Spoofing Technique Based on Digital Radio Frequency Memory and Chaotic Algorithm

AMIR ALMSLMANY
Electrical Engineering
Faculty of Engineering, Alexandria University
Alexandria, EGYPT
mslmany@gmail.com

Abstract: - This paper proposes an airborne self-deception jammer (ASDJ) model based on chaotic algorithm and random sub-nyquist sampling (CA/RSN), this jammer generates false targets with finer resolution and different power using logistic map, these false targets retains the information of the airborne platform and their power level varies around the real platform echo power, the random sub-nyquist sampling greatly reduces the demand on sampling rate and processing speed, then a false scene at different ranges and power levels are created on the victim radar scope to provide an effective protection for the airborne platform from the ground radars and missile stations, the simulation was done on a model of Yake-42 plane to validate the effectiveness of the proposed jamming model.

Key-Words: - Deceptive; Chaotic; Jamming; Radar; Spoofing; Nyquist.

1 Introduction

The principle that says "the best way for defense is attacking" can be realized in communication systems, the great development in using air frames, such as (airborne radars, UAVs) for targets detection in both military and surveillance applications, attracts the researchers to support these air frames by robust means of immunity against the electronic counter measurements (ECM), and from being detected by the ground radars or attacked by surface to air missiles(SAM), the electronic counter-counter measurements (ECCM) introduces the ability of anti-jamming and clutter rejection using deferent techniques, such as space-time adaptive processing (STAP), from these points of view, this paper proposes an airborne self-deception jammer (ASDJ) model for countering the threats of the ground radars and missile stations against the airborne radar.

With the capability of high speed sampling and replication of the wideband radar signals, the DRFM is widely used in the active coherent jamming [8] – [12], and the scatter- wave jamming (SWJ) for countering SAR. Deception jammer generation is an application of the digital radio frequency memory (DRFM), it can analyze the parameters of the intercepted radar signals rapidly, and produce jamming signal rapidly and repeat it in current radar repetition interval to form high fidelity track jamming [7].

For the SWJ, first, the intercepted radar signals are sampled and stored by the jammer which is spatially separated with the radar. After that, the jamming signal formed by retransmitting all the samples to the moving target. Second, the jamming

signal is modulated and scattered by the target. The scattering wave (i.e. jamming signal) including the reflectivity function of the target arrives at the radar receiver and is finally collected by it.

All transmitted pulses are similarly sampled, retransmitted, scattered at different aspects caused by the relative motion of target and finally recorded by the radar receiver to form a two-dimensional (2D) matrix, which is the number of range cells against the number of pulses, in each pulse repetition interval (PRI). Finally a number of false targets will be generated on the radar display; the great advance in modern radar systems increases the capability of identifying the true targets.

There are some literatures works that proposes jamming model on fighter planes for protecting the target from being engaged from the enemy's missiles. The typical self-protection jammer is the ALQ-122 deceptive radar jammer, which was used on the B-52 and E-3 aircraft, coupled with AN/ALT-16 power amplifiers, to generate false targets, complements ALQ-155/ALT-28 noise jammers against CW radar, and chaff (electronic warfare) [24], but for the case of airborne radar, no references tried to support it by jamming source as a way for immunity, recently references [30, 29, 16] proposed a model for countering bistatic ground ISAR from a ground jammer source based on sub-nyquist sampling, that greatly reduced the demands

on sampling rate, processing time, but the probability of radar detection to detect the true target still high.

In this paper a new model for countering ground radars from airborne jammer source attached to airborne radar ASDJ was proposed, this model based on using random sub-nyquist sampling (RSN) interval, and chaotic algorithm (CA) to generate a number of false targets at random ranges and with different power, these power values is changing around the true target (airborne radar) echo power, this will increase the false targets influence on the ground radar, that will decrease the ground radar probability of detection for the true target.

The second section discuss the signal model and the model geometry, the third section demonstrates the random sub-nyquist sampling theorem, and chaotic algorithm, the section three shows the simulation results and validation, finally section five concludes the proposed model.

