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SEARCH RADAR AUTOMATION: AN/SYS-1 AND BEYOND

Having pioneered the Typhon radar concept, a revolutionary advance in shipboard surveillance that later led to the Aegis system, the Laboratory made a second major advance in radar surveillance through the development of the SYS-1 automatic detection and tracking system. In contrast to Typhon, SYS-1 relies on inputs from existing Navy search radar that hitherto had required extensive human operator attention to provide a useful surveillance picture even in a clear environment. Applying a total system approach based on a fundamental understanding of radar and the environment, the Laboratory invented a means of suppressing superfluous radar noise without practical loss of detection sensitivity and developed computer logic to distinguish air targets from clutter echoes, determine their coordinates, and display them to the combat system. Today, many Terrier and Tartar ships are equipped with SYS-1 or one of its derivatives, making it possible to network accurate information from these and Aegis ships with the other combatants in a task force so as to effect a powerful integrated battle group defense.

INTRODUCTION

"I cannot shoot a duck I do not see." This remark, which is attributed to Admiral I. C. Kidd, Jr., USN, succinctly states the air surveillance problem from a military viewpoint. Although the Laboratory had been totally immersed in the problem of guided missiles for fleet air defense, APL's involvement in the surveillance problem was peripheral until the late 1950s. The surveillance function, along with command and control, was considered by the Navy to be external to any particular weapon system and was the responsibility of the Bureau of Ships—wholly outside the scope of APL's responsibilities and those of its sponsor, the Bureau of Ordnance.

In 1957, APL's Advanced Air Defense Study brought forth the realization that the Navy's traditional approach to surveillance was inadequate and would make effective defense of the fleet impossible in the future. From this study emerged the threat picture of surprise, confusion, and saturation, and to counter it the concept of an automated multi-function array radar that performed the dual functions of surveillance and fire control. Thereafter, with no license to do so, APL made a revolutionary advance in shipboard surveillance in the form of the Typhon radar, which later became embodied in the Aegis system (see Gussow and Prettyman, this issue).

The second APL contribution to shipboard radar surveillance, and the main topic of this article, followed as a consequence of the Laboratory's realization of the inadequacy of conventional surveillance systems and of the fact that a radically new radar could not be retrofitted on the Navy's Terrier and Tartar fleet. What was needed was some way to make the Navy's existing surveillance radars dramatically more effective. This was the objective of what became known as the SYS-1 system—an objective that originally raised much skepticism but that was eventually achieved beyond all expectations.

During the late 1960s and early 1970s when the SYS-1 was taking form, other efforts were under way to upgrade the surveillance effectiveness of the fleet, under the sponsorship of the Bureau of Ships. The fact that the APL concept succeeded whereas others failed was largely attributable to the total system approach that was taken and to a fundamental understanding of the surveillance environment, notably the physics of radar clutter (radar reflections from land, sea, and weather). The APL approach was to divide the task between two complementary interacting elements: a hardware element that conditioned the output of the radar to suppress superfluous noise and provide a signal with a controlled false-alarm rate, and a software element (operating in a general-purpose digital computer) that provided the logic to distinguish air targets from clutter and interference, determine their coordinates and rates, and designate them to the weapon system. This balance of functions enabled the system to be relatively simple and to operate over a wide range of environments.

SEARCH RADAR

Invented before World War II and quickly flowering into widespread use during that war, radar (radio detecting and ranging) provides an important means for sensing the environment at and above the surface of the Earth. By the end of World War II, the use of radar for surveillance was well established. In a conventional search radar, a beam of radio-frequency energy is swept over a volume of space surrounding the radar by mechanically rotating a highly directional antenna at constant angular velocity.

The detected reflected energy (signal) is displayed on a cathode ray tube. The intensity of the beam is made proportional to the signal amplitude, and the beam is deflected from the center of the tube by an amount proportional to the time delay of the echo (range) and at an angle corresponding to the angular direction of the center of the antenna beam (bearing). This display, called a plan position indicator (PPI), is visually scanned by a human operator who interprets the echoes displayed. Electronic cursors on the display enable the operator to measure the range and bearing of echoes of interest. The echoes from ships or aircraft (blips) are distinguished from those of land or weather (clutter) by the operator. Under environmental conditions normally prevailing at sea, this interpretation process is quite demanding on the operator, especially for the microwave radars used for three-dimensional (3D) surveillance (Fig. 1).

From the beginning, electronic circuits were devised to help the operator by suppressing clutter returns and enhancing target signals. The number of these "fixes" quickly proliferated. Unfortunately, no single fix was universally effective, but when fixes were employed in various combinations, some improvement could usually be achieved in the environment of the moment. By the early 1960s, most search radars had at least a half dozen of these operator-selectable signal processing features, with names such as log video, sensitivity time constant, fast time constant, and fast automatic gain control. Used under the wrong conditions, a particular feature would diminish the likelihood of target detection, and even the most skilled operator was usually reduced to trial and error in its application. Thus, detection and tracking of targets by radar required operators who were not only attentive and skilled in recognizing target blips in the presence of noise and clutter, but also highly knowledgeable of the many selectable signal processing features of the radar and the appearance of the environments in which their use would be beneficial.

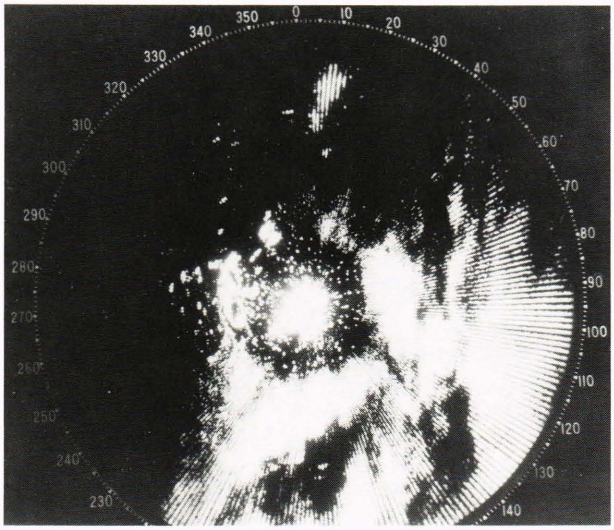

Figure 1. 3D radar plan position indicator (PPI) display. Aircraft appear as one or two small dots; the annular ring around the center is sea clutter; and the large bright masses are returns from weather and land.

Recognizing the time-intensive nature of the operator's task, the pragmatic approach of providing multiple plan position indicator displays and operators was adopted early. The senior operator would manage the radar controls and scan the display for new targets. As each new target was detected, it was handed off to one of the assistant operators, who would track it by observing the position of its blip on each scan of the radar beam until it disappeared. Although effective in increasing the number of tracks that a ship could maintain, this people-intensive approach became increasingly impractical in the years following World War II as economic pressures mandated reduced ship manning and the need to provide even small ships with the capability to track large numbers of targets. The significance of this capacity problem was demonstrated by tests conducted at APL in the 1960s that showed that an operator could sustain accurate track on at most six aircraft in a clear environment for normal radar scan periods of eight to ten seconds. In the presence of clutter or radar interference, the number decreased drastically.

