

APL CONTRIBUTIONS TO AEGIS

The AEGIS Weapon System, designed in the late 1960's and engineered in the late 1970's to defend against antiship missile threats in the 1980's and beyond, required an extensive research and development effort. APL has played a significant role in AEGIS development, with contributions in many technical areas from theoretical analysis and equipment design through system operational test and evaluation.

INTRODUCTION

Contributions of the Applied Physics Laboratory to AEGIS Combat System Development began in the mid-1960's when the concept of an advanced weapon system employing a high performance Multi-Purpose Phased Array Weapon Control Radar was first adopted in the Baseline Systems established by the Advanced Surface Missile Systems (ASMS) Assessment Group. Significant technical breakthroughs in radar technology subsequently were achieved in the Laboratory during the 1967-1970 period of advanced development. When the AEGIS Program began engineering development in 1969, APL, the Navy, RCA (AEGIS prime contractor), and other industrial organizations supported AEGIS system design and integration to insure the utilization of this advanced radar technology. With AEGIS now in the production cycle, much of the APL effort has shifted to applications of AEGIS in Battle Group operations and to technical support for an AEGIS upgrading program now in progress. Many of the outstanding APL achievements in support of AEGIS are featured in articles in this issue. This article provides an overview of the change in Laboratory emphasis as the program developed and will highlight specific contributions that are not discussed in other articles.

THE ADVANCED DEVELOPMENT PROGRAM AT APL

The ASMS Assessment Group recommended a baseline weapon system design that required a phased-array radar capable of surveillance, of rapid establishment of tracks having sufficient precision for midcourse control of the missile and pointing of an illuminator, of communicating guidance and control information to the missile, of performing these functions fully automatically, and of operating satisfactorily in electronic countermeasures. The success of the ASMS radar depended on satisfactory completion of developments in many technical areas, but even more so on the ability to integrate these equipment items into a producible, maintainable, multi-function system. APL acted to reduce the risks associated with commitment to this new weapon system by

conducting an advanced engineering development program in radar technology. The Advanced Multi-Function Array Radar (AMFAR) System was the nucleus of the 1967-1970 development program. The AMFAR development provided a means both for assuring that the maturity of certain key components was satisfactory for support of engineering development and for demonstrating that the resultant radar system could satisfy operational requirements for surveillance, tracking, and missile guidance with strong resistance to electronic countermeasures. System reaction time, availability, and maintainability requirements were also shown to be met by the baseline design using technologies ready for engineering development. Key components and concepts developed and proven ready for use by the AMFAR development included: (a) crossed-field amplifier (CFA) microwave power tube, (b) series regulator CFA control for MTI stability, (c) hysteresis loop latching ferrite phase shifters, (d) planar phased-array design, (e) electronic countermeasures resistance of the waveforms and processing, (f) automatic acquisition and track in all environments, (g) beam-by-beam computer control, (h) automatic readiness testing, and (i) automatic fault isolation. Each of these important APL contributions to the basic AEGIS radar design made during the advanced development stage is expanded upon in the AMFAR article.

Contributions were made in related ASMS system areas during advanced development. Midcourse guidance algorithms were developed and missile performance baselined, using models of the radar missile and target tracking performance combined with STANDARD Missile kinematic simulations.

The Laboratory further supported the advanced development of AEGIS through an availability evaluation of the baseline ASMS. The analysis used an APL General Purpose System Simulator (computer) for system modeling. The investigation included a systematic examination of the changes in availability introduced by equipment parameter variations. The major parameters examined in the analytic simulation of system operability were equipment reliability, redundancy, and replacement time in the event of failure. The investigation verified that the baseline

ASMS could meet the stringent availability requirements in the most difficult operational environments.

