Simulation of SAR Jammer Techniques and Hardware Implementation for Point Scatterer Modelling

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***Abstract*— In this paper, the effectiveness of different jamming techniques against synthetic aperture radar (SAR) systems is provided. Some derivations regarding the noise jamming immunity of SAR systems are made and the results obtained are compared with the simulation results. Noise jamming techniques based on playback of pre-recorded noise sequence and repeater techniques based on random false targets are proposed. Simulations are used to show the effectiveness of those techniques for different jamming to signal ratios. A hardware structure for SAR jammer is proposed together with possible simplifications.**

Keywords- SAR; Electronic Counter Measure (ECM) ; Noise Jamming.

I. INTRODUCTION

SAR is an imaging radar which transmits phase or frequency coded pulses to target region and forms 2D reflectivity image by coherently processing collected pulse returns. The final image is the Radar Cross Section (RCS) Distributions of point scatters on the surface. Different from their optical counterparts, SAR radars can form high resolution images of target regions in all weather conditions.

Jamming against SAR systems can be thought as protecting strategic regions from monitoring and this makes it an important problem in Electronic Warfare (EW). Jamming a SAR system is an easier problem compared to conventional radar jamming in some ways. SAR systems usually work with a fixed Pulse Repetition Interval (PRI) and frequency which makes them unprotected against jammer tracking. They also have large bandwidth and can easily be located in frequency by Electronic Intelligence (ELINT) systems.

It is also hard to generate an effective ECM signal against SAR systems. First of all, SAR radars are always highly coherent radars with both fast time and slow time operations in their receivers and this makes them immune to noise jamming. SAR images have high correlation, so low pass filtering or reconstruction algorithms using this correlation can be used to correct jammed images.

SAR Jamming has been studied for a long time but it is still a current research area. Several studies on the simplest jamming technique, noise jamming effectiveness have been published [1], [2]. Deceptive techniques using Digital Radio Frequency Memory (DRFM) which create spurious images in SAR scene is also a popular research area [3], [4]. Electronic Counter Counter Measure (ECCM) techniques for countering SAR jammers have been studied deeply due to their similarity to conventional radar ECCM [5][6][7].

The rest of the paper is structured as follows. In Section II, an introductory information on SAR performance parameters and image construction is provided. Section III gives a classification of SAR ECM techniques in literature together with a comparison of their effectiveness. In Section IV, simulation results regarding the effectiveness of different jamming techniques will be provided. In Section V, a hardware structure for implementing SAR jammer will be proposed. Section VI concludes the paper.

II. SAR BASICS

One of the most important performance criteria for imaging radars is the final image resolution. Since SAR is a 2D imaging system, resolution is defined in both range and azimuth. Resolution in range can be improved by using pulse compression techniques. Resolution in azimuth can be approximated using 3dB pattern width times the range (R).

The cross range resolution ΔCR can be approximated using (1) where λ is the wavelength and L_{az} is the antenna size in azimuth direction [9].For a low resolution at long range, the antenna size requirement becomes unrealizable.

$$\Delta CR = R\frac{\lambda}{L_{az}} \tag{1}$$

In SAR systems, a synthetic antenna array is formed by using the assumption of limited change in imaging region and a uniform motion of the radar platform during the imaging period. By using the size of this synthetic array, a large azimuth size L_{az} and high azimuth resolution is obtained for imaging. During the motion of the platform, a sequence of pulses is transmitted in the direction perpendicular to the platform motion. The pulses are transmitted at a rate defined by pulse repetition interval (PRI). If the platform speed is given by v and the duration of pulse integration is T_{INT}, then the aperture length will be the platform speed times the pulse integration time. The resultant azimuth resolution of the constructed image can be calculated using (2). [9]

$$\Delta CR_{SAR} = R\frac{\lambda}{2vTA} \tag{2}$$

 ISBN: 978-1-61208-453-4

There is a large number of algorithms related to image formation for SAR. Since these are not related to the subject of this paper, only a brief summary of the simplest algorithm (Doppler Beam Sharpening) going back to 1965 (Carl Wiley) will be described here.