Two types of air surveillance radars are installed on all guided missile ships: 3D radar that measures target elevation, as well as range and bearing, and provides the main source of target designation to the weapon system, and a two-dimensional (2D) radar that supports long-range detection and serves as a backup in the event of casualty to the 3D radar. The 3D search radars evolved from the height finder radars of World War II and have a rotating antenna that radiates a sequence of stacked pencil beams to determine target elevation. The less complex 2D radars employ a broad vertical (fan) beam to sweep the air volume and are direct descendants of the World War II air search radars. They generally operate at frequencies between 200 and 1200 MHz, making them less affected by weather clutter than 3D radars, which operate at frequencies around 3000 MHz.

MANUAL TARGET DETECTION

Observations during firing tests of the Terrier, Tartar, and Talos (3T) anti-air (AA) missiles at sea clearly demonstrated problems in initial radar target detection, evaluation, and assignment to missiles. Observation of search radar operation and analysis of radar scope photography showed both the difficulty of the operator's task and the time disparity between target disclosure by the operators, display of a detectable signal by the radar, and the range at which the theory of the time predicted that a detectable signal should be displayed. In addition to embarking on an effort dedicated to continued test and assessment of AA-related search radar performance that spanned more than two decades, APL also undertook studies directed at better understanding the problem and developing means to correct it.

Initial corrective efforts were concerned with aiding the operator by providing improved video displays using new cathode ray tube phosphors, display setup procedures, and novel modes of display such as time compression. Time compression, initially conceived by the Naval Electronics Laboratory, offered a helpful means to detect targets in noise or point clutter. When video from four

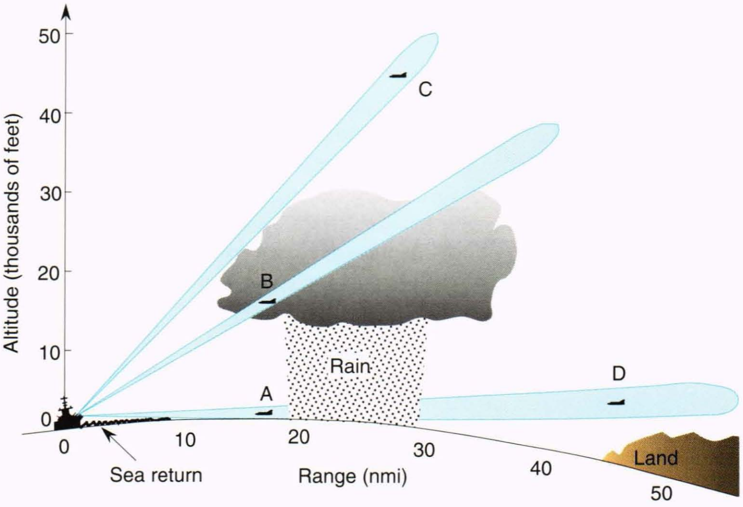

Figure 2. Problem of detecting targets in the presence of clutter with three-dimensional search radar. Four aircraft (A–D) are shown flying at various ranges and altitudes, but only one of them (B) is directly in a clutter zone.

or five successive radar scans is stored and then played back about ten times faster than real time, air targets appear as a sequence of coherently moving blips, whereas clutter remains essentially fixed and noise appears as scintillation. Unfortunately, despite intensive efforts, the technology of the time did not support production of a practical time compression display, although the principle was very valuable in the laboratory for use in analysis of recorded radar video.

The necessity of using a plan position indicator display for manual target detection and tracking with a 3D radar, where clutter or jamming are present in the vertical scan plane containing a target, largely negates the advantage of vertical beam directivity, since the videos from all of the beams that make up the elevation scan are collapsed together on the plan position indicator. This situation is illustrated in Figure 2, which shows a hypothetical radar environment consisting of a rainstorm between 20 and 30 nmi, land beginning at 45 nmi, and sea return out to about 10 nm. Four aircraft (A–D) are shown flying at various ranges and altitudes, but only one of them (B) is directly in a clutter zone. Whereas targets A, B, and C would be clearly visible in their respective elevation beams, when the beam returns are all collapsed on the plan position indicator display, all targets are obscured by clutter at higher or lower altitudes and probably would not be detected. In 1965, Alexander Kossiakoff, then the Associate Director of APL, recognized that if extended clutter and noise that were strong enough to obscure a target were suppressed from the display, then targets in the clear, above and below the obscured beam region, would be visible to the operator. Working in conjunction with James R. Austin, circuits were devised that, using a moving detection window with a width proportional to the range resolution of the radar, produced an adaptive signal threshold by comparing the amplitude of the signal in the detection window with that in a few resolution cells preceding and following the window. When the signal in the window exceeds a threshold developed from the surrounding cells, a detection is declared, and the video in the window is passed on for display (Fig. 3).

Experimental models of the adaptive threshold video processor were first tested in the laboratory and then demonstrated to be effective in tests with radars at sea. Surprisingly, this concept had not been applied to radar previously, nor was it accepted readily as a decisive advance over conventional fixed-threshold detectors. Accordingly, it was not pursued into the full-scale engineering stage until considerably later, as an integral part of an automatic detection and tracking system.

AUTOMATIC TRACKING

Early in its military application in World War II, radar was put to use for naval gun fire control. The precision

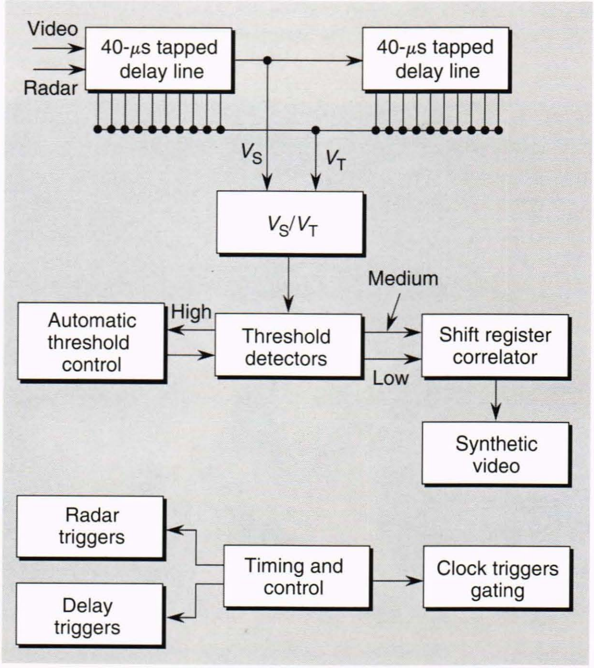

Figure 3. Block diagram of the original adaptive video processor. V_S = signal voltage; V_T = threshold voltage.

range measurements* provided by radar were superior to those obtainable with optical range finders, particularly in haze and darkness. The electronic technology of the time supported the automation of target range and, later, angle tracking for the radar-equipped directors; by the end of the war (1945), several models of operationally effective fire control radars were in service. With the successful development of AA-guided missiles by APL, this technology was used by the Navy for the directors to provide their fire control.

