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The Intermittent Sampling Motion Scatter Wave Jamming against Waveform Agile SAR/GMTI

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Abstract

A new method jamming against Waveform Agile SAR/GMTI (Ground Moving Target Indication) is proposed, which is called the intermittent sampling motion scatter wave jamming. This jamming can form multi-false vivid targets scene taking the real moving targets' all scattering information. The intermittent sampling repeater can also repeat in the waveform agile SAR current pulses. As a clever jamming mode, this jamming may realize electronic counter measure (ECM) against waveform agile SAR. Detailed discussions about the jamming performance are given. The processing output of the jamming is derived theoretically. The superiority of this jamming is analyzed in theory. The theoretical feasibility and validity are proved by simulation experiments.

Keywords

SAR, Intermittent Sampling, Waveform Agile, Electronic Counter Measure (ECM), Scatter Wave Jamming

1. Introduction

Synthetic aperture radar (SAR) is an all weather imaging radar, and SAR Ground Moving Target Indication (GMTI) capability is an important means for strategic reconnaissance and battlefield surveillance systems, which makes it a sever threat to important military targets. Therefore the jamming technology for countering SAR/GMTI has become an important issue in Electronic Counter Measure (ECM) area. Now the active decoy jamming based on DRFM(Digital Radio Frequency Memory) could achieve high processing gain from coherent signals processing in [1]-[6]. But this traditional direct-path repeater decoy jamming against SAR based on re-

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peating the former time SAR pulse is difficult to adapt quickly large pulse width waveform agile SAR in [3]. The frequency-jump burst (FJB) waveform is discussed for SAR-GMTI in [7]. And the new method jamming against Waveform Agile SAR/GMTI is necessary for protecting these important military targets.

So a new jamming based motion jammer and the intermittent sampling scatter wave (ISMSC) jamming against waveform agile SAR/GMTI is proposed, called the intermittent sampling Motion scatter wave jamming. The Motion jammer can repeat waveform agile SAR subsection signal in the currently pulse with little delay by the intermittent sampling repeating. It might takes advantage of the intermittent sampling scatter wave jamming against waveform agile SAR GMTI. Firstly, the model of intermittent sampling motion scatter wave jamming is established for waveform agile SAR\GMTI. Secondly, the jamming is imaged in the theory, and characteristics of the jamming imaging are analyzed in the waveform agile SAR\GMTI. In the end, the simulation experiments are shown that the different typical jamming scenarios are imaged. The theory and imaging characteristics of the second part are verified by simulation experiments.

2. The Model of Intermittent Sampling Motion Scatter Wave Jamming

The principles of intermittent sampling Motion scatter wave jamming are shown as follows: the waveform agile SAR signal is being high-fidelity intermittent sampled and is modulated by motion jammer projecting to the selected area as soon as probably. Then the next section signal is intermittent sampled, Motion modulated and projected to the selected area. The jamming is received as the current pulse target echo being received. The different pulses will work as this pulse. Then the intermittent sampling motion scatter wave jamming is formed.

As we known, waveform agile SAR system also utilizes the two-dimension LFM (Linear Frequency Modulation) pulse signal. LFM signal with unit amplitude can be written as:

$$s(t) \equiv s(\hat{t}, t_m) = \mathrm{rect}\left((t - t_m)/T_p(m)\right) \cdot \exp\left[\mathrm{j}2\pi\left(f_0 t + (\mu_r + \gamma_m)\hat{t}^2/2\right)\right] \tag{1}$$

where $\mu_r + \gamma_m$ is the mth pulse chirp rate, μ_r is the chirp rate median, γ_m is the mth pulse chirp rate agility modulation, and f_0 is carrier frequency, $\hat{t}$ is the fast time (in range), and t_m is the slow time(in azimuth). ($m = 0, \pm 1, \pm 2, \pm 3, \ldots$)

2.1. Intermittent Sampling

The intermittent sampling function can be written as in [6]:

$$p(t) = \mathrm{rect}\left(\frac{\hat{t}}{T_w}\right) \otimes \sum_{n=-\infty}^{+\infty} \delta\left(\hat{t} - nT_s\right) \tag{2}$$

Where T_s is the period of sample, T_w is the sample pulse width, "$\otimes$" denotes convolution, $\delta(\cdot)$ is Dirac function.