The position of a point scatterer on a target region can be defined by using the axis parallel to platform motion (X axis) and the range axis (R) perpendicular to the motion. Let u define the position of the platform on synthetic aperture. If the distance to the imaging region is much larger than the diameter of the target region, then the distance to the point scatterer can be approximated using (3) where x is the position on X axis.

$$R(u) = \sqrt{(u-x)^2 + R^2} \approx R + u\frac{x}{R} + \frac{x^2}{2R} \quad (3)$$

Assuming the output of fast time match filter is approximated by $\delta_D(t-R(u))$ in baseband, the phase lag $\Theta(u)$ of pulse return from a point scatterer at coordinates (x,R) can be calculated using (4).

$$\Theta(u) = (R + u\frac{x}{R} + \frac{x^2}{2R})\frac{4\pi}{\lambda} \quad (4)$$

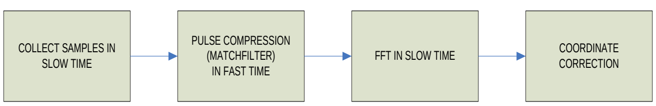

Figure 1. Doppler Beam Sharpening Algorithm

When we differentiate this phase lag with respect to u, we obtain a linear relation with x given by (5). The position of scatterer in azimuth corresponds to a complex sinusoid in slow time and by using the frequency of this sinusoid, we can obtain the azimuth position. By using all the assumptions stated above the simplest image formation algorithm "Doppler Beam Sharpening" can be summarized as stated in Figure 1.

$$\frac{d\Theta(u)}{du} = \frac{4\pi x}{\lambda R} \quad (5)$$

III. DEFINITION AND TYPES OF SAR ECM

SAR ECM can be defined as techniques which prevent a target from imaging, classification and identification of objects on a region by creating distortion or false targets in the resultant image. Possible techniques against SAR are classified as Passive, Non-Coherent, Semi Coherent and Coherent in [11].

Passive techniques include usage of reflectors and surface materials absorbing radar pulses. As stated in [10], by using special materials, a decrease of up to 15 dB in radar cross section (RCS) can be obtained.

In non-coherent techniques, the jam signal does include radar center frequency but does not have any other correlations with the radar pulse. The jam signal is filtered in both fast time and slow time processing. Noise techniques are included in this group.

In semi coherent techniques jam signal is constructed by using target pulses recorded on Digital Radio Frequency Memory (DRFM) but the phase relation from pulse to pulse is not considered. Fast time match filtering does not decrease jam signal power but the power of the jam signal is decreased during slow time processing.

In coherent techniques, pulse to pulse phase relation is controlled such that the jam signal can pass both fast time and slow time operations with minimum loss. The most important gain in such techniques is that, a false target defined in both azimuth and range direction can be formed, resulting in a deception effect.

All SAR systems have a slow time processing which makes them highly resistive against noise jamming techniques. First, some calculations related to signal to noise ratio (SNR) in SAR receiver are provided. In these calculations, the noise source can be the thermal noise, jammer noise or sum of them.

Assume the azimuth resolution of the system is w_a. The required aperture length for this resolution can be calculated using (6). As shown in [9] two point scatters Δx separated from each other will have a Doppler difference given by (7). The maximum Doppler difference that can occur along the aperture length will correspond to $\Delta x = D_{SAR}$ and this will require a sampling rate of $1/\Delta F_D$. The aperture length is also limited by Θ_{az}*R. By using (1), (6) and (7) we obtain a minimum pulse repetition frequency (PRF) for a system given by (8). The number of pulse returns along aperture can be calculated using (9).

$$D_{\mathrm{SAR}} = \frac{\lambda R}{2w_a} \quad (6)$$

$$\Delta \mathrm{F_d} = \frac{2v\Delta x}{\lambda R} \quad (7)$$

$$PRF_{\min} = \frac{2v}{L_{az}} \quad (8)$$

$$n_c = \frac{D_{\mathrm{SAR}}PRF_{\min}}{v} = \frac{\lambda R}{w_a L_{az}} \quad (9)$$

$$\mathrm{PCF} = PW * BW \quad (10)$$

The SNR gain obtained by pulse compression on range axis can be calculated using the Pulse Compression Factor (PCF) given by (10) where PW is the pulse width and BW is the band width of the SAR pulse.