AEGIS ENGINEERING DEVELOPMENT AND SYSTEM INTEGRATION

The Secretary of Defense approved the AEGIS Engineering Development Program in late 1969. This event marked a transition in the nature of APL's contribution to AEGIS. With a prime contractor identified, APL became Technical Advisor to the Navy program management. An early example of the nature of this role resulted from a directive to the Navy included in the program approval from the Secretary of Defense. The Navy was directed to engage in a comprehensive examination of the system design to identify means for introducing simplification. At the request of the Navy, APL examined the contractor's proposed system design and identified several promising approaches for simplification. In particular, it appeared that both the transmitter and signal processor designs could be simplified. The initial AEGIS System design called for four transmitters, four phased arrays, two signal processors, and two computer control systems per radar system, i.e., two transmitters, two phased arrays, a signal processor, and a control computer complex both fore and aft on the ship. The APL simplification study identified means to eliminate one transmitter at each end through use of a high-power microwave switch, to combine signal processor functions into a simplified central unit, and to combine the control functions into a single memory sharing multiple CPU machine. APL led the requirements definition and evaluation efforts associated with introduction of these configuration changes into the engineering development process.

APL has continued to serve as Technical Advisor, providing assurance that the contractor's design will satisfy Navy technical requirements, identifying areas of risk in this regard, proposing alternative approaches more likely to meet technical requirements, and conducting critical evaluation of these alternatives. Some specific examples of these continuing activities are given in the following sections.

The Coherency Test Set

A significant Laboratory contribution to the AEGIS Program was the development of a Coherency Test Set to support the transmitter development and system integration of the SPY-1A Radar System. This effort was prompted by the technical questions that persisted regarding the performance capability of the AEGIS transmitter design, which employs multiple crossed-field amplifier tubes in a parallel configuration. This configuration, which was selected to generate the required power levels while having inherently high system reliability under casualty conditions, was chosen after comparisons with alternative designs having fewer tubes.

In the SPY-1A transmitter configuration, a single high-power output pulse is the vector summation of

each of the individual lower power output pulses of the crossed-field amplifier tubes. This parallel tube arrangement led to concern about the intrapulse amplitude and phase stability characteristics of such a transmitter operating in the SPY-1A, particularly because this radar employs a variety of waveforms and pulse lengths. Pulse-to-pulse coherence in a sophisticated radar such as the SPY-1A is important for accurate predictions of target parameters such as velocity and range. The Laboratory designed the Coherency Test Set to measure and record the gain transfer function (phase and linearity) of the individual crossed-field amplifiers. A data reduction process was then employed to characterize the radar system performance, which in essence validated the parallel amplifier concept of the SPY-1A transmitter.

Figure 1 illustrates the key operational features and test capabilities of the Coherency Test Set. Radar frequency signals generated by the Coherency Test Set are injected into selected ports of the parallel tube transmitter so that the phase stability, fidelity, and amplification characteristics of a given crossed-field amplifier can be measured. The signal samples, obtained on a pulse-to-pulse basis, are recorded on magnetic tape and subsequently computer processed for performance validation of all radar modes, including the capability of the SPY-1A radar in the moving target indicator (MTI) mode. This Coherency Test Set was initially used during the qualification testing of the SPY-1A transmitter and was subsequently employed throughout the engineering development and system integration phases of the transmitter test program.

Array Waveguide Switch

The ASMS radar concept, translated to the initial AEGIS design, employed a single high-power microwave transmitter assembly for each antenna array. The investigation of system simplification indicated that a significant cost reduction could be realized, while retaining the same level of radar performance, if a single high-power transmitter could be time-shared between a pair of phased-array antennas via a high-power microwave multiswitch assembly. A consequence of this simplified configuration was the requirement for waveguide switches capable of reliable operation under high-power conditions. Waveguide switches capable of satisfying the operational requirements were not then available from the microwave industry.

