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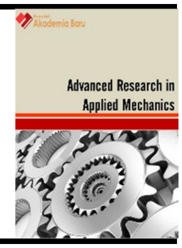

Hardware Implementation of Proposed CAMP algorithm for Pulsed Radar

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ABSTRACT

In this paper, a proposed CAMP algorithm is suggested to reduce the complexity and the processing time imposed by the original CAMP algorithm [1]. Hardware implementation of Compressive Sensing Radar Signal Processing (CS RSP) by using the proposed Complex Approximate Message Passing (proposed CAMP) Algorithm is performed using FPGA processor. The modified CAMP algorithm combines the advantages and avoids the disadvantages of the original CAMP algorithm to achieve the maximum probability of detection, Pd, at the same time with the minimum processing time and less hardware complexity. The implemented schemes are tested experimentally and evaluated with simulated radar signal for different target and noise situations.

1. Introduction

In 2004, Donohue and Candes proposed Compressive sensing theory, which showed that a signal having a sparse representation can be recovered exactly from a small set of linear, non-adaptive measurements [2]. CS theory combines the sampling and compression to reduce the signal sampling rate, the cost of the transmission, and the processing time. The CS theory shows that, when the signal has the characteristic of sparsity, the original radar signal can be exactly or approximately reconstructed from under-sampled measurements [3]. The process of compression and reconstruction of radar signal using CS theory is organized as follows:

Firstly, sparse representation of a signal mean that the number of unuseful values (zero elements or samples) is larger than the number of useful values (non-zero elements or values). Precondition of compressive sensing theory is that the radar signal is sparse or compressible. According to the definition of the sparsity property, so the pulsed radar signal is considered as a sparse signal, as the number of targets is typically much smaller than the number of resolution cells in the illuminated area or volume [4].

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Secondly, the sensing matrix, A, represents a dimensionality reduction of the radar signal. The sensing matrix maps, RN, where, N, is generally large (length of high dimensional radar signal) into RM, where, M << N, (under-sampled radar signal). It is designed using the Restricted Isometry Property (RIP), and the Incoherence property to ensure that the sparse radar signal, x, can be reconstructed perfectly [4].

Finally, the radar signal can be reconstructed by using one of the reconstructed algorithms of CS theory. ℓ1-norm minimization algorithm requires very few measurements but is computationally more complex. On the other extreme are combinatorial algorithms, which are very fast, but require many measurements that are sometimes difficult to obtain. Iterative thresholding algorithms are in some sense a good compromise between those extremes concerning computational complexity and the required number of measurements [4].

This paper is organized as follows; after the introduction, section 2 gives a survey on the bases of CAMP algorithm. Section 3 focuses on the feature of the proposed CAMP algorithm. Simulation results are performed in section 4. Hardware implementation of CAMP algorithm is presented in section 5. Experimental results of the implemented proposed CAMP algorithm is presented in section 6. Finally, conclusion comes in section 7.

2. Complex Approximate Message Passing (CAMP) Algorithm

CAMP algorithm is one of the most successful algorithms for the CS problem [6]. The CAMP algorithm is considered to be as the AMP algorithm for reconstructing the radar signal but in the complex domain [7]. On the other hand, CAMP algorithm is better than the AMP algorithm in the radar signal processing as the radar applications needs a complex analysis, where each non-zero element of the radar signal corresponds to the (complex) Radar Cross Section (RCS) of a target and may include propagation and other complex factors normally associated with the radar equation. On the other hand, CAMP shares some interesting features with AMP [8]. The flow chart of the implemented CAMP algorithm is shown in figure 1 [10].

