THE PHASED ARRAY SUCCESS STORY
SIX YEARS OF AN/FPS-85 OPERATION

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Abstract

The success of a large phased array which has been in operational inventory for nearly six years is unique. The author suggests reasons for its relatively low cost development and maintenance. System concepts which have contributed most to the unprecedented "blue-suit" operation and maintenance are reviewed.

Introduction

The AN/FPS-85, the Air Force's large phased array radar used to detect, track, identify, and catalog earth-orbiting objects and ballistic missiles has been a major success. This system located at Eglin Air Force Base in northwest Florida became operational in 1968 and has been performing its mission successfully since that time. It is most significant that this system[1], designed, built, and tested by Bendix Communications Division, has been operated and maintained entirely by Air Force personnel over the past six years.* It is a tribute to the government/contractor teamwork that a one-of-a-kind system of such complexity could be brought into military inventory at so low a cost and with so few problems. This is an opportunity to look at the technical features that contributed to this success. Also, it is time to check on its current state of operational proficiency, and most important of all, its relatively low cost of maintenance.

Before discussing these technical features of the AN/FPS-85 system that contribute to its success, the management philosophy of both the Air Force and the Bendix Corporation in the undertaking should be reviewed. The Air Force prepared a realistic performance specification with expansion requirements that would reduce obsolescence for years to come and held costs by establishing a fixed price ceiling. Bendix management accepted the challenge with the full intent of producing the system without specification relief. The good faith and integrity of the contract parties assured the success from a management point by meeting their objectives.

It is significant that the fixed-price performance specification permitted the Air Force to monitor the contract with few personnel until acceptance testing of the completed system. On the other hand, with a turnkey type contract, fewer Bendix personnel were required to interface with the Air Force project office and greater flexibility was permitted within subsystem designs. Trade-offs could be made quickly within the system engineering group without obtaining Air Force approval on details.

Development Philosophy

While Ballistic Missile Defense radars were being developed by the Army as part of the large Nike-Zeus and later the Safeguard systems, which required high confidence nuclear environment testing, the Air Force concentrated their efforts to produce a satellite surveillance system within a relatively small R&D budget. To stay within the small budgeted amounts, the Bendix/Air Force development philosophy was to use state-of-the-art existing hardware, to value engineer the larger number of simple modules for low cost, and to reduce maintenance to routine low skill level tasks.

This philosophy exploits the basic philosophy of phased arrays, that is, the use of low cost, wide tolerance, easily manufactured, identical modules to feed an array of elements. High power and high gains are achieved through numbers. Many of the problems encountered by the "awesome collection of phased array prototypes"[2] were circumvented by using components that had been proven by earlier usage. System concepts were validated by Bendix in the two development prototypes constructed for the Air Force prior to the present system. The present system was started in March 1965. Contrary to a published article electronically steered phased arrays have been put to real use. That is, detecting and tracking the thousands of earth satellites daily. The FPS-85 has not had the publicity associated with BMD radars because, comparatively speaking, very little money, approximately $100 million, has been spent by the Air Force on this operational system and its prototypes.

Obsolescence

Is a phased array obsolete if it uses tubes? Will the cost of a transmitter tube per element drive the maintenance cost beyond reason? For example, why did the AN/FPS-85 use tetrodes as RF power amplifiers in 1965 when solid-state components appeared so promising? The answer is simple, the tubes were less expensive! They still are today! A tube used in communications transmitters was chosen because it was readily available. Production facilities could absorb the additional demand without costly investment. Thus, the entire transmitter module with power amplification after the phase shifter was produced for a price approaching the cost of high power solid-state phase shifters used in other prototypes.

Even more important, the replacement of the 4CPX250 tetrode in failed transmitter modules has not required even the modest expenditure of time or money anticipated. The design objective was to have a transmitter MTBF of 5.000 hours. This would mean approximately one module repair cycle per hour or eight man hours per day because removal of a module from the face, replacement of the tetrode, and realignment represents one-third man hour of labor. The transmitter module MTBF has improved to over three times the design objective. This means the transmitter module maintenance accounts for three man hours per day. The transmitter repair shop is almost deserted even when manned. The shop certainly does not host a large number

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* Air Force Responsibilities:

RADC had technical development responsibility.

ESD had administrative responsibility.

ADC has the operations and maintenance responsibility.

Sacramento Air Logistics Center has logistics and engineering support.

of personnel feverishly working to keep transmitters available for replacement as some people imagine. Since random failures of transmitter modules only reduce the power output slightly, and 500 modules can be removed before the performance is reduced by approximately 1.0 dB, the system could even be operated for nearly two months without transmitter module replacement.

