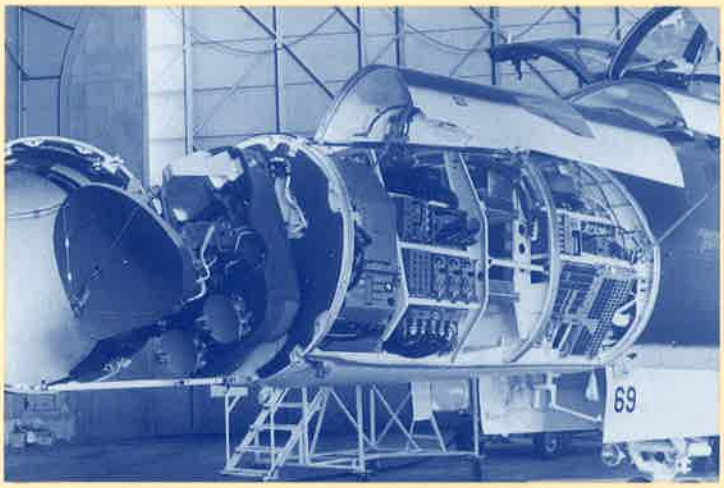
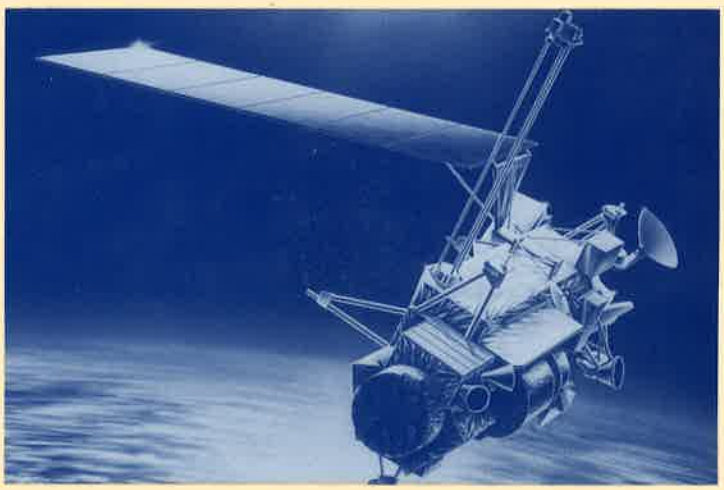
# *Progress in Defense and Space*

## A History of the Aerospace Group of the General Electric Company

Major A. Johnson



1961 brought the retirement of HMED General Manager, Jack Farrell, after a long and successful GE career. Joining GE on the apprentice program, Jack Farrell had risen up through engineering to become HMED General Manager without benefit of a college education. He appreciated the value of formal education, however, and became a Trustee of LeMoyne College in Syracuse. Jack Farrell is remembered as a gentle man who took an interest in all his employees and treated them with great respect.

The new HMED General Manager, in 1961, was Bob Brown. The Marketing subsection managers then reported to Tom Paganelli, as Manager of HMED's Systems Operation. In addition to the transfer of Missile Guidance Engineering and the 412L engineering to DSD, other engineering organization changes were made. Gene Peterson, who had headed the Communications and Data Handling subsection moved to Pittsfield to replace Gerry Hoyt as General Manager of the Ordnance Systems Department. He was replaced in Syracuse by Joe Wainright. HMED's sonar engineering became the Undersea Acoustics Systems Engineering subsection, headed by Ken Greenhalgh, and the radar engineering was divided between Earl Stebbins, as Manager of the Marine and Ground Radar Systems subsection, and L.H.Lynn, as Manager of the Ordnance Radar Systems Engineering subsection.

In the spring of 1962, Bob Brown went to Washington, D.C., to head the Defense Programs Operation of the Electronic and Flight Systems Group. Tom Paganelli was appointed the new General Manager of HMED. Charlie Beard was then appointed to be Manager of Marketing. The Specialty Devices Operation, under Lindon Saline, was also transferred from DSD to HMED in 1962. In 1963, when Lindon Saline left, his position was taken over by Don Uren. Burt Brown returned from his Department of Defense position, in 1963, to take over HMED's Systems Operation. When Charlie Wayne left GE to head the Syracuse University Research Corporation, which had been established originally by Dr.W.R.G.Baker, C.K.Fulton was appointed to head the Advanced Projects Development Section. 1963 also brought Hugh Mease to Tom Paganelli's HMED staff, as Manager of Business Development Planning. This position had originally been established within HMED Marketing and had previously moved with Marketing into the Systems Operation.