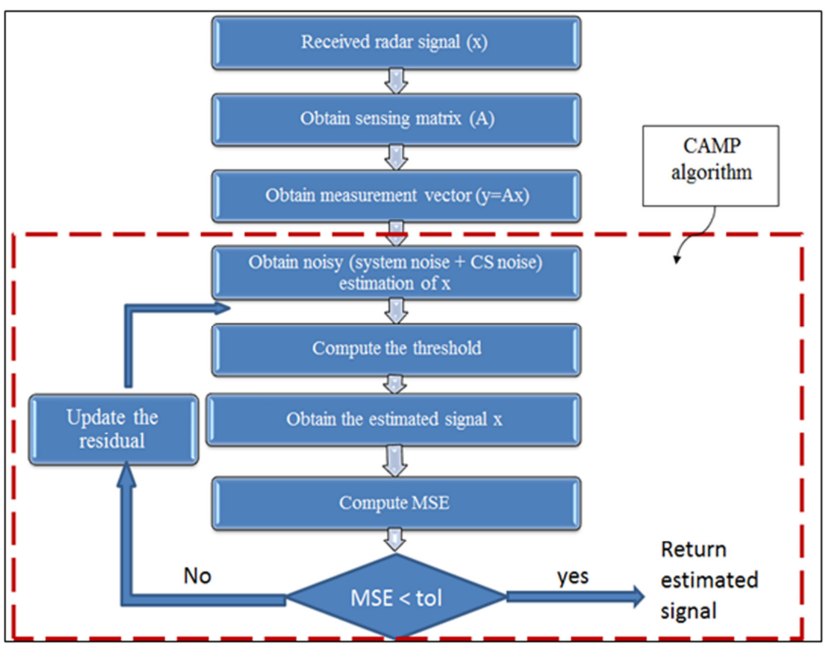


Fig. 1. Flow chart of CAMP algorithm

According to the flow chart of the CAMP algorithm, the iteration computational complexity of the CAMP algorithm is high. This high complexity is due to updating the measurement vector (update residual) in each iteration which requires the matrix-vector multiplications in each iteration and number of iteration in order to reconstruct the radar signal. Secondly due to the number of iterations which are performed to reconstruct the radar signal successfully [9].

3. Proposed Complex Approximate Message Passing (CAMP)Algorithm

A suggested proposed CAMP algorithm based on simulation trails has been performed for reconstructing the radar signal. In this algorithm the sensing matrix, A, is designed to be a constant matrix which satisfies the two properties (incoherence property and restricted isometry property) of designing the sensing matrix which are discussed before.

The sensing matrix, A, is generated randomly by matlab package to achieve the Restricted Isometry Property and the Incoherence Property. The sensing matrix is chosen according to the best result for reconstructing the radar signal, after performing a large number of trails by the original CAMP algorithm. The modified CAMP algorithm is less complex than the original CAMP algorithm as it reconstructs the radar signal with one iteration and consequently does not need to update the measurement matrix, y. Figure 2 shows the flow chart of the CS theory for reconstructing the radar signal by using the modified CAMP algorithm.

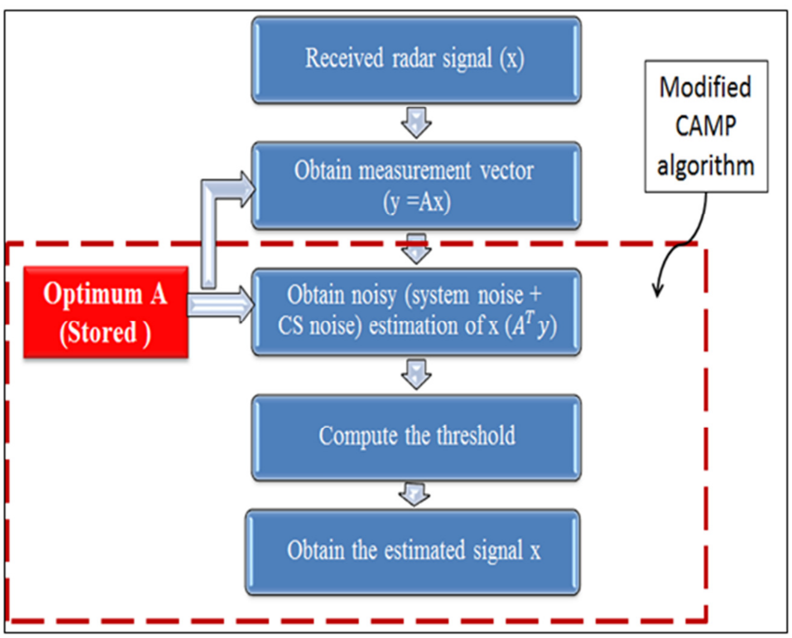


Fig. 2. Flow chart of the proposed CAMP algorithm

The general block diagram of the implemented CAMP algorithm is shown in figure 3, the received radar signal is assumed to be a pulsed radar signal with duration of 1 us and 3 ms repetition period. The received radar signal is converted into digital form by means of ADC with a sampling rate of 1 MHz, which is chosen according to Shannon sampling theory.

