

# AEGIS: ADVANCED MULTI-FUNCTION ARRAY RADAR

Development of the Advanced Multi-Function Array Radar (AMFAR) by APL in the late 1960's represented a new dimension in radar system technology. AMFAR demonstrated the feasibility of automatic detection and tracking with resistance to environmental clutter through computer control. The development of automatic detection and tracking capability in AMFAR eliminated the inherent delays, errors, and saturation associated with manual control of the radar. This pioneering effort laid the foundation for Radar System AN/SPY-1A, the Weapon Control Radar System now being produced by RCA as a major element of the AEGIS Weapon System for TICONDEROGA (CG-47).

## INTRODUCTION

Substantial advances in technology are often the result of revolutionary approaches. Such a revolution in technology gave the AEGIS program its initial direction and head start at APL. The Advanced Multi-Function Array Radar (AMFAR) became the advanced development model for the AEGIS AN/SPY-1A Radar System, which will go to sea in TICONDEROGA (CG-47) in 1983. It not only brought all elements of the radar system together in a technology demonstration, but also demonstrated automatic detection and tracking of all air targets plus inherent resistance to natural and man-made clutter with computer control of the radar. It was conceived, designed, developed, and tested during the period 1964 to 1969.

The Advanced Surface Missile System (ASMS) Assessment Study, published in 1965, identified the requirement for a phased-array radar with high resistance to electronic countermeasures and with combined surveillance, tracking, and missile guidance capabilities. "Phased array" refers to an antenna technology that uses computer-directed orders to the radiating antenna to point or direct the radiation and electronically control the phase of the radiation from individual radiators located on the surface of the antenna. The advantage of phased arrays is that the antenna does not have to point physically at each target and, as a result, many targets can be tracked simultaneously by a single system. The radiation from the radar can be controlled selectively to point in different directions — many times each second — and thus the radar can replace many individual track radars.

AMFAR was the result of the program designed to demonstrate radar performance and reduce technological risks for engineering development of the ASMS-specified radar. The ASMS radar depended on successful development efforts in several areas. Such

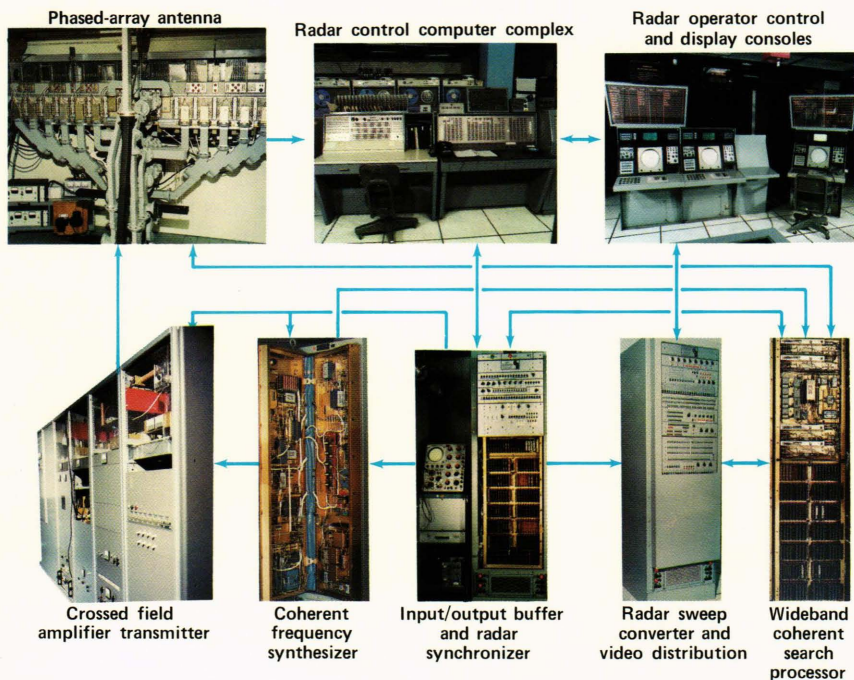
a program for an operational system carried elements of risk in committing manpower and resources to then untested concepts. Thus, the purpose of the AMFAR program was to demonstrate and test these concepts.

