

Effect of Jamming Technique on the Performance of Direct Sequence Spread Spectrum Modem

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Abstract— In the domain of electronic warfare, jamming is an eavesdropping application. A lot of effort has recently been directed into developing practical algorithms for spectral estimation of target modems. Spread Spectrum systems spread the information bearing digital signal across a broad bandwidth. Spreading the energy of a bounded energy data signal across a very wide bandwidth causes the energy present at any particular frequency or small frequency band to be insignificant. Often, it is too small and can be modeled as thermal noise at that frequency. In this context, this paper presents an innovative architecture of a jammer for efficient jamming of DSSS signals. This work includes a complete design and simulation of Jammer and compares the effect of innovative jamming technique on the performance of a DSSS signal with those available in the literature. Effectiveness of jamming is also visible in our comparison.

Keywords— Direct Sequence Spread Spectrum System (DSSS), Spectrum Estimation, Jamming, Levinson Durbin Algorithm, Noise

I. INTRODUCTION

Jamming activity can impact the timeliness of the information exchange, at least temporarily, slowing that exchange. Jamming can also affect the relevancy of information, because if it arrives at the intended destination too late to be of use; the information then becomes irrelevant [1]. The optimum communication system has Bit Error Rate (BER) lower than around 10^{-3} (on average, one bit is in error out of 1,000). Jamming techniques attempt to raise the BER to 10^{-1} or higher. If this level of BER is achieved then a jammer is said to be successful [2].

Antijam (AJ) communication techniques were developed to facilitate communications when an adversary wanted to deny the communicator the ability to communicate. Communication Electronic Warfare (EW) intercepts or denies communications and consists of three main components: 1- Electronic Attack (EA), 2-Electronic Support (ES) and Electronic Protect (EP) [3, 4, 5].

Spread Spectrum (SS) communication technology was developed as a communication technique that provided Low Probability of Intercept (LPI), Low Probability of Exploitation (LPE), or simply put as an AJ technique [1, 2, 3]. In SS systems the transmission bandwidth is much higher than the minimum required bandwidth to transmit the information. Two predominant types of SS communication techniques are

Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS) [6]. This paper presents an innovative implementation of a jammer that focuses on successfully jamming a DSSS system operating in an AJ environment.

Section II highlights the fundamental theory of DSSS jamming. The design methodology of this implementation is elaborated in Section III. Section IV includes the simulation and synthesis results and a comparison is drawn with previously proposed jamming techniques. Important results from this study are summarized in the conclusion section.

II. DESIGN METHODOLOGY

The proposed communication system in the presence of jammer, shown in Fig. 1, captures DSSS transmitted signals that have been corrupted with Additive White Gaussian Noise (AWGN). The very first thing a jammer has to do is to detect the AJ communication signals. This is the task performed by the Receiver [7, 8].

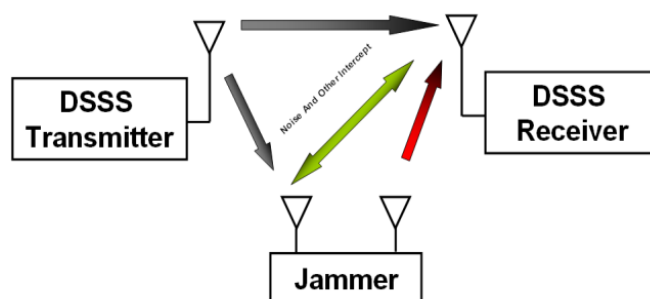


Figure 1. Communication System Model

A compressive receiver, shown in Fig. 2, is a receiver that performs a continuous scan over a frequency range of interest. For detection of DSSS systems, the compressive receiver performs a continuous fast scan over W_{ss} (the bandwidth of the spread signal) or a substantial part of it [9, 10]. The output of the compressive filter has energy at a certain time instant that corresponds to the location in frequency of the input signal. Thus, a time-to-frequency transformation has occurred. By measuring the time from the start of the sweep to when that energy appears, the radio frequency can be determined.