Then SAR signal intermittent sampling $s_1(\hat{t}, t_m)$ can be written as:

$$s_1(\hat{t}, t_m) = s(\hat{t}, t_m) \cdot p(\hat{t}) \tag{3}$$

The jammer delay in repeater can be controlled by the jammer in a short interval after receiving the SAR signal. This jamming can also be repeated directly after sampling and modulated, or repeated several times called duplication repeater.

Considered efficient of jamming power, usually, the jammer is working in sample storage, or in repeating jamming. If sampling period is determined, the style of intermittent sampling may be identified.

2.2. Motion Modulation

Signal sampling interval to the original signal transmitted delay time τ_r is usually a constant, so direct repeating jamming delay time is $\tau_r = \tau_s + T_w$, corresponding the qth repeating delay time in duplication repeating is $\tau_r(q)\ q = 1, 2, \cdots, Q$.

The jamming layout is shown as **Figure 1**, v is the SAR platform speed. Because of the fact that the transmitting and receiving elements are within a small physical area, the multi-static data may be viewed as monostatic SAR data as the coordinates of the platform are varied in slow time phase centers [6].

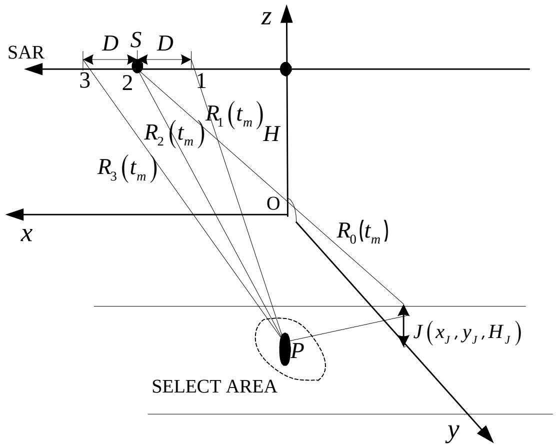


Figure 1. The jamming layout.

Three-channel SAR is studied in this paper, the transmit channel is the 2th channel. SAR l th channel antenna coordinate along the track is $(vt+(l-2)D,0,H_0)$. The Motion jammer J is in Y axis, which coordinate is $(v_{xj}t, y_j+v_{yj}t, H_j)$. In the selected regions, a scatter unit point P coordinates is $(x+v_{xp}t, y+v_{yp}t, z)$. Then the distance of point P jamming signal from the SAR transmitter to the l th channel antenna receiver is:

$$R_l(t_m) = R_{SJ}(t_m) + R_{JP}(t_m) + R_{Pl}(t_m) \qquad l=1,2,3 \tag{4}$$

where R_J is the close distance from the jammer J to SAR phase center S, R_0 is the close distance from the point P to SAR phase center S. When $|R_J - R_0| \ll R_J$, $R \equiv (R_0 + R_J + R_{JP})/2$, $R \approx R_J \approx R_0$. c is light speed.

So we can get Doppler f_J of moving jamming from P and Doppler chirp μ_J is:

$$\begin{aligned} f_J &\approx \frac{(x_P - x_j)(v_{Px} - v_{jx}) + (y_P - y_j)(v_{Py} - v_{jy})}{R_{jp}\lambda} + \frac{v_{Py}y_P + v_{jy}y_j + x_P v_{Px}}{R\lambda} \\ |f_J| &< \frac{|v_{Px} - v_{jx}| + |v_{Py} - v_{jy}| + |v_{Py} + v_{jy}|}{\lambda} \\ \mu_J &= \frac{\left((v_{Px} - v_{jx})^2 + (v_{Py} - v_{jy})^2\right)}{R_{jp}\lambda} + \frac{(v - v_{Px})^2 + v_{Py}{}^2}{R\lambda} + \frac{\left((v - v_{jx})\right)^2 + v_{jy}{}^2}{R\lambda} \end{aligned} \tag{5}$$

T_L is synthetic aperture time.