During this period, efforts were also directed at applying this technology to search radars to provide an automatic track-while-scan capability. Particularly notable were the efforts by Bell Telephone Laboratories on behalf of the Navy. An automatic target evaluation, weapon assignment system was built and installed in the (AA gun) cruiser *North Hampton*, and modified versions were also installed in the first Terrier-guided missile cruisers, *Boston* and *Canberra*. Although well engineered, these systems were less than successful, not only because of the limitations of the available vacuum tube analog technology, but also because of the low data rate ("looks" at the target separated by intervals of eight seconds or more), target signal fluctuations due to propagation effects, and false tracks or track loss in the presence of clutter.

Although the automatic tracking feature of these systems was useful only under the best of conditions, the rate-aided track circuits provided were of significant help for radar operator tracking. On the basis of an initial target position input by an operator and updates of that position on succeeding radar scans, these circuits compute the rate of motion of the target and position a cursor on the scope at the current predicted position of the target. Rate-aided tracking was included in all of the Bell-designed analog weapon direction equipment installed on Terrier and Tartar ships and, in digital form, continues to be provided for tracking in the Naval Tactical Data System (NTDS).

With the wide availability of general-purpose digital computers and their use in the NTDS for modernizing ships' Combat Information Centers, a new attempt at search radar automatic detection and tracking was initiated under the Bureau of Ships sponsorship. As a part of the NTDS effort, a system consisting of a radar video processor and a detection and tracking computer program was installed in the USS *Oriskany* for collateral testing during NTDS operational evaluation. The radar video processor provided the analog interface with one of the ship's radars and converted the radar video to digital form and interfaced with the NTDS computer. Unfortunately, the simple fixed detection threshold of the radar video converter was incapable of handling clutter, which inundated the computer with false targets. A succession of development and procurement of improved radar video converters and computer code failed to produce an operationally effective automatic radar tracking adjunct to NTDS. Although these approaches did not succeed in tracking uncooperative aircraft, they did produce a beacon video processor that provided the NTDS complex with the capability to automatically acquire and track Identification, Friend or Foe (air traffic control) beacon responses. The beacon video processor was installed on major ships, such as aircraft carriers and cruisers, and provided accurate position information on friendly aircraft equipped with beacons.

EARLY APL EFFORTS

The initial and most comprehensive APL approach to solving the critical problem of providing anti-air warfare (AAW) weapon systems with a timely, accurate, comprehensive picture of the air situation in all environments was the concept of a fixed-array, multi-function, electronically scanned radar performing the functions of surveillance, fire control, and missile guidance. This revolutionary concept was first demonstrated in the Typhon program (see Gussow and Prettyman, this issue). Freed from the rigid regime imposed by continuous mechanical rotation of the antenna, this radar could sequentially devote the time and energy necessary to automatically track all targets of importance and then allocate the remaining time and energy to a systematic search of the surrounding air space.

Regrettably, the technology to support the frequency diversity phased-array radar, with its thousands of radiating elements, had not matured when the Typhon prototype was built. The resultant developmental difficulties, coupled with competing financial needs, led to the cancellation of the Typhon program. The Typhon concept, however, was used as the basis of a successor program, Aegis, that followed a decade later and produced a new generation of powerful AAW ships now being introduced into the fleet.

Through its participation in the 3T Get Well program in the middle 1960s, APL had become aware of the inadequacy of the radar surveillance systems in the Navy's rapidly growing guided missile fleet. It was also clear that the Terrier and Tartar ships would never accommodate a radically new and complex radar system such as Typhon or Aegis, and that any solution to their surveillance problems must use the existing search radars with only limited modifications. Since rapid reaction time and the capacity to handle a multiplicity of target tracks could not be achieved by reliance on manual detection and tracking, the radar automation problem that had frustrated previous efforts had to be solved.

A concept for automating the operation of a conventional 3D surveillance radar was proposed by Alexander Kossiakoff in 1966, building on the successful development of the adaptive video processor and the availability of small, affordable, digital computers. The concept involved using the adaptive video processor to suppress regions of extended clutter or noise jamming, while retaining full sensitivity in clear regions. The thresholded radar pulses would be entered into a digital computer, along with the radar beam bearing and elevation, and compared with returns from previous scans. Those showing systematic variations in range and bearing (and el-

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*Fortunately, precision was required rather than accuracy. Since the fall of the shot and the target were simultaneously observable by the radar, errors in radar target range measurement and gun laying could be calibrated out by orders for small changes in gun elevation called "spots."

evation) would be classified as belonging to air tracks. Because of the efficient operation of the adaptive video processor in controlling the false-alarm rate into the computer, it was envisaged that more than a hundred targets could be tracked simultaneously, even using a relatively modest computer (in contrast to the maximum NTDS limit at that time of thirty-two tracks).

The details of this concept were developed in a series of brainstorming meetings, and a preliminary design of an ADT computer program soon followed. All indications were that the concept was eminently practicable.

A potential obstacle to the Navy's acceptance of an automatic detection and tracking (ADT) system for current ships was that the conclusion that current Navy surveillance systems were inadequate to support AAW weapons was not widely held in the Navy. On the contrary, most Combat Information Center officers believed that their operators, using rate-aided tracking, were detecting and tracking all targets of interest effectively. As part of the continuing APL effort to get operational data on this question, APL obtained permission to send a team of observers aboard the USS *Mahan*, operating in the Gulf of Tonkin, to make recordings of radar video and NTDS tracks for subsequent analysis. This operation, called project SNAPSHOT, was led by R. Robinson, who had previously converted a commercial tape recorder (RAVIR) to record radar video with high fidelity, along with timing, coordinates, and other signals necessary for playback reconstruction.

Following a month of operations in the Gulf of Tonkin, the RAVIR tapes were analyzed at APL both manually and by the use of an early experimental version of the APL ADT system using an adaptive video processor and a program running on the Univac 1230 computer. The results were dramatic. Manual reconstruction of air tracks by slow-motion scan-by-scan playbacks of recorded radar video produced a wealth of well-defined tracks. When overlaid on the recorded NTDS tracks, however, the correlation was extremely poor. Analysis showed that track crossings or target fades confused the operators, and many tracks were not detected near clutter regions. In contrast, when the playbacks were processed by the experimental ADT, the great majority of the tracks were detected and maintained in track. The results demonstrated to APL that ADT was absolutely essential for effective surveillance in operational environments and that the APL technical approach represented a sound basis for system design.