2 Model geometry and signal model

Jammer source is supposed to be placed on airborne radar, and the victim is ground monostatic radar. The airborne radar is embedded on the coordinates xoy, the origin point o is the center of the airborne radar, the radar motion is described by the circular motion and its rotational rate is defined as w, because the jammer source is on the airborne radar so the distance between the airborne radar and the ground monostatic radar R_R is equal to the distance between the jammer source and the radar and equals R_J, the airborne radar has N scatterer points and the position of each point is (x_i, y_i), and the angle between any scatterer point and x axis is θ_i (rad/s), the geometry of the airborne radar carrying deception jammer source and the monostatic radar is illustrated on Fig. 1.

Suppose that the monostatic radar transmit linear frequency modulated (LFM) signal with central frequency f_o, the pulse width is τ, and the chirp rate is Γ, the signal formulation is as follows [29],

$$S_t(t_f, t_s) = rect\left(\frac{t_f}{\tau}\right).\exp\left(j2\pi\left(f_o t + \frac{\Gamma}{2}{t_f}^2\right)\right), \quad (1)$$

where S_t is the monostatic radar transmitted signal, t_f is the fast time, t_s is the slow time, $t = (t_f + t_s)$ is the total time, and,

$$rect\left(\frac{t_f}{\tau}\right) = \begin{cases} 1 & if \ \left|\frac{t_f}{\tau}\right| < 0.5 \\ 0 & otherwise \end{cases} \quad (2)$$

The transmitted signal will be modulated and scattered by the airborne radar (the target of the monostatic radar), the scattered signals will then collected by the monostatic radar receiver, these signals will be stored in two dimensional matrix, we supposed that the airborne radar is moving with a circular motion its rotational rate is w, considering the scattering center of the airborne radar is at $i(x, y)$, so that the received signal by the monostatic radar receiver will be as follows,

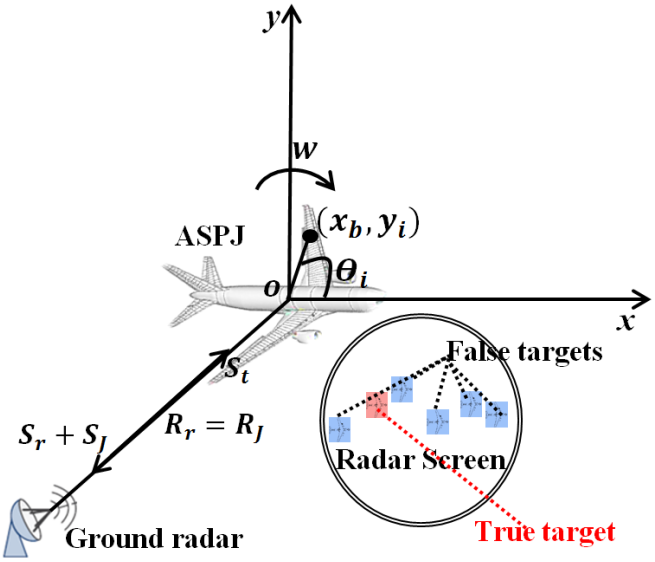


Fig. 1. The geometry of the ground monostatic radar, and the jammer source on board of airborne radar.

$$S_r(t_f, t_s) = \sum_{i=1}^{N} \sigma_i rect\left(\frac{t_f - \Delta t}{\tau}\right).\exp\left(j2\pi\left(f_o\left((t_f - \Delta t) + t_s\right) + \frac{\Gamma}{2}(t_f - \Delta t)^2\right)\right), \quad (3)$$

where S_r is the received signal from the target (airborne radar), σ_i is the scattering coefficient, and

$$\Delta t = \frac{2(R_r + \mathbf{x}sin\,\theta_i + \mathbf{y}cos\theta_i)}{\mathbf{v}}, \quad (4)$$

where $(\mathbf{x}sin\,\theta_i + \mathbf{y}cos\theta_i)$ is the vector from the origin point o to the scatterer point i, v is the speed of the EM waves.