The signal “detected” by the Jammer is passed into the autocorrelator. Autocorrelation is the correlation of a large (of a well-defined length) segment of the signal with itself [11]. In this block, a large sequence of pulses in the time domain is correlated with itself and the resulting sequence is passed to the Levinson–Durbin algorithm [1, 12].

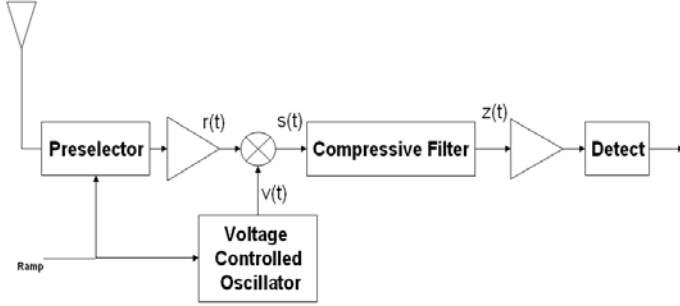


Figure 2. Compressive Receiver

The Levinson-Durbin algorithm adaptively estimates the coefficients of dynamic pulse shaping filter. The estimation problem is to determine whether a noise signal $y[n] = i[n]$ or a signal plus noise $y[n] = x[n] + i[n]$ is present [13, 14]. Consider a real Wide Sense Stationary (WSS) random process $x[n]$ as the response of a minimum phase system $L[z]$, which is a ratio of $N[z]$ and $Q[z]$, with input as a white noise process $i[n]$. The function $L[z]$ is called the innovation filter of $x[n]$ and its inverse $\Gamma[z]$ the whitening filter of $x[n]$. The process $i[n]$ will be called the innovation of $x[n]$. A process $x[n]$ is of finite order if its innovation filter $L[z]$ is a rational function of z as indicated below in (1). The equation models an Auto Regression Moving Average (ARMA) process of order (G, H) . If $N[z]$ is not equal to one, we have an all-pole or Auto Regression (AR) process of order G . However, if $N[z]$ and $Q[z] = 1$ we have an all-zero or Moving Average (MA) process of order H .

$$L[z] = \frac{N[z]}{Q[z]} = \frac{\sum_{k=0}^H p_k z^{-k}}{1 + \sum_{k=1}^G d_k z^{-k}} \quad (1)$$

In the time domain, the input-output relation of the model is given by (2):

$$l[n] = -\left(\sum_{k=1}^G d_k l[n-k]\right) + \left(\sum_{k=0}^H p_k i[n-k]\right) \quad (2)$$

The model filter coefficients p_k and d_k are related to the autocorrelation sequence $R[n]$ of the random incoming signal $x[n]$ by the following relationship:

$$\begin{bmatrix} R[0] & R[-1] & \bullet & \bullet & R[-G] \\ R[1] & R[0] & \bullet & \bullet & R[-G+1] \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ \bullet & \bullet & \bullet & \bullet & \bullet \\ R[G] & R[G-1] & \bullet & \bullet & R[0] \end{bmatrix} \begin{bmatrix} 1 \\ d_1 \\ d_2 \\ \bullet \\ d_G \end{bmatrix} = \begin{bmatrix} P_o \\ 0 \\ 0 \\ \bullet \\ 0 \end{bmatrix} \quad (3)$$

The matrix equation shown above is more commonly known as Yule-Walker equation [2, 3, 12]. In this matrix equation, P_o is the average power or the peak of autocorrelated sequence.

