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MONTEREY, CALIFORNIA

**ACTIVE ELECTROMAGNETIC SIGNAL DECOHERENCE
TECHNOLOGIES AND TECHNIQUES FOR NAVAL TACTICAL
APPLICATIONS**

by

Ric A. Romero

October 2023

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Monterey, California 93943-5000**

Ann E. Rondeau
President

Scott Gartner
Provost

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This report was prepared by:

Ric A. Romero
Professor

Reviewed by:

Douglas Fouts, Chairman
Electrical and Computer Engineering

Released by:

Kevin B. Smith
Vice Provost for Research

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ABSTRACT

This work introduces an active electromagnetic decoherence technique for naval tactical application. Specifically, this work introduces a method that decoheres a deterministic radar waveform called linear frequency modulation (LFM) into a random signal. Detection performance is evaluated with the use of MATLAB software via Monte Carlo simulation. The transmit waveform shaped-LFM waveform was very effective in degrading the percentage (probability) of detection (Pd) and percentage (probability) of false alarm (PFA) of the threat radar system via reported Pd and PFA performance curves.

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I. INTRODUCTION

A. BACKGROUND

Active sensors such as radar systems transmit various waveforms. One common radar signal is the linear frequency modulated (LFM) waveform. In this study, the goal is to produce a technique that can “decohere” a deterministic waveform (e.g., LFM) such that it becomes a random signal (like noise) that can be used as interference to a threat radar and thereby reduce its effectiveness to detect a target. In other words, such a technique is very useful in electronic warfare (EW) applications.

The transmit waveform shaped (TWS) noise jammer technique was first introduced in [1]. That work described the main procedure used in generating a decohered signal from a simple deterministic pulse. It should be noted that most of the resulting contents in this report are found in a Master’s thesis [2] authored by USMC Capt. Tristan Pietrzak at the Naval Postgraduate School who helped in this particular Naval Research Program (NRP) project. In other words, this document may be considered as an abridged stand-alone report based on [2].

B. OBJECTIVES

The first objective of this project is to produce a method to generate a *decohered* version of a deterministic waveform, specifically an LFM waveform. The decohered version, which is denoted as TWS-LFM, is used as interference to a threat radar. The second objective is to evaluate the effectiveness of the TWS-LFM interference by evaluating the performance curves, namely, probability of detection (Pd) and probability of false alarm (PFA).

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II. LFM SIGNAL, TWS METHODOLOGY, AND MONTE CARLO SIMULATIONS

A. LINEAR FREQUENCY MODULATED SIGNAL

An LFM signal is also called a chirp waveform. It has a magnitude spectrum illustrated in Figure 1. Note that the amplitude axis is in dB while the frequency axis is normalized.