3 Proposed model performance analysis

Fig. 2 displays the block diagram of the proposed ASDJ model, it shows the signal trajectory starting

from the ground radar that sends its transmitted signal $S_t(t)$ to the airborne target that receives the signal $S_r(t)$, and start the sampling process using the random sub-Nyquist sampling signal $X(t_f)$ that was generated using local oscillator, the sampled signal passes through DAC, the output of the DRFM process is the deceptive jamming signal S_{DJ} carrying the information of the real target, this signal will be amplified using power amplifier, this amplifier output will be multiplied by random number sequence that was generated using the chaotic algorithm (logistic map), and then the amplifier output will be transmitted again towards the radar.

3.1 Random sub-nyquist sampling

The nyquist sampling theorem provides a prescription for the nominal sampling interval required to avoid aliasing. The sampling frequency should be at least twice the highest frequency contained in the signal, so the mathematical form of this theory is [16]:

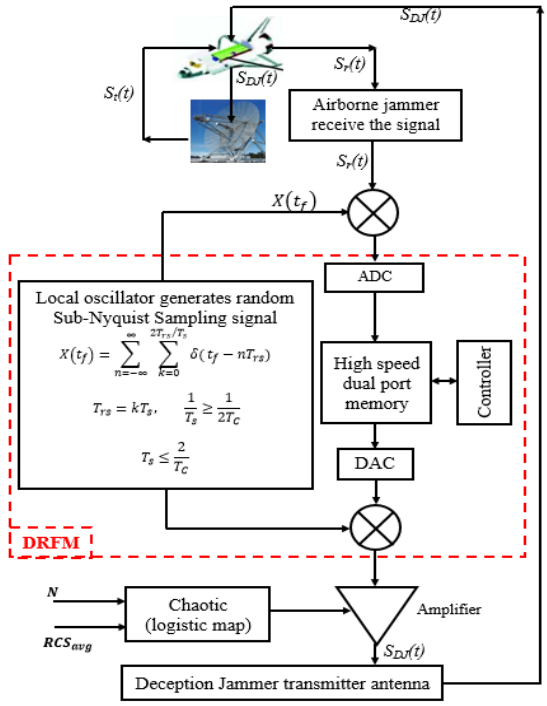


Fig. 2. The proposed model ASDJ block diagram.

$$f_s \geq 2f_c, \tag{5}$$

where f_s is the sampling frequency, and f_c is the maximum frequency in the signal that will be sampled. In practice, fast sampling of wideband RF signal and real time processing of vast data have rigorous requirement on hardware, sometimes indeed can't realize. In order to solve this problem, we use the random sub-nyquist sampling theorem, the sampling signal is composed of a set of impulse trains with period T_{rs} which is much larger than the nyquist sampling period T_N, while the monostatic radar sends the transmitted signal towards the target (airborne radar), the deception jammer receiver receives this signal and start sampling at the fast time, the random sub-nyquist sampling signal can be written as [30]:

$$X(t_f) = \sum_{n=-\infty}^{\infty} \delta(t_f - nT_{rs}), \tag{6}$$

where n is the number of samples, and its frequency spectrum [30] after applying Fourier series is:

$$X(f) = f_{rs} \sum_{n=-\infty}^{\infty} \exp(-j2\pi n f_{rs}), \tag{7}$$

where f_{rs} is the random sampling frequency. After sampling the received signal by the jammer using sub-nyquist sampling, the replica of the intercepted radar signals, $S_J(t_f, t_s)$ is obtained with a delay time to consequently generate a sequence of Chirp pulses. Each pulse has the same time frequency property as radar echoes, accordingly the same processing gain in signal process, it is consistent with the range profile mechanism of multi scattering center target [30]. And these pulses will be amplified by the power amplifier. So the jammer signal before amplifying can be represented as:

$$\begin{aligned} &S_{DJ}(t_f, t_s) \\ &= \sum_{i=1}^{N} \sigma_i rect\left(\frac{t_f - \Delta t_1}{\tau}\right).rect\left(\frac{t_s}{T_D}\right).X(t_f). \\ &\quad exp\left(j2\pi\left(f_o\left((t_f - \Delta t_1) + t_s\right)\right.\right. \\ &\quad \left.\left. + \frac{\Gamma}{2}(t_f - \Delta t_1)^2\right)\right), \end{aligned} \tag{8}$$

where T_D is a short duration time for observation,

$$\Delta t_1 = \frac{2(R_J + x sin\,\theta_i + y cos\theta_i)}{c}, \tag{9}$$

because $R_R = R_J$ so $\Delta t_1 = \Delta t$.