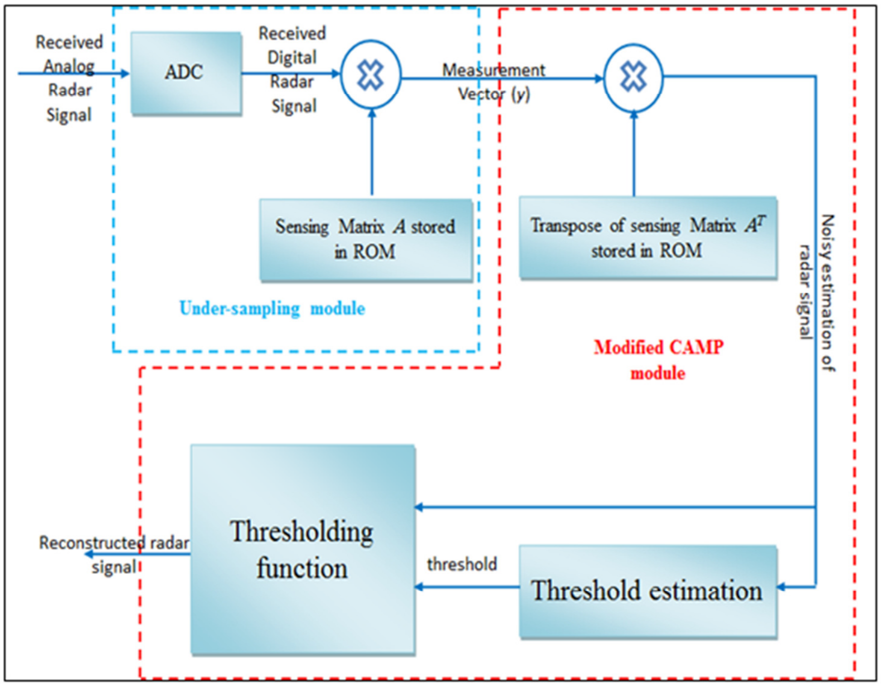


Fig. 3. Block diagram of proposed CAMP algorithm

The proposed CAMP algorithm consists of two main modules Under-sampling module, and CAMP module. To clarify and design each part of the proposed algorithm a zoom in is taken on each module. Firstly Under-sampling module which is used to generate the measurement vector, y, after converting the received radar signal to samples by using the ADC, by using the sensing matrix, A, which is generated randomly in the matlab-program (to satisfy the incoherence and the Restricted Isometry Properties), and is stored in a Rom (as an array) in the under-sampling module in the off-line case with dimensions 11X16. The output measurement vector, y, has a dimensions of 11 samples. Finally, the proposed CAMP module which is used to reconstruct the sparse radar signal from a small number of samples, smaller than the Nyquist rate. The output from the generating measurements module is the measurement vector, y, feds a smaller number of samples than the Nyquist rate samples to the CAMP module. The CAMP module is responsible for reconstructing the chosen window of the received digital radar signal by using the measurement vector, y. The CAMP (reconstruction) module consists of the noisy estimation sub-module, the threshold estimation sub-module, the soft thresholding function sub-module, and the division sub-module.

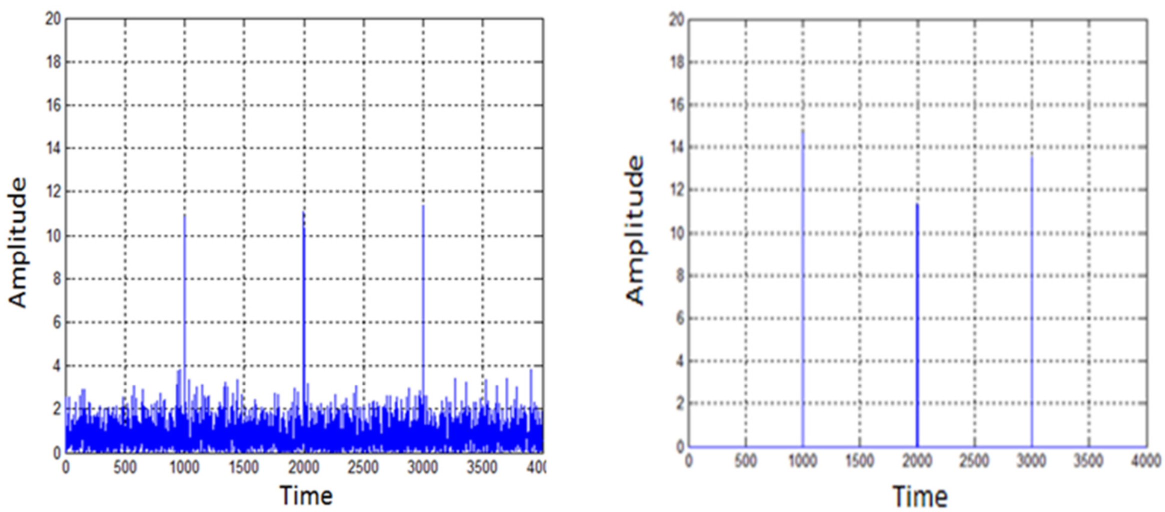
4. Simulation Results

Simulation results are obtained for reconstructing the radar signal from a small number of measurements (samples) by applying the radar signal to the proposed CAMP algorithm. Consider a received radar signal with frequency of 1 GHz (pulse width = 1 ns), the pulse repetition frequency is 1 MHz (Tr = 1 us) and the sampling frequency according to Nyquist rate is 4 GHz, so the number of samples in radar signal (length of the radar signal) is 4000 samples (N =4000). The received radar signal is considered to have only one target with four samples in the target cell, so the number of non-zero coefficients (k = 12). The number of measurements (under-sampling) is 133 samples (M = 1200) according to the incoherence property (M = k2lnN = (12)2 ln (4000) = 1194.34 ≈ 1200 samples).

The signal sparsity ρ=K/M=0.01 and under-sampling factor δ = M / N = 0. 3. The probability of false alarm, Pfa, is chosen to be 10-5. The Sensing Matrix is a random matrix to satisfy the RIP and the incoherence property. The received radar signal is considered to be contaminated with an Additive White Gaussian Noise (AWGN), with zero mean, unity variance and SNR=10 dB. The simulation results is performed to insure that the proposed algorithm can reconstruct the received radar signal from a small number of measurements, and to evaluate the performance of the proposed algorithm with respect to the original CAMP algorithm.