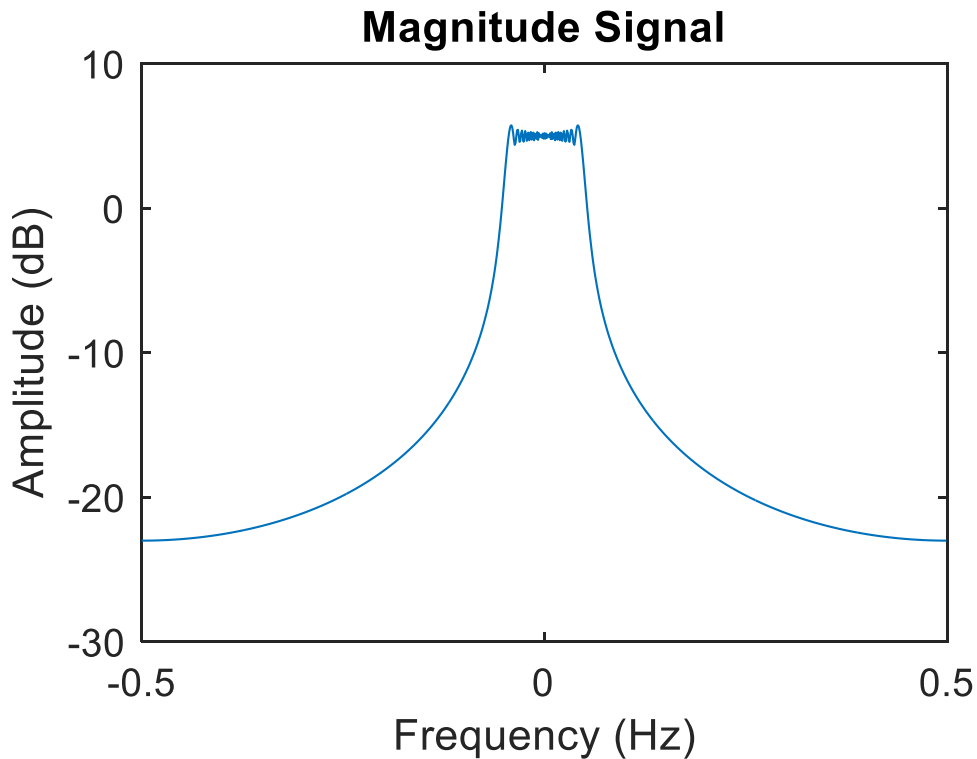


Figure 1. Magnitude spectrum of an LFM signal.

B. TRANSMIT WAVEFORM SHAPED INTERFERENCE METHODOLOGY

In this section, we describe the TWS methodology that is used to decohere a signal into a random one. The first step is to create the convolution matrix of the LFM waveform. From the convolution matrix, the autocorrelation matrix is formed. Using MATLAB as a signal simulator, the additive white Gaussian noise (AWGN) vector is generated. The noise vector is multiplied by the LFM's correlation matrix, yielding a decohered TWS-LFM waveform that has random amplitude, phase, and frequency

contents. An example TWS-LFM waveform is generated and its magnitude spectrum is shown in Figure 2.