These jamming signals in addition to the true target signal will be received by the monostatic ground radar receiver, these data will be stored in 2D matrix, and then applying range compression

using matched filter to achieve high resolution range profile, the signal will be in the following form,

$$S_{DJ}(r,t_s)=\sum_{n=-\infty}^{\infty}\sigma_i f_s\tau.rect\left(\frac{t_s}{T_D}\right).\\ sinc\left(\frac{2B}{c}\left(r-\frac{\Delta t_1}{2c}-\frac{nf_sc}{2\Gamma}\right)\right).\\ \exp\left(-j2\pi\frac{f_o}{c}\frac{\Delta t_1}{c}\right), \quad (10)$$

where *r* is the range cell, and *B* is the bandwidth of the transmitted signal. The Doppler frequency for position $i(x,y)$ in the jamming signal is as follows [3],

$$f_D(i)=\frac{1}{2\pi}.\frac{d}{dt}\left(2\pi\frac{f_o}{c}\frac{\Delta t_1}{c}\right). \quad (11)$$

applying the Fast Fourier Transform (FFT) in the slow time domain, the false target signal at the range Doppler domain has been deduced as follow,

$$S_{JDr}(r,f)=\sum_{i=1}^{N}\sum_{n=-\infty}^{\infty}\sigma_i f_s\tau T_D.\\ sinc\left(\frac{2B}{c}\left(r-\frac{\Delta t_1}{2c}-\frac{nf_sc}{2\Gamma}\right)\right).\\ sinc\left(T_D\left(f-f_D(i)\right)\right), \quad (12)$$

where f is the Doppler frequency.

From (12), a set of false target signals are induced along the down range direction in the Range Doppler plane, each n represents a false target signal due to *i* scatterrer point of the target, and this signal will appear in many range cells, these false target signals is a replica of the real target signal and distributed in different range cells, so that for the monostatic radar it's hard to take the engagement decision with the real target [3].

3.2 Chaotic algorithm

Among the various nonlinear considered chaotic mappings, the most famous is the so-called logistic map, which is the most famous example of 1-D chaotic maps.

$$x_{l+1}=\mu x_l(1-x_l),\\ 0\le\mu\le 1 \text{ and } 0\le\mu\le 4 \quad (13)$$

where μ is the bifurcation parameter and x_l is the initial condition of the map. In this map, the next state x_{l+1} of the chaotic system is fully described only by the present state x_l. The logistic-map behaves mostly chaotic when $3.57\le\mu\le 4$ so by adopting and controlling the logistic-map initial conditions parameters (μ and x_l) we can take full advantages of the Logistic mapping to generate a chaotic pseudo random sequence that can be used as a chaotic pseudo random generator (CPRG). These resulting pseudo-random sequences are very irregular and unpredictable (the more unpredictable, the closer to random). We also note that any small change in the initial condition yields to a significantly different sequence of random numbers that for a very little shift in the bifurcation parameter it gives a totally different random sequence, the logistic random number generator is infinite, aperiodic and not correlated.

