FUTURE AIR DEFENSE MISSILE SYSTEMS
(Part 2)

Figure 14 depicts a typical three bit digital latching ferrite same shifting element. Like the diode element, it contains the rear radiator, a waveguide containing the cores, the three bit circuitry, and a front radiator.

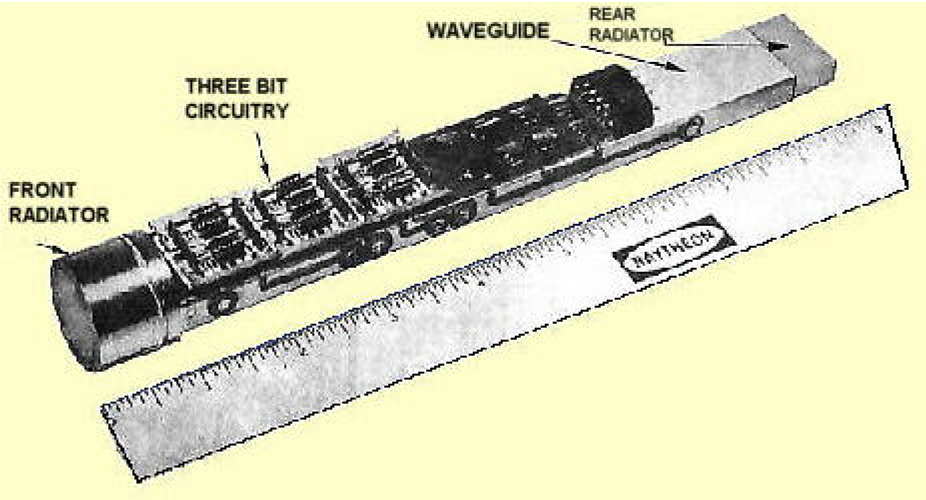

Figure 14. Ferrite Elements

(a) This element is composed of a rectangular waveguide, terminated on each end with the RF radiator. The three bit phase shift circuits, together with the logic switches, are mounted on a length of flat cable which ends in a 14 pin plug. Through this plug and flat cable pass the steering signals from the beam steering computer. The flat cable also provides the latching or charging wires for each core.

(b) In the transmit mode, RF energy impinges on the rear radiator which transfers it to the waveguide. In the receive mode, it passes the received signal back to the receiver feed horn.

(c) The RF energy now travels through the waveguide to the three ferrite cores. The beam steering computer has already "set" the condition of the phase shifters which are coupled or "latched" to the cores by the flat cable. If a 180 degree phase shift is desired, only the rear bit affects the RF energy. If 135 degrees shift is required the 90 and 45 degree bits are used. Thus any combination shifts are possible from zero through 315 degrees in 45 degree increments. Again, the three bit circuitry acts in the sae manner as shown on figures 7 and 8.

c. With any type phase shifting element, control signals for each element originate as digital commands in the system computer which orders the hen steering computer to select the required elements and phase shift for the next array beam transmission.

(1) The four bit element receives a four bit word as represented in table 1. Composite commands made up of those four bit words applied to several thousand elements provide the required "look angle" in both azimuth and elevation.

(2) The three bit phaser serves the same purpose as the four bit, but uses different circuitry. Here the element receives a three bit word as presented in table 2. Again a composite word is generated in the beam steering computer to properly steer the beam from several thousand elements.

6. ANTENNA SYSTEMS.

a. Phased array radars perform essentially the same functions as conventional rotating radars. Phased array systems however, perform these functions much more rapidly and with increased accuracy. The phased array antenna is truly the heart of the array radar. Like a human eye, it scans a large volume of space, and like the eye, may "look" at a number of objects simultaneously. The array antenna is composed primarily of the face structure which holds the individual elements, some form of cooling for the array, and it may contain portions of the beau steering computer or program. It is connected to the transit and receive feed horns either optically "space fed" or with coaxial cable or waveguides.