**Entry into ballistic-missile-defense radar**

APDS and MOSAR

The General Electric TEMPO organization, in Santa Barbara, had studied the ballistic-missile defense (BMD) problem earlier, and Heavy Military had thought about it, but the step which ultimately led to BMD radar

business was a planning meeting held in Syracuse, in 1958, which was sponsored by Paul Howells and Dale Ashcroft of HMED's Advance Engineering. Walt Hausz, of TEMPO, was invited to present the basic requirements for BMD radars. Also present at the meeting were George Feiker of the General Engineering Lab, Don Kuhn of the Electronics Lab and Major Johnson of HMED's Marine and Ordnance Radar Engineering. The meeting served to guide the HMED and Laboratories IR&D planning for phased-array radar antenna development over the following few years.

The Bell Telephone Laboratories (BTL) had begun studying the ABM problem in 1955 for Army Ordnance and for the Air Force, as a follow-on to their previous work on the Nike air-defense systems. In 1957, the Army awarded Western Electric and BTL prime contractor systems responsibility for the development of an anti-intercontinental-ballistic-missile (AICBM) defense system which became known as Nike-Zeus. This began the development of a new Nike-Zeus missile, a target track radar (TTR), a Zeus acquisition radar (ZAR), a discrimination radar (DR), and missile track radars (MTR) for developmental test, both at the White Sands Missile Range, in New Mexico, and over a new Pacific Missile Range, extending from Vandenberg Air Force Base, in California, to the Kwajalein Atoll in the Marshall Islands of the South Pacific.

As the early Zeus development and test program got underway, BTL began to consider the potential advantages of phased-array antennas to their system. These included: (1) increased blast resistance capability, (2) greater power handling capability, (3) flexibility of beam adjustment, and (4) capability of combining several functions in one radar. After studying the theoretical capabilities and limitations of phased-array antennas, BTL received authorization to proceed with a prototype design in June, 1961, and a request for proposal (RFP) was issued to industry. This radar was initially named ZMAR (Zeus multifunction array radar).

Within GE, the ZMAR RFP was answered by a combined effort of HMED's Systems Operation and its Advanced Projects Development Section (APDS). The GE proposed radar relied heavily on APDS's modulation scan technique to provide the requested multibeam flexibility. This technique became known as MOSAR (modulation-scanned array radar). In their review of the GE proposal, BTL was intrigued by the MOSAR approach, but wary of its novelty. They gave the ZMAR (later called MAR-I) contract to Sylvania, but gave a $2.5-million MOSAR development contract to GE. In the statement of work, GE was "challenged" to demonstrate that MOSAR could be made to work. Gene Nordell, of APDS, was appointed project engineer for the MOSAR contract. The system built for the demonstration was an L-band linear receiving array of 43 elements with signal bandwidth of 30 MHz. The importance of its successful demonstration was the follow-on request of GE by

BTL, in 1963, to study the application of MOSAR to the Nike-X system which evolved from the Nike Zeus development.

Nike-X signal-processing and beamforming

Concurrent with the array-beamformer work, Manny Dominguez, of HMED's Advanced Projects Development Section, began working with BTL, in 1963, to apply GE's various signal-processing techniques to the problem of discriminating ballistic-missile reentry vehicles from accompanying chaff and decoys. Manny's work paid off, in 1964, with a contract to develop and build the Discrimination Signal-Processor (DSP) for the Nike-X MAR-II radar..

Raytheon was also actively working with BTL on phased-array radar at the same time. In December, 1963, Raytheon received a contract to develop a missile site radar (MSR). This was an S-band radar which was to have its own command and control so as to provide autonomous operation for defense of small cities. Raytheon also received a contract to develop a long-life, wideband L-band traveling-wave-tube (TWT) for use in the MAR-II transmitter.

As a result of the Nike-X MOSAR application studies, GE received, in 1964, a contract from BTL to build an experimental planar-array antenna beamforming system (BFS) aimed at the Nike-X MAR-II radar. Because of the size of this effort, which totaled more than $50-million before its completion, and the parallel Discrimination Signal-Processor contract, a separate Nike-X Programs Operation was set up within HMED to handle it. This organization was established in 1965 and headed by C.K.Fulton, who had previously headed the Advanced Projects Development Section. Reporting directly to C.K.Fulton, were Ben Geyer as Technical Director, Bill Kimbell as Program Manager of Beamforming and Beamsteering, Jim Kovarik as Manager of System Engineering, Hal Towlson as Manager of Equipment Engineering, Joe Carr as Manager of R&QA, Jack Gorham as Manager of Logistics and Bob Richards as Manager of Program Integration. Within Marketing, Bill Squires was assigned Manager for Nike-X Programs, and within Manufacturing, Charlie Walker was responsible, with Jon Canolesio playing a day-to-day role in establishing producibility of the system elements required. With the completion of the Discrimination Signal-Processor in 1965, Manny Dominguez became Manager of Signal Processing in APDS, which was then headed by Major Johnson.

The MOSAR approach, as used for the linear-array demonstration was modified to handle the planar-array BFS of greater than 2000 elements because the processing bandwidths would have been unmanageable. A beamforming approach, known as Modified Johnson Scan, was used to

handle the greater number of elements, while preserving the beamshaping flexibility and number of simultaneous beams which could be produced.