We should first generate a random vector from the logistic-map for a given data block length N and certain bifurcation (μ) and initial value x_0 parameter as.

$$x_{l+1}=\mu x_l(1-x_l),\\ l=0,1,2,\dots,N-1 \quad (14)$$

The next step is that we need to convert this random vector into a random numbers sequence as. [20]

$$R_l=Ax_l(mod\ \theta) \quad (15)$$

where $R_l\in Z^+$ and θ and A are selected constants. For example, if $A=10^7$, $x_0=0.3, \theta=256$ and $\mu=3.9$, then from (14) we have,

$$x_1=\mu x_0(1-x_0)=3.9*(1-0.3)=0.819$$

$$x_2=3.9*0.819(1-0.819)=0.5781321$$

$$\dots$$

$$R_1=Ax_1(mod\ \theta)=10^7*0.819(mod\ 256)=48$$

$$R_2=10^7*0.5781321(mod\ 256)=73$$

$$\dots \quad (16)$$

In our algorithm, we convert the logistic random vector to a random numbers by very simple criteria by sorting this random vector in ascending way then we take the actual position of this sequence.

This random number will be multiplied by the amplifier output to get the jamming signals with different amplitudes according to this random number generated from logistic map. The CPRG sequence randomness is shown in Fig. 3 which indicates that this interleaved sequence combines a good randomness characteristic in addition to its secured chaotic behavior.

3.3 False target signals generation conditions

The interval between two adjacent false target signals from the same scatterer point [15] is given by

$$\Delta r = \frac{cf_s}{2\Gamma}, \tag{17}$$

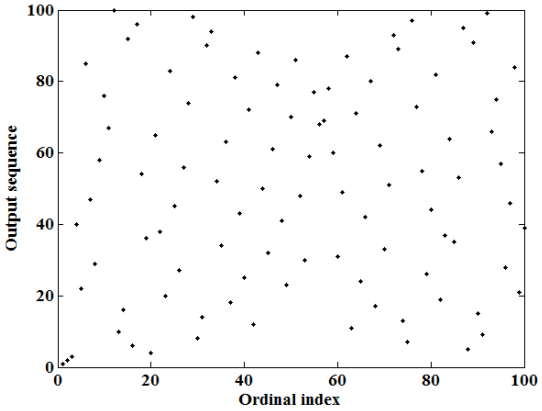


Fig. 3. CPRG Sequences Randomness for N = 100 bits, μ= 3.99, and x_n = 0.03.

From (17) we can see that Δr is proportional to the sampling frequency f_s when Γ is constant. In order to calculate the maximum number of false target signals that can be generated, the sampling frequency f_s should satisfy a good resolution between two adjacent false target signals, consider a target takes up d_r in the down-range direction in order to obtain a good resolution of the two adjacent false-target signals [15], Δr should satisfy that

$$\Delta r = \frac{cf_s}{2\Gamma} \geq d_r, \tag{18}$$

or,

$$T_s \leq \frac{C}{2\Gamma d_r} \tag{19}$$

Otherwise the false target signals will interact each other's, if the signal plane occupies d_{r-max} along the down-range direction, so that the maximum number of false targets [15] is given as

$$N_{max} = \left\lfloor \frac{2\Gamma T_s}{C} d_{r-max} \right\rfloor + 1, \tag{20}$$

where $\left\lfloor \frac{2\Gamma T_s}{C} d_{r-max} \right\rfloor > \frac{2\Gamma T_s}{C} d_{r-max}$

3.4 Probability of detection for the monostatic radar

For the ground monostatic radar, the detection probability can be obtained from the probability of detection theory as [16]

$$P_d = \int_T^{\infty} P(v)\, dv, \tag{25}$$

where $P(v)$ is the probability density of the power of IF target signal plus noise and T is the threshold level for the case of nonflactuating target model, with individual pulse detection, the $P(v)$ is

$$P(v) = \frac{1}{1+SNR} exp\left[\frac{-v}{1+SNR}\right], \tag{26}$$

so detection probability P_d of the real target is:

$$P_d = exp\left[\frac{-T}{1+SNR}\right] \tag{27}$$

In order to calculate the root mean square error RMSE for the results as a relation with SNR, it can be calculated from:

$$RMSE_{sub-nyquest} = \frac{\Delta r}{\sqrt{2(SNR)}} = \frac{c}{2B\sqrt{2(SNR_{sub-nyquest})}} \tag{28}$$

