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Improving Clutter Suppression in Navy Legacy Radars

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Introduction: New Navy missions in littoral regions have accentuated the need for improved radar performance in a heavy clutter environment. While new solid-state phased-array radars, currently under development, are specified to have a much improved clutter suppression capability, a large number of ships using older tube-based transmitters will continue to have a major role in Naval operations for years to come. For many of these radars, the ability to suppress clutter is limited by intra-pulse noise generated in the Crossed-Field Amplifiers (CFA) used as the final power amplifiers of the transmitter. The cost of replacing such transmitters with more stable and lower-noise alternatives is usually deemed much too costly.

In an effort directed at improving clutter suppression in such Navy Legacy radars, without the need for major transmitter modifications, NRL has been pursuing the development of a new signal processing technique, referred to as transmitter noise compensation (TNC). This technique compensates for intra-pulse transmitter noise, as well as power supply instabilities, by capturing and processing an accurate replica of each transmitted pulse in real time. Subsequently, through pulse-to-pulse comparisons, the measured transmit errors are used to derive a digital filter, which compensates for the transmitter instabilities in the digital signal processor (DSP), thus improving the suppression of returns from strong clutter.

A preliminary feasibility study proved that this technique should be capable of providing more than a 10-dB improvement in clutter suppression. This paper describes the TNC technique and outlines the results of an experimental study on the AN/SPY-1B radar aimed at demonstrating the practical feasibility of the TNC technique.

Transmitter Noise Compensation: In simple terms, the TNC technique is similar to the classical “coherent-on-receive” moving target indicator (MTI) approach,¹ but instead of making a single complex correction to all the received clutter returns, specific corrections are made on all the samples across the duration of the radar pulse width, based on a direct measurement of the waveform of each transmitted pulse. Since once the transmit signal is radiated it is deterministic, the samples of each pulse can be used to equalize received signals within a coherent processing interval (CPI), resulting in a significantly improved

clutter suppression. The errors on each transmitted pulse can be referenced either to the ideal waveform or to the first transmitted pulse in a coherent dwell. Challenges with this technique are to obtain a high-quality sample of the transmitted pulse and to implement efficient signal-processing algorithms, which equalize the returns over an entire coherent dwell.

A block diagram describing the basis of the TNC principle is shown in Fig. 4, and the corresponding mathematical approach is summarized by the following equation:

$$\text{Output} = [C \otimes SE] \otimes \left[F^{-1} \left\{ (F(S))^* \cdot \frac{F(S)}{F(SE)} \right\} \right].$$

A sample, SE , of each of the transmitted radar signals in the CPI is down converted, filtered, and digitized in a separate receive channel. The total radar return is the convolution of the transmitted signal, SE , and the clutter reflectivity, C . Pulse-to-pulse differences are defined by their spectral ratio, $F(S)/F(SE)$, which is multiplied by the matched filter function, $F(S)^*$, and then transformed into an error-correcting finite-impulse-response by taking the inverse Fourier transform. Here S denotes the ideal desired radar waveform and $F(\cdot)$ is the Fourier transform. This error-correction/matched filter response is convolved with clutter returns to obtain the corrected output, which is sent to the MTI filter or pulse Doppler processor.

Experimental Study: For the experimental study, data was collected on the AN/SPY-1B radar at the U.S. Navy Surface Combat Systems Center (SCSC) at Wallops Island, VA, using a data recording system developed and operated by the Naval Surface Warfare Center (NSWC). Referring again to Fig. 4, both the transmit sample and radar returns, from nearby clutter sources, were recorded after the analog-to-digital converters (ADCs) for a large number of consecutive MTI dwells in each beam position. The transmit sample is the combined output of the 32 CFAs in the AN/SPY-1B. Due to significant levels of transmitter leakage into all the receiver channels during the transmit pulse, a 10-km optical delay line was used to delay the transmit sample. The clutter return signals from actual clutter sources were fed directly to the receiver without the use of an optical delay line, since the clutter sources were located 4 to 5 nmi from the radar. The outputs from the receiver were sent to the data recording system where each was digitized in 14-bit, 100-MS/s ADCs.

Data Analysis: A Matlab program was used to compute the clutter improvement factor (CIF) with and without TNC, as described by the functional

diagram in Fig. 4. Gated transmit and clutter samples were input to the calculation and filtered to separate the individual subpulses. The filtered pulses were then compressed and compensated for the transmitter noise, and a three-pulse dwell was used to compute MTI residue.

Figure 5 shows an example of the outputs from the analysis program based on a single CPI. The single-pulse compressed output is plotted in black at the top and its peak value serves as the amplitude reference. The normal MTI output is plotted in blue and the TNC-compensated MTI output is plotted in red. Notice that the compensated residue has much less energy, but it is spread farther in time. The improvement CIF value given in this figure is the difference of the total integrated energy under the MTI and MTI + TNC waveforms across their total time duration. Figure 6 shows histograms of more than 300 dwells with and without the TNC technique. With the TNC technique applied, a median improvement of more than 15 dB was achieved in this particular case.