The GE Nike-X BFS program continued through many successful milestones, and the experimental system was demonstrated in 1967. At that time, however, BTL decided to implement the MAR-II radar with a simpler switched phase-delay approach called the board steering system (BSS), which they had been investigating independently. As a result, the GE MAR-II contract was terminated. To ease the transition, BTL asked the GE team to help them in some of the initial implementation of the BSS system. It was disappointing to the GE team to see the BFS development cut short, but their successful efforts were undoubtedly important to a BTL decision to award a Perimeter Acquisition Radar (PAR) development contract to GE. This effort is covered later in this chapter. The MAR-II radar was later cut back in capability, renamed, and finally terminated in 1969 by the Army's Advanced Ballistic Missile Defense Agency (ABMDA).

**Problems and changes of the 1960's**

Tom Paganelli's early years as HMED General Manager had their problems. The period of high production on air-defense radar was coming to a close, and defense spending, in general, started to turn down. HMED employment fell from a high of 6000 in mid-1963 to about 3500 in mid-1965. Recalling these times in an interview with the author, just prior to his retirement, Paganelli admitted that when he became General Manager he didn't know know how to use his staff to solve the problems that came up. He was used to doing everything himself. He soon found that their advice on problems, such as employee morale in the face of the employment reduction, was very valuable. He gave talks to all HMED employees about the business prospects and plans in February, 1964, and again in February, 1965. In 1965, the two principal HMED programs were the SQS-26 sonar and the Nike-X radar development. Although a large number of sonars of the SQS-26 family were eventually produced by HMED, the ballistic-missile-defense business remained one of intensive engineering development and little production quantity.

In 1964, longtime HMED Engineering Manager, Ed Herzog, moved over to a position in the Electronics Laboratory. After a period of search for a suitable replacement, Tom Paganelli appointed Don Uren as HMED's Manager of Engineering in 1965. 1965 also brought a number of other HMED staff changes. To accomodate Burt Brown's continued commitment to a number of DOD special assignments he was named Senior Consultant. The Systems Operation he had led was redesignated the Systems Engineering Operation, and George Woodward was appointed its manager. When Finance Manager, Dyle Henning, left GE for a position with Ingersoll Rand,

he was replaced by Bill Anger. When Joe Barratt, long HMED's Manager of Manufacturing, retired in 1966, he was replaced by Wilson (Bill) Davidson.

The demand of the various military customers for more attention to their programs in the early 1960's led Tom Paganelli to the concept of appointing a program manager for the larger programs. A program manager was responsible for all aspects of his assigned program and reported initially to Tom Paganelli, although all the work on his program was to be accomplished by the various function sections of the department. It was the beginning of what has been referred to as a matrix organization. The first HMED department instruction defining program manager responsibilities and authority within HMED was written by Paganelli and issued in 1964. As the concept was implemented, however, it soon became evident that the programs managers needed an administrative reporting point other that the department general manager. As a result, in 1965, Paul Teich was appointed as a "den mother" for the programs managers of that time. The position was officially titled Manager of Program Support Operation. Paul Teich was not too happy that his responsibilities were only administrative, but a few years later, as we shall see, these evolved into more complete responsibility for the programs assigned.

The Nike-X programs were not included under Paul Teich, but were grouped under a new Nike-X Programs Operation led by C.K.Fulton. As this operation was established, Major Johnson was appointed Manager of the Advanced Projects Development Operation. Pressures on the SQS-26 sonar program brought the assignment of George Woodward as SQS-26 Program Manager in 1966. The Systems Engineering Operation then became the Systems Engineering Subsection under Engineering and was led for about a year by Bob Finney. George Woodward reported to the Defense Electronics Division Manager, Charlie George, for the execution of the SQS-26 Program from 1966 until 1968, when he became General Manager of the Large Systems Department responsible for the GE-600 series computer. During this period, he reported to Gerry Hoyt until Hoyt left GE for Western Union in 1967, and then to Charlie George.

Marketing Manager, Charlie Beard, left HMED in 1967, but was not directly replaced. Don Uren moved over to the Electronics Laboratory in 1967 and was replaced by Henry Lehmann, who returned to General Electric to take the position. Lehmann had gone to General Learning from the Apollo Support Department nearly two years earlier. To strengthen the HMED Engineering organization, Henry Lehmann brought Don Beilman over from the Electronics Laboratory, to head Radar Engineering, and Bob Bruce from the 412L Program to head Sonar Engineering. Bill Jenkins was made Manager of Information Systems Engineering, John Chiasson was appointed Manager of Logistics, and Earl Stebbins became Manager of Documentation

Engineering. The HMED Advanced Projects Development Operation title was also simplified to Advanced Development Engineering (ADE).