In order to avoid matrix inversion in system (3), which requires $O(n^3)$ time complexity, it can be solved using the fast Levinson-Durbin algorithm which has complexity of order $O(n^2)$ only. This algorithm exploits the Toeplitz property of $(G+1)$ by $(G+1)$ matrix in equation - 3. Because of the structure of the Toeplitz matrix, the matrix equation can be solved as follows:

Levinson-Durbin Algorithm

The Levinson-Durbin Algorithm recursively calculates d_k and average normalized power P_k in the time varying component of the signal $x[n]$. In our simulation model, the base cases for the Levinson-Durbin algorithm are:

$$d_1[1] = \frac{R[1]}{R[0]} \quad (4)$$

$$P_1 = (1 - d_1^2[1]) \cdot P_o \quad (5)$$

The n^{th} values are:

$$d_n[n] = \frac{1}{P_{n-1}} \cdot \left[R[n] - \sum_{k=1}^{n-1} d_k[n-1] \cdot R[n-k] \right] \quad (6)$$

$$P_n = (1 - d_n^2[n]) \cdot P_{n-1} \quad (7)$$

$$d_j[n] = d_j[n-1] + d_n[n] \cdot d_{n-j}[n-1] \quad (8)$$

The likelihood ratio is given by:

$$z = \frac{P_o}{P_G} \quad (9)$$

The likelihood ratio is compared with the threshold and the decision of whether or not the signal is present, is made. The block diagram of Levinson-Durbin algorithm is shown in Fig. 3.

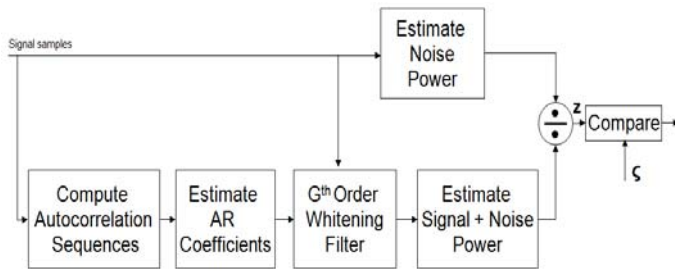


Figure 3. Levinson-Durbin Algorithm

The dynamically changing array of coefficients, $d_0, d_1 \dots d_G$, is now fed into the filter $L[z]$, see (1). The response of the filter to a pulse train is dynamically changing (which is an estimate of the shape being transmitted by the DSSS transmitter) and is to be transmitted by the jammer [15]. The energy of this signal is also dynamically varied. This is done by scaling the energy of estimated shape with P_G . Block diagram of filtering operations is shown in Fig. 4.

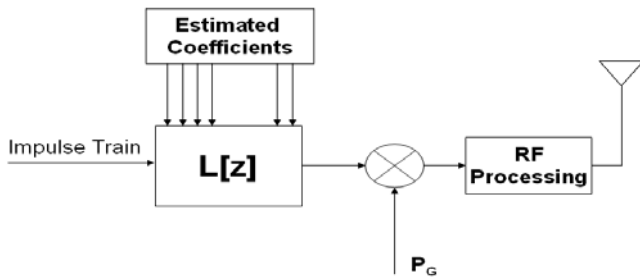


Figure 4. Pulse Shape Estimation

After successfully completing the signal processing tasks, jammer is ready to affect the relevancy of information. We need to do RF processing at the transmitter before finally transmitting the jamming signal. Since the shape of the transmitted signal is dynamically changing the RF processor has to be capable of handling these changes.

The approach explained above is efficient, takes less time to estimate spectral contents of a DSSS signal and makes a strong and powerful attack on its target forcing it to make false decision [16]. Overall proposed DSSS jammer architecture is shown in Fig. 5.

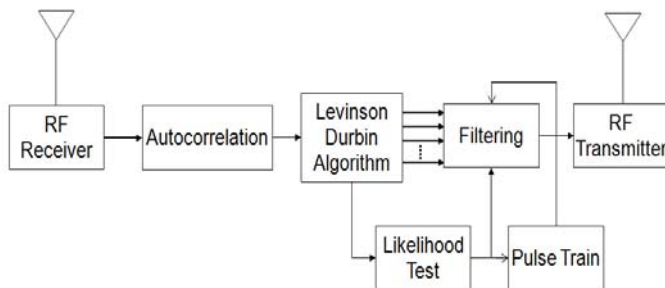


Figure 5. DSSS Jammer

III. SIMULATION AND SYNTHESIS RESULTS

A. Simulation without Jammer

When a signal is received at the DSSS receiver, the effectiveness of the receiver can be studied by measuring the bit error probability P_E at various values of bit energy E_b relative to the constant noise floor N_0 (both above and below it). For each value of normalized bit energy, E_b / N_0 , we have taken ten thousand samples in order to attain a smooth curve. The results of this, experimentation, are summarized in Fig. 6. Ideally the curve should fall drastically down to zero as E_b / N_0 increases beyond one. However, the processing gain, G_p , has a remarkable effect on the shape of the curve.