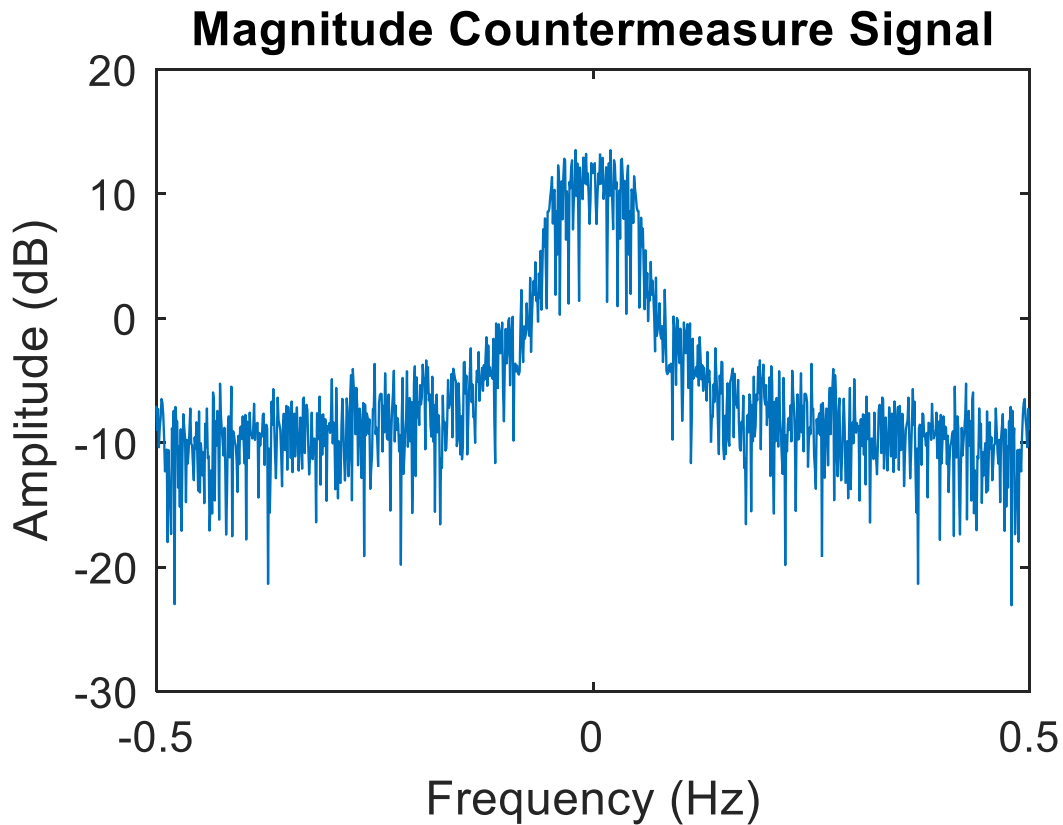


Figure 2. Magnitude spectrum of the TWS-LFM signal.

C. MONTE CARLO SIMULATIONS

One of the main goals of this research is to evaluate the performance of the decohered TWS-LFM waveform's effect on the detection performance of the threat radar in which the waveform may be used as a countermeasure. Again, the two performance metrics of interest are probability of detection (Pd) and probability of false alarm (PFA).

To generate these detection curves, Monte Carlo simulations are implemented where LFM and noise signals are generated. When an LFM signal is present, the number of detections is recorded and divided by the number of trials yielding percentage (probability) of detection. When only noise is present, the number of false detections is recorded which yields percentage (probability) of false alarms.

III. RESULTS AND FINDINGS

A. PROBABILITY OF DETECTION RESULTS

As mentioned, several intermediate results are reported in [2]. In this section, we present the bottom-line Pd effects of the TWS-LFM decohered waveform on detection performance of the threat system.

Illustrated in Figure 3 are resulting Pd curves when a coherent detector is used. Note that “SN” in the figure legend pertains to spot noise jamming (SNJ) and the appended number in the legend pertains to the jammer-to-noise ratio (JNR) in dB. Also note that the relative bandwidth of the LFM radar waveform is 10% while the SNJ occupies 100% of the allotted bandwidth. The No Jammer legend of course implies no jamming countermeasure is utilized. In detection problems, high SNR is needed to maintain a specified detection probability, i.e. the radar’s required Pd. Clearly, when interference is present, Pd degrades depending on JNR. However, it is clear that the TWS-LFM waveform is more effective in degrading the performance of the radar in the high SNR region compared to that of the SNJ waveform.

Another popular receiver detection method is the non-coherent detection technique where only the magnitude of the signal received is utilized. The Pd curves for non-coherent detection are illustrated in Figure 4. Again, the “SN” in the figure legend pertains to SNJ, the appended number in the legend pertains to the JNR in dB, and the relative bandwidth of the LFM radar waveform is 10% while the SNJ occupies 100% of the allotted bandwidth. The No Jammer legend implies no jamming countermeasure is utilized. Recall that in detection problems, high SNR is needed to maintain a specified detection probability. Thus, it is clear that the TWS-LFM waveform is more effective in degrading the performance of the radar compared to that of the SNJ waveform even if the non-coherent detection method is used.