4.1 Reconstruction of Received Radar Signal

Figure 4 shows the simulation results for reconstructing ideal signal with three targets by using the proposed CAMP algorithm.



(a) (b)

Fig.4. Simulation results for reconstructing real radar signal with three targets by using the proposed CAMP algorithm (a) Received real radar signal, and (b) Reconstructed radar signal

As shown in figure (4), It consists of two graphs. Graph (a) represents the original received radar signal. Graph (b) represents the reconstructed radar signal by the CAMP algorithm from a small number of measurements M (δ = 0.3). The under-sampled radar signal is reconstructed by using the original CAMP and the modified CAMP algorithm perfectly. It is clear that the original and reconstructed radar signal targets are in the same positions, so, the original CAMP and the modified CAMP algorithm can perfectly reconstruct the received radar signal from under-sampled measurements (lower number of samples); however the reconstructed signal seems to be better than the received noisy radar signal.

4.2 Performance Evaluation

The performance of the original CAMP and the modified CAMP algorithm can be evaluated by Receiver Operating Characteristic curve (ROC), to insure that the modified CAMP can improve the Signal-to-Noise Ratio (SNR) of the radar signal during the reconstruction process with a small number of measurements (samples) like the original CAMP algorithm.

There are two factors that can improve the SNR, the first factor is to amplify the amplitude of the radar signal, and the second one is to reduce the noise level, so the original and modified CAMP algorithms can improve the radar signal by reducing the noise level. Figure 5 shows, a comparison between the original CAMP, and the modified CAMP algorithms, at probability of false alarm Pfa = 10^{-6}.

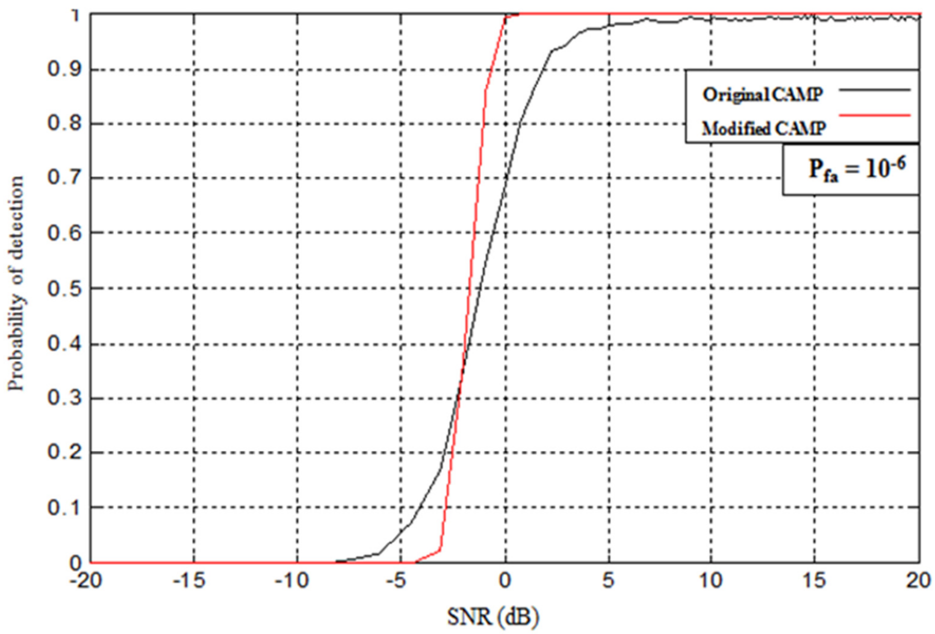


Fig. 5. ROC curves for reconstructing a real radar signal with three targets using the original CAMP algorithm, and the modified CAMP algorithm P_{fa} = 10^{-6}

In this paper the proposed CAMP algorithm shall be used instead of the original CAMP algorithm, as it improves the radar performance than the traditional radar signal processors. On the other hand it is less complex than the original CAMP algorithm. In the next section the modified CAMP algorithm shall be implemented using Field Programmable Gate Array (FPGA).

5. Hardware Implementation

In this section, an overview on FPGA structures and design steps shall be presented. Design and implementation of the proposed CAMP algorithm is introduced and illustrated by block diagrams explaining each sub-module supported with experimental results. The proposed CAMP algorithm is implemented on a Xilinx Spartan 3 - 3AN (XC3S700AN in FGG484 package) FPGA (speed grade -4) with the same throughput target for problems with a matrix A of size 11X16 [10]. Figure 6 shows the schematics diagram of the proposed CAMP algorithm, which is generated by the Xilinx package ISE13.1 program.

The Model-Sim simulation results are performed and presented in Figures (7), (8), (9), and (10). Model-Sim is a tool that integrates with Xilinx ISE to perform simulation and testing. Simulation is used to make sure that the logic of a design is correct and make sure that the design will behave as expected when it is downloaded onto the FPGA chip.