Key ASMS technology areas addressed by the AMFAR program included (a) transmitter tube design, (b) planar phased-array design, (c) electronic countermeasures resistance, (d) automatic detection and tracking, (e) all-environment operation, (f) computer control, and (g) automatic fault isolation. The AMFAR developments embraced a total radar system design to incorporate all of the risk items identified in the study by the ASMS Assessment Group. The major elements of AMFAR consist of a high power radar frequency transmitter, a phased-array antenna, a signal processor system, a computer control system, and an automated (computer-controlled) test system. These subsystems were designed, constructed, and integrated into the AMFAR system as shown in Fig. 1.

## TRANSMITTER DEVELOPMENT

The ASMS study proposed a radar transmitter that employed several crossed-field amplifiers (CFA) operating in parallel. The CFA is a variation of the magnetron familiar to many people as the source of power in microwave ovens. This represented a new concept in high-power transmitter tubes, and the parallel operation of multiple tubes presented inherent difficulties in operability. In 1965, APL awarded a subcontract to Varian Associates to develop such a tube. The tube was incorporated into AMFAR, which then became an experimental setup for the assessment of tube operability and suitability for use in the ASMS Radar System.

The experience gained in the AMFAR transmitter development ultimately resulted in a recommendation for a slight redesign of the tube in the engineer-



**Figure 1** — Successful development of the Advanced Multi-Function Array Radar (AMFAR) by APL paved the way for the automatic radar detection and tracking capability of the AEGIS Weapon System. This pictorial diagram shows the system components of AMFAR.

ing development model of the SPY-1A transmitter to satisfy high reliability requirements. Subsequent transmitter reliability measurements on the SPY-1A have verified that early decision.

## PHASED-ARRAY ANTENNA DEVELOPMENT

The phased-array antenna is one of the system elements that make the SPY-1A radar unique. With a phased array, it is not necessary to point a radar antenna mechanically in order to track targets. Energy from the transmitter is delivered to the antenna and distributed to several thousand individual phase shifters. The phase shifters are used to steer the radar beam electronically, under computer control, to any angle. This allows rapid movement of the radar beam throughout its coverage volume so that several hundred targets can be tracked concurrently by the same radar. Four such arrays are required to provide coverage of all zones around a ship.

As part of the AMFAR development effort, a small but complete phased-array antenna was built employing a new type of phase shifter. APL had been working since 1963 to overcome temperature sensitivity problems that existed with array designs using conventional ferrite phase shifters. A special garnet ferrimagnetic material was chosen for the AMFAR phase shifter design because it proved relatively insensitive to temperature variations under high power operation. The development effort was successful, and the array components went through a complete program for reliability assessment at high power.

The successful outcome of the early development work by APL, coupled with temperature stability complications surfacing in the AEGIS system prime

contractor's initial array design, led to a redirection of the original design approach of the SPY-1 array. The phase shifter development initiated under AMFAR by APL was used as a basis for the engineering development of the phased-array antenna for AEGIS.

## RADAR COMPUTER CONTROL PROGRAM

The Advanced Multi-Function Array Radar contained another unique feature. The cycle-by-cycle transmit/receive operations of the radar were controlled by a digital computer. The radar control program was required not only to execute logical functions of scheduling, tracking, and testing, but also to perform those functions within a single transmit/receive period in order to keep the radar and computer in time synchronization. This concept, initiated in AMFAR, was subsequently carried over to the current SPY-1 radar development, SPY-1A. To ensure this time synchronization, a large number of computer assessment techniques were designed during the AMFAR development and the subsequent engineering development phase of the SPY-1. A Computer Timing Monitor developed by APL was able to examine for the first time the exact execution time of particular blocks of computer program code under realistic operating conditions. This equipment has been used continuously by the system contractor during the AEGIS development program.

## OPERATIONAL READINESS TEST SYSTEMS

During the latter stage of the TYPHON Program, it became evident that there were significant problems in the operability and maintainability in complex sys-

tems of the type built for TYPHON and proposed for the ASMS. It was imperative that an automated test system be developed with the radar to provide for operational assessment and fault isolation.

The AMFAR program identified some entirely new test concepts that provided a statistical analysis of the system's operability. These concepts were based on simulated inputs and computer assessments of the outputs, in addition to computer-based fault localization and isolation. As a result of that early effort, these system concepts were expanded and engineered into the AEGIS Combat System. The automated test system currently implemented within AEGIS, directly related to this early effort, is called the Operational Readiness Test System.