4 Simulation and Results

In order to validate the proposed ASDJ model we suppose that the Yake-42 plane is the airborne model that carries the ASDJ, we will simulate the detection of this model from the ground monostatic radar using regular detection but under the deception jamming effect, it has 330 scatterer points, it occupies 35m down range and 30m cross range, the radar operating frequency is 10GHz, the transmitted signal is LFM signal with 100μs, the bandwidth is 1GHz, number of transmitted pulses are 512pulse, the monostatic radar receiver contains 1024 down range cells, 512 cross range cells, PRF1kHz, the range resolution 0.15m, the transmitted radar power 1kW, the jammer transmitted power 360W, maximum range 600km, the radar antenna gain is 30dB, and the jammer antenna gain is 30dB.

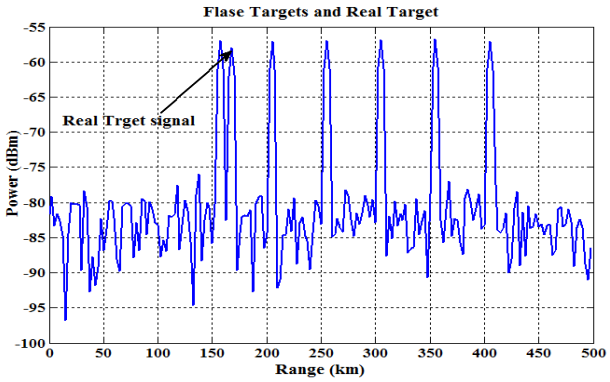
We supposed that the ground monostatic radar transmits LFM signal towards the airborne jammer,

the airborne jammer receiver receive this signal and start sampling it at the Sub-Nyquist rate 4MHz, then modulate these samples and convert to continuous signal again, the constructed jamming signal are transmitted toward the ground radar, this jamming signal are shifted in time with the radar received signal, this shift in time will be translated in range shift, by decreasing the sampling frequency, at constant chirp rate Γ, and constant d_{r-max}, Fig. 4(a) shows that under sampling frequency 2MHz we can get 6 false targets, Fig. 4(b) we use sampling frequency 4MHz to generate 5 false targets, the real target range in Fig. 4. is 170km, we can see that in all cases the real target power is lower than the false targets power to satisfy a valuable deception jammer, and to validate the power requirement condition in (24), all these results was done without using chaotic algorithm and with a fixed sub-nyquist rate, Fig. 5 shows the echo signal received by the ground radar after applying the chaotic algorithm and using random sub-nyquist sampling, from this figure we find that the probability of miss was increased so that the ground radar cannot detect the real target from the received signal.

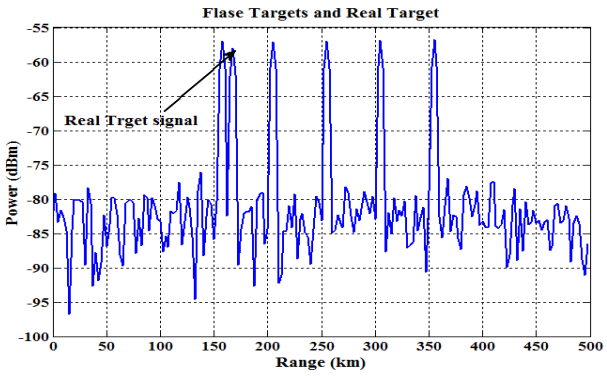
In our simulation T_S was chosen to give a good resolution between false targets so we take $T_S \geq 0.43\mu s$ according to (19), to make sure for this condition we can see that for maximum false targets number (6 targets), the $T_S = 0.5\mu s$, $\geq 0.43\mu s$, so we got a high resolution between false targets with maximum number of false targets.

The received echoes from the real target (the desired signal) and the noise will also be received by the monostatic radar. To validate the performance of the jamming, we add the desired signal and the Gaussian distributed complex noise into the jamming signal (the unwanted signal). Suppose that the desired signal and the unwanted one combined with the Gaussian noise are processed by monostatic radar signal processor simultaneously.