The superior reliability of solid-state components is evidenced in the receive array where the MTBF again has exceeded design objectives. Module failures require repair action at the rate of approximately one per day.

The AN/FPS-85 certainly is far from obsolete. In fact, if another system were built today, it is suspected that the engineering required to change only the documentation would cost more than the projected maintenance savings due to updating circuits to today's components.

Success Features

The fact that this system exceeded all of its performance specifications during its final tests in 1968 is documented. I would like to provide even further statistics on operation and maintenance but must qualitatively refer to these cost/performance factors to remain within security constraints. There are six features that stand out as contributors to the low cost and trouble free "blue-suit" maintenance and operation.

Simple Identical Modules

Although the two UHF arrays occupy a large area, the simplicity of having many identical modules mounted just behind each active radiating element is the most important success feature. These low power, wide tolerance, easily maintained, replaceable during operation, plug-in modules are mounted as shown in Figure 1. Both the transmitter modules in the square uniform illuminated aperture on the left and the receive modules in the octagonal space taper illuminated aperture on the right in Figure 1 were designed for low cost production. This low cost simple straight forward design permits them to be easily repaired in a production type jig by low skilled personnel.

Calibration/Maintenance Philosophy

The philosophy of providing each subsystem with a built-in stand-alone test/calibration loop and of closing the entire system with an internal test loop is the second most important feature. The system loop tests are automatically run by the computer during tactical operation so any degradation can be spotted immediately. The offending subsystem can be spotted for automatic or manual switching to a redundant backup as available. A failed subsystem or portion thereof can be isolated for repair/calibration using its own built-in test loop.

Since the system interleaves search and track, there is plenty of dead time during the track pulse-burst-periods to inject simulated targets for overall performance checks, test signals for calibration of subsystems, and test signals for isolation of failures in off-line subsystems. The provisions in the system design for these built-in tests that are accomplished without interruption to continuous operation and are performed automatically in most cases have returned their initial costs several fold in reduced maintenance cost and in system availability worth.

Continuous 24-Hour per Day Operation

The third most important feature of successful operation deals with operational usage rather than inherent design. The system operates continuously 24-hours per day. Redundant equipments are supplied in the signal and data processing chains so repairs/calibration/maintenance can also be performed in these subsystems without turning the system off. Manual as well as automatic switchover is provided. The fact that the system is needed 24 hours per day and can be maintained without shutdown certainly contributes to its continued success.

Performance Margin

What improves the performance of a radar more than 3 dB additional power-aperture? The conservative design necessitated by the fixed price performance specification resulted in 3 dB more power-aperture than the design objective and 5 dB more than the minimum specified value. This contributed immeasurably to the system's success. The conservative design included a small reserve in each module because, normally, when purchasing a large quantity of components, the statistical mean tends to shift more toward poorer performance than that experienced in engineering models and, when setting tolerances for acceptance of modules from an assembly line, the distribution becomes skewed toward the poorer performance. Although these shifts came true, they were to a lesser degree than expected so the overall system performance exceeded the design objective. The system therefore performs better than minimum specifications. Extra power-aperture and better than specified inherent accuracy certainly contribute to the success.

Radar/Computer Interface

The general purpose computer and the radar/computer interface have a major contribution to operability. The interface was designed with the philosophy that any large commercial machine could be wheeled up to run the radar. This, of course, could not be carried through in detail, but such a philosophy coupled with employing a computer that has broad usage in commercial endeavors has bypassed numerous problems experienced by others.

Commercial Programming Support

The programming has been successful, not only because the standardized system software has been used to its fullest extent, but because the large real-time computer programs were rigorously tested during their development. The real-time operational programs were structured to allow realistic simulation testing. Changes made to these programs today are also rigorously tested against the simulator before they are tried on-line. As a result, the programming change procedures have been very successful.

System Future

The operational life of the system will far exceed the 10-year life expectancy specified in the original design. With 6 years operation nearly completed and a strong performance record to date, the life should exceed 20 years. The system was designed with expansion capability that has gone untapped.

To be responsive, a system must have flexibility. Because the AN/FPS-85 is automatically controlled by computer programs, operational flexibility is primarily dependent upon these programs. The Air Force has contracted with Bendix to rewrite the computer program to include those changes in requirements that have evolved during the several years operation. Also, a digital signal processor is being added to increase the repertoire of chirp waveforms to improve operational utility. But in summary, the system operates as planned and has been one of the best performance per dollar investments in the DoD inventory.