The Laboratory's first opportunity to apply its ADT concept to a shipboard system was to a subsidiary but significant surveillance function, that of height finding. The Navy's installation of AN/SPS-48 search radar aboard two guided missile cruisers, the USS *Daniels* and the USS *Belknap*, provided an opportunity for the Laboratory to demonstrate its new capabilities by developing and building ordnance alterations for the weapon direction equipment Mk 8 (developed by Bell Telephone Laboratories) installed in those ships. Ordnance Alteration 6959 enabled the weapon direction equipment to automatically measure the height of targets being tracked by operators using the SPS-48 radar's nine simultaneous vertical-stacked beams of video (Fig. 4). Previously, using the single-beam AN/SPS-39A radar, the operators had to observe and enter the target's height from a height display. Since no practical means for the simultaneous display of nine beams of video was available, the employment of an APL adaptive video processor and a hardened commercial general-purpose digital computer (Honeywell DDP-516) to automatically measure target height provided an attractive means to solve the problem. With in-service support provided by the Naval Surface Missile Systems Engineering Station, the equipment remained in opera-

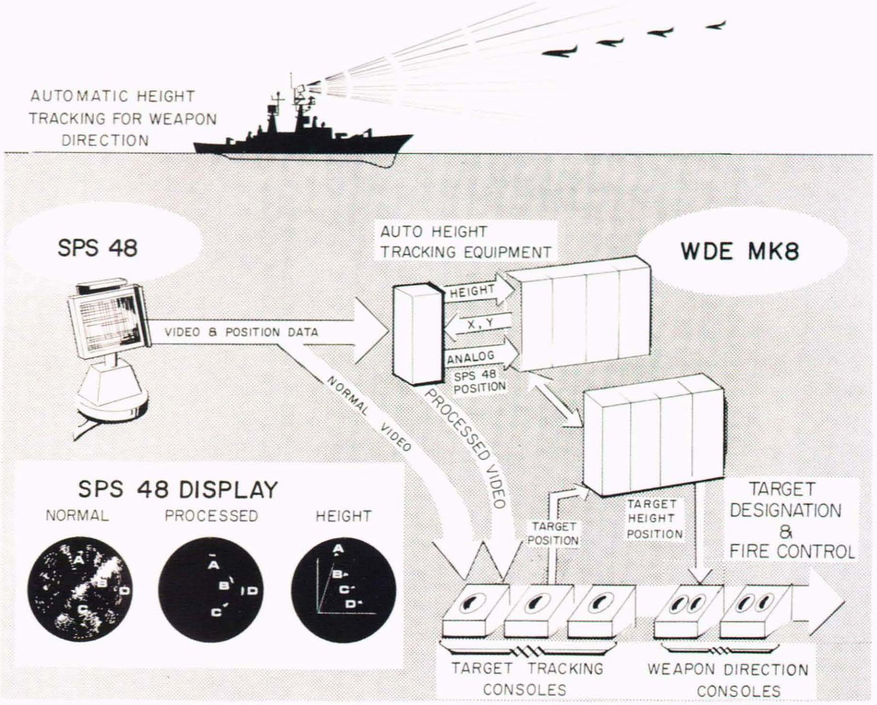

Figure 4. Automatic height tracking system in the USS *Belknap* and the USS *Daniels*. WDE = weapon direction equipment.

tional service until the unit on the *Belknap* was destroyed by fire resulting from a collision with the USS *Kennedy*, and the unit on the *Daniels* was retired as a part of Standard Missile 2 modernization. The success of this effort was due in great part to the efforts of several APL Space Department personnel as well as Joe Phipps (adaptive video processor), Steve Tsakos (computer program), Russell Phillippi (test), and George Emch.

RADAR DETECTION SYSTEM

In 1969, the Laboratory defined an ADT system designated as the Radar Detection System (RDS), the forerunner of SYS-1. This work was done in conjunction with the Threat Responsive Weapon Control System development programs for the Terrier and Tartar missile weapons systems. In addition to an updated adaptive video processor, the RDS used a Honeywell DDP-516 for digital data processing. A simplified block diagram of the system is shown in Figure 5. Radar video is processed in the adaptive video processor, where target detections are generated on the basis of threshold crossings, wide pulse discrimination, and hit correlation within a partial elevation scan. All of the target detection and track logic, as well as system control, is contained in the computer program. The RDS was developed by a team headed by James Austin, and Kim E. Richeson was the principal architect of the RDS computer program.

During the early winter months of 1970, the RDS was tested at the Mare Island NTDS test site. The tests demonstrated the success of the adaptive video processor and the ADT program, even under the conditions of adverse clutter and the mountainous environment in which the tests were conducted.

Earlier in 1970, a major fleet exercise (ROPEVAL 1-70) was held and provided a wealth of information. This exercise demonstrated quite clearly the inadequacies of the current shipboard equipment with respect to target detection and continuity of track. It also provided the Laboratory with another set of raw data for use in further development of the ADT computer program.

When intensification of U.S. naval operations in the Indochina theater (Vietnam) and the threat poised by U.S.S.R.-supplied Viet Cong highlighted the need of the Navy for effective radar air surveillance, the Bureau of Weapons requested that APL initiate a crash effort to provide several ADT units for use with the SPS-48 radars in Terrier ships. Although the subsequent operational situation did not dictate the deployment of this equipment to Southeast Asia, this effort materially advanced the maturity of the APL ADT effort.

The Bureau of Ships, unsuccessful in its efforts in general-purpose radar ADT, funded the development of an automatic target detection capability for the SPS-48 radar by its manufacturer. Although the resulting SPS-48 ADT functioned only in the most favorable environment, it was placed into service and provided 3D radar inputs for the Terrier SM-2 system until it was superseded by an APL-conceived integrated ADT (IADT) system (SYS-2) in the New Threat Upgrade.

AN/SYS-1

As noted previously, the Bureau of Ships had been sponsoring the development of ADT systems at its radar contractors and did not recognize the worth of the APL concept in the early 1970s. With the Bureau of Ships effort concentrated on ADT for the newer SPS-48 radar, however, APL turned its efforts to automating the AN/SPS-39 and AN/SPS-52 3D radars, which performed the surveillance function on Tartar destroyers. Figure 6 is a pictorial representation of the APL ADT system, illustrating the successive stages of processing of the search radar video through the adaptive video processor and finally the display of automatically generated tracks for designation to weapons.

With support from the Navy's guided missile project office, a Development Assist Project, DS/652, was established to test the APL system aboard the USS *Somers*, a Tartar guided missile ship of the latest design. The APL system installed on the *Somers* was designed to operate with either the ship's 3D radar or its SPS-40 2D long-range air search radar to investigate the potential advantage of integrating both sensors.