## SIGNAL PROCESSOR DEVELOPMENT

The remaining technology issues on ASMS radar design centered on the signal processor for AMFAR. The function of the signal processor is to receive, amplify, and process the signals received by the radar from targets and the environment. The processing involves statistical examination of the returned signals to separate target returns from competing signals (such as clouds, rain, ground clutter, and electronic jamming). The signal processor must make appropriate decisions on targets (range, angle, and speed) under all environmental conditions, without errors induced by the competing signals. This capability is essential for all-environment automatic detection and tracking.

The AMFAR signal processor comprised three elements: a waveform and frequency generator, a synchronizer to develop the required precision timing signals, and the signal processor itself. These elements embodied a host of features now contained in the SPY-1A Radar System that were then revolutionary in nature.

The waveform and frequency generator development led to a new modulation technique that reduced the extraneous transmit signals outside of the desired radar band. This enabled the radar to meet electromagnetic compatibility specifications. The modulation technique set new standards for phase-coded signals and is now used in the SPY-1A. The modulation technique was useful because it removed all discontinuities in the waveform and, as a result, reduced the undesired sideband transmissions.

The synchronizer development again broke new ground with a special-purpose timing computer that could develop any sequence of timing signals for the radar by programming the computer appropriately. (The technique was subsequently employed by the SPY-1A contractor because of the inherent simplicity of the design and flexibility of the programmable device.)

To discriminate against noise, distributed radar returns, and nonmoving targets, the signal processor itself used phase-coherent digital-pulse-compression processing and non-phase-coherent multifrequency sampling techniques, coupled with coherent cancellation of sequential returns. (Coherent digital-pulse-

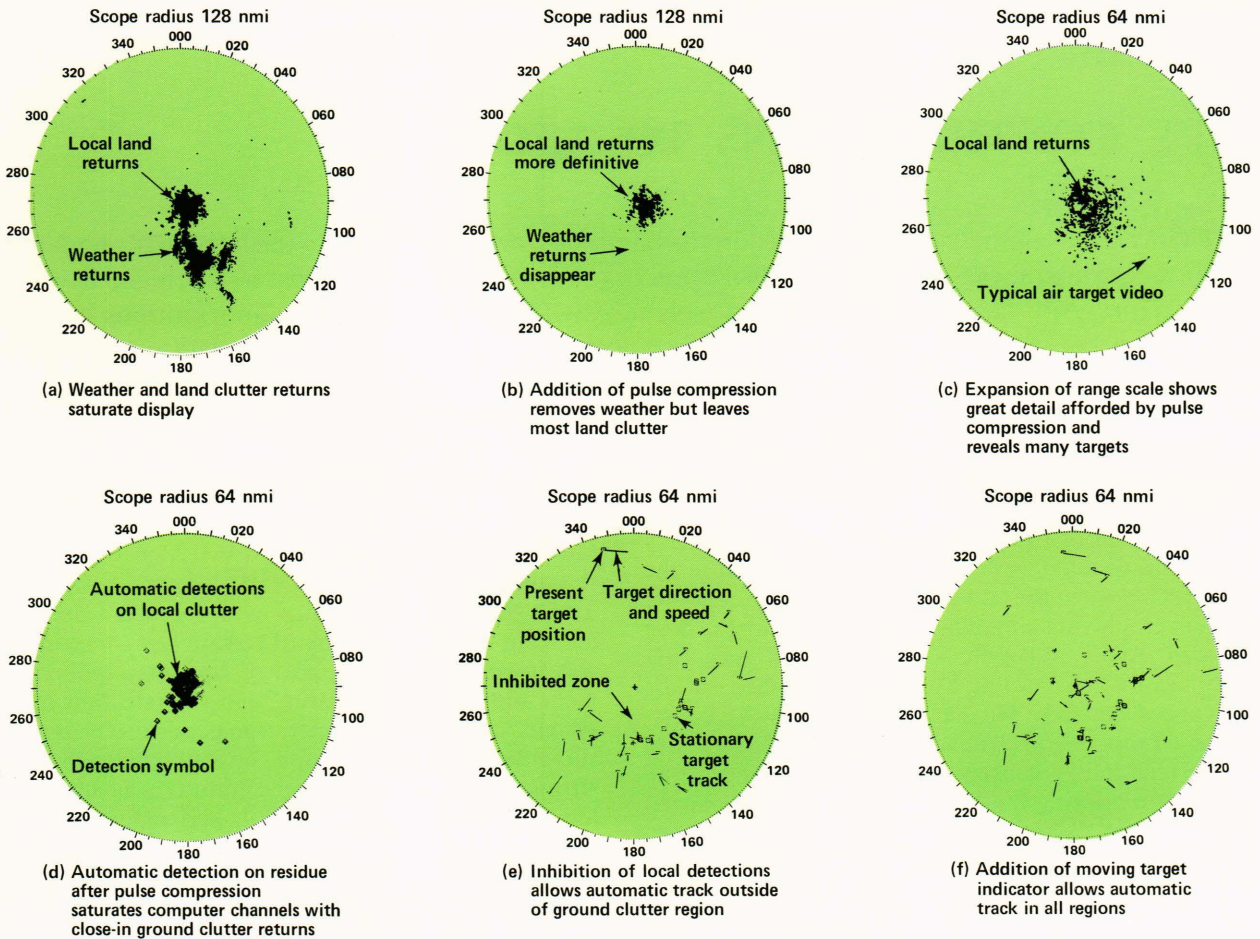
compression refers to signal-processing techniques in which the phase of the radar signal return versus time is measured and cross-correlated with the phase sequence of the transmitted signal. Return signals that match the transmitted phase signal correlate in the digital pulse compressor while noise does not. Moreover, the correlation exists for only the instant of time that the entire sequence exists in the digital processor. For example, a 100 microsecond pulse with 0.2 microsecond phase coding will give target position to a measurement accuracy of 0.2 microsecond, i.e., pulse compression. Noncoherent multifrequency sampling refers to the process of doing coherent sampling on multiple frequencies and summing the results of the coherent processes after detection in each coherent channel.) There are substantial statistical advantages to the combined processes. These techniques are now embodied in the SPY-1A radar.