The simulation results at three different cases (regular sampling, Nyquist sampling, and Sub-Nyquist sampling) at SNR= 5 are shown in Fig. 6, from this figure we can find that the probability of error (1-probability of detection) in case of Sub-Nyquist case is 0.9, in case of Nyquist sampling is 0.75, and in case of regular sampling is 0.23, so that the monostatic radar has a highest probability of error in case of the proposed model (lowest probability of detection).



(a) [17]



(b) [17]

Fig. 4. The received signal (Real target + false targets), at different sampling frequency. (a) $f_S = 2$MHz. (b) $f_S = 4$MHz.

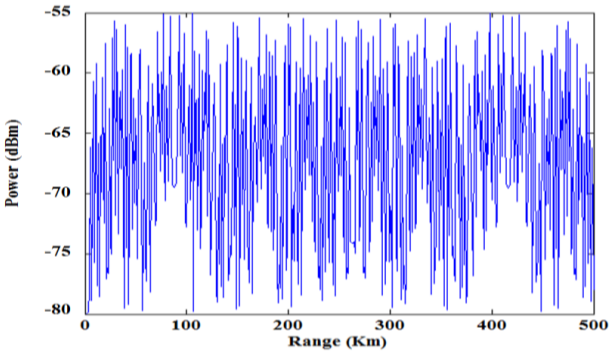


Fig. 5. CPRG output sequence using Logistic-map with different bifurcations, N = 100 bits and $x_n = 0.3$.

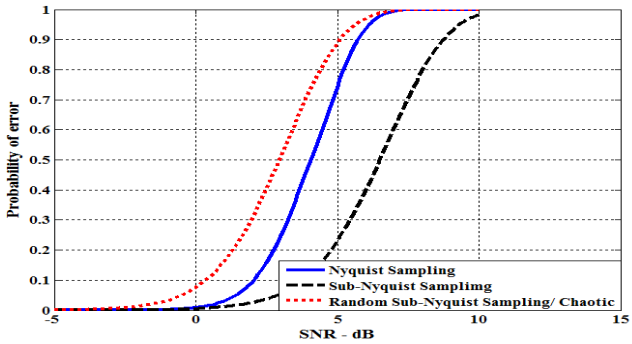


Fig. 6. The probability of error of the ground monostatic radar in different cases.

Proportional with the SNR, Fig. 7. Shows that the RMSE for the Sub-Nyquist rate is the least RMSE compared with the RMSE in case of regular sampling and Nyquist sampling.

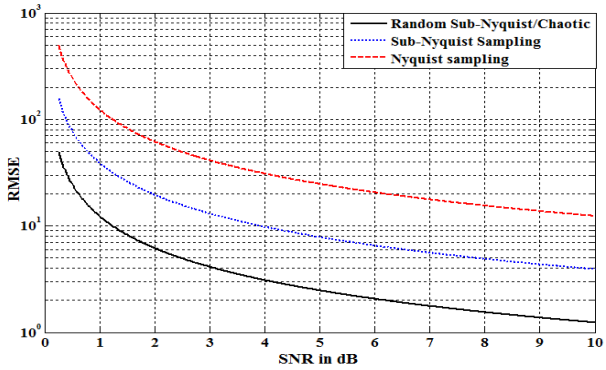


Fig. 7. The RMSE as a relation of SNR at different cases.

5 Conclusion

The main contribution for this paper is to propose an ASDJ, by using DRFM based on Random Sub-Nyquist sampling theory and chaotic algorithm, the simulation results showed that the number of false targets increased by decreasing the sampling frequency, in the same time the resolution between the false targets was calculated and adjusted to the optimum value in order to be not detected by the monostatic radar, using the Chaotic algorithm provided more effectiveness to the false targets signals by generating different amplitudes, and also the random sub-nyquist sampling make the interval between false targets different that increases the probability of error for the ground monostatic radar, finally the RMSE for the proposed model is the lowest compared with other classical methods.