When the jammer is moving as $v_{xj} = r_j \cos(2\pi f_m t), v_{yj} = r_j \sin(2\pi f_m t)$, as the scatter point P $v_{xp} = 0$, $v_{yp} = 0$ the jamming can be seen as Motion, and Doppler f_J of moving jamming from P is simplified as:

$$\begin{aligned} f_J &\approx \frac{r_j}{\lambda}\left(\frac{\sin(2\pi f_m t) y_P + x_P \cos(2\pi f_m t)}{R} - \frac{(x_P - x_j)\cos(2\pi f_m t) + (y_P - y_j)\sin(2\pi f_m t)}{R_{jp}}\right) \\ &= \frac{r_j}{\lambda}\sin(2\pi f_m t + \theta_P) \\ \tan\theta_P &= \frac{R_{jp}x_P + R(x_j - x_P)}{R_{jp}y_P + R(y_j - y_P)} \approx \frac{R(x_j - x_P)}{R_{jp}y_P + R(y_j - y_P)} \end{aligned} \tag{6}$$

The jammer delay in repeater can be controlled by the jammer in a short interval after receiving the SAR signal. The jamming can be repeated directly after sampling and being modulated once, or repeated several times called duplication repeater. Signal sampling interval relative to the original signal transmitted by the delay time τ_r is usually a constant, direct repeating delay time is $\tau_r(1)$, corresponding the qth repeating delay time in duplication repeating is $\tau_r(q) \quad q = 1,2\cdots Q$.

2.3 The Model of Intermittent Sampling Motion Scatter Wave Jamming Signal

Then the time correspond to point P jamming repeated directly signal from the SAR transmitter to the receiver is: $\tau_{sl}(t_m) = \tau_r(1) + R_l(t_m)/c$, this signal of jamming received by the l th channel antenna can be written as:

$$s_{jl}(\hat{t}, t_{ml}) = A_l(\hat{t}, t_{ml}) s_1(\hat{t} - \tau_{sl}(t_m), t_{ml}) = A s_1(\hat{t} - \tau_{sl}(t_m), (t_m + (l-2)D/2v)) \tag{7}$$

where $A_l(\hat{t}, t_m)$ is jamming signal amplitude of the l th channel receive corresponding the point P at this time. Neglect the point P scattering diversity, as $A_l(\hat{t}, t_m)$ can be simplified as A which is determined by the point P and SAR gain, and $(l-2)D/2v$ is the data channel deviation relative to center channel in the slow time, which is primarily due to the relative physical distance of the l th channel to the center channel in the azimuth [6].

SAR is receiving the whole jamming of each scatter point in the selected region surface, which form the whole intermittent sampling Motion scatter wave jamming. So the whole corresponding jamming signal can be written as

$$s_{Jl}(\hat{t}, t_m) = \sum_q \oiint A(q; x, y, z) s_1(t'', t_{ml}) dP \tag{8}$$

where $t'' = \hat{t} + \tau_s(1) - \tau_s(q) - \tau_s(x, y, z, t_m)$ is the q th repeater jamming fast time, dP is scatter point integral unit, $A(q; x, y, z)$ is jamming signal amplitude of the point P received by the SAR at qth time.

3. Jamming Image

The jamming received by SAR is indeed subject to the same signal processing steps of the real target echo, and what may be influenced on the SAR imaging is interpreted as the output of the 2-D LFM the jamming match filtering. So jamming pulse compression is given in the following part.