A special development program to address the problem of designing a high-power switch was initiated and carried out under APL's direction. Candidate switches were designed by several contractors and evaluated at APL under the required high-power operating conditions. The final results of the evaluation supported the feasibility of the proposed system simplification. The SPY-1A Radar Engineering Development Model installed in USS NORTON SOUND employed a transmitter configuration that used a production version of this radar frequency micro-

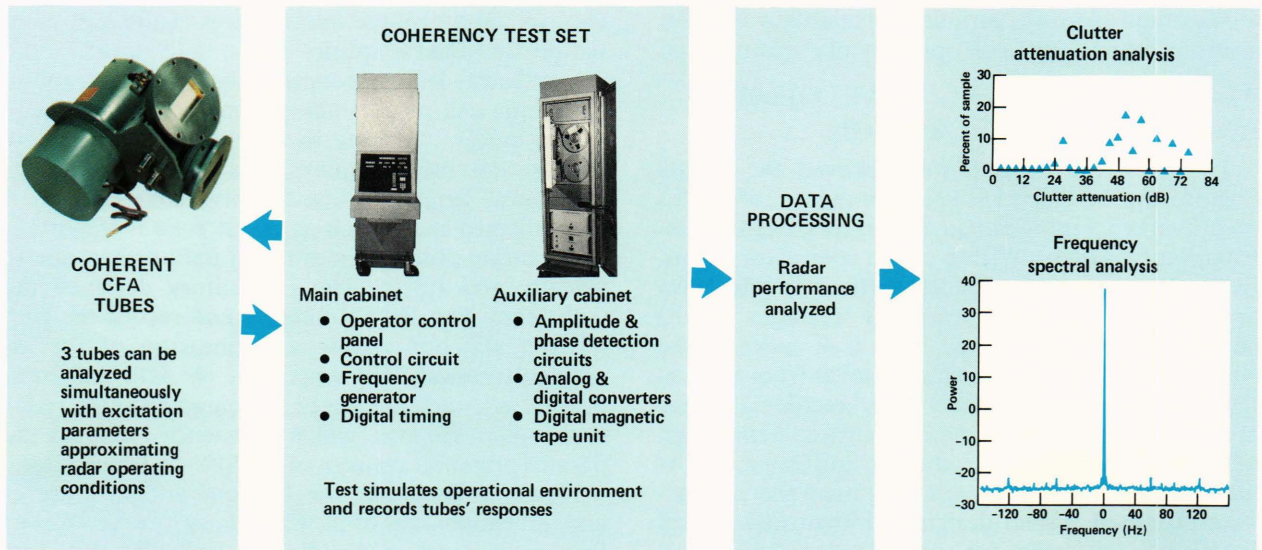


Figure 1 — The Coherency Test Set was developed to demonstrate the feasibility and operability of the AEGIS transmitter design, which employs a parallel crossed-field amplifier tube configuration. This equipment allows the intrapulse characteristics of the crossed-field amplifiers to be measured individually for phase stability, fidelity, and amplification. A computer simulation of the AEGIS signal processor was then used to predict the radar system performance achievable with complex radar waveforms and the parallel tube transmitter design.

wave switch (Fig. 2). The success of the program paved the way for a further simplification of the SPY-1A Radar System in which the switching function is accomplished at reduced power levels.

Signal Processor

The initial design concept for the SPY-1A Radar System employed a separate signal processor for each pair of array antennas. The function of the signal processor, in the most elementary sense, is to generate designated waveforms for radar frequency transmission and to process selected received returns under computer control. The multifunction SPY-1A Radar was designed to operate in a wide variety of search, detection, and track modes and to do so in a countermeasures or clutter environment. This capability required a complex design in the signal processor equipment, which made it a prime candidate for a design-simplification effort.

Further, the Laboratory had initiated an investigation of a more effective MTI design for the AEGIS radar, which resulted in the formation of a Navy and contractor working group to address this problem. APL developed a simplified design for an MTI that was installed and evaluated in AMFAR. The simplified design featured a unique radar waveform that resulted in improved performance in combined clutter and countermeasures environments. The essential features of the design were incorporated into the SPY-1A MTI. There were other features in the overall signal processor redesign that were derived from independent studies that APL had performed that were directed toward small-ship application of the AEGIS Weapon System. The design simplification resulted in a significant improvement in time usage efficiency, which made it possible to replace the two signal processors in the original design with a single central