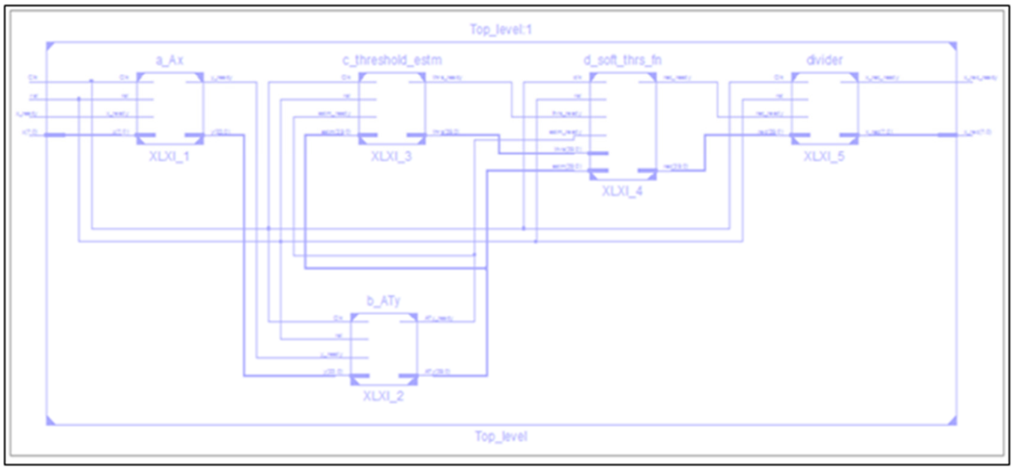


Fig. 6. Schematic diagram of proposed CAMP algorithm

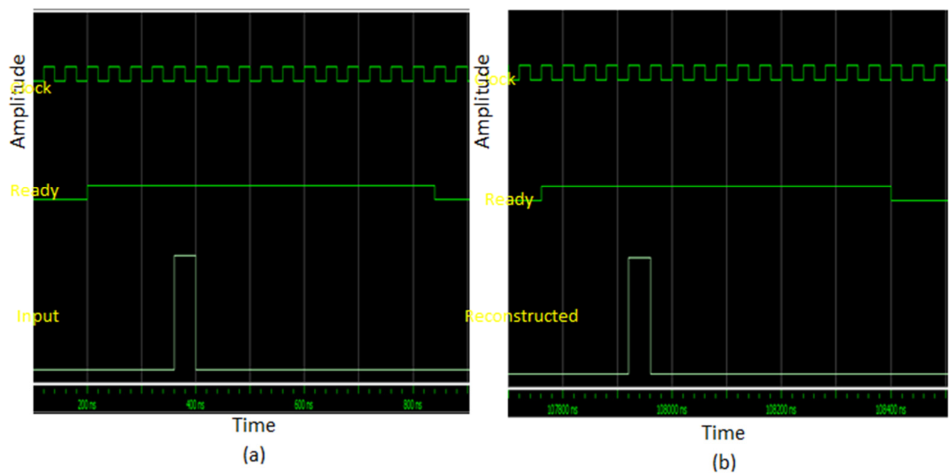


Fig.7. Model-Sim simulation results for CAMP algorithm for reconstructing the ideal radar signal with single target (a) original radar signal, (b) reconstructed radar signal

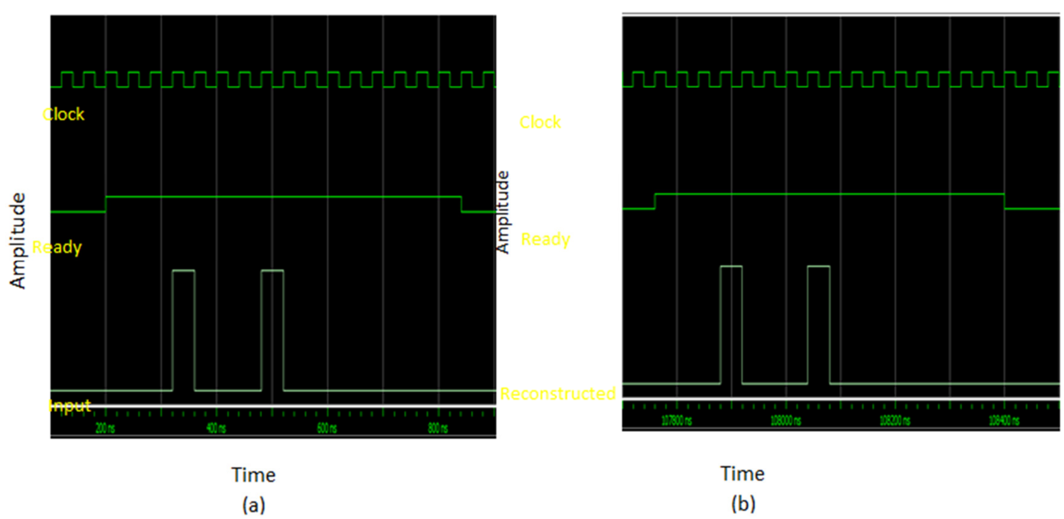


Fig. 8. Model-Sim simulation results for CAMP algorithm for reconstructing the ideal radar signal with single target (a) original radar signal, (b) reconstructed radar signal

The input is considered to be the received radar signal (vector, x,) which contains 16 samples with 8 bits length for every sample. After designing the proposed CAMP algorithm using the VHDL code, the function and timing simulation for the design shall be performed in order to insure that it is doing its function correctly.