Since Tartar destroyers were not then equipped with NTDS, it was also necessary to provide means to display and

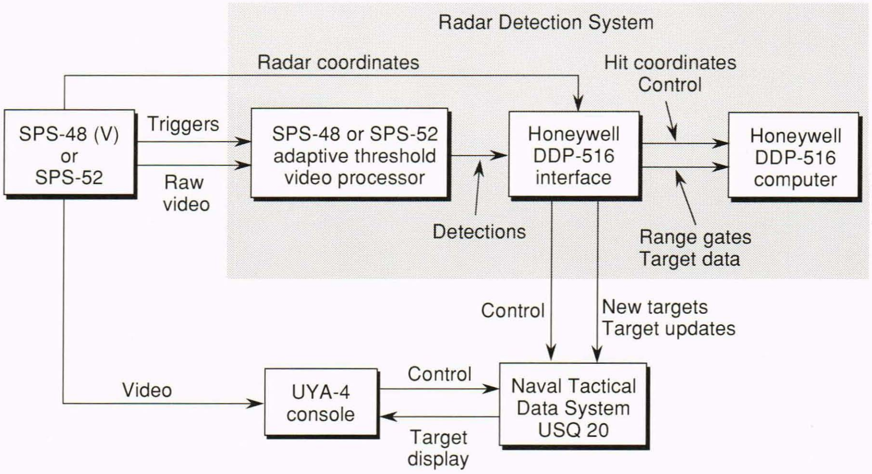

Figure 5. Block diagram of the Radar Detection System.

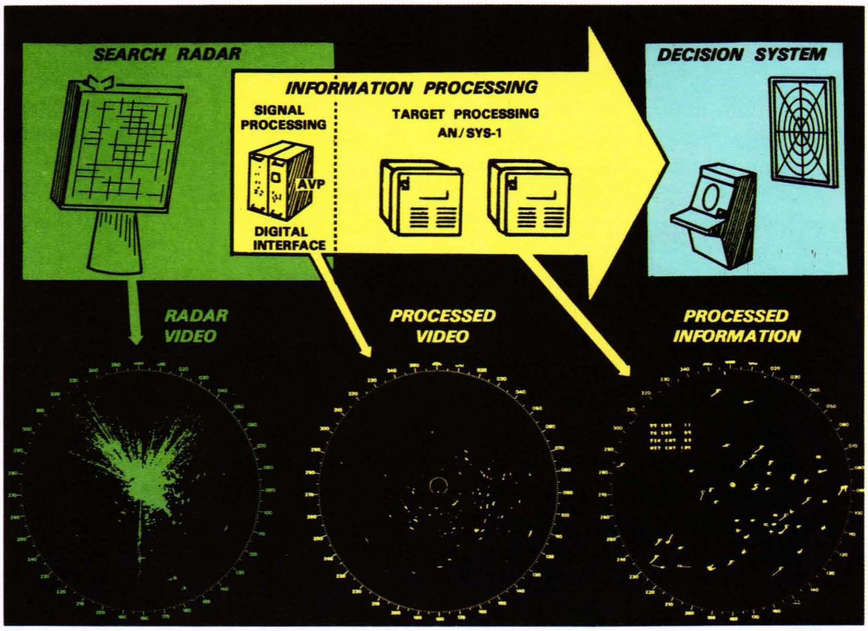

Figure 6. AN/SYS-1 detector/tracker set data flow. AVP = adaptive video processor.

distribute the system track outputs. Means were also provided to enable designation of ADT tracks directly to the fire control systems via the weapon direction equipment.

In the *Somers* tests, which were conducted off the coast of California in March and April 1973, the performance of the APL ADT system was very good (see Fig. 7). The capability to automatically detect and track large numbers of aircraft in the at-sea environment without creating an unacceptable number of false tracks was impressive. Of particular importance was the improvement achieved in target designation to the fire control system, which was reduced from minutes to seconds. As noted by the ship's captain, Commander W. E. Vollmer, in his comments on the operation, "[I] am extremely impressed by additional capability provided by SYS-1. Most significant is the designation speed and precision that enable fire control to lock on at speeds never before experienced." Analysis of recorded outputs of the 3D and 2D radars also showed their complementary nature in providing continuous tracking of marginal targets.

SYSTEM DESIGN

Given the success of the development assist test, the Navy decided to proceed with the APL development, now designated as AN/SYS-1, as a part of the Tartar DDG-2/15 Class Upgrade Program. Based on Navy studies of available alternatives suitable for modernization of these classes, the proposed program included outfitting the ships with a version of NTDS, replacing the analog weapon direction equipment with a new digital system, and modernizing its search radar suite. In recognition of the significant advantages that could be obtained by exploiting the complementary characteristics of the ship's radars, especially in electronic countermeasure and clutter environments, central to the new radar suite concept was an IADT system that would employ the outputs of the ship's search radars to form a single unduplicated track picture.

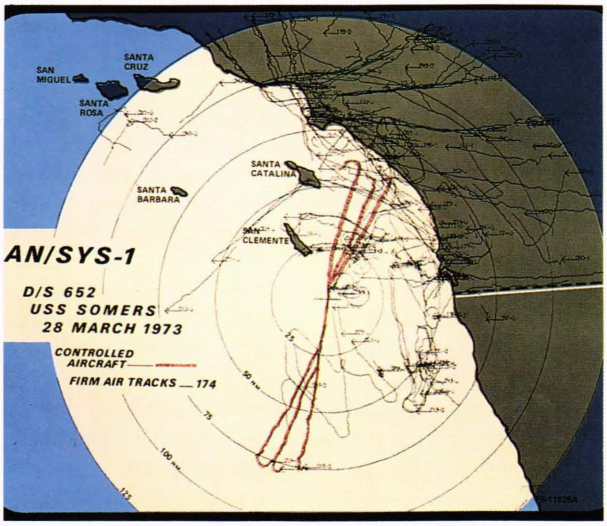

Figure 7. Twenty-seven–minute computer plot of SYS-1 tracks, operational verification exercise, 28 Mar 1973, showing good track continuity and complete coverage (143 tracks). Test aircraft are indicated by red, and non-exercise aircraft (commercial and military) are indicated by black.