The SNR gain in slow time processing is equal to the number of pulses processed in slow time n_c. In order to avoid Doppler ambiguities, an over sampling factor K_a is used. This factor is known as "Azimuth oversampling Factor" and has an effect in SNR gain. By combining all factors, SNR gain in SAR receiver is calculated using (11).

$$\mathrm{GAIN_{SNR}} = \frac{PW * BW * R * \lambda * K_a}{w_a * L_{az}} \quad (11)$$

$GAIN_{SNR}$ only correspond to SNR gain in receiver. There are other factors effecting the amount of jamming noise power on the receiver system such as the attenuation due to distance between jammer and SAR, positioning of the jammer outside the main lobe of the SAR, mismatch between jammer and SAR frequency bands .

The immunity of SAR receiver against noise jamming is due to the fact that the noise samples sum up non-coherently in SAR receiver. An alternative technique to barrage, spot, pulsed noise techniques is the usage of the same prerecorded noise signal for each pulse. In this technique, a pre-calculated noise sequence is recorded to a memory and used repetitively. This will result in a filtering in fast time however due to pulse to pulse coherency, there will be lines in the resultant SAR image. The effectiveness of this technique will be shown in the simulations section.

In semi coherent techniques, recorded radar pulses are used to generate jamming signal, however the motion characteristics of the platform is not used for transmission timing or modulation of jammer signal. As a result, in semi coherent techniques phase coherency in slow time (azimuth) is not possible. Due to this fact, jamming signal power does not decrease during fast time match filtering but decreases during slow time operations.

Assume a technique similar to false target generation against conventional radar is used. A copy of the radar pulse is transmitted back after a fixed period of time. Since the timing of the jamming pulse is independent of radar position, there will be a scattering in the resultant SAR image. When the delay between pulse arrival to jammer and jam signal transmission is zero, there would be no scattering in resultant image and a single point scatterer in jammer location will appear in resultant image. When the delay between SAR pulse arrival and jam signal transmission is increased, the scattering in resultant SAR image will increase. In other words, if we want to create a single point scatterer with coordinates (R_{FT} ,X_{FT}), then the delay at different platform positions must be ΔT_{FT} .(12)

$$\Delta T_{FT} = \frac{2}{c}\sqrt{(u - x_{FT})^2 + (R_J + R_{FT})^2} \qquad (12)$$

Parameters u and Rj (Jammer distance in range direction) are unknown parameters for semi coherent techniques, so they cannot be used while calculating the timing of jammer pulse transmission. An interesting example to semi coherent techniques is described in [12] where a random phase modulation is combined with noise jamming. Another example to semi coherent techniques, named in this paper as random range false target technique, is transmission of a radar pulse copy at random range or ranges. For each PRI, the delay between pulse arrival and transmission varies in an interval [T_1 T_2]. By this technique, a region in radar image corresponding to delays [T_1 T_2] can be filled.

Coherent techniques, similar to semi coherent ones use radar pulse as a source for jamming signal generation. Different from the semi coherent case, the platform position is used for jam signal timing, so a coherency in slow time is also possible.