Firstly, repeating directly jamming of point P is matched filtering of fast time in the waveform agility SAR for channel 2, this output is:

$$\begin{aligned} y_l(\hat{t}, t_m) &= s_{jl}(\hat{t}, t_m) \otimes \mathrm{p}_m(-t) \\ &\approx T_s / T_w A \exp\left[-\mathrm{j}2\pi(f_0 + f_J)\tau_{sl}(t_m)\right] \mathrm{rect}\left(\tau'/2T_p(m)\right)\left(T_p(m) - |\tau'|\right) \\ &\quad \bullet \sum_{n=-\infty}^{+\infty} \mathrm{sinc}(nT_s / T_w) \mathrm{sinc}\left[\left((\hat{t} - \tau')\right)\left(\mu_r T_p - (\mu_r + \gamma_m)|\hat{t} - \tau'|\right)\right] \\ &\equiv \sum_n G_R(n) \exp\left[-\mathrm{j}2\pi(f_0 + f_J)\tau_{sl}(t_m)\right] \end{aligned} \tag{9}$$

where $\tau' = \tau_s(t_m) + (n/T - f_J)/(\mu_r + \gamma_m) \approx \tau_s(t_m) + n/(T_s(\mu_r + \gamma_m))$ is the corresponding fast time after being matched filtering. ($n = 0, \pm 1, \pm 2, \pm 3, \ldots$) It is shown that the jamming matched filtering in fast time generates to the envelope convolution for the trigonometric functions as the target echo. And the intermittent sampling motion scatter wave jamming image focuses very well in fast time.

Next jamming in waveform agility SAR is matched filtering in azimuth (slow time), the azimuth match filtering function is $h_a(t_m) = \mathrm{rect}(t_m/T_L) \cdot \mathrm{e}^{-j\pi\mu_a t_m^2}$, so the output can be written as:

$$\begin{aligned} y_{2l}(\hat{t}, t_m) &= y_{1l}(\hat{t}, t_m) \otimes h_a(t_m) \\ &\propto \sum_n G_R(n) \exp\left[-\mathrm{j}2\pi(f_0 + f_J)\left(\left(\frac{(vt_m)^2}{2R_J} + \frac{(vt_m - x)^2}{2R_P}\right)/c - \mathrm{j}\pi f_J(2-l)D/v\right)\right] \\ &\quad \otimes \mathrm{rect}(t_m/T_L) \cdot \exp\left(j2\pi f_0 (vt_m)^2/(R_J c)\right) \end{aligned} \tag{10}$$

If the azimuth mismatch can be ignored, the jamming is similar to a decoy jamming. Transforming from frequency domain to time domain, $y_{11}(\hat{t}, t_m)$ can be written as:

$$y_{2l} \propto \sum_n G_R(n)(T_L - |t'_m|) \mathrm{rect}(t'_m/2T_L) \mathrm{sinc}\left[\mu_\alpha(t_m - t'_m)(T_L - |t_m - t'_m|)\right] \exp\left[-\mathrm{j}\pi f_J(2-l)D/v\right] \tag{11}$$

where T_L is synthetic aperture time, $t'_{ml} \approx R_P x / [(R_P + R_J)v] - f_J v / \mu_a$ is the corresponding peak in the slow time which shows the jamming imaging amplitude peak point in azimuth, and it closes to in the middle of the selection scatter point and jammer location.

Of course, when the whole jamming of the selected region surface can be seen false moving targets, the output imaging being focused of the jamming can be written as:

$$y_{Ql} \propto \sum_q \oiint T_w / T_p(m) A(q;x,y,z) \operatorname{sinc}\left[\mu_\alpha \left(t_m - t'_m\right)\left(T_L - \left|t_m - t'_m\right|\right)\right] \\ \sum_{n=-\infty}^{+\infty} \operatorname{sinc}\left(nT_w / T_p(m)\right) \operatorname{sinc}\left[\left((\mu_r + \gamma_m)\left(\hat{t} - \tau'\right)\right)\left(T_p(m) - \left|\hat{t} - \tau'\right|\right)\right] \mathrm{dP} \tag{12}$$

So the intermittent sampling motion scatter wave jamming can be described as follows: When the delay τ_s is constant, $\left|R_J - R_p\right| + \tau_s c / 2 \ll R_J$, $f_d(m) T_L^{\,2} / f_0 \le 1$, the jamming imaging can be seen vivid targets, the jamming being matched filtering can be focused, and the whole jamming might be focused to form false area vivid targets.