The equipment that constitutes the SYS-1, as illustrated in Figure 8, includes two UYK-20 computers, two NTDS-type operator consoles, a magnetic tape unit for computer program loading, an external information converter to input the ship's course to the computers, and a multiplex unit and casualty switches to enable system reconfiguration in the event of casualty to one of the computers.[1,2] Although technically not a component of SYS, the radar video converters (including the adaptive video processor) associated with the radars feeding the system are critical to its successful operation. To take advantage of the special knowledge and skills resident with the industrial contractors for each particular radar type, the equip-

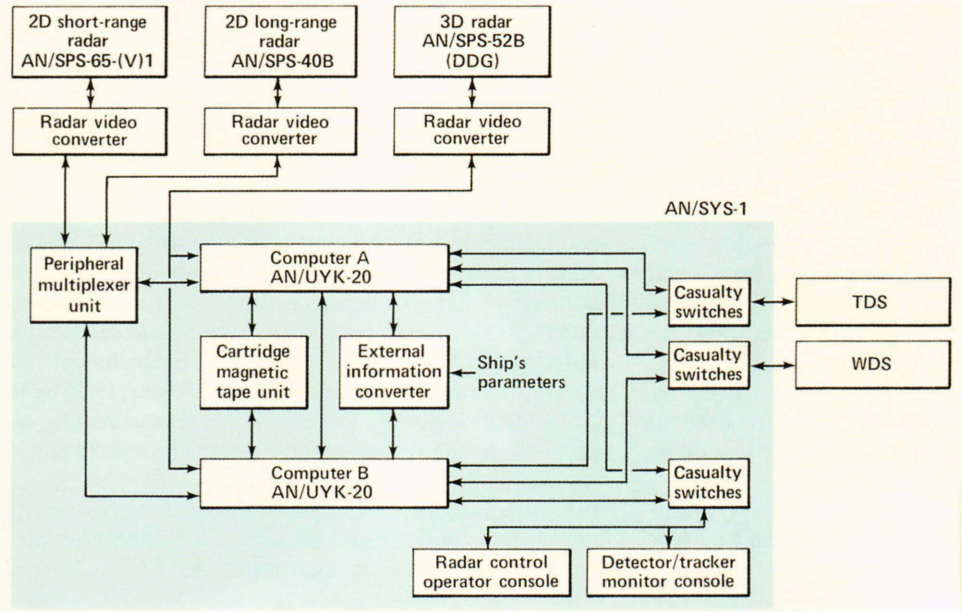

Figure 8. AN/SYS-1 system equipment. TDS = Tactical Data System; WDS = Weapon Direction System. (Reprinted from Ref. 2, p. 269.)

ment is produced in accordance with detailed specification provided to the Navy by APL. First articles are subject to extensive collaborative design review and intensive interface testing with SYS.

The computer program that articulates the system runs in two computers, designated A and B. In the SYS-1 Engineering Development Model (EDM) (which is also roughly illustrative of the elements of most later SYS variants), digitized radar contact data are fed to computer A while computer B interfaces with the operator consoles, Tactical Data System, and Weapon Direction System (Fig. 9). Four program modules—program executive, interface, monitor, and utilities—effect system-level functions. The program executive module manages overall program operation. The time usage and processing loads of all of the other modules are monitored, and this information is used to dynamically control the priority of execution routines to maintain balanced operation. This

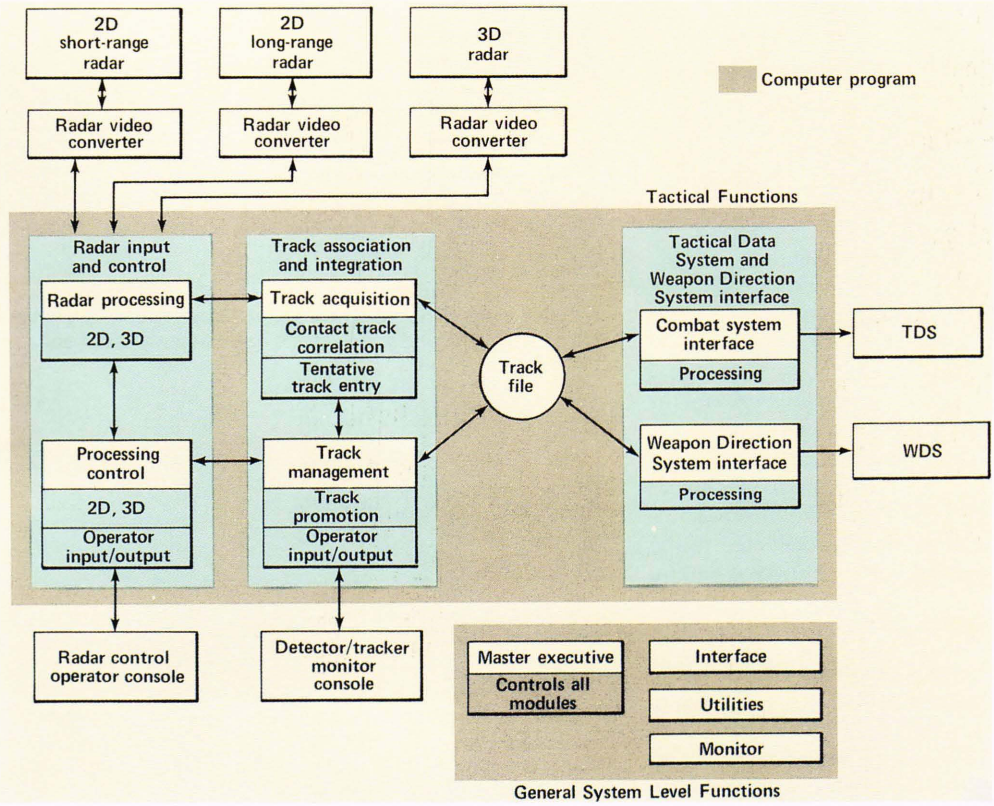

Figure 9. AN/SYS-1 IADT computer program modular organization and system interfaces. TDS = Tactical Data System; WDS = Weapon Direction System. (Reprinted from Ref. 2, p. 269.)

module also performs the usual executive functions such as program initialization and instruction fault processing, as well as effecting power failure detection, shutdown, and recovery.

The radar processing modules act to identify target returns in the data stream coming from each radar. Contacts (targets) are transferred from the converter to the SYS radar processing module associated with the particular radar. A set of entry criteria, based on system load and operator-defined environmental factors, is applied to each contact to reject those not likely to be from real targets.

The accepted contact files are passed to the track acquisition module, which maintains a track file by updating existing tracks, initiating new tracks, and resolving track conflicts when they occur. Contacts are used to update the track filters, which use an approximation to a nonlinear Kalman filter.

The track management module systematically evaluates all of the tracks in the track file to maintain a current track quality rating based on the number of accepted contact reports, the prevailing clutter and countermeasures environment, and whether the target trajectory described could be flown by a real target. There are three levels of track quality: tentative, assumed, and firm.

The functioning of the three preceding modules is regulated by the processing control module, which automatically acts to maintain an acceptable data rate and to maintain new track formation at a reasonable level. Because the radar operating environment is continually changing, the classification criteria must also be continually adapted to the nature of the environment.

The tracks developed by the system are reported to the ship's Tactical Data System by the combat system interface module. When a track's quality reaches firm, it is automatically reported to the Tactical Data System as a new track, and in response to periodic Tactical Data System requests, position updates for it and all other firm tracks are transmitted. Tentative tracks that satisfy quick-reaction criteria are also automatically reported to the Tactical Data System. Although the possibility that these tracks may be false is increased, the shortened reaction time obtained fully justifies the inconvenience when threatened by low-flying antiship missiles.