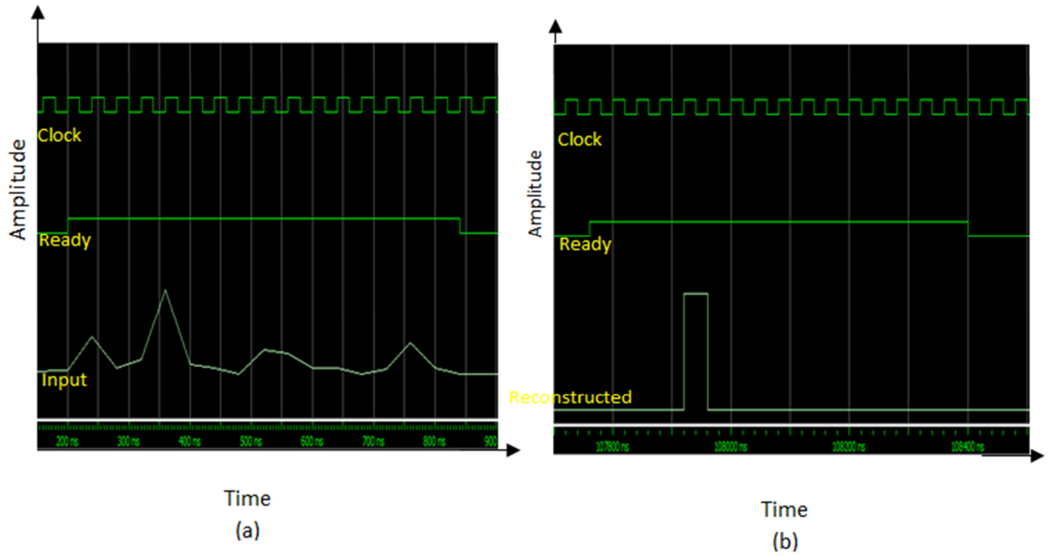


Fig. 9. Model-Sim simulation results for CAMP algorithm for reconstructing the ideal radar signal with single target (a) original radar signal, (b) reconstructed radar signal