Conclusions: Based on the analysis of experimental data taken with the AN/SPY-1B radar, it has been shown that the proposed TNC technique can improve radar detection of small targets in clutter by more than

10 dB. This agrees well with initial theoretical predictions. While the TNC technique only works in a single designated unambiguous pulse repetition interval (PRI) following the transmitted pulse, it would be well suited for medium pulse-repetition-frequency (PRF) radars where significant clutter is unlikely to extend over more than one PRI interval. The TNC processing can be easily adapted to future radar upgrades and should be extremely cost competitive compared to alternative transmitter improvements, in particular, if it can be implemented as part of an overall radar signal processor upgrade.

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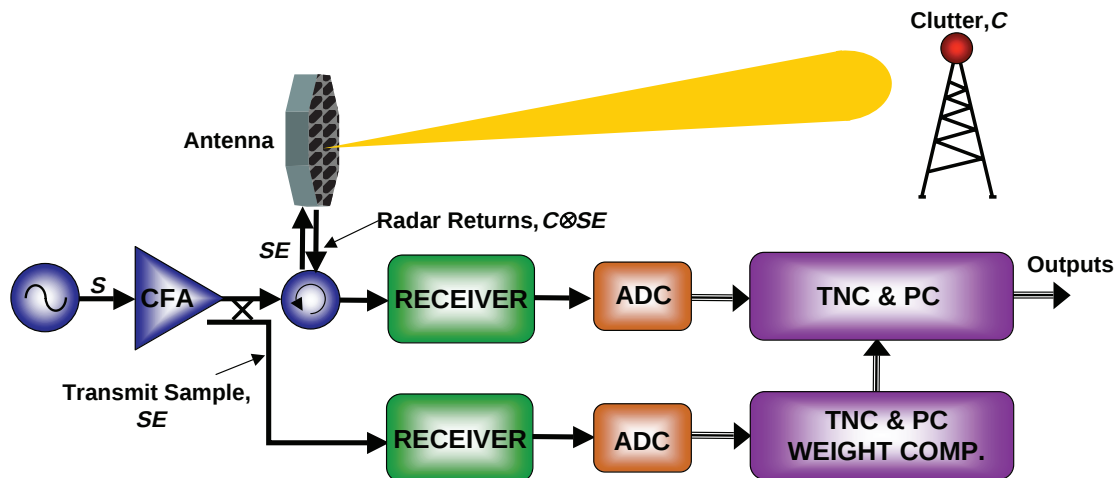


FIGURE 4
Transmitter noise compensation functional block diagram. TNC: Transmitter Noise Compensation, PC: pulse compression.

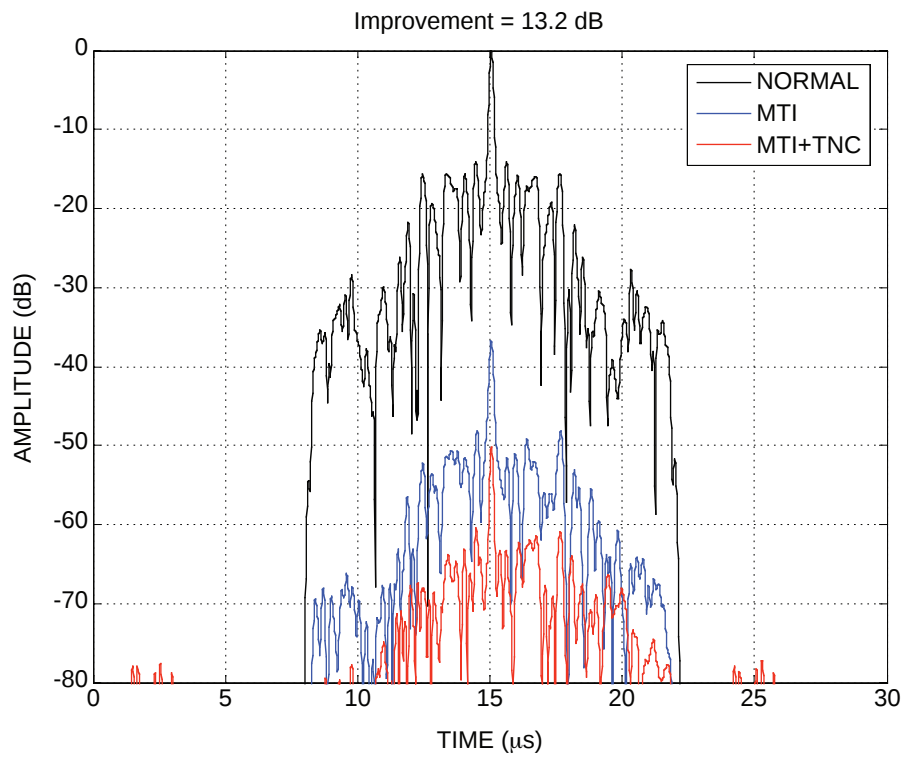


FIGURE 5
Sample output of the data analysis program.



FIGURE 6
Histogram of CIF with and without TNC using a TV tower on Chincoteague Island as a clutter source.