The general reorganization of 1968 brought a number of changes. HMED was renamed Heavy Military Electronic Systems (HMES) and was assigned to the new Electronic Systems Division, headed by Dr. Roy Beaton. The marketing function was divided among the programs organizations which were now: Surface-based Electronics Programs (SEP), headed by Paul Teich; Major Radar Electronics Programs (MREP), headed by Don Beilman; Undersea Electronics Programs (UEP), headed by Bob Bruce; and Guidance and Control Programs, headed by Parker Knight. The Guidance and Control Programs efforts had formerly been part of the Radio Guidance Operation, which was discontinued in 1966. When Parker Knight left the following year, responsibility for the Guidance Programs (launch support and missile-borne beacons) was reassigned to SEP. SEP also included Field Programs and R&QA.

HMES Engineering was also reorganized to match the new programs organizations: Surface Radar Engineering was headed by Bill Jenkins; Major Radar Engineering was headed by Bill Kimbell; PAR Engineering was headed by Manny Dominguez; Sonar Engineering was headed by Don Connelly; Systems Engineering was headed by John Chiasson; and a new Equipment Engineering subsection was headed by Jim Kovarik. Don Ward took over Logistics Engineering. A new Microelectronics Engineering subsection was also set up under John Phelps, who moved from Advanced Development Engineering to take the assignment. The primary thrust of this new position was to set up an HMES facility for the manufacture of hybrid integrated circuits. The approach taken was the use of silk-screened thick-film components and connections on various substrates. The first production component of the new facility was phase-shifter units which were used for the Hardsite radar array in the early 1970's. When John Phelps left for a position in Schenectady in 1970, the hybrid microelectronic work was taken over by Walt VonSeggern reporting to Equipment Engineering manager, Jim Kovarik.

Henry Lehmann once commented of the contrasting management styles of Programs Managers, Don Beilman and Paul Teich. Don Beilman was a driving individual. When a new proposal or contract activity began, he would call a meeting of the assigned people, outline his plan for the effort and indicate the course of action for each of the major participants. In similar situations, Paul Teich would call a meeting, ask various individuals what needed to be done and how everything should be accomplished and arrive at a consensus plan for all to follow. Both approaches seemed to be equally successful.

**Further BMD and surveillance radar**

The Perimeter Acquisition Radar (PAR)

As the MAR-II developments progressed, BTL responded to the Army to investigate answers to a national concern about an "Nth country" threat. Various systems were considered which might use less costly radars than the developing MAR-II. These led to consideration of VHF (~200 MHz) phased-array acquisition radars which would be used in conjunction with MSR radars. In the fall of 1966, BTL issued an RFP to industry for the development of a suitable VHF radar, to be known the perimeter acquisition radar (PAR). Within GE, responsibility for response to the PAR RFP was assigned to C.K.Fulton's Nike-X Programs Operation, and Ernie Ruterman was appointed Program Manager. Because of their experience with the UHF (~400 MHz) FPS-85 array radar, Bendix was thought by GE to be the contractor to beat. However, HMED's engineering talent was up to the task, and a proposal was prepared and submitted. In December, 1966, GE was awarded the PAR contract with a schedule for completion of design definition by July, 1967.

The initial PAR task was a study to determine whether the radar should be at UHF or VHF. Major Johnson was appointed Director of a Technical Steering Group to undertake this study and provide guidance to Engineering on the overall radar design. In making the frequency trade-off study, the possibility of solid-state transmitters was suggested by the successful development of VHF solid-state amplifiers by the GE Electronics Laboratory during 1966. This development was extended to UHF during 1967. When the decision was made to go UHF in July, the possibility of a solid-state transmitter looked like a good bet to GE, but BTL decided on a TWT transmitter. The TWT's were to be based on scaling of the Raytheon MAR-II L-band design to UHF. Interesting though, was the use of solid-state driver-amplifiers for the PAR TWT transmitters.