In view of the AN/FPS-85 cost/performance record, can the DoD afford to develop another sensor type? It has proven that low cost building blocks in this type system are cost effective. The number used in a system can be varied to fit the need.

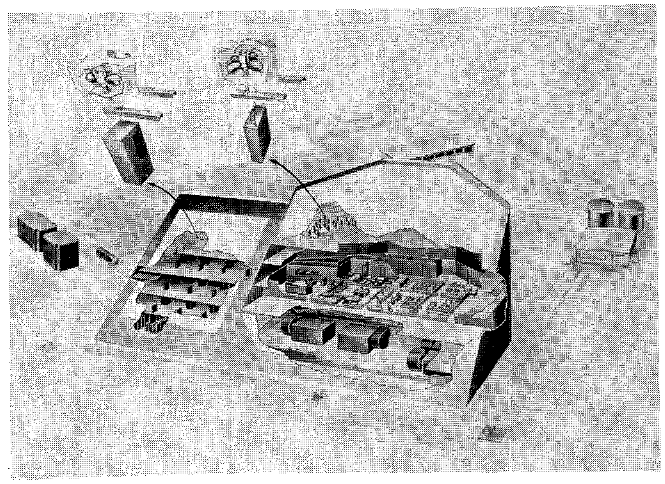

Fig. 1. Artist concept of a cutaway view showing how transmitter and receiver modules are mounted behind the array face.

References:

[1] The AN/FPS-85 Radar System, J. Emory Reed, Proceedings of the IEEE, Vol. 57, No. 3, March 1969.

[2] What is Holding Back the Phased Array?, Dr. Joseph F. White, The Microwave Journal, Vol. 15, No. 9, September 1972.

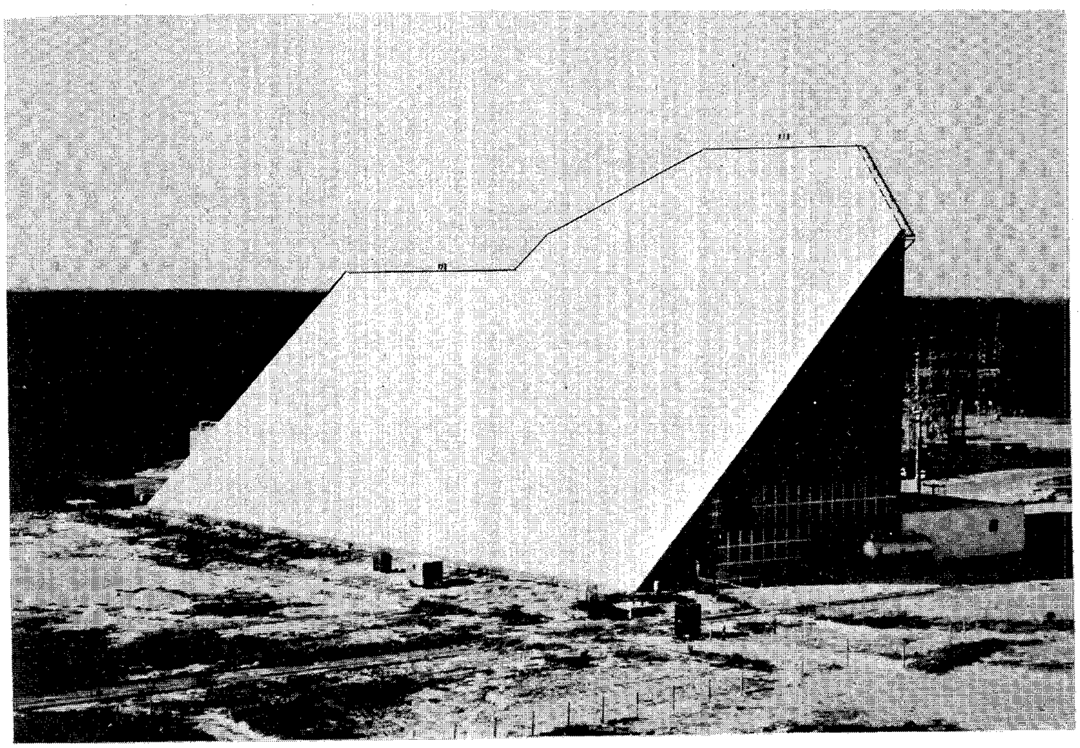

Fig. 2. External view of the AN/FPS-85. The transmitter array is square and the receive array is octagonal. The face is 318 feet long and 143 feet high.