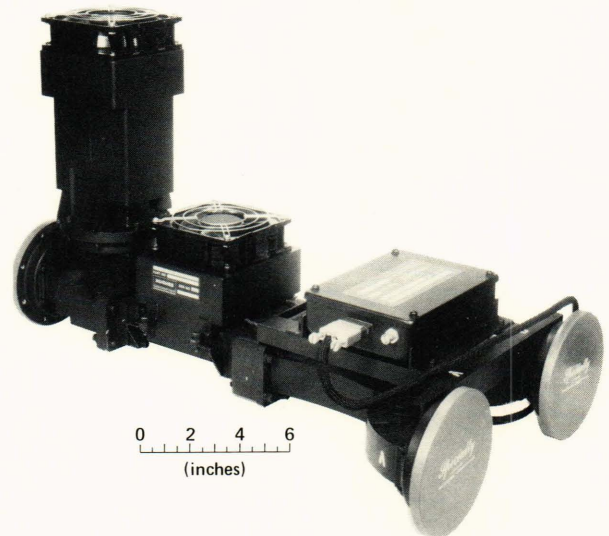


Figure 2 — The early Advanced Surface Missile Systems radar concept was simplified to permit a single transmitter to be time-shared between a pair of phased-array antennas. The required high-power operation and the demand for microsecond switching speed and reliability translated into a special kind of high-power waveguide switch design, developed under the direction of APL.

signal processor, as currently used in the SPY-1A design.

The STANDARD Missile Uplink Receiver

The Navy's STANDARD Missile employs an on-board uplink receiver for midcourse guidance commands transmitted by the SPY-1A Radar System. Technical questions arose during missile and radar integration testing about the suitability of this receiver in an electronic countermeasures environ-

ment and under conditions characterized by transmitted waveform distortions. A STANDARD Missile uplink receiver was subsequently procured and evaluated by APL, with AMFAR as the source of the transmitted waveform. The STANDARD Missile guidance section that contained the uplink receiver under evaluation is shown in Fig. 3.

The test program verified that the uplink receiver was overly sensitive to transmitted waveform variations and to interference. An optimized algorithm for the signal processing segment of the uplink receiver was subsequently designed and implemented with improved hardware at APL and tested with AMFAR. The resultant receiver design greatly improved the STANDARD Missile-2 link operability in a distorted waveform or countermeasures environment or both. The APL improvements in uplink receiver design have now been incorporated into the STANDARD Missile Production System.

AEGIS WEAPON SYSTEM UPGRADE

Development of the AEGIS System has been guided by a directive from the Under Secretary of Defense for Research and Engineering to keep the program abreast of current engineering technology during the course of the weapon system development. This directive has been fulfilled during the 10-year development cycle by the continual infusion of modern technology into all elements of the AEGIS Weapon System design. Such a development philosophy has also resulted in significant system simplification, with attendant cost and weight reduction. With the objective of keeping AEGIS at the forefront of engineering technology, the Laboratory has continued to investigate and evaluate the application of advanced technology to the major elements of the AEGIS Weapon System. An upgraded AEGIS Weapon System development program, which is in consonance with the technical recommendations of APL, was recently initiated. Included in it are the AN/SPY-1B and Vertical Launching Systems.

The AN/SPY-1B Radar System

The Laboratory has long been a leading technical advocate for a SPY-1A Radar System upgrade. The period of time between development of a concept and actual deployment of military systems requires consideration of the impact of new technologies as the systems are developed and the inclusion of these technologies in the basic system whenever this is feasible. These upgrade programs, more popularly known as Pre-Planned Product Improvements (P³I) do not reflect enhanced capabilities against ever-increasing threat levels but very often result in less weight and lower cost for the systems. Recently, the thrust has been toward decisions for a major upgrading of several portions of the AEGIS Weapon System. A performance upgrade in the radar domain became possible primarily because of two significant developments in the last decade. The first of these was the rapid growth of solid-state technology, which led to