IV. SIMULATIONS

In this section, simulation results regarding effectiveness for different ECM techniques will be provided. The effect of Jamming to Signal ratio J/S is also simulated. The results validate the derivation provided in (11). In these simulations, the SAR system is assumed to be using the “2D Match Filtering and Frequency Interpolation” image formation method provided in [13]. The jammer is assumed to be protecting a region which is defined by a set of point scatterers shown in Figure 2. Each point scatterer is shown with a white dot and assumed to have the same RCS. The jammer location is the center of that region. Some of the SAR parameters chosen may differ from typical SAR systems. The reason for these selections is minimizing simulation run times. The SAR system parameters used in simulations are listed in Table-1. Using these parameters, the SNR gain or noise jamming attenuation in the receiver will be nearly 61 dB.

Figure 2. Set of Point Scatterers in target region

TABLE I. TABLE 1 SIMULATION SAR PARAMETERS

Center Frequency	1 GHz
Range	4 km
Aperture Length	1300 m
Number of Pulses processed	2470
Azimuth resolution	1.5m
Range resolution	1.25m
Bandwidth	100 MHz
Target Region Width (Azimuth)	200 m
Target Region Width (Range)	800 m

In Figures 3,4,5,6 2D and 3D plots of resultant SAR image magnitudes reconstructed under J/S ratios of 30 dB, 40 dB, 50 dB, 60 dB are provided. Up to the J/S ratio of 50 dB, point scatterers can clearly be selected. For the J/S of 60 dB, point scatterers are not distinguishable and lost in noise, which is an expected result since J/S improvement on receiver was calculated as 61 dB.