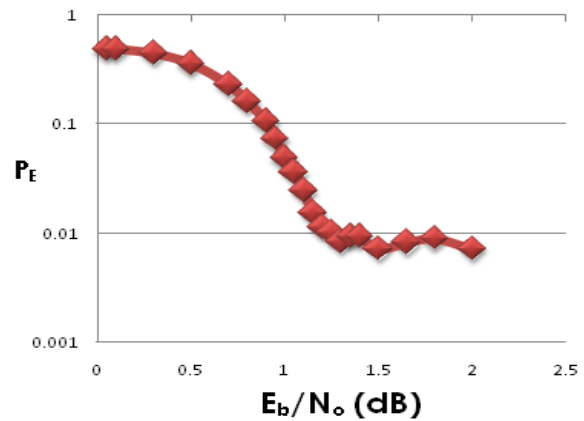


Figure 6. Curve between E_b / N_0 & P_E

B. Simulation with Jammer

The results in the presence of Jammer are presented in Fig. 7. The curve attained has maintained its downward slopping trend (particularly so, the y-axis crossing on both curves is exactly the same which it should be), which is a proof of correct simulation model. At the same time the bit error probabilities have substantially increased (the upward shift of the curve with the jammer relative to the one without it) [17].

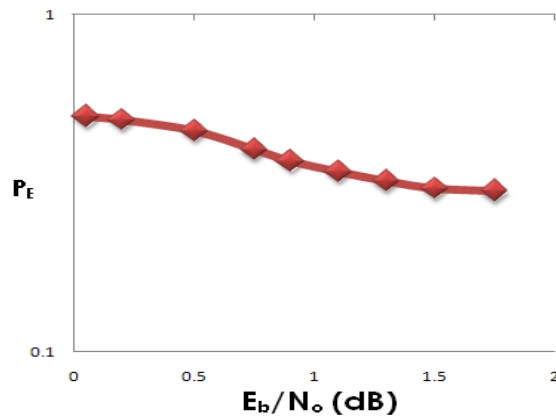


Figure 7. A Curve between E_b / N_0 & P_E

Above results were validated after comparing them with the theoretical curves of a DSSS Modem [18] as indicated in the inner curve of Fig. 8. Comparison is done with the

approach presented in [1], and it is observed that the performance of proposed jamming technique is more effective (around 9.1%).

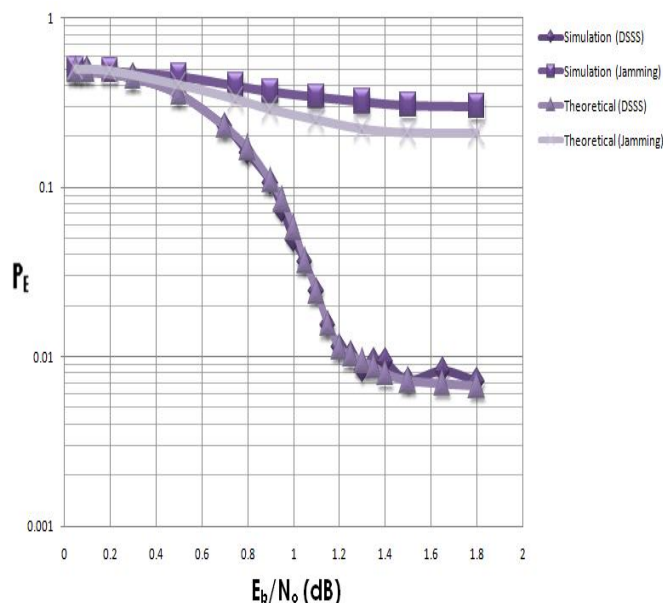


Figure 8. Comparison between Simulated Results and Theoretical Results

IV. CONCLUSIONS

An efficient adaptive signal extraction technique has been proposed to intelligently jam the Direct Sequence Spread Spectrum Modem. The proposed jamming strategy indicates that the algorithms used can significantly enhance the Bit Error Rate of its target. The proposed technique also helps in analyzing a DSSS modem under high probability of intercept scenarios.