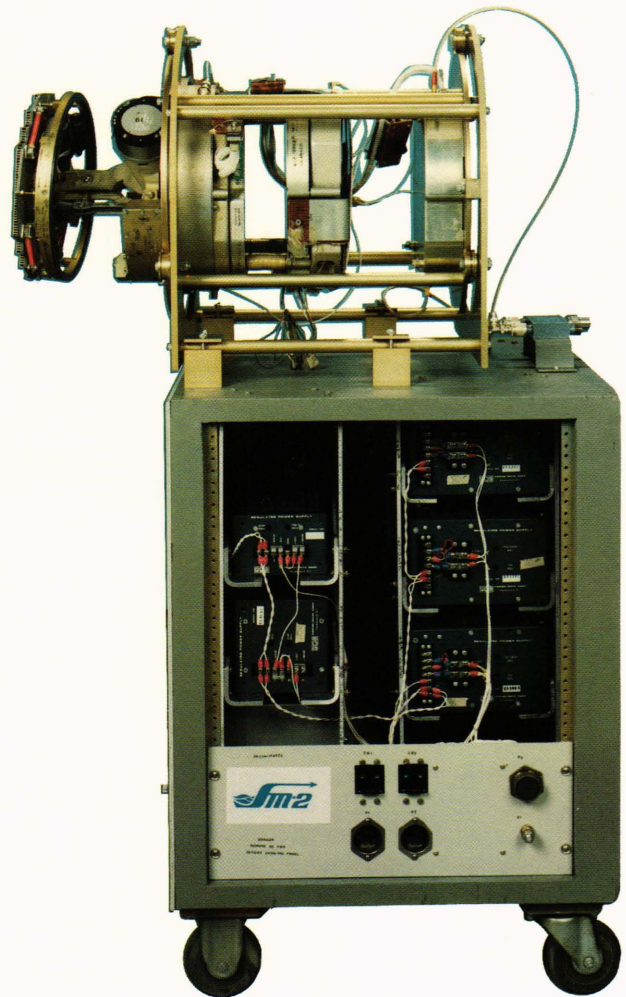


Figure 3 — The STANDARD Missile uplink receiver is shown in this photograph of the missile guidance section. APL performed a technical evaluation that indicated that the uplink receiver performance was overly sensitive to distorted transmitter waveforms and electronic countermeasures environments. An optimized algorithm for the signal processing segment of the receiver was designed and evaluated at APL, using AMFAR, and was later incorporated into the STANDARD Missile System.

highly miniaturized circuit designs. The second development was the evolution of phased-array technology. Consequently, it has become possible not only to effect a major upgrading of radar system performance but to accomplish the improvement in concert with a significant cost and weight reduction.

The upgraded signal processor of the SPY-1B Radar System will take advantage of the integrated high circuit densities available in the 1980's and the associated low unit logic function cost to increase processing efficiency and to add some important new electronic counter-countermeasures capabilities. A key element of the signal processor upgrade will be construction of the digital signal processing equipment with bipolar Very Large Scale Integration circuits, which have recently become available commercially. The use of complementary metal-oxide semi-