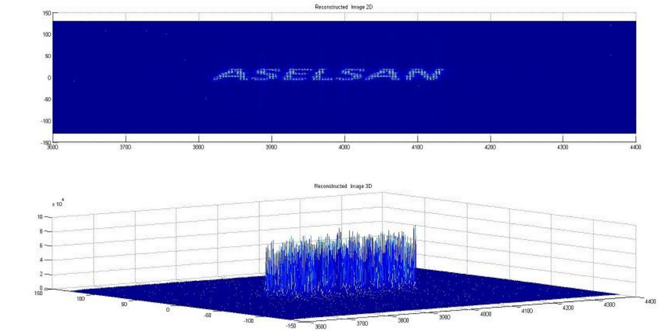

Figure 3. Barage Noise J/S :20 dB

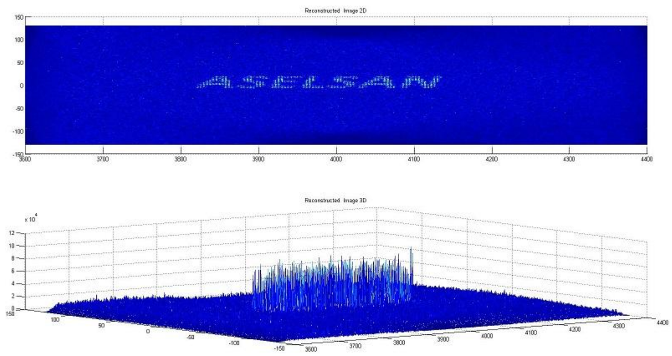

Figure 4. Barage Noise J/S :40 dB

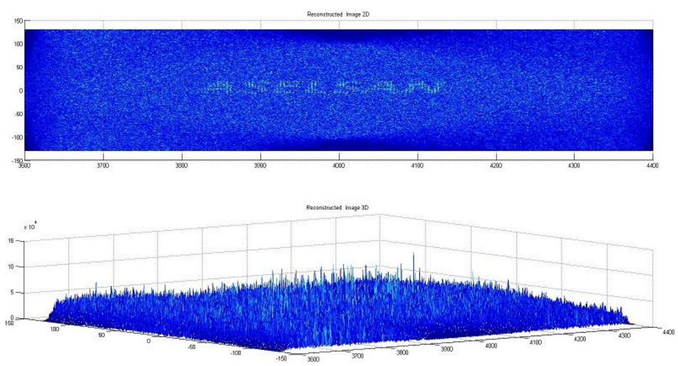

Figure 5. Barage Noise J/S :50 dB

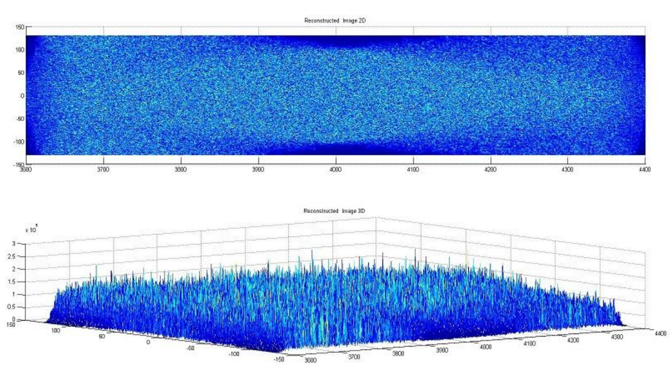

Figure 6. Barage Noise J/S :60 dB

As described in Section IV, a non-coherent noise jamming technique where a prerecorded noise sequence is repetitively transmitted in each PRI is also simulated. Such a technique would require tracking of SAR pulse timing and a sufficient memory for noise sequence recording. The expected result is a filtering in fast time and obtaining a coherency in slow time. The simulation results provided in Figures 7 and 8 show lines in the resultant SAR image which shows that a coherency in slow time is obtained. Figure 7 shows the resultant image for J/S ratio of 50 dB and Figure 8 shows the resultant image for J/S ratio of 60 dB.

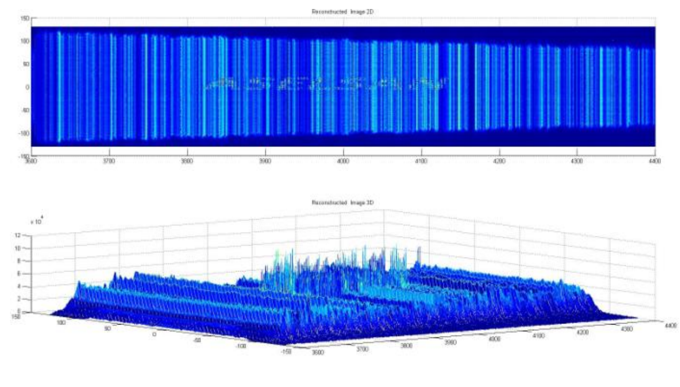

Figure 7. Repeater Noise J/S:50dB

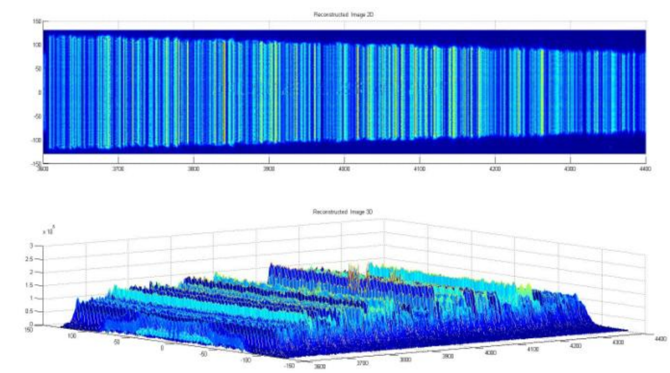

Figure 8. Repeater Noise J/S:60dB

As an example to semi coherent techniques, radar pulses are retransmitted with 16 different delays and the resultant SAR image is shown in Figure 9. As expected, a simple repeater with zero delay will result in a strong point scatterer in jammer coordinate. With an increase in pulse delay, the scattering in azimuth axis increases and the jamming effectiveness decreases due to blurring.

For simulating random delay pulse repetition technique, each radar pulse is delayed and retransmitted with 16 different delays in each PRI. The obtained results are shown for different J/S ratios. Figures 10, 11 and 12 show results for J/S ratios of 20 dB, 30 dB and 40 dB cases. 40 dB J/S case seem to be more effective on SAR system compared to barrage noise jamming case with the same J/S due to coherency in fast time.