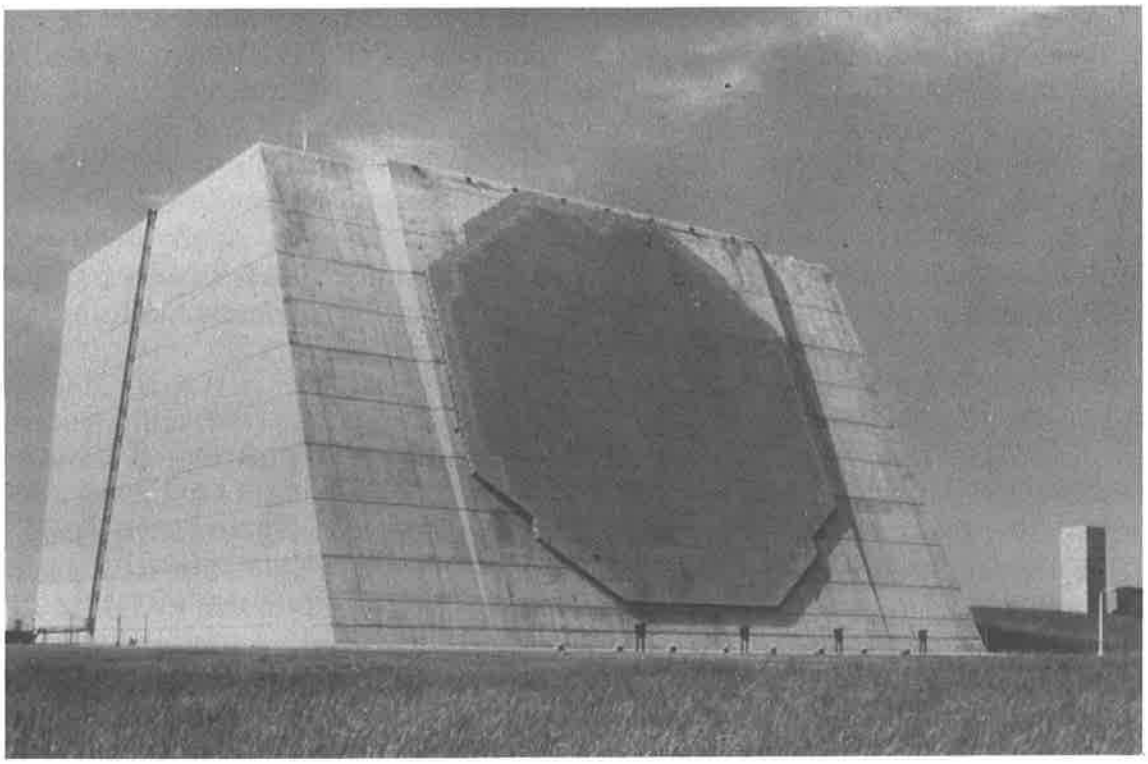
In December, 1966, the Department of Defense, through the Army Nike-X Project Office, asked Western Electric and BTL to study a deployment model of the Nike-X system designed to combine area-defense against a Chinese Peoples Republic (CPR) attack with hard-site-defense capabilities against a USSR attack on US strategic forces. The study was strongly constrained by considerations of cost and early deployment. The result, in November, 1967, was a BMD system proposal, designated Sentinel, with initial area defense capability growable to include defense of ICBM bases. The initial deployment was to include ten sites using six PAR's, 17 MSR's, 480 Spartan missiles and 220 Sprint missiles. The ten sites included Boston, Chicago and Grand Forks, North Dakota. Construction was started on the first PAR site near Boston in 1968, but strong opposition developed over the construction of such sites and the deployment of missiles with nuclear

warheads for ABM defense. As a result, construction of the Sentinel sites was suspended pending a review of Sentinel by President Nixon. In March, 1969, Nixon announced that the Sentinel system would be substantially modified into a new deployment called Safeguard. First priority would be protection of the US retaliatory forces, with a growth option to protect against a possible CPR attack. The authorized sites went through a number of changes, but settled down on four, the first of which was begun near Grand Forks, North Dakota, and the second, begun at Malmstrom AFB in Montana.

In mid-1967, as Henry Lehmann became HMED's Manager of Engineering, the HMED Nike-X engineering functions were put under Don Beilman's Radar Engineering Subsection. Ed Balian became Manager of the Nike-X BFS Engineering Unit, and Harry Pywell became Manager of the Nike-X PAR Engineering Unit. After overseeing the BFS contract termination, C.K.Fulton left GE to join Anaren, a startup company established by Hugh Hair and Carl Gerst, originally from the GE Electronics Laboratory and then with the Syracuse University Research Corporation. The responsibility for the remaining Nike-X programs was placed with the newly established Major Radar Electronics Programs organization. Monny Moncrief was made the Program Manager for the remaining BFS work. By the end of 1968, Ed Koprowski was appointed Program Manager for the PAR Production, and Ernie Ruterman was designated Program Manager for the PAR Prototype Radar.

The PAR radar development was a major development in every sense. It required new component and subsystem development for every principal function. Some of the key developments were: the radiating elements, a hardened, folded, crossed-dipole design; the phase-shifters, implemented in diode-switched air-dielectric transmission-line; the TWT amplifiers, scaled to UHF by Raytheon from their MAR-II L-band design with GE's help; and subsystems for performance monitoring, fault location and test. The complete array radar had a detection range of more that 1200 miles, used more than 6000 radiating elements and phase shifters, 128 TWT final transmitter amplifiers and 256 receiver modules. It was housed in a concrete building about 200 feet square and 130 feet high with 11-foot thick walls to harden it against nuclear blast. Barry Narcisse served as GE PAR Site Manager in North Dakota from 1971 to 1973, the period which brought the radar into operation. The PAR radar was accepted by BTL in August, 1973, and was integrated into the overall defense system by August, 1974. The site was turned over to Army operation in October, 1974.