References:

[1] Chen, V.C., Miceli, W.J. Simulation of ISAR imaging of moving targets, *IEE Proc. Radar, Sonar, Navig.*, vol. 148, no. 3, pp. 160–166, 2001.

[2] Berger, S.D., Digital radio frequency memory linear range gate stealer spectrum, *IEEE Transa. Aerosp. Electron. Syst.*, vol. 39, no. 2, pp. 725–735, 2003.

[3] Liu, Q.F., Xing, S.Q., Wang, X.S., Dong, J., Dai, D.H., The interferometry phase of In SAR coherent jamming with arbitrary waveform modulation, *Prog. Electromagn. Res.*, vol. 24, pp. 101–118, 2012.

[4] Liu, Q.F., Xing, S.Q., Wang, X.S., Dong, J., The 'slope' effect of coherent transponder in In SAR DEM, *Prog. Electromagn. Res.*, vol. 126, pp. 125–133, 2012.

[5] Hu, D.H., Wu, Y.R., The scatter-wave jamming to SAR, *Acta Electron. Sin.*, vol. 30, no. 12, pp. 1882–1884, 2002.

[6] Pan, X., Wang, W., Feng, D., Huang, J., Fu, Q., Wang, G., Rotational micro-motion modulated jamming for countering ISAR based on intermittent sampling repeater, *Prog. Electromagn. Res.(C)*, vol. 36, pp. 41–56, 2013.

[7] L. Zhang, M. Xing, C. Qiu, J. Li, and Z. Bao, Achieving higher resolution ISAR imaging with limited pulses via compressed sampling, *IEEE Geosci. Remote Sens. Lett.*, vol. 6, no. 3, pp. 567–571, Jul. 2009.

[8] D. Donoho, Compressed sensing, *IEEE Trans. Inf. Theory*, vol. 52, no. 4, pp. 1289–1306, Apr. 2006.

[9] Xu Shaokun, Liu Jihong, Fu Yaowen, Li Xiang, Deception Jamming Method for ISAR Based on Sub-Nyquist Sampling Technology, *Signal Processing (ICSP), 2010 IEEE 10th International Conference*, oct. 2010, pp. 2023 – 2026.

[10] Candès, E.J., Wakin, M.B., An introduction to compressive sampling, *IEEE Signal Process. Mag.*, vol. 25, no. 2, pp. 21–30, 2008.

[11] M. Barbary, Peng Zong, A Novel Stealthy Target Detection Based on Stratospheric Balloon-borne Positional Instability due to Random Wind, *Radio Engineering*, vol. 23, no. 4, pp. 1192-1202, Dec. 2014.

[12] Murino, V., Trucco, A., Regazzoni, C.S., Synthesis of unequally spaced arrays by simulated annealing, *IEEE Trans. Signal Process.*, vol. 44, no. 1, pp. 119–122, 1996.

[13] Xiaoyi Pan, Wei Wang, Dejun Feng, Yongcai Liu, Qixiang Fu, Guoyu Wang, on deception jamming for countering bistatic ISAR base on Sub-Nyquist sampling, *Radar, Sonar & Navigation, IET*, vol. 8, no. 3, pp. 173-179, 2014.

[14] Mohd. Ahmed, Parameterized DRFM Modulator for ECM Systems, *International Journal of Advanced Electronics & Communication Systems*, vol. 1, no. 1, pp. A56, feb. 2012.

[15] Xiufeng, S., Peter W., Shengli, Z. Jammer detection and estimation with MIMO radar, *Signals Systems and Computers (ASILOMAR) Conference*, 2012, pp. 1312 – 1316.

[16] Amir Almslmany, Qunsheng Cao, Caiyun Wang, Anew airborne self-protection jammer for countering ground radars based on sub-nyquist, *IEICE electronics express*, Vol.12, No.10, pp. 1-11, 2015.

[17] A Almslmany, C Wang, Q Cao, Advanced deceptive jamming model based on DRFM Sub-Nyquist sampling, *Applied Sciences and Technology (IBCAST), 2016 13th International Bhurban*, pp. 727-730, 2016.