The weapons system interface module provides the interface with the Weapon Direction System. This module responds to requests from that system for track data on targets designated for engagement.

A casualty computer program is maintained ready for loading on the magnetic tape unit. This program, a reduced version of the operation program, requires only a single computer. When one of the computers fails to operate, the second computer senses the failure and automatically causes all radar inputs to be connected to the operating computer and then loads the casualty program.

DEVELOPMENT AND TEST

Assembly of the SYS-1 EDM equipment and development of the computer programs at the Laboratory were accomplished from 1974 to 1977 under the leadership of Paul G. Casner. With APL assistance, an Industrial Agent was competitively selected by the Navy with the view that this agent, Norden Systems, having participated in the EDM work at APL, could then proceed to produce the production systems. With Norden personnel in residence, the system including the three associated search radars was put into operation at APL (Figure 10). The readiness of the EDM system for operation was decisively demonstrated to the Navy in a graduation exercise.

Technical evaluation and operational evaluation were conducted in a West Coast Tartar destroyer. The USS *Towers* received a temporary installation of the proposed upgrade system, including prototypes of the three search radars, SYS-1, the Tactical Data System, and the Weapon Direction System. The at-sea phase of the technical evaluation was conducted from February to May 1978 by the Naval Ship Weapons Systems Engineering Station; APL provided technical assistance under the leadership of Eugene Frekko.

During this phase of the evaluation, an extensive series of tests was conducted in clear, clutter, and radar jamming environments to map the performance of the new surveil-

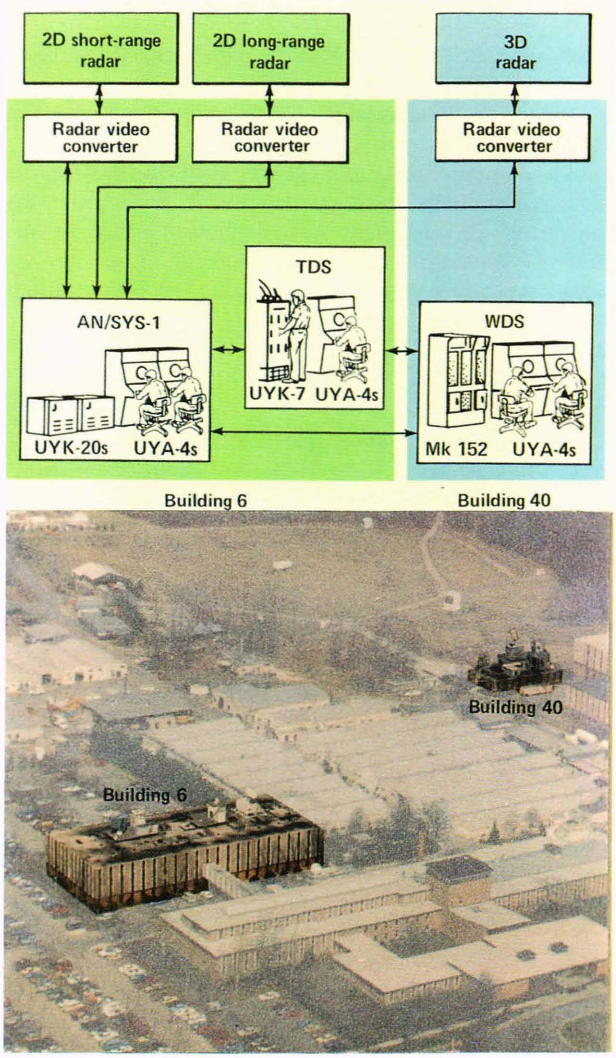

Figure 10. The APL land-based test site was established to exercise AN/SYS-1 with the other major elements of the DDG-2/15 class combat weapon system. TDS = Tactical Data System; WDS = Weapon Direction System. (Reprinted from Ref. 2, p. 272.)

lance system (the three search radars and SYS-1). Test aircraft were controlled to fly in radially from extreme range toward the ship, maintaining constant speed and altitude. Data were collected on detection, track continuity and accuracy, and false track generation. The results of these tests clearly demonstrated the excellent performance of the new system. The complementary coverage of the three radars integrated by SYS-1 enabled it to dependably detect targets at greater ranges and to maintain continuous, accurate track over the full volume of radar coverage.

Although prompt detection and accurate tracking of targets are important attributes of an ATD, it is essential that it not report false detections or allow tracks reported for targets to stray from the true target path. Such false tracks can result in the assignment of weapons to phantoms or a weapons search for a real threat in the wrong place. During the initial part of the technical tests on the *Towers*, an excessive number of false tracks were observed; computer program processing changes were devised that maintained the false track rate at an acceptable level throughout the remainder of the tests.

When the technical capabilities of the new combat system were fully tested and demonstrated to function as specified, the evaluation was handed over to the Operational Test and Evaluation Force to determine if the system was operationally effective and suitable. In this phase of testing, which extended from June to September 1978, the system was operated exclusively by *Towers* personnel, and all contact with the developing agents was prohibited. During twenty-six days of at-sea tests using more than 300 single or multiple test aircraft sorties, the performance of SYS-1 was tested in a variety of simulated tactical situations, and tests were also conducted to permit comparison of the capability of a ship equipped with SYS-1 and an equivalent ship employing manual detection and tracking. The material reliability of the system was observed, and during the more than 1000 hours of operation during the test, no failures to the SYS equipment or computer programs were experienced. On the basis of the results of these tests, the Operational Test and Evaluation Force determined that SYS provided a significant improvement over manual systems, was operationally effective and suitable, and, subject to some minor conditions, should be approved for service use (see Fig. 11).

During the five years between the proposal for the modernization of the DDG-2/15 classes of Tartar destroyers and the approval for service use by the Chief of Naval Operations, the age of the ships, coupled with increasingly limited naval funding by Congress, led to the decision to modernize only three ships of the DDG-15 class. Australia and the Federal Republic of Germany had procured Tartar ships of the same class, and SYS-1 variants were procured by these countries under the U.S. Military Assistance Program for all of their ships of the class. Italy, Spain, and Japan obtained AN/SPS-52 3D radars for ships of their navies and, impressed by the performance provided by SYS-1, they also procured SYS-1 variants tailored where appropriate to operate with their indigenously produced 2D search radars and combat system equipment. In these on-going efforts, APL has continued to assist the Navy as its Surveillance Systems Integration Agent, technical advisor, and evaluator of the production system designs produced by the Industrial Agent (Norden Systems).