TABLE 1

FOUR BIT WORDS

Word	**Phase Shift Degrees**
0000	0
0001	22.5
0010	45
0011	67.5
0100	90
0101	112.5
0110	135
0111	157.5
1000	180
1001	202.5
1010	225
1011	247.5
1100	270
1101	292.5
1110	315
1111	337.5

b. When high power is desired, most arrays use a single final amplifier whose output is fed to many antenna elements. If the same array is used for both transmitting and receiving, some type of duplexer or separate feed horns are required.

c. One of the significant advantages of a phased array system is the time share principle wherein the same array is used for acquisition, tracking and missile guidance. The various functions are performed on a time share basis. The only restrictions are radar power, time required to perform each function, and the quantity of elements in the array. As an example, a radar may be searching a volume of space and monitoring 50 incoming targets . Once threat verification is established, the system now monitors perhaps 30 subjects, but tracks 10 targets and engages all 10 from multiple missile launchers.

TABLE 2

THREE BIT WORDS

Word	Phase Shift Degrees
000	0
001	45
010	90
011	135
100	180
101	225
110	270
111	315

d. Arrays may be considered as active element or passive arrays. In the active array, a transmitter or receiver or both connected directly to each element. In the passive array, only transmitter and one receiver is used for the entire array.

e. The two basic categories of phased array radars are the confined feed and the apace or optical feed.

(1) In the confined feed, the energy is contained within a structure of waveguide, coaxial cable, or a strip line. There are many variations of confined feeds. At the lover end, strip line is often used although its loss is higher than a waveguide. In a confined feed, the phase errors are regular which leads to high side lobes. This can be reduced only by using more bits per phase shifter. With this method precise impedance matches along the connecting cable or waveguide, depending upon its length, are mandatory. Although this method does not suffer from RF spill over as the space feed method does; it loses some of its glow when several thousand elements are considered . Under the configuration shown in figure 15, the "plumbing" problem can become extremely severe.

(2) In the optical feed system, figure 16, there is no physical connection between the radiating elements on the array face and the output of the final amplifier.

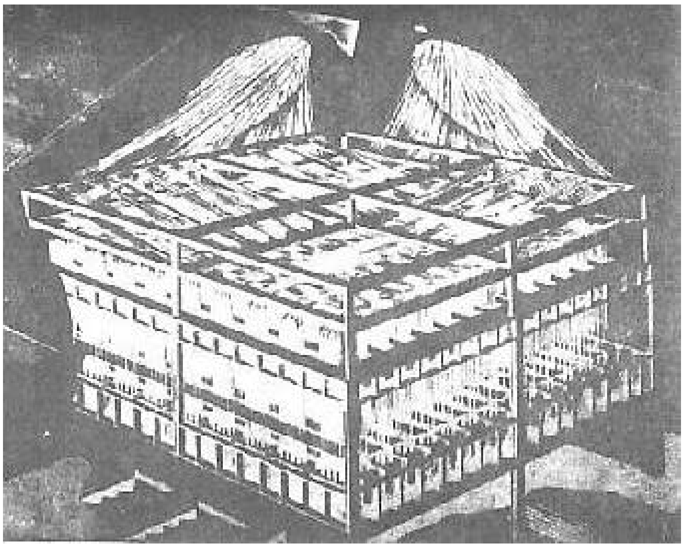

Figure 15. Confined Feed Configuration

(a) The transmitter feed horn assembly is optically aligned with the center axis of the array antenna. The transmitter feed horn receives energy from the transmitter and space feeds it to the rear radiators of the array as depicted in figure 16. This energy is then radiated through the phase shifters and out the front radiators of the element into space.

(b) In the received mode, the beam steering computer commands the phase shifters to duplicate the transmit phasing. This causes the reflected information received by each element to be combined into a single beam which is then focused on the system's receive feed horn. In the optically fed array the transmit and receive feed horns are physically displaced, therefore, a correction is applied by the computer to electrically compensate for this physical displacement.