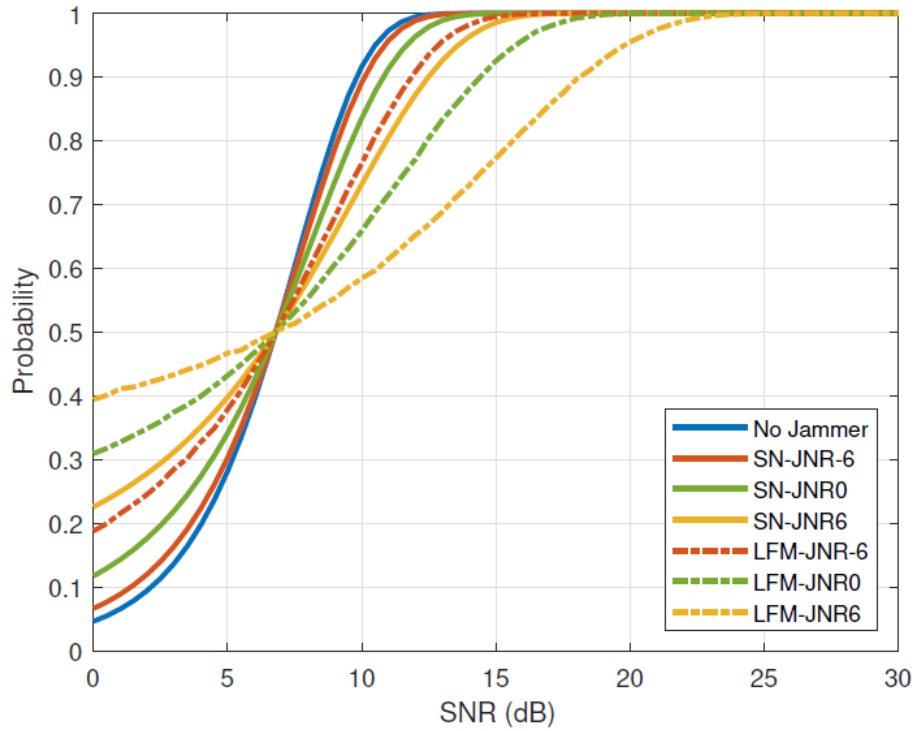


Figure 3. Pd curves for TWS-LFM, SNJ, and without jamming (coherent detection).

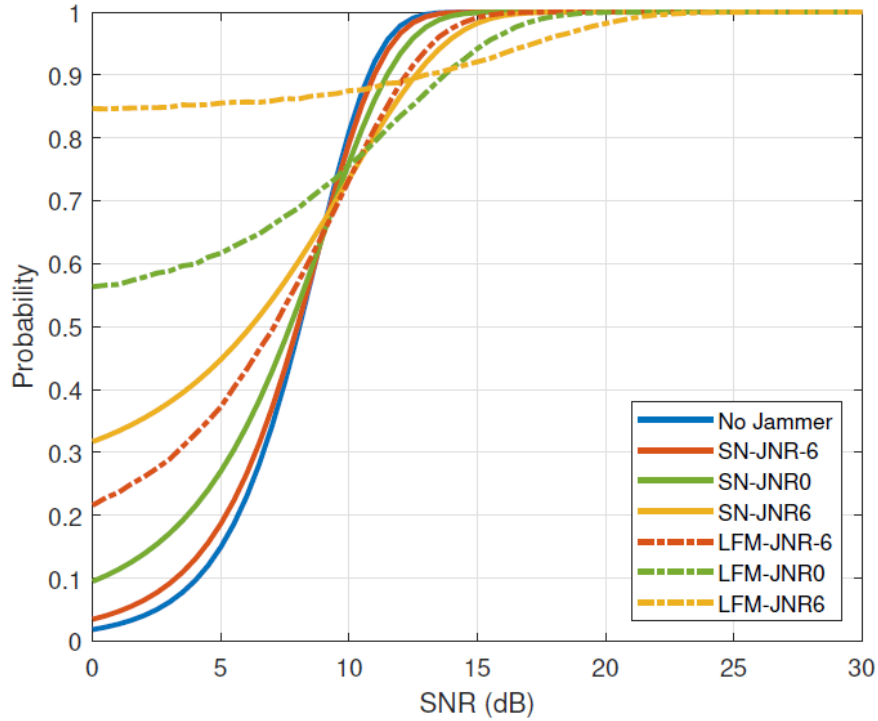


Figure 4. Pd curves for TWS-LFM, SNJ, and without jamming (non-coherent detection).

B. PROBABILITY OF FALSE ALARM RESULTS

In this section, we present the bottom-line PFA effects of the TWS-LFM decohered waveform on detection performance of the threat system. Via Monte Carlo simulation, the two sets of PFA curves (as a function of JNR) corresponding to both coherent detection and non-coherent detection are shown in Figure 5. In this case, the threat radar's required PFA is 0.001. The appended numbers in the legend pertain to the relative bandwidths of the LFM to SN bandwidth. For example, "B01" means 0.1 (which is 10%). Notice that the PFA degrades with the use of SNJ and TWS-LFM (for various relative bandwidths). But it is clear that any TWS-LFM decohered interference is more effective than SNJ in causing more false alarms in the threat radar's receiver.

