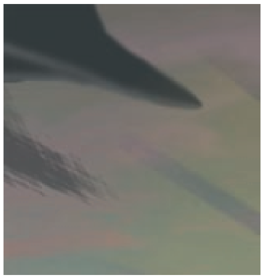

Coherent Radar: Guest Editor's Introduction

Russell Rzemien

Everyone knows that echoes are caused by sound reflecting off objects. The presence of too many reflectors, however, frequently makes it impossible to distinguish a particular echo in the presence of the background "clutter" (not to mention the effects of absorption and the presence of other noise sources that jam or mask the echo). A similar situation exists for radar where, instead of sound, the reflected radio waves from targets of interest must compete with energy scattered from natural objects such as the sea, rain, or land. Some of these objects reflect signals that are orders of magnitude larger than the target echo.

Early radars, compared with modern day microwave radars, operated at relatively low frequencies and thus were relatively immune to most types of natural clutter. During World War II, the advantages and problems associated with high-powered microwave radars became apparent. The primary advantage was the ability to build reasonable-size antennas that provided the desired gain (hence, increased target detection range) and narrow beam (hence, increased resolution, or ability to separate closely spaced targets) required to perform air and surface surveillance tasks. The increase in operating frequency and the corresponding decrease in the wavelength of the transmitted signal resulted in increased backscatter from natural objects in the environment. An early example is that of a 3-GHz microwave early warning radar developed by the Massachusetts Institute of Technology's Radiation Laboratory. During preproduction testing at Tarpon Springs, Florida, the system demonstrated its effectiveness at long-range target detection, but also its ability to detect thunderstorms.[1]

It was known that coherent radar signal processing (i.e., processing that uses the phase or frequency of the transmitted and received signals) could be used to discriminate moving targets from weather and other types of background clutter. The technology required to successfully implement this type of processing, however, was not available until after World War II. The development of the klystron amplifier in the early 1950s made it possible to achieve effective moving target indicator performance because it could generate a high-power microwave pulse of sufficient phase and frequency stability. Such stability in both the transmitter and receiver is the primary prerequisite for effective coherent signal processing. (For an overview of the development of radar, see Ref. 2.)

This issue of the *Technical Digest* examines coherent signal processing techniques as applied to radar systems, hence the term coherent radar. A coherent radar compares the phase or frequency of a target echo with a stable oscillator or reference signal source. Natural objects, such as trees or islands, tend to be relatively steady in phase or frequency. (An important exception is the Doppler-shifted frequency of echoes from weather phenomena.) However, moving targets such as aircraft or ships cause echoes that vary compared with the stable source. These variations can be used to detect the presence of a moving target, measure the target speed relative to the radar, or determine other characteristics of the target such as the type of jet engine it is using.

The opening article by Hanson and Marcotte examines aircraft wake vortex detection using a bistatic continuous-wave radar. Large aircraft create vortices of sufficient magnitude to pose serious safety problems, particularly for small aircraft. The use of bistatic radar, (i.e., a radar that uses a non–co-located transmitter and receiver) to detect the presence of objects in the environment is a technique that pre-dates the more popular pulse radars that one normally associates with surveillance systems. Coherency in this case is obtained by using samples of the transmitted waveform itself. The authors describe how a continuous-wave signal can be used to monitor the environment for the presence of wake vortices. To improve sensitivity, an acoustic pumping technique was employed that enhances, under normal atmospheric conditions, the amount of energy scattered to the receiver. The existence of a strong vortex in the scattering path will disturb the received signal, thereby providing a means to detect the phenomenon.

Another area of radar signal processing using coherent techniques is synthetic aperture radar, or SAR (see the back cover of this issue for an example). Originally discovered in the early 1950s, SAR uses high-range-resolution waveforms and synthetic aperture techniques to produce images of objects. Range resolution ultimately depends on the bandwidth of the transmitted pulse, the simplest case being a very short time-duration pulse (narrow pulses translate into signals whose spectral content is broad in the frequency domain).

Typically, range resolution is obtained by transmitting a long time-duration pulse that is either phase or frequency modulated (or coded), and then processing the pulse on reception to produce a narrow range response. This has the advantage of increasing the total amount of energy reaching a target, hence increasing sensitivity, without sacrificing range resolution. It also permits operating transmitters at lower peak power amplitudes, which is desirable for a number of reasons beyond the scope of this introduction.

The narrowness of the radar beam in either azimuth or elevation is inversely proportional to the size of the antenna aperture. A synthetic or virtual antenna of large length can be created by using a small antenna and moving it through space. Signal processing techniques are then employed to construct high-resolution images.

The article by Griffith discusses some of the problems associated with SAR. Phase errors, whose sources include uncompensated platform motion, and transmitter and receiver instabilities degrade the coherency of the system and produce smeared or distorted images. The author describes a method of estimating these errors using measurements of the phase history associated with stationary targets in the radar's field of view. The error is removed from the raw data, and the image is reconstructed with significantly improved quality. An example of this technique using data taken from the Naval Air Defense Center P3 aircraft SAR is given.

Bric discusses in detail a specific case of SAR where target instead of radar motion provides the different aspect angles needed to form the image. Such systems are referred to as inverse SAR or ISAR. He describes a reconstruction paradigm, tomographic processing, that can be used to coherently reconstruct an image incrementally as data become available. A shortcoming to reconstruction techniques is the degradation in image quality due to sidelobe energy generated during the data processing. The article provides interesting results in both simulated and real data, showing that significant performance improvements via sidelobe energy reduction can be achieved.