7. COMPUTER CONTROL.

a. The advent of phased array techniques has produced a significant in crease in the data gathering capabilities of radar. However, to utilize the flexibility of the phased array radar, and to use the large amount of data collected, equally flexible, equally fast data processing is necessary. This requirement is satisfied by the use of a digital computer to provide central control and data processing for all the radar subsystems.

b. Among the characteristics of digital computers that make them success ful in a radar system are their computation ability, decision making ability, their perfect memories, precision, reliability and flexibility. Digital computers can perform all numerical functions. They add, subtract, divide, multiply, compute trigonometric data, differentiate and provide coordinate trans formation.

c. Many digital computers already operate long periods continuously with out failure. Technological and manufacturing improvements of the foreseeable future should increase this capability. Since a digital computer is a general purpose device, it can be designed and built before it is known exactly how it is going to operate the radar. The computer program is developed with the radar system, and it can be modified to meet changing system requirements and parameters.

d. In operation, a digital data processing system for an array radar, figure 17, instructs the transmitter to provide the necessary signals for transmission and then instructs the receiver and video processor for further analysis and processing. The monitoring equipment allows the computer to function as a piece of built-in test equipment (BITE) by injecting test signals when required for calibration and radar status monitoring.

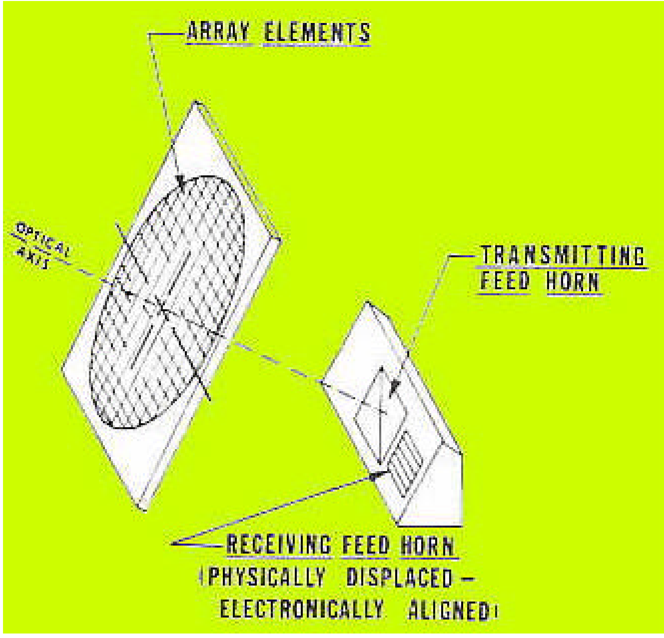

Figure 16. Optical Feed Configuration.

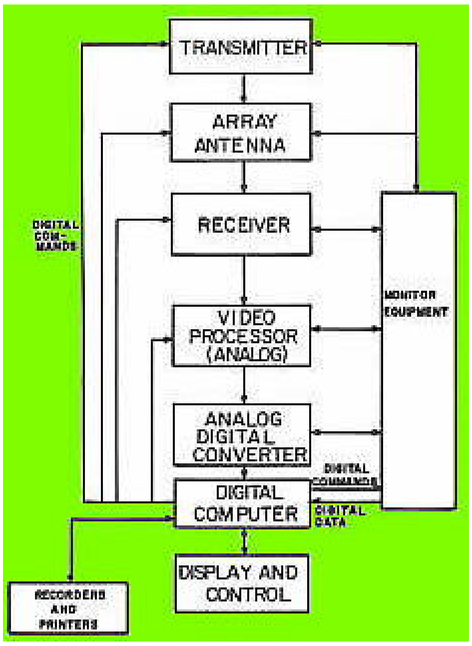

Figure 17. Array Radar.

(1) In the search function the radar attempts to locate targets in its volume of interest. The computer sends commands, via the beam steering circuits and the array antenna, to move the radar beam systematically through the volume of interest or responsibility. During research, a signal or return significantly different from its contemporaries may be detected. The computer may differentiate between this signal ad others by directing a close scrutiny of that point in space. And, after many observations, may determine with a high degree of probability that a target in fact exists.