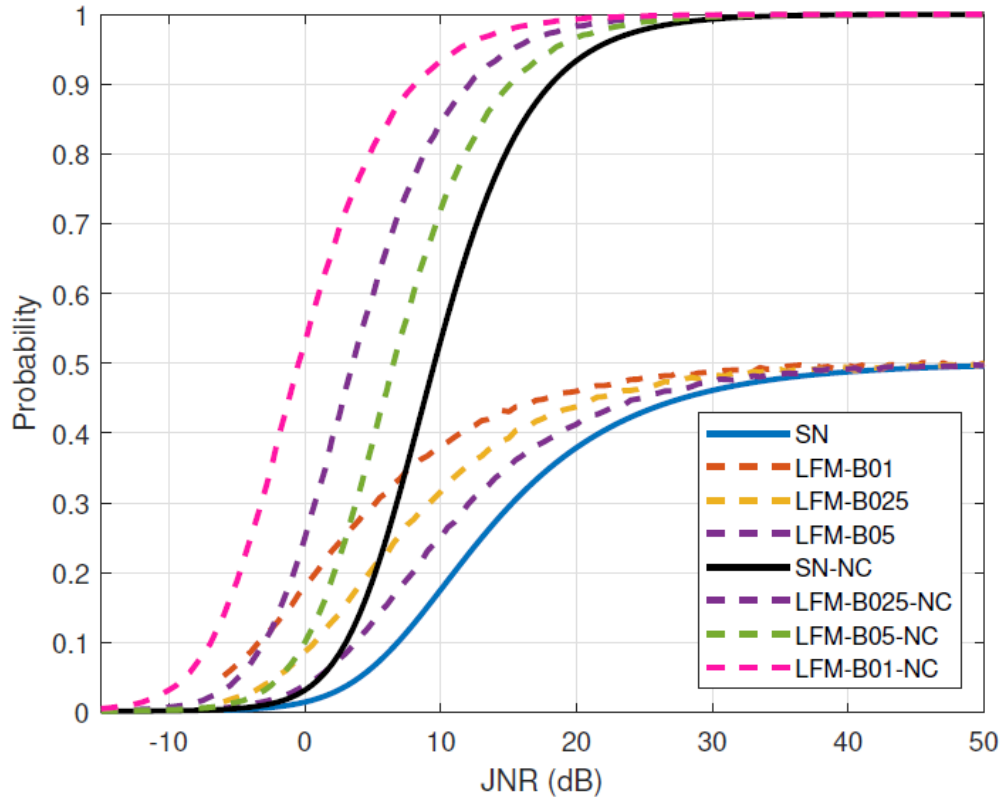


Figure . PFA curves for TWS-LFM and SNJ (coherent and non-coherent detection).

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IV. SUMMARY AND RECOMMENDATION

A. SUMMARY

In conclusion, this project developed an active decoherence technique by producing a random TWS-LFM waveform versus a deterministic one.

Moreover, it was shown that the TWS-LFM waveform was more effective in degrading the threat radar's detection probability (P_d) compared to the SNJ waveform for both coherent and non-coherent detection methods.

Lastly, it was shown that the TWS-LFM waveform was more effective in degrading the threat radar's false alarm probability (PFA) compared to the SNJ waveform for both receiver detection methods.

B. RECOMMENDATION

The recommendations for further work are the following: a) it is proposed to continue the research by investigating other waveforms and b) it is proposed to apply the technique in hardware experiments to assess practical effects in electronic warfare scenarios.

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LIST OF REFERENCES

- [1] A. Feltes and R. Romero, “Electronic protection mitigation techniques against transmit waveform shaped noise jammers,” *International Radar Conference 2021* (Virtual), Atlanta, GA, May 2021
- [2] T. Pietrzak, “Analysis of linear frequency modulated pulse-shape interference,” M.S. thesis, Dept. of Elec. and Comp. Eng., NPS, Monterey, CA, USA, 2021

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