In the area of radar system development and evaluation, the Laboratory frequently uses a coherent data collection and analysis methodology to meet program needs of Navy sponsors. Such an approach is essential to a thorough understanding of system performance since target and especially radar environment models used to assess system performance are typically approximations. Unfortunately, many of the details missing from these models have a significant impact on system behavior. To obtain the radar's eye view of the world, specialized instrumentation is developed to collect the digitized, unprocessed radar data. The article by Rzemien describes the challenges associated with providing the required instrumentation. Design requirements, interface issues, and instrumentation architecture are presented for several systems. The impact of some of these devices in their respective programs is the subject of several of the following articles.

Roulette and Skrivseth describe some of the Laboratory's contributions to improving the performance of the AN/SPS-48E radar digital moving target indicator. The AN/SPS-48E is a long-range air surveillance radar that uses narrow azimuth and elevation beams to provide a full three-dimensional search capability. This system is found on Navy carriers, cruisers, destroyers, and amphibious assault ships. As described in the article, coherent data collected and analyzed by the Laboratory led to system modifications that contributed significantly to improved system performance, particularly in the presence of strong land clutter. Coherent data analysis also demonstrated that system performance would be further improved by using velocity estimation techniques in the automatic tracker. As a result, an engineering development model of a special auxiliary detection signal processor was developed by the Laboratory (Ref. 3, pp. 394–397) that became the basis of a deployed field change to the radar set.

Oliver Hazard Perry class frigates use the Mark 92 fire control system radars to provide surveillance and tracking for ship self-defense. The Modification 6 upgrade to this system included a new coherent transmitter and receiver. Fong and Kay describe APL's role in supporting this development effort. The need to collect coherent track radar data, along with the search data, necessitated the development of a fast and sophisticated data storage device. Automated data reduction and analysis programs developed at the Laboratory were used to aid the Navy and the radar contractor in evaluating and improving the system during the initial development stages. Follow-on testing off both coasts, and most recently in the Arabian Gulf, provided invaluable data for use in radar environment studies. As in the case of the AN/SPS-48E, expertise gained in this program would be applied to a prototype new signal processor and tracker for the older Modification 2 version of the Mark 92 fire control system (Ref. 3, pp. 387–391). One of the unique features of this device was its ability to collect coherent data that could be played back in real time into the processor. After data have been collected, this ability allows real-time evaluation of processing algorithms, as often as needed, without incurring the expenses associated with range facilities or at-sea tests.

The final example of coherent data collection to benefit radar development programs pertains to the Phalanx close-in weapons system. This system provides ship self-defense capability, primarily against so-called leaker threats, i.e., attacking aircraft or missiles that were not neutralized using other ship defense systems. The search radar system was upgraded from an analog to a digital coherent processor in the 1980s. The article by Rzemien and Roulette describes how coherent data were used to support evaluation of this new processor and the new waveforms used by the radar. Early testing indicated false-alarm problems (a false alarm is a detection caused by either noise or environmental factors) in the presence of strong clutter that were not initially understood. Examination of the coherent data demonstrated that the receiver amplifier gains needed to be readjusted to optimally match the dynamic range of the receiver to its coherent stability. The article also discusses uses of the data in areas such as surface target detectability, electromagnetic interference investigations, and radar environmental studies.

As air threats become smaller (in radar cross section) and fly closer to the sea or land, a defensive missile faces problems similar to those confronting surveillance radars, i.e., how to distinguish the threat from the background clutter. The radar configuration is that of a bistatic radar, with the radar transmitter located on ship (the illuminator) and the radar receiver located on the missile (the seeker). The article by Marcotte and Hanson describes a system developed by APL that provides engineers and analysts with the seeker's perspective of the radar environment. The Laboratory has placed Standard Missile hardware in a pod for use aboard a specially instrumented aircraft. This "captive" seeker provides data needed to accurately model surface reflections. The system includes real-time signal processing capabilities, onboard the aircraft, that allow immediate evaluation of an ongoing test. Therefore, test modifications are possible that can result in optimal use of limited, and expensive, test range time. The article describes how APL's captive seeker efforts contribute to various missile and radar programs and how the system is being upgraded to maintain its utility to missile system design at the Laboratory.

A recurring theme throughout many of these articles is the relationship between radar performance predictions and accurate environment models. Modern coherent radar signal processors can be accurately modeled because of the digital nature of these devices, which lend themselves to easy replication in a computer program. Clutter environment models, particularly those involving inhomogeneous land masses, are more challenging. Such models are, by necessity, statistical approximations to the real world. Lin and Reilly describe a site-specific approach in which terrain clutter and target visibility are characterized for a specified radar in a particular coastal environment. The model takes into account the location of the ship, the site-specific terrain topography, the radar parameters, and propagation effects. Although not specifically requiring coherent data, the effort has used the extensive, high-dynamic-range clutter data available from the coherent data collectors described in earlier articles. Correspondence between model predictions and these databases is evident in both the geographic patterns and the statistical distribution of the clutter. The approach promises to provide the fidelity required to accurately assess the capabilities of radar systems in the littoral environment.

It is hoped that the articles in this issue will not only provide the reader with a glimpse of the breadth of the Laboratory's work in the area of coherent signal processing, but will also demonstrate the importance of in-depth, hands-on experience when dealing with these highly capable and complex radar systems. For in the end, achieving optimal radar performance requires a fundamental understanding of the system and its operational environment, and this understanding can only be achieved by viewing the world through the eyes of the radar.

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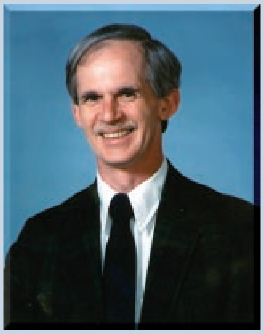

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