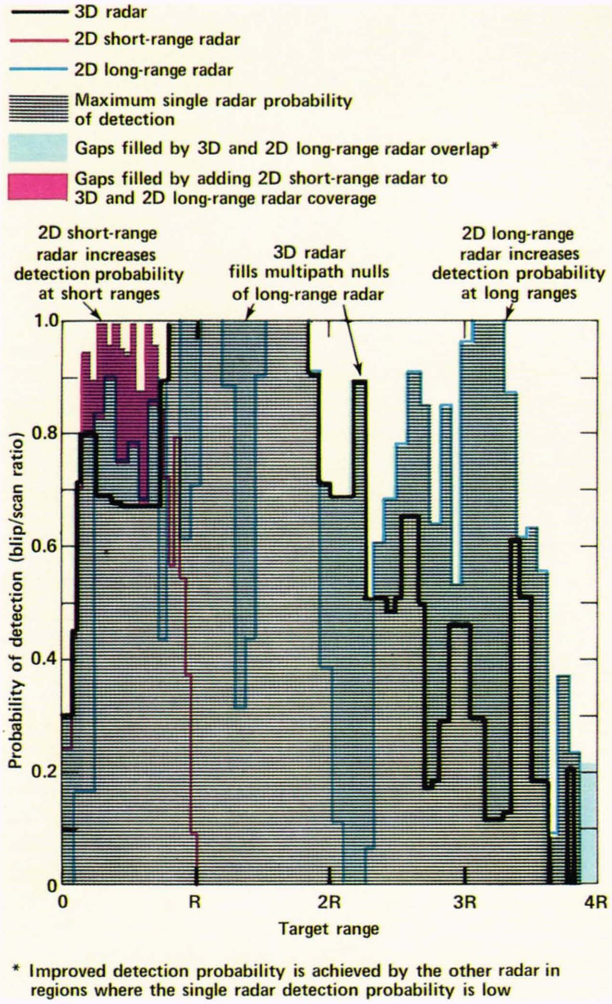

Figure 11. Composite radar-measured blip scan plot versus range for medium-altitude aircraft in a clear environment. (Reprinted from Ref. 2, p. 274.)

BEYOND SYS-1

In the mid-1970s, during the development of the SYS-1 EDM, the Naval Sea Systems Command commissioned a study to determine the capabilities of Terrier and Tartar cruisers against the projected threat of bombers armed with highly capable anti-ship missiles and to provide a plan to increase Terrier and Tartar effectiveness against this threat. The APL-led study group assessed the limitations of the then current systems employing Standard Missile 2 and defined system modifications necessary to overcome the projected threat. A principal element of the proposed ship system modifications was the development of a highly capable automated surveillance system based on an APL advanced IADT system concept. The Navy elected to pursue this New Threat Upgrade modification,[3] and detailed design and development of the AN/SYS-2 IADT system and modifications to the associated SPS-48 (3D) and SPS-49 (2D) air search radars commenced. The salient difference between the SYS-2 and SYS-1 articulated systems is the capability of SYS-2 to automatically effect dynamic changes in the mode of operation of the associated search radars to deal with the tactical situation and the operating environment. For example, the radiated power of the 3D radar can be concentrated on regions of tactical interest and elevation scanning, and can be modified to track targets at high elevation angles. Similarly, the 2D radar can be controlled by SYS to employ moving target indicator (MTI) modes of operation in cluttered regions while avoiding the losses associated with MTI by using normal modes in clear regions. An engineering development model of the New Threat Upgrade modifications was the subject of technical and operational testing on the *Mahan* in 1982 with highly successful results.[4]

Early in the 1980s, the development of automatic gridlock by the Aegis Battle Group Coordination Program[4] required effective automatic detection and tracking by the SPS-48 radars installed on aircraft carriers. The installed SPS-48 Automatic Target Detection System employed a fixed-threshold detector and was plagued with either excessive false tracks or reduced detection sensitivity in all but crystal-clear operating environments. As a part of an experimental Automatic Gridlock Demonstration System installation in the *Kennedy*, APL provided a Detection Data Converter for temporary use with the SPS-48 in place of the ATD.[4] This equipment and ADT computer program were based on SYS technology and provided very satisfactory performance. The fleet was very impressed with this equipment and urged expeditious production to replace the SPS-48 ATD. The Navy decided to procure field change kits for the radar that incorporated this technology and mandated that the production design of the SPS-48E New Threat Upgrade should also employ the same adaptive threshold design (the New Threat Upgrade SPS-48 EDM still employed a fixed threshold). With this development, all of the modern AA ships of the Navy have fully effective automatic detection and tracking. Currently, the Navy, with APL assistance, is proceeding with the development of a SYS variant for the FFG's, a SYS-2 variant to provide integrated ADT for the aircraft carriers and Wasp class of amphibious assault ships.

CONCLUSION

For many years, APL has recognized the vital importance of effective radar detection and tracking in AAW. With the unique capabilities and resources of a university laboratory, the problem has been subjected to experimental and analytic investigation, theory has been created and expanded, and a practical solution has been developed. As a result of the tenacious pursuit of these activities, the navies of the United States and its allies have available to them effective search radar automation technology.

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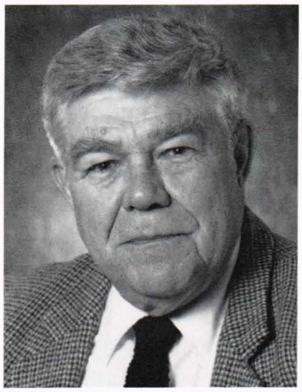
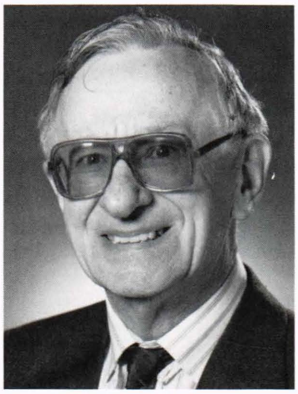
THE AUTHORS



GEORGE F. EMCH received his B.S. degree in 1947 from Trinity College, Hartford, Connecticut. He joined APL in 1948 as an Associate Physicist and specialized in the employment of analog computers in the dynamic analysis of guided missiles. In 1959, as Project Engineer, he was responsible for the development and operation of the APL Electronic Countermeasures Battle Simulator. Shortly after his appointment as the Assistant Group Supervisor in the Bumblebee Dynamics Group in 1962, Mr. Emch joined the newly created Fleet Systems Department, where he served first as the Assistant Group Supervisor and then as the Group Supervisor of a progression of groups specializing in the detection and control elements of combat systems. He was the Assistant Supervisor of the Surface Combat Systems Program Office before his retirement at the end of 1990.



GLENN I. KIRKLAND was educated at Carnegie–Mellon Institute in his home town of Pittsburgh, Pennsylvania. He received his master's degree in physics in 1942, but his doctorate was interrupted by World War II. He joined the staff of APL in July 1945, working on the development of the proximity fuze. In 1957, he was appointed to the Principal Professional Staff. At retirement in 1984, his main activity was systems analysis. Since retirement, he has been active with the Alzheimer's Association and is now best known for his role in award winning television programs about his former wife, Grace.