 ISBN: 978-1-61208-453-4

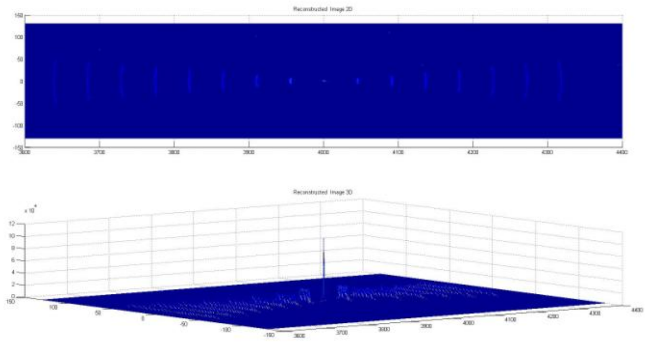

Figure 9. 16 Multiple False Target

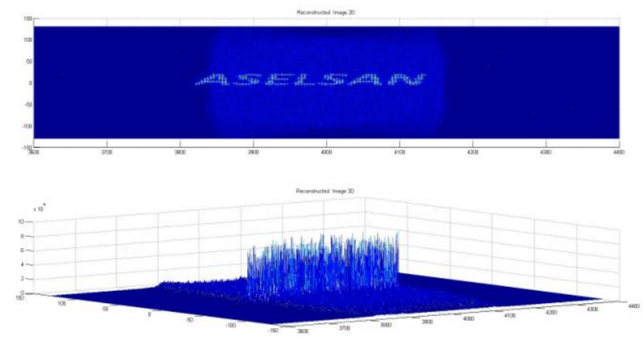

Figure 10. Random Range Multiple False Target J/S:20 dB

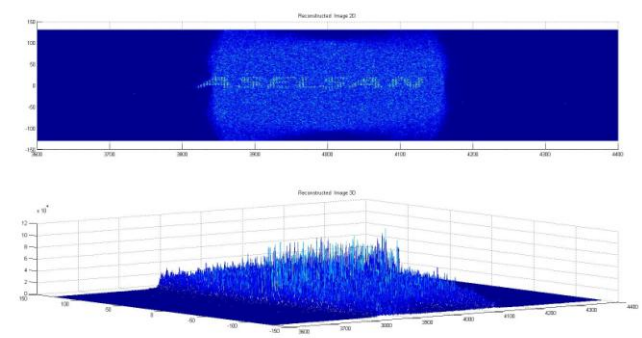

Figure 11. Random Range Multiple False Target J/S:30 dB

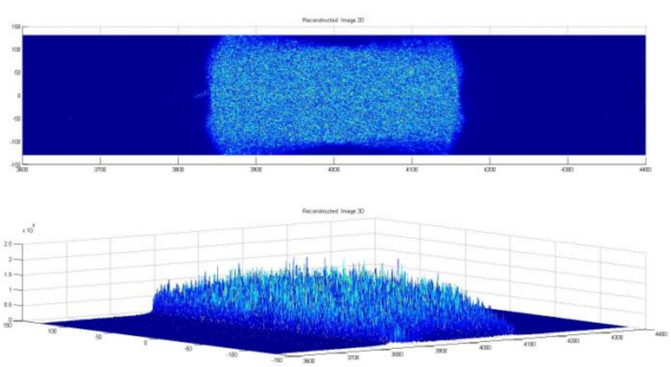

Figure 12. Random Range Multiple False Target J/S:40 dB

V. HARDWARE IMPLEMENTATION

In this section, a hardware structure for implementing SAR jammer will be proposed. The proposed HW structure is shown in Figure 13.