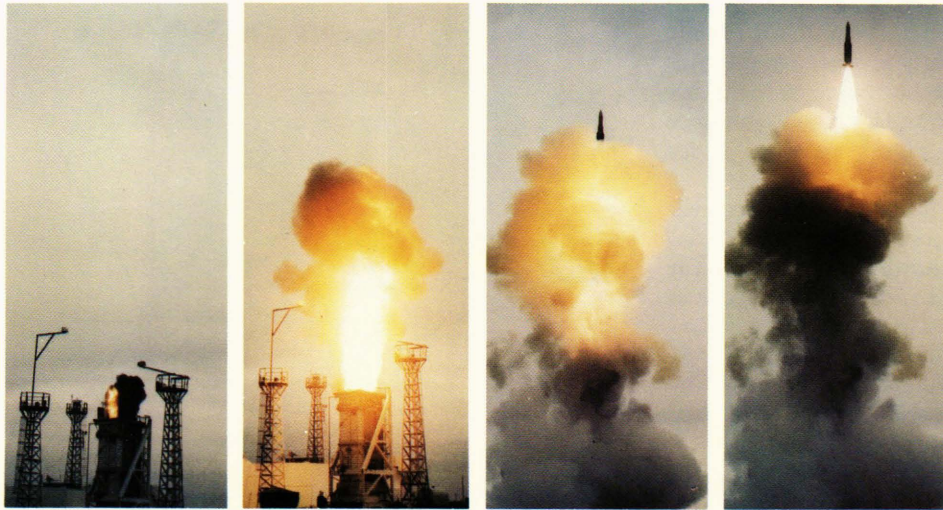


Figure 4 — A STANDARD Missile-2 firing from a Vertical Launching System at White Sands Missile Range in early 1981. APL has been weapon system and missile integration advisor to the Navy on this new launching system since development began in 1977. The Laboratory will participate in the Vertical Launching System critical design review process and the system integration and testing phases at contractor and Navy facilities.

conductor circuits was also considered, but the approach selected offers significantly greater cost savings for equivalent performance. The density of the Very Large Scale Integration hardware will be such that the sampling rate and the quantization level can both be greatly increased to improve the signal processor efficiency. Overall, the upgraded signal processor will provide an enhanced level of radar performance, with a concomitant significant volume and cost reduction.

Current array antenna technology has established that the manufacturing capability is available for producing microwave components and subsystem assemblies with very small tolerances. These small manufacturing tolerances are mandatory for producing arrays that can generate antenna patterns having very low sidelobe levels. (This is an essential performance characteristic for improved radar capability against electronic countermeasures.) Additional refinements in component configuration and fabrication and in active element phase control will lead directly to the development of the performance-upgraded SPY-1B array, with its attendant cost and weight reductions.

In order to cope with the growing threat, higher transmitter peak and average power levels at the radar frequencies will be required in future versions of the SPY-1 radar. An increase in the average power output of the SPY-1B transmitter will be achieved by upgrading the crossed-field amplifier and crossed-field amplifier modulator that are presently employed. APL is actively involved in the SPY-1B transmitter design and in research and development of all subsystems for an advanced AEGIS transmitter design.

The Vertical Launching System

The AEGIS Weapon System now employs the Mk 26 Guided Missile Launching System, a highly developed type of dual-missile rail launcher. At the Martin

Marietta Corporation, the Navy is developing a Vertical Launching System that is modular in design and houses missiles in canisters that serve also as missile launchers. This modular design will permit utilization of not only the STANDARD Missiles but also the ASW standoff weapon and TOMAHAWK Missiles. Thus, the Vertical Launching System will increase the ability of the AEGIS Weapon System to engage air, surface, and subsurface targets simultaneously. The first ship of the CG-47 class that will be equipped with these new launcher systems is projected to be CG-52.

The Laboratory has had a major role as weapon system and missile integration advisor to the Navy on the Vertical Launching System Program since development began in 1977. APL's function has been expanded and now includes critical review of the Vertical Launching System design. In addition, APL will be involved in the integration and testing of the Vertical Launching System to be performed at contractor and Navy facilities. STANDARD Missile-2 was fired from the Pre-Production Model One of the Vertical Launching System at White Sands Missile Range in early 1981 (Fig. 4). The technical evaluation of the Vertical Launching System with the AEGIS Weapon System and the STANDARD Missile occurred between October 1981 and February 1982 in USS NORTON SOUND.

CONCLUSION

Working in partnership with the Navy and contractors, APL has pioneered in many new and innovative developments and made significant contributions to the development of the AEGIS System since the mid-1960's. The requirements for the baseline weapon system design recommended by the ASMS Assessment Group outpaced the technology available at the time. The AEGIS Weapon System that evolved from that early system definition is a tribute to the technical ingenuity and innovation of a large engineering community that teamed together to solve

a wide variety of technical problems. APL performed much of the preliminary research and development of automatic weapon detection and tracking system concepts and hardware that are now embodied in AEGIS. The Laboratory also made major contribu-

tions in engineering, testing, and refining of AEGIS equipment and operational concepts during system development. Even now, the upgrading of the AEGIS Weapon System continues as it is being constructed and implemented in the Fleet.