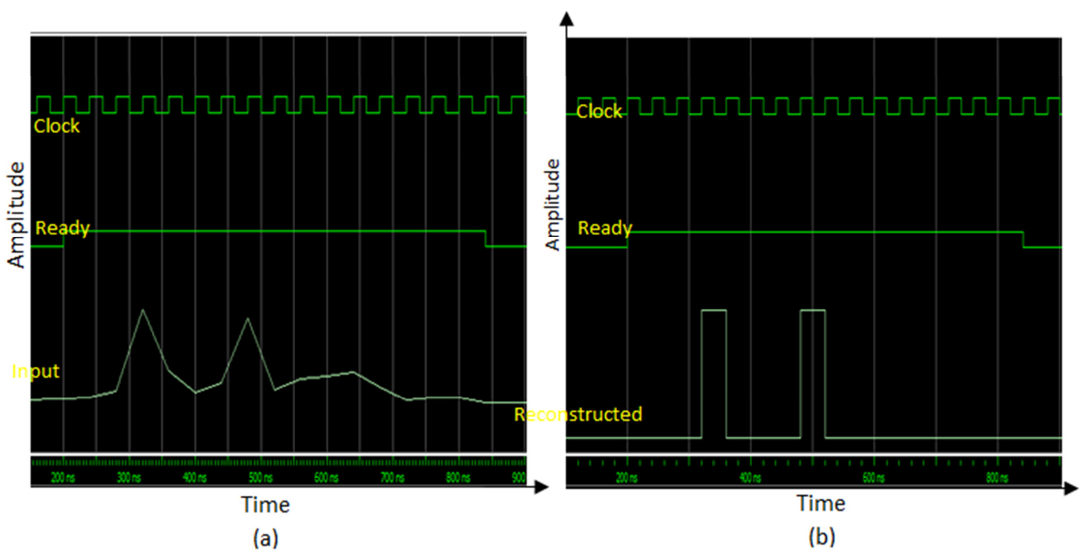


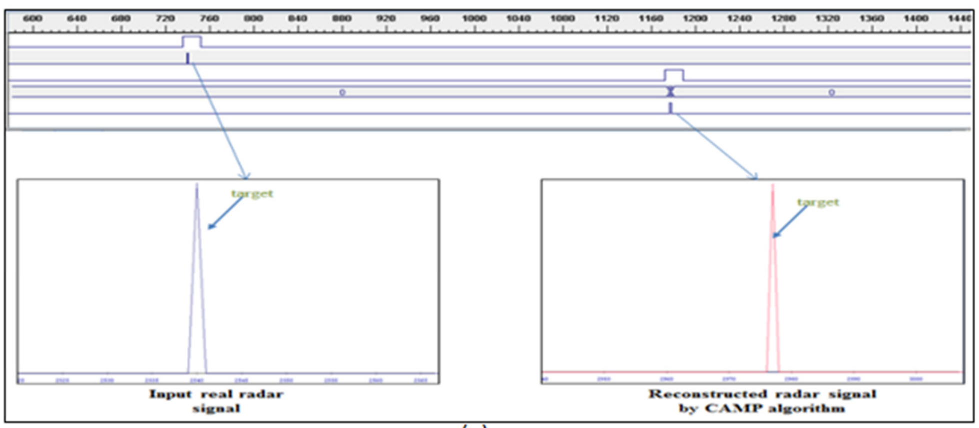
Fig. 10. Model-Sim simulation results for CAMP algorithm for reconstructing the ideal radar signal with single target (a) original radar signal,(b) reconstructed radar signal

As shown in figures 7-10, the received radar signal is considered to have one and two targets, so the number of non-zero coefficients is $k = 1$ or $k = 2$ (sample at the pulse width), and the signal sparsity $\rho = K / M = 0.053$ and under-sampling factor $\delta = M / N = 0.18$. The reconstructed radar signal by the CAMP algorithm is completely like the original radar signal. By comparing the simulation results between figure (7), figure (8), figure (9), and figure (10) with the simulation results of the original CAMP algorithm which is performed in [9], the processing time for reconstructing the received radar signal by using the proposed CAMP algorithm takes 17440 ns with 50 MHz clock oscillator, which is smaller than the processing time for reconstructing the received radar signal by using the original CAMP algorithm which takes 107560 ns.

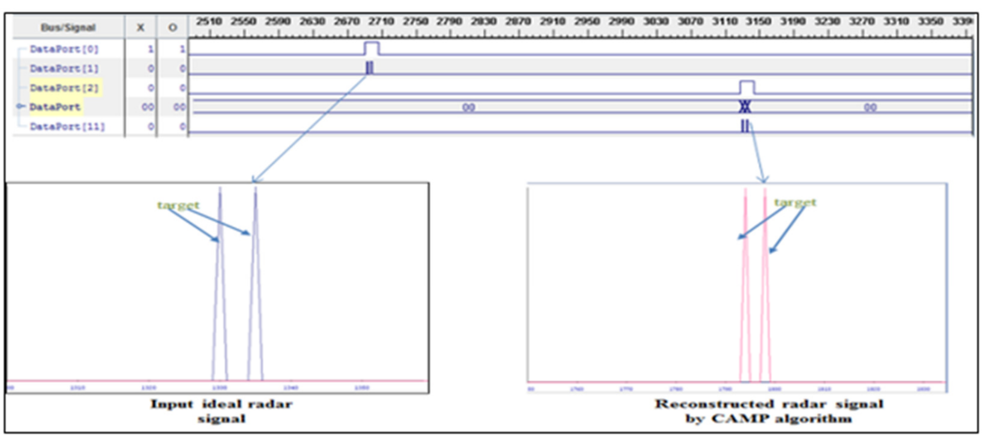
The modified CAMP algorithm is faster than the original CAMP algorithm, and it is more simpler than the original CAMP algorithm (original CAMP algorithm takes 2689 clock cycle, and proposed CAMP algorithm takes 216 clock cycle).

6. Experimental Results

The following results are obtained by using ChipScope tool (related to Xilinx), which reserve memory blocks in the implemented FPGA chip to store the selected signals for specified period of time. Then, the selected signals can be viewed in different forms on the computer display. This method is very simple and effective in evaluating the implemented hardware. Figures 11 shows, the experimental results for the reconstructed received radar signal using the CAMP algorithm by using ChipScope software.

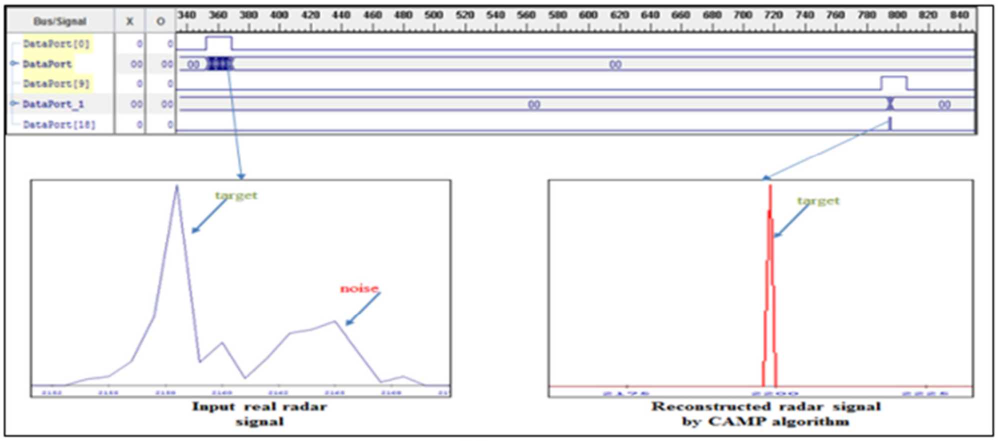


(a)