(2) A target track normally includes data on position and velocity, and may include other parameters such as size, heading, altitude and time of last observation. For a radar to gather data on a target it must make an observation at the location of that particular target in space. The computer determines where and how frequently to "look". Based on this tracking data, the computer draws certain conclusions about it . That is, does it possess the characteristics of a winged aircraft, tactical ballistic missile, or Intercontinental Ballistic Missile (ICBM) . In the case of ICBM's it may discriminate between accompanying decoys and the actual threat vehicle

e. To achieve optimum benefits from a phased array radar's capabilities, an energetic, stringent management program must be employed. The digital computer is an excellent manager of the total radar resources. It select. a specific frequency out of the frequency band, determines whether long or abort pulse bursts are required and directly controls the array beam steering and electronic scanning functions. In short, it insures maximum usage of all radar resources at any given time and at a speed that could never be duplicated using the human operator .

f. Mother area in which the computer performs admirably is the trans fer of data from one radar to another over digital radio links . The computers can exchange data on incoming targets among adjacent systems to assist one another in solving tracking and engagement problems .

g. After the radar system has been brought to operating condition its various subsystems must be constantly monitored and evaluated to guard against performance degradation . Large arrays have thousands of single channels that must have accurately controlled phase and amplitude characteristics. In addition, a large radar may have hundreds of teat points that require monitoring in times varying from seconds to . Some malfunctions may be corrected by computer controlled adjustments, some by manual adjustments, and some by subassembly replacement .

8. SUMMARY.

a . Phased arrays are finding increased application within the Department of Defense. Their vast data handling ability will likely encourage their use in the civilian world as well . Conceivably they could alleviate much of the burden now experienced by ground controllers at our overcrowded air terminals.

b . The largest operational phased array is the AN/FPS-85 employed by the Air Force. The system, located at Eglin Air Force Base, Florida, was designed and constructed by Bendix Corporation. With a range of several thousand miles, the FPS-85 detects, tracks, identifies and catalogs earth-orbiting objects and ballistic missiles. The sensor views all but extremely high altitude satellites twice a day. Sensor functions center around the computer because of the many concurrent actions. Although the operator influences the operation and monitors the system's activity, radar control does not require human intervention.

c. An advanced phased array system has been developed for the Navy by Hughes Aircraft Company. The antenna, entitled ESAIRA (Electronically Scanned Airborne Intercept Radar Antenna) provides air to air search, multiple target tracking, terrain following/avoidance and ground mapping at high data rates. ESAIRA employs a 36-inch diameter planar array composed of 2400 radiating elements.

d. One of the Army's phased array systems has been field tested in Vietnam. It is a fixed perimeter system used to penetrate dense foliage. Results so far are very encouraging and more of these units will find their way to Southeast Asia.

e. The largest Army phased arrays are the two massive radars developed for the SAFEGUARD system. One has a range beyond a thousand miles, contains thousands of elements, and is housed in a 40,000 square foot building over a hundred feet tall. The other has a shorter range and occupies a 50,000 square foot building, 90 feet high, figure 18. Processing and controlling the tremendous amounts of data is accomplished by one of the most sophisticated computer systems ever designed.

f. Nor is the Field Any application being overlooked. Raytheon is designing and building a highly complex densely packaged system called SAM-D (Surface to Air Missile Development). Its capabilities far exceed those of air defense systems employed today. Tightly packed aboard a combat vehicle, SAM-D will use a single radar to conduct all the functions of acquisition, track and guidance necessary for its air defense role, figure 19.