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REFERENCES

- [1] Richard A. Poisel. Modern Communications Jamming Principles and Techniques. Artech House Boston London.
- [2] Athanasios Papoulis and S. Unnikrishna Pillai. Probability, Random Variables and Stochastic Processes, 4th Edition.
- [3] Peyton Z. Peebles, JR. Probability, Random Variables and Random Signal Principles, 4th Edition. McGraw-Hill International Edition.
- [4] Alberts, D. S., J. J. Garstka, and F. P. Stein, Network Centric Warfare Developing and Leveraging Information Superiority, 2nd Edition, Washington, D.C., DoD C4ISR Cooperative Research Program, August 1999.
- [5] Kenneth Young, Terleiv Maseng, Randall Landry, "Military Communications", IEEE Communications Magazine, Vol. 47, No. 10, October 2009, pp. 36-38.
- [6] John G. Proakis. Digital Communications, 4th Edition.
- [7] A.E. El-Mahdy, "Partial band jamming of multicarrier frequency hopping-binary phase shift keying receiver over a Rayleigh fading channel with imperfect channel estimation" published in IET Communications, August 2009.
- [8] Zeng, M., and Q. Wang, "On the Probability Distribution of Differential Phase Perturbed by Tone Interference and Gaussian Noise," IEEE Transactions on Communications, Vol. 47, No. 4, April 1999, pp. 508-510.
- [9] Harms, B. K., and D. R. Hummel, "Calculation of Detection Probability for Frequency Compressive Receivers," IEEE Transactions on Aerospace and Electronic System, Vol. AES-21, No. 1, January 1985, pp. 106-116.
- [10] Li, K. H., and L. B. Milstein, "On the Use of a Compressive Receiver for Signal Detection," IEEE Transactions on Communications, Vol. 39, No. 4, April 1991, pp. 557-566.
- [11] Torrieri, D. J., "Fundamental Limitations on Repeater Jamming of Frequency-Hopping Communications," IEEE Journal on Selected Areas in Communications, Vol. 7, No. 4, May 1989, pp. 569-575.
- [12] Sanjit K. Mitra. Digital Signal Processing, A Computer Based Approach, 3rd Edition.
- [13] Sharnain, P. and L. B. Milstein, "Minimum Mean Square (MMSE) Receiver Employing 16-QAM in CDMA Channel with Narrowband Gaussian Interference," Proceedings IEEE MILCOM 1999.
- [14] Thomas, J. and E. Geraniotis, "Joint Iterative MMSE Multiuser Detection and Narrowband Jammer Suppression in Coded DS-SS Channels," Proceedings IEEE MILCOM 1999.
- [15] Turin, G.L., "An Introduction to Digital Matched Filters," Proceedings of the IEEE, Vol. 64, No. 7, July 1976, pp. 1092-1112.
- [16] Hang Wang, Jingbo Guo, Zanj Wang, "Evaluation of Security for DSSS under Repeater Jamming", ICC 2007 Proceedings.
- [17] Samer S. Saab, Jad G. Hobeika, and Iyad E. Ouass, "A Novel Pseudorandom Noise and Band Jammer Generator Using a Composite Sinusoidal Function", IEEE TRANSACTIONS ON SIGNAL PROCESSING, VOL. 58, NO. 2, FEBRUARY 2010.
- [18] Bernard Sklar. Digital Communications Fundamentals and Applications, 2nd Edition. Prentice Hall.