In May, 1972, the Strategic Arms Limitation Treaty (SALT-I) was signed by the US and the USSR. This treaty permitted only one ABM defense site for the offensive forces and one for the National Command Authority around Washington, D.C. Later the US Government decided not to proceed with



Perimeter Acquisition Radar

Safeguard defense of Washington, D.C. As a result the completion of the second PAR radar by General Electric was terminated in October, 1972. However, over the duration of the GE PAR contract, it represented a total business for HMED of over $300-million. The GE people who worked directly with BTL found the programs undertaken for them especially rewarding because of the rapport which developed with the BTL engineers and management.

Pave Paws

The cut back of the PAR contract because of the SALT-I accord left the second PAR radar about 80% complete. MREP General Manager, Don Beilman, went looking for a customer for this equipment. He found interest in the Air Force in its application for defense against a submarine-launched ballistic missile (SLBM) threat. However, development of a new program for this application was a slow process within the Government, and Don Beilman left HMED, in mid-1973, before anything materialized. George Woodward became his replacement as head of MREP, and in mid-1974, HMED General Manager, Tom Paganelli, was promoted to be the Electronic Systems Division General Manager, replacing Roy Beaton. Don Beilman's

proposed application of the PAR equipment for SLBM surveillance continued to develop within the Air Force and became known as Pave Paws. Although it was hoped that Pave Paws could become a sole-source contract for GE, the slow development of the program dictated against this. A competitive RFP was issued in 1975, and GE, Raytheon, and Westinghouse submitted proposals. By this time, the extra PAR parts were no longer in GE's hands, and the Pave Paws contract was awarded to Raytheon in April, 1976, as a result of a lower quotation. From a technical standpoint, it is interesting that the Raytheon Pave Paws radar is based on solid-state transmitter modules.

Hardsite defense

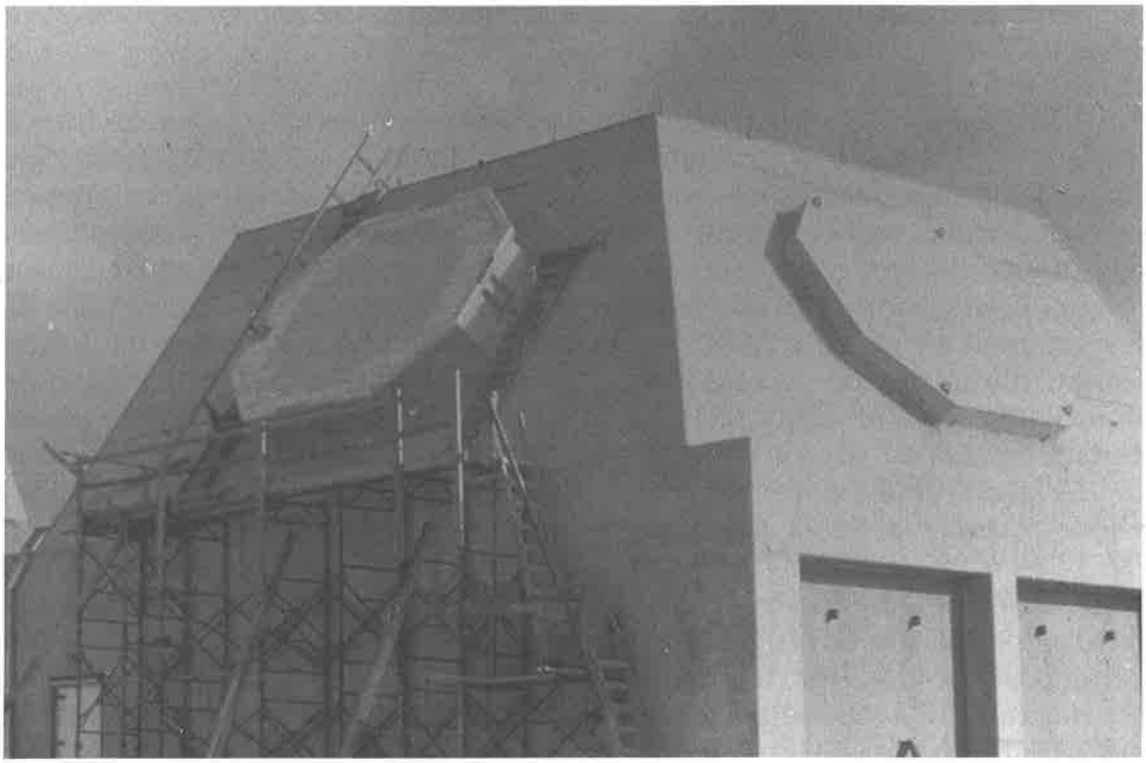
During the development of the PAR radar, the Army Advanced Ballistic Missile Defense Agency (ABMDA) was formulating a next generation system for the defense of hardened missile silos. Anticipating the SALT-I accord, they were looking for a way to have such a system ready for rapid employment, should the political situation call for it, while not violating the treaty requirements. They had funded Raytheon to study a mobile hard-site defense system called VIRADE, and during 1969 and 1970, they funded Hughes, RCA, Raytheon, Westinghouse, General Research Corporation, and others on studies of the problem, known as MDS-1. General Electric followed this activity but was unable to participate because of a lack of systems image with ABMDA. Although Manny Ares of Advanced Development Engineering (ADE) had worked with ABMDA in BMD Research and Development (R&D) activities, attempts to participate directly in Hardsite related R&D contracts were unsuccessful. The biggest HMED Hardsite marketing push by Virg Thayer was to sell a sole-source study for application of the tandem-series-feed (TSF) array antenna which had been developed internally and was a key element in the HMED ASMS proposal to the Navy.