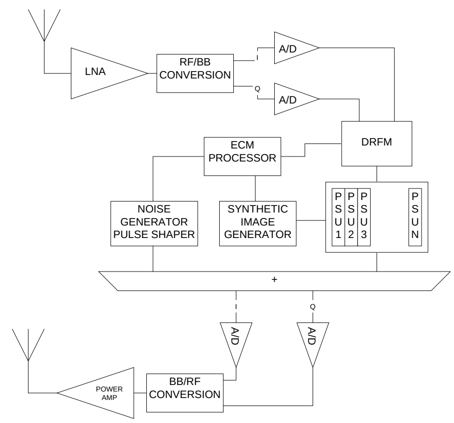

Figure 13. SAR Jammer HW Realization

The jamming techniques described above include generation of noise type and repeater type jamming techniques. Noise type jamming includes generation of pulsed or continuous wave type noise generation in radar band. Deceptive techniques aim to create false images. For this purpose assuming a baseband processing in jammer, the false objects are modeled using a point scatterer array as shown in (13) where p(t) is the radar pulse, g_i is the gain coefficient corresponding to RCS of the scatterer and fd is the frequency shift corresponding to the coordinate of the point scatterer in azimuth axis.

$$J_{PS} = \sum p(t - td_i) g_i e^{j2\pi fd_i t} \qquad (13)$$

The proposed HW structure realizes signal processing on a sampled baseband signal. First, the SAR pulse is recorded on DRFM and the main delay corresponding to the difference of delays between SAR to jammer and SAR to false image coordinates is realized on this memory. The false target is separated into point scatterers with different gain corresponding to their RCS, frequency shift corresponding to their azimuth positions and different delay lines corresponding to differences between point scatterer delays. The Point Scatterer Unit (PSU) array in Figure 13 realizes this using multiple PSU units. The outputs of the PSU are summed up and transmitted back to target. A synthetic image generator block continuously updates PSU parameters by using the coordinate estimation of the SAR platform. The number of PSU units is an important performance parameter for the effectiveness of the jammer. In order to have sufficient PSU units, the resource consumption of those units is an important consideration. If the frequency shift is implemented using complex I/Q (In

 ISBN: 978-1-61208-453-4

Phase and Quadrature Phase) data, a complex multiplication with 4 multipliers will be necessary. Similarly, the gain corresponding to RCS of the point scatterer would require 2 multipliers on and Q channels. Figure.14 proposes a structure for PSU realization, which does not have any multipliers.

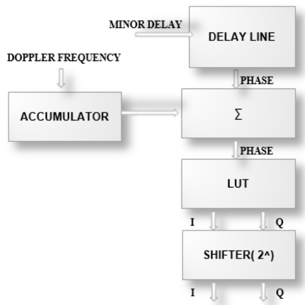

Figure 14. Point Scatterer Unit Realization

The sampled baseband signal is first converted into phase using COordinate Rotation DIgital Computer (CORDIC) algorithm or a low latency Look Up Table based algorithm described in [14] before the PSU array. Each PSU unit has its own minor delay line for compensating delay differences among modelled point scatterers. A frequency shifter, which is realized with an adder and accumulator, adds frequency modulation information coming from the synthetic image generator (SIG) block. The control of noise generator and SIG is done by an ECM processor. The signal in phase format is converted to Baseband I/Q signal using the look up table (LUT). The usage of LUT for phase to I/Q conversion is the main disadvantage in this structure. Assuming a 6 dB gain resolution would be sufficient, the RCS differences between point scatters are realized using shift registers which are controlled by SIG. Another advantage of this structure is the independence of the ECM signal from the SAR signal power due to I/Q to phase, phase to I/Q conversion where the amplitude information is completely lost. For realizing repetitive noise jamming technique, DRFM has a write port from ECM processor so that a pre-calculated noise pattern can be written to and repetitively read out of DRFM.

