones. The received echo values are populated in a matrix. The filter logic is applied to detect the edges. After the filtering if the Matrix contains nonzero elements, then we conclude that there are moving targets in the vicinity of the Radar.

D. Range and Velocity estimation

The range of a target is the distance between the target and radar. The target's range, is computed by measuring the time delay, Δt, it takes a pulse to travel the two-way path between the radar and the target. Since electromagnetic waves travel at the speed of light, c, then

$$R = \frac{c\Delta t}{2}$$

Where R is the range.

Radars use Doppler frequency to extract target radial velocity (range rate), as well as to distinguish between moving and stationary targets or objects such as clutter. The Doppler phenomenon describes the shift in the center frequency of an incident waveform due to the target motion with respect to the source of radiation. Depending on the direction of the target's motion, this frequency shift may be positive or negative.

The Doppler frequency is given by equation

$$f_d = f_r - f_t = 2v\frac{f_t}{(c - v)}$$

Where fd is the Doppler frequency, V is Velocity, C is speed of light and ft is transmitted frequency.

The velocity can be calculated using the above equation as

$$V = (cfd) / (2ft)$$

The Fig.6 shows the simulation. Where AT is the received signal, ST is the sent signal and Rvel is the velocity. The moving_target_present bit is set to 1 if a moving target is present. The corresponding velocity is shown for that target.

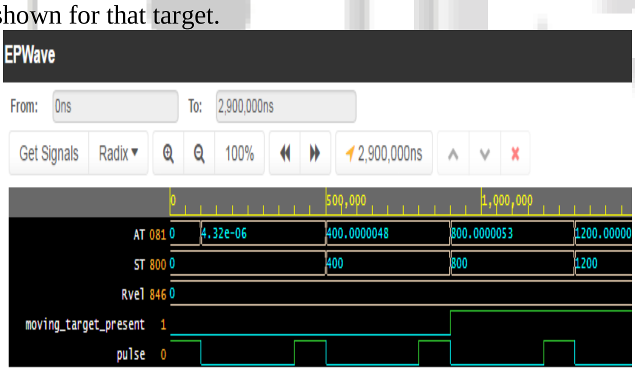


Fig. 6: Simulation result

E. Doppler Dilemma (Range and velocity Ambiguity)

The modulation of the carrier frequency is a periodic sequence of rectangular pulses. The frequency spectrum of the transmitted signal is a line spectrum. The line spacing of the spectrum is equal to the Pulse Repetition Frequency or PRF. PRF is number pulses transmitted per second. The received frequency spectrum can only be used for unambiguous velocity measurements when the displacement of the received spectrum is smaller than the line spacing in the spectrum. Doppler frequency must be lower than the PRF or the PRF must be higher. This unambiguity is shown in Fig 7.

We can calculate the range of unambiguous radial speed using below equation

$$Vr < c\ fprf/2\ ft$$

Where fprf is pulse repletion frequency and ft is transmitted frequency.

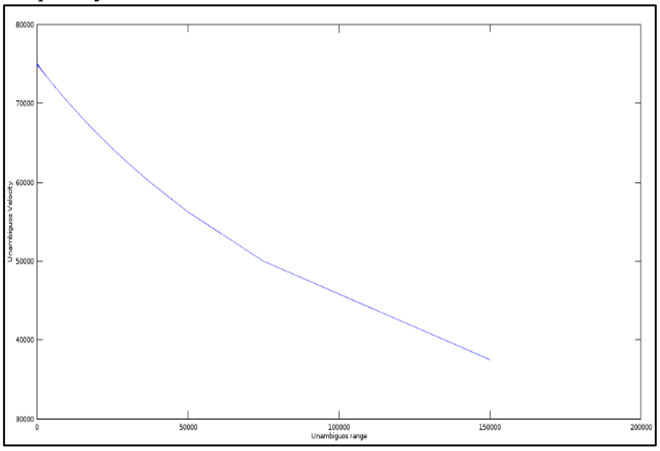


Fig. 7: Velocity vs Range plot

The maximum unambiguous range at which a target can be located so as to guarantee that the leading edge of the received backscatter from that target is received before transmission begins for the next pulse. This range is called maximum unambiguous range. The pulse repetition frequency determines this unambiguous range of a give radar before ambiguity starts to occur. This is plotted in Fig.8. This range can be determined by the equation

$$Rmax = c(PRT-Pw)/2$$

Where c is the speed of light, PRT is the pulse repetition time and Pw is the pulse width.

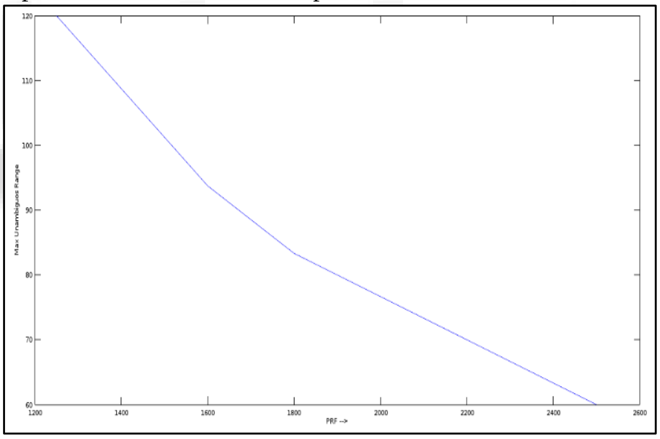


Fig. 8: Range vs PRF plot

III. RESULT AND DISCUSSION

In this paper we have proposed an implementation of radar signal processing model on a tiled architecture. We have simulated this tiled architecture in Xilinx with Verilog language. The plots for various operation like detection, MTI, location determination and unambiguity condition were already shown in previous section.

A good choice of PRF to achieve a large unambiguous range will be a poor choice to achieve a large unambiguous velocity and vice versa. By selecting the appropriate PRF by referring the Fig.9, this ambiguity problem can be solved.

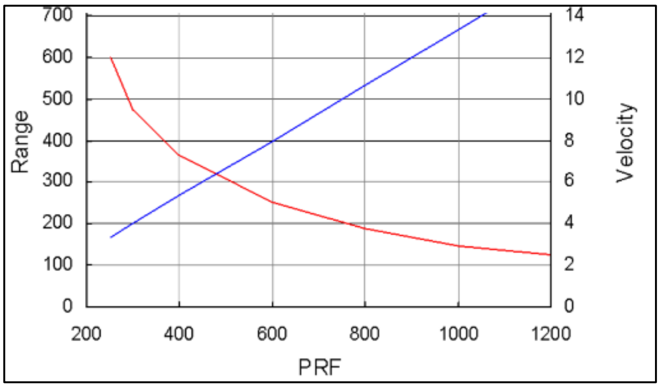


Fig. 9: Prf Selection Plot

IV. CONCLUSION

The Radar Signal Processing Chain On Multiprocessor Heterogeneous Tiled System On Chip (Soc) Architecture Has Successfully Implemented. This Uses Multiple Programmable Processor Tiles With Different Functionalities That Operates Concurrently. This Improves The Computational Efficiency. The Tiled Architecture Was Simulated In Xilinx With Verilog Language. The Various Ambiguity Conditions Were Analyzed.

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