When the jamming imaging can be seen as false targets, the performing for GMTI can be written as:

$$\mathbf{I}_{12} = y_{12} - y_{22}$$
$$\mathbf{I}_{23} = y_{22} - y_{32}$$
$$\mathbf{I}_{mov} = \mathbf{I}_{23} * \mathbf{I}'_{23} \approx \left|y_{22}\right|^2 \left|\exp\left(\mathrm{j}\varphi_J\right) - 1\right|^2$$

where the moving phase for false target is $\varphi_J = -\pi f_J (2 - l) D / v$ that is modulated by the jammer.

4. The Simulation Experiment

The jamming power is constant, and type jamming is compared against waveform agile SAR and GMTI. SAR carrier frequency is 1 GHz, bandwidth is 100 MHz, modulation frequency agility is random, and chirp rate modulation agility $\max\left|\gamma_m / \mu_r\right|$ is 0.3; azimuth beam angle is 3.6 degrees.

The stationary jammer1 coordinate is $(0, 7960, 30)$, or moving jammer 2 coordinate is $(3t, 7960 + 0.2t, 30)$. In the selected regions, select area stationary target 1 coordinate at $(0, 7990, 0)$, moving scatter target 2 coordinate is $(-10, 8012.5 + 0.3t, 0)$ and moving scatter target 3 coordinate is $(10, 8012.5 - 0.5t, 0)$, The selected area without any motion and the jammer 2 location is shown as **Figure 2**.

SAR transmit power is 4.5 KW, antenna gain is 35 dB. The jammer power is 10 W. And jammer antenna gain is 12dB, and jammer pulse interval error mismatch is 5dB. And intermittent sampling repeating period is T_s = 0.10 μs.

For the stationary jammer 1, and jamming SAR imaging and GMTI is simulated, and the images are shown as **Figure 3(a)**, **Figure 3(b)**. These jamming can be focused and form false moving targets as the real moving targets. The residual energy image and GMTI can be seen as theoretical analysis.

For the moving jammer 2, and jamming SAR imaging and GMTI is simulated, and the images are shown as **Figure 4(a)**, **Figure 4(b)**. These jamming also can be focused and form false moving targets as the real moving