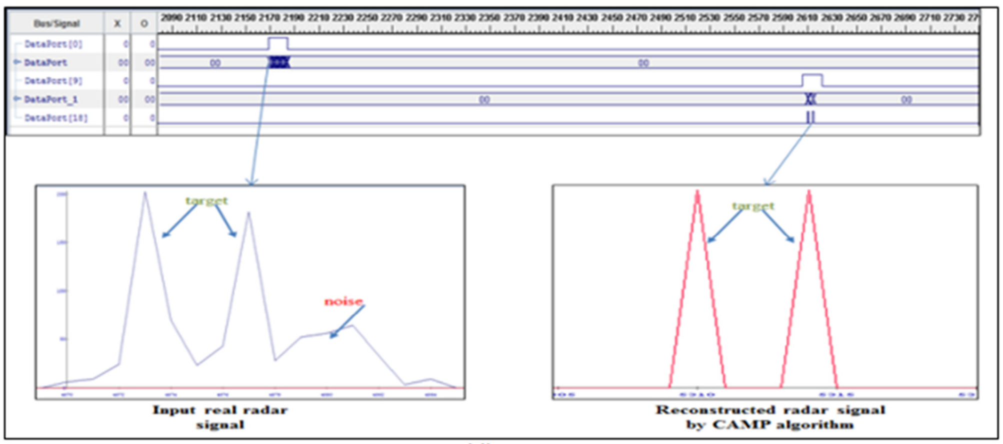


(b)

Fig. 11a. Experimental results for CAMP algorithm for reconstructing the radar signal using ChipScope (a) ideal radar signal with single target, (b) ideal radar signal with two targets



(c)



(d)

Fig. 11b. Experimental results for CAMP algorithm for reconstructing the radar signal using ChipScope (c) real radar signal with single target, (d) real radar signal with two targets.

The implemented CAMP algorithm using Spartan 3-3AN FPGA produced by Xilinx occupied 31 % of the slices of registers (26999 of 54576), and 61 % of slices LUTs (16785 of 27288), and 39 % of DSP slices (23 of 58).

7. Conclusion

The modified CAMP algorithm succeeded to reconstruct the received radar signal (under-sampling 75%) with a slightly degraded detection performance than the original CAMP algorithm. The proposed CAMP algorithm is based on selecting an optimum sensing matrix using simulation trails off line. By doing this, the hardware complexity and less processing time are achieved compared to the original CAMP algorithm. The modified CAMP algorithm improves the processing time for reconstructing the radar signal better than the original CAMP algorithm (16%). The implemented modified CAMP algorithm is less complex (33% of the used chip) than the original CAMP algorithm (289% of the used chip). The proposed CS radar signal processor is more complex than the traditional sub-pulse matched filter but it gives a better detection performance (ROC 15 dB higher in SNR).

References

[1] Herman, Matthew A., and Thomas Strohmer. "High-resolution radar via compressed sensing." *IEEE transactions on signal processing* 57, no. 6 (2009): 2275-2284.

[2] Baraniuk, Richard, and Philippe Steeghs. "Compressive radar imaging." In *Radar Conference, 2007 IEEE*, pp. 128-133. IEEE, 2007.

[3] Ender, Joachim HG. "On compressive sensing applied to radar." *Signal Processing* 90, no. 5 (2010): 1402-1414.

[5] Lei, Zhu, and Qiu Chunting. "Application of compressed sensing theory to radar signal processing." In *Computer Science and Information Technology (ICCSIT), 2010 3rd IEEE International Conference on*, vol. 6, pp. 315-318. IEEE, 2010.

[6] Shah, Sagar, Yao Yu, and Athina Petropulu. "Step-frequency radar with compressive sampling (SFR-CS)." In *Acoustics Speech and Signal Processing (ICASSP), 2010 IEEE International Conference on*, pp. 1686-1689. IEEE, 2010.

[7] Maleki, Arian, Laura Anitori, Zai Yang, and Richard G. Baraniuk. "Asymptotic analysis of complex LASSO via complex approximate message passing (CAMP)." *IEEE Transactions on Information Theory* 59, no. 7 (2013): 4290-4308.

[8] Maleki, Mohammad Ali. *Approximate message passing algorithms for compressed sensing*. Stanford University, 2010.

[9] Anitori, Laura, Matern Otten, Wim Van Rossum, Arian Maleki, and Richard Baraniuk. "Compressive CFAR radar detection." In *Radar Conference (RADAR), 2012 IEEE*, pp. 0320-0325. IEEE, 2012.

[10] Technical Manual, “Spartan-3A/3AN FPGA Starter Kit Board User Guide“, Xilinx, Inc., 2008.