The signal processor examines the entire sequence of signal returns collected by the radar antenna and makes decisions on the location of air targets. It is the device that buffers the real world into the computer and allows automatic detection and tracking by the computer. An example of the signal processor and AMFAR capability as a whole is shown in Fig. 2. The photographs were taken during the heavy rainfall from Hurricane Camille, which passed to the south of the Washington, D.C., area in the late summer of 1969. Both nonprocessed and processed radar returns are shown, as are detections declared by the radar control computer operating on the complete picture. Where the computer detection channel was saturated by returns from terrain, targets could not be detected without computer adaptation to the situation.

The computer maps the environment as seen by the signal processor and determines whether normal detection and track modes are inadequate in some areas. It also determines when a stationary target discrimination mode, commonly called moving target indicator (MTI), is required in the area immediately around the site because of close-in ground clutter returns. Automatic detection and tracking of targets is maintained outside the clutter zone using normal modes of operation. In Fig. 2e, target detections declared by the signal processor are passed to the radar control computer, which takes the range and angle measurements from the signal processor. Targets detected are maintained in a track data file within the radar control computer and are portrayed on displays as symbols, with vector leaders indicating location and velocity of the targets. The computer then instructs the signal processor to fill in the close-in zone with MTI modes to cancel nonmoving targets and to track moving targets. This allows the radar to track targets in both the close-in zone and beyond it, where non-MTI modes are adequate.

## CONCLUSION

The automatic detection and tracking performance of the AMFAR under wide variations of adverse conditions, coupled with engineering innovation and de-



**Figure 2** — The Advanced Multi-Function Array Radar automatically detects and tracks targets under all environmental conditions. The capabilities of the radar are demonstrated here in a series of photographs showing processing steps to provide automatic target detection and track in both ground clutter zones and rain clutter from Hurricane Camille.

velopment, represents the baseline of the AEGIS SPY-1A radar. This automation has resulted in a reduction in manual operation to the point where the operator is required only to establish zones and doctrine. Computer adaptation to the situation handles the remaining problems far more accurately and promptly than an operator.

The success of the AMFAR development was a notable achievement in the evolution of surface missile

system design at APL. The advanced and innovative solutions for many technical design problems that were incorporated in AMFAR cleared the way for competitive bids on the engineering development of the AEGIS Combat System. With the successful demonstrations of AMFAR capabilities at APL in the late 1960's, the theoretical concept of an automatic detection and tracking system became a reality with state-of-the-art equipment.