VI. CONCLUSION

In this study, effectiveness of non-coherent, semi coherent and coherent techniques against SAR radars are compared and some simulations results for those techniques are shown. The advantage of using semi-coherent techniques over non-coherent techniques are shown. A non-coherent technique based on repetitive transmission of pre-calculated noise signal is proposed and the effect obtained with this technique is shown using simulations. The effect of random delay repeater techniques is also simulated for different J/S cases and its area covering effect is shown. A possible HW realization of the SAR ECM generator system is proposed. A structure for false image generator which uses multiple point scatterers modelling is proposed. For realizing several PSU in the same HW, a simple structure for PSU without any multipliers is proposed and its advantages and disadvantages compared to straightforward implementation are stated.

REFERENCES

[1] K. Dumper, P.S. Cooper; A.F. Wons, C.J. Condley, and P. Tully, "Spaceborne synthetic aperture radar and noise jamming," Radar 97 Oct 1997 , pp.411-414 doi: 10.1049/cp:19971707

[2] R.S. Harness and M.C. Budge, "A study on SAR noise jamming and false target insertion" SOUTHEASTCON 2014, March 2014 pp.1-8 doi: 10.1109/SECON.2014.6950729

[3] X.He, J. Zhu, J.Wang, D. Du and B. Tang, "False Target Deceptive Jamming for Countering Missile-Borne SAR" IEEE 17th International Conference on Computational Science and Engineering (CSE), Dec 2014, pp.1974-1978, doi: 10.1109/CSE.2014.364

[4] Q. Sun, T. Shu, S. Zhou, B. Tang and W. Yu, "A novel jamming signal generation method for deceptive SAR jammer" IEEE Radar Conference, May 2014 , pp.1174-1178, doi: 10.1109/RADAR.2014.6875774

[5] M. Soumekh "SAR-ECCM using phase-perturbed LFM chirp signals and DRFM repeat jammer penalization" IEEE Transactions on Aerospace and Electronic Systems, Jan. 2006, pp.191-205, doi: 10.1109/TAES.2006.1603414

[6] Y. Chunrui, M. Xile, Z. Yongsheng, D. Zhen and L. Diannong, "Multichannel SAR ECCM based on Fast-time STAP and Pulse diversity" IEEE International Geoscience and Remote Sensing Symposium (IGARSS), July 2011, pp.921-924, doi: 10.1109/IGARSS.2011.6049282

[7] L. Wei, W. Xingliangand and W. Xian-ming, "Anti-jamming techniques for synthetic aperture radar" IEEE International Geoscience and Remote Sensing Symposium, July 2009, , pp.IV-605-IV-608, doi: 10.1109/IGARSS.2009.5417449

[8] W.W.Goj "Synthetic Aperture Radar and Electronic Warfare" UK Artech House 1993.

[9] M. A. Richards, "Fundamentals of Radar Signal Processing", USA: McGraw-Hill, 2005.

[10] L. Nan and Q. Changwen, "Research on jamming synthetic aperture radar technologies" Asian and Pacific Conference on Synthetic Aperture Radar, Nov. 2007, pp.563-566, doi: 10.1109/APSAR.2007.4418674

[11] Q. Liu, S. Xing, X. Wang, J. Dong, and D. Dai "A Strip-Map SAR Coherent Jammer Structure Utilizing Periodic Modulation Technology" Progress In Electromagnetics Research B, Vol.28, 111-128, 2011,doi:10.2528/PIERB10120901

[12] W.Ye, H. Ruan, S. Zhang and L. Yan, "Study of noise jamming based on convolution modulation to SAR" International Conference on Computer, Mechatronics, Control and Electronic Engineering (CMCE), Aug. 2010, pp.169-172, doi: 10.1109/CMCE.2010.5609875

[13] M.Soumekh "Synthetic Aperture Radar Signal Processing with MATLAB Algorithms." New York: J. Wiley, 1999.

[14] R. Gutierrez, V. Torres and J. Valls "FPGA-implementation of atan (Y/X) based on logarithmic transformation and LUT-based techniques",Journal of Systems Architecture 2010, pp 588–596

 ISBN: 978-1-61208-453-4