GE was finally successful in two ways in 1970. They won one of the second-go-around MDS-2 studies and also an unsolicited TSF study from ABMDA. During October, 1970, the Army approved a Hardsite development program, and the industry began to form teams to respond to the RFP. HMED's MREP, under Don Beilman, decided to team with the MacDonnell Douglas Aircraft Company (MDAC) and a teaming agreement was signed with them in January, 1971. Other members of the MDAC team were TRW, CDC and Sylvania. Bill Kimbell was appointed Hardsite Program Manager, and Chuck Clarkson, of Advanced Development Engineering, was the initial Systems Engineer. During early 1971, GE provided a resident team headed by Chuck Clarkson at MDAC, Santa Monica, to support the pre-CD (Contract Definition) effort, and a close working arrangement was developed. A key interface at MDAC was Gus Eykholt, who had previously worked at ABMDA,

and with whom Chuck Clarkson had gotten acquainted in his ADE R&D activities.

In May, 1971, MDAC, Hughes and Raytheon received awards for the Hardsite Program Contract Definition Phase, roughly a 9-month effort. The GE radar design was based on application of the S-band TSF array antenna technique which had been proposed for ASMS. However, Hardsite required a new physically-hardened antenna, as well as a completely new radar system design. Design of the GE Hardsite radar drew on several of the recent HMED development efforts: the ASMS radar definition study, the PAR radar system design, digital signal-processor approaches studied within ADE and most importantly the TSF array techniques which included latching ferrite phase-shifters developed over a number of years by Dick Kinsey. The ferrite cores for the phase-shifters were fabricated and fired in HMED's ceramic facility whose primary product had been piezoelectric sonar transducer elements. The phase-shifter drivers for Hardsite became one of the first production jobs for HMED's new hybrid-integrated-circuit facility. In addition, ADE was also building a phased-array facility radar which incorporated many of the techniques needed for the Hardsite design. This facility was used to demonstrate GE's capabilities in array-radar design and construction to MDAC and ABMDA. The GE Hardsite physical design called for the electronics to be assembled and tested in large 12x40-foot modules which could be stored for indefinite periods and transported, emplaced and quickly interconnected for full operation. The array face was to be a complete assembly (ultimately 15x18x7 feet) which could be mounted in the prepared opening of a concrete bunker and withstand the overpressure and thermal loading of fairly close nuclear warhead detonation.

In March, 1972, MDAC was awarded the Hardsite development contract. The program name was changed shortly thereafter to Site Defense, so that the GE's radar became known as SDR. The radar development continued steadily, the first electronic module enclosures arriving in Syracuse from MDAC in June, 1975. During 1975, budgetary cutbacks in the overall program changed the objectives to one of feasibility test rather than a completed system design, and the name was changed again to System Technology Program, but the schedule for radar delivery to the Kwajalein missile test site in mid-1976 remained intact. In April, 1976, the completed STR antenna assembly was shipped to HMED's Cazenovia antenna test site for testing. Forty GE families moved to Kwajalein in 1976 under Site Manager, Don Duecker, for STR installation, test and operation and the completed radar went on the air at Kwajalein in January, 1977, a month ahead of schedule. GE involvement in STR continued into 1980, and the total program represented about $130 million in sales.



Site Defense radar at Kwajalein

Another GE effort which was to become part of the overall Army System Technology Program was the Digital Convolver System (DCS) built on a contract for Lincoln Laboratory. DCS was a flexible signal processor originally planned for an Advanced Tactical BMD Radar by the Army Ballistic Missile Defense Advanced Technology Center (BMDATC). It was a dual fast-Fourier-transform (FFT) processor with up to 16K transform size which could provide matched-filtering for any radar waveform within that dimensionality and with a bandwidth up to 30 MHz. The contract was pursued by Manny Ares of ADE and won in the Fall of 1974. Lou Eber was assigned as project engineer, and Lowell Bauer played a key role in developing the flexible processor control. The DCS was successfully completed and delivered to Lincoln Laboratory in 1979. The Advanced Tactical BMD Radar never came into being, however, and the DCS was used for signal analysis on the ABMDA System Technology program.

Other missile-surveillance efforts and fading hopes.