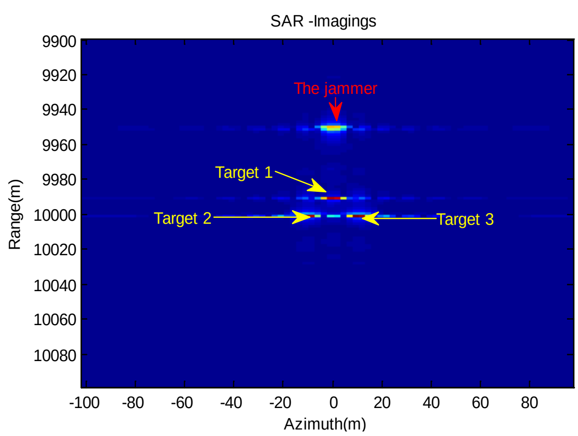
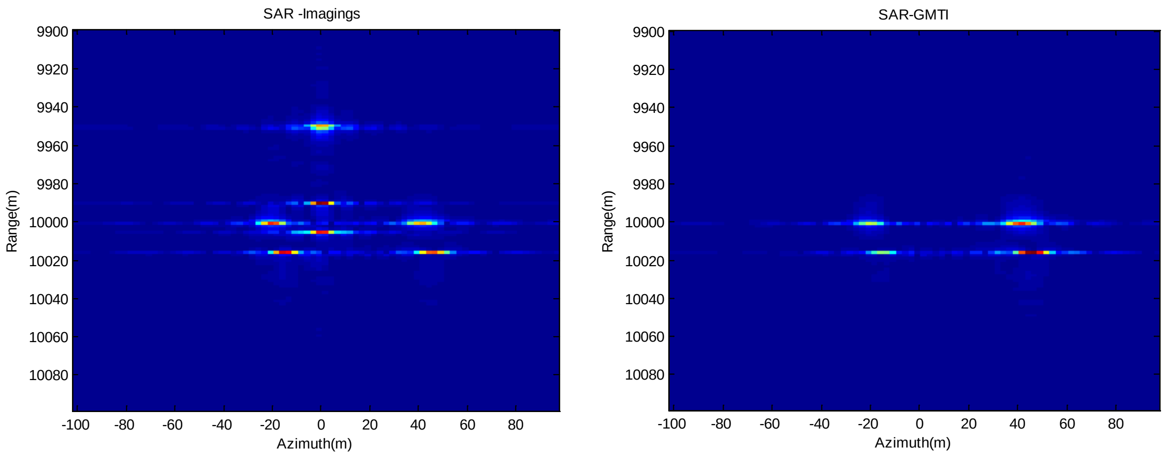
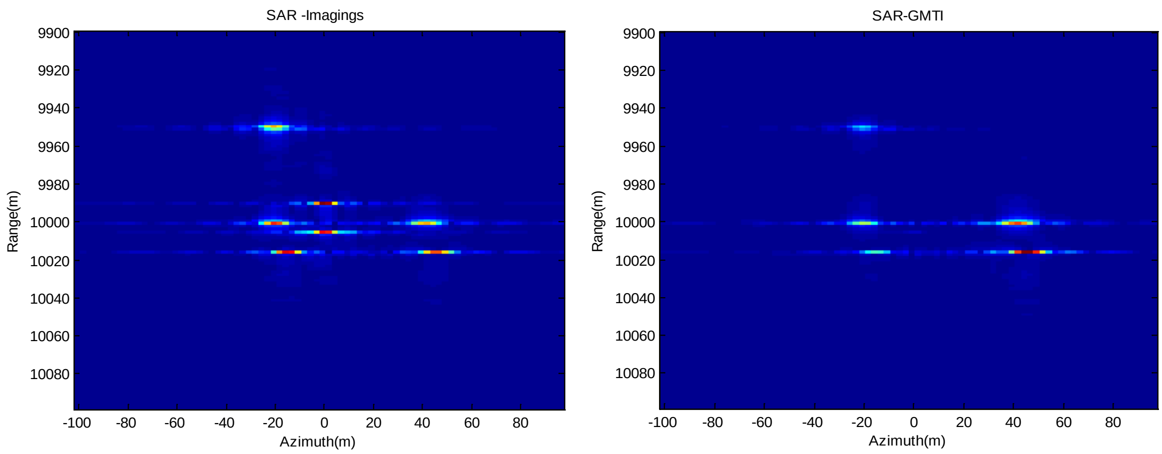


Figure 2. Selected area and jammer location.



(a) (b)

Figure 3. Motion modulation scatter-wave jamming of stationary jammer1 and scene images simulation images. (a) Image; (b) Image after GMTI.



(a) (b)

Figure 4. Motion modulation scatter-wave Jamming of moving jammer 2 and scene images simulation images ($\tau_s = 0.1 \mu s$). (a) Image; (b) GMTI.

targets. The residual energy image and GMTI also can be seen as theoretical analysis.

When mismatch can be neglected, the figures show that the intermittent sampling motion scatter wave jamming focuses very well. Experiment has proved this jamming can form vivid moving targets and be focused as vivid area image, which take the real targets' all scattering information and does not need to estimate the SAR's transmitted signal parameters. This jamming technique is effective, and feasible in practice, which has the prominent advantages against multi-channel SAR. The intermittent sampling repeater jamming can adapt to the waveform agile SAR current pulses. The jamming provides a new feasible approach against waveform agile SAR and GMTI.

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