In 1973, the Air Force issued a request-for-proposal for a new phased-array radar for installation at Shemya, Alaska, to observe the terminal phase of Russian missile flight tests which would impact off the coast of the

Kamchatka Peninsula. The new radar was code-named Cobra Dane. A General Electric proposal effort was undertaken in competition with Raytheon. Because of the multiple object tracks required over a limited angular volume, a multiply-space-fed array was proposed as a reasonable-cost approach. The approach was new to GE designs, but had been used by Raytheon for several applications, including their Patriot radar. When the winner was announced, it was Raytheon. Ironically, they had proposed a constrained-feed approach, which was similar to previous GE designs. This radar was later designated the FPS-108.

Another competition with Raytheon was the Cobra Judy shipboard missile-test surveillance radar, which was also to utilize a phased-array antenna. Al Harper, who had joined General Electric from a previous position with the Army Ballistic Missile Development Agency, led the GE proposal effort in 1978. Although the proposal submitted was felt to be a very good one, it was unsuccessful. Raytheon had submitted a lower price in their best-and-final offer and won the development contract early in 1979. This radar was later designated the SPQ-11.

In 1977, Manny Ares took on responsibility for the BMD business under George Woodward. One of the first potential programs that Manny went after was an Army program aimed at developing a defense of hardened ICBM sites known as Low Altitude Defense (LOAD). In 1978, two CD studies were won by GE, one investigating a monostatic radar approach, the other investigating a bistatic radar approach. Sperry also won a monostatic study, and RCA won a bistatic study. The bistatic approach was later terminated, but the monostatic approach led to a complete GE design concept, including a very hard X-band array antenna concept by Dick Kinsey. Development proposal requests were issued by the Army in 1980. Hal Lyness was appointed GE Program Manager. A conversation by Tom Paganelli with the responsible Army General convinced Paganelli that they were so interested in a "systems contractor" that GE had little chance of winning, and he decided to no-bid the program. As a result, Raytheon won the program sole-source in the Spring of 1981. By this time MREP had been discontinued, and BMD pursuit had been reassigned to Paul Teich's Surface-based Electronics Programs (SEP). Under Paul Teich, Lloyd Spafford had been assigned responsibility for the BMD Programs previously followed by Manny Ares. Spafford and Kinsey tried to sell Raytheon on using GE's hardened antenna, but they didn't buy it, even with Army encouragement based on successful testing of the GE hardened elements. The program was renamed Sentry and Raytheon spent about $150-million over several years with many false starts, and the program was cancelled in 1984.

With the demise of Sentry, a new Army program was started in 1984, which aimed at terminal BMD. This was called the Terminal Imaging Radar

(TIR) and was also to be an X-band array, but with very broad bandwidth to facility coherent-radar imaging of its targets as a discrimination aid. Because the successful pursuit of the program would have required considerable resources, SEP's new General Manager, Jud Gostin, decided against following it further in light of his other opportunities, and it was dropped. Raytheon and Westinghouse bid and won study contracts in 1985. GE did win a subcontract to Lockheed on the High Endoatmosphere Defense Study (HEDS), which also used a similar terminal-imaging radar, but the effort did not lead to significant following business for GE.

**Working toward HF over-the-horizon radar**

HF over-the-horizon (OTH) radar makes use of frequencies in the "short-wave" (~10-100 meters) part of the radio spectrum where the radiated energy is refracted by the ionosphere back to the earth. Frequencies in the HF band (~3-30 MHz) are generally used for long-range communications. Radar operation in this band permits aircraft, ship and missile detection out to ranges of several thousand miles since the line-of-sight horizon range limitation is removed by the ionosphere's refraction. Although long ranges are achievable, OTH radars often have a minimum range on the order of 500 miles because restrictively low frequencies would be required for sufficient refraction to closer ranges. HF radars avoid interference with communications service in the same band by searching across their frequency band for a clear channel before radiating.

General Electric work with OTH radar first began as a result of pioneering work at the Naval Research Laboratory (NRL) in the 1950s. An important need of OTH radar is removal of strong clutter return signals, and this is generally achieved by high dynamic range Doppler frequency filtering. This filtering requires bandwidths ranging from a few tenths of a Hertz to a few Hertz wide. The NRL workers felt that magnetic drum storage, as used for digital computers of that era, would be a good way to achieve suitable filter responses and would permit time-compressed read-out. The GE Electronics Laboratory in Syracuse had developed a good magnetic storage drum for the Air Force OARAC computer. Based on this work, NRL awarded a contract in June 1955 to the Electronics Laboratory to develop a magnetic-drum based Doppler processor. It was titled MADRE for Magnetic Drum Recording System and became the basis of a complete MADRE OTH radar which NRL put on the air in 1961. The GE work for MADRE was primarily one of providing components for the NRL system. GE's Technical Products Department provided the 50 KW HF transmitter for the MADRE radar. Lee Holtzclaw was a member of this first Electronics Laboratory team.

GE support of NRL on the MADRE radar continued into the 1970's, focusing primarily on extending the state-of-the-art in high dynamic range