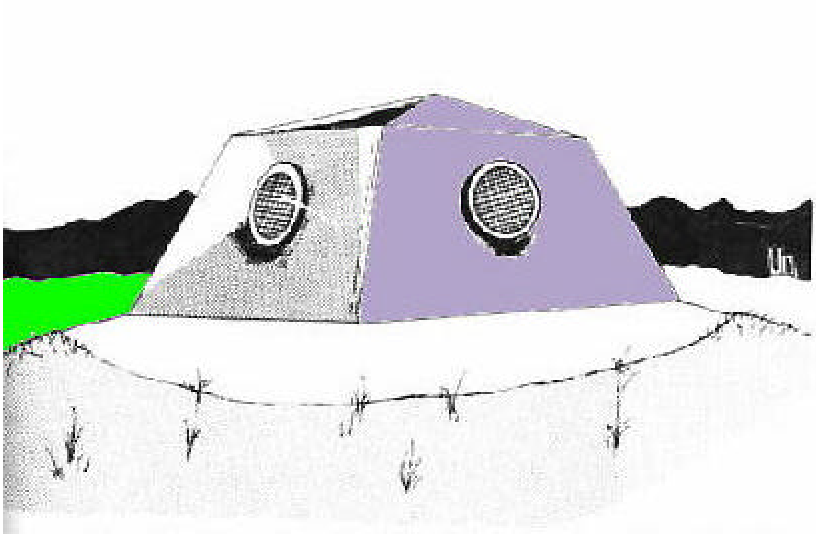

Figure 18. Safeguard Phased Array.

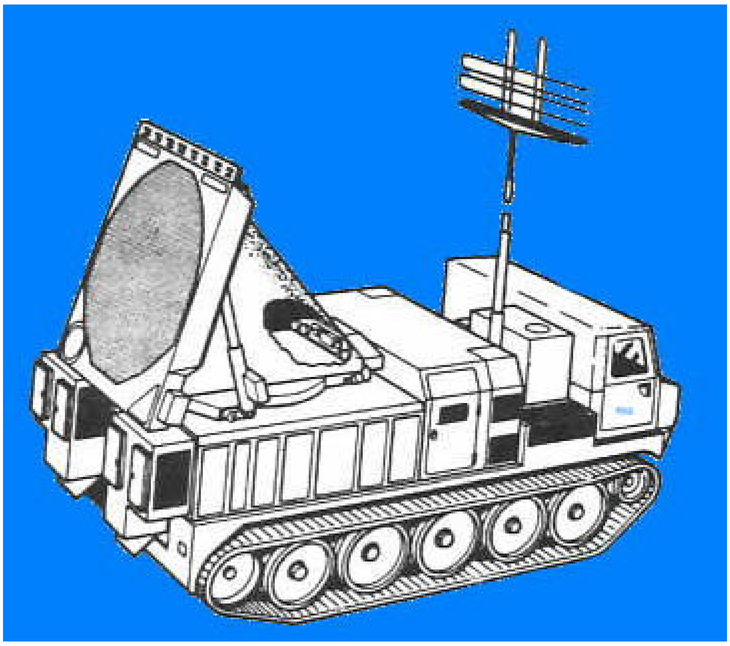

Figure 19. SAM-D (Early Tracked Vehicle Configuration).

MMS SUBCOURSE NUMBER 175, FUTURE AIR DEFENSE MISSILE SYSTEMS

EXERCISES FOR LESSON 1

1. Around an array of two or more elements, the field at any point is equal to what combination of the fields from the individual elements?

A. Product of the field from one element times the number of elements
B. Scalar sum
C. Vector sum minus the scalar difference
D. Vector sum

2. A possible type of phase shifter could be

A. digital, proportional to an applied current.
B. analog, digital.
C. ferrite, diode.
D. reciprocal, diode.

3. A passive array would be one with

A. one transmitter and receiver for each element.
B. one transmitter and receiver for all elements.
C. a transmitter for all elements and a receiver for each element.
D. a transmitter for each element and a receiver for all elements.

4. Computerized monitoring equipment can

A. inject test signals.
B. discriminate between targets.
C. produce commands for a display and control system.
D. determine that a target exists.

5. A disadvantage of an optical feed antenna system is

A. amount of "plumbing" necessary.
B. high side lobes.
C. RF spill over.
D. requires precise impedance matches.

6. A horizontal linear array, with tine-delays on the inputs to the elements such that the delays increase from left to right, will produce a beam that is

A. vertical and steered to the right.
B. horizontal and steered to the left.
C. vertical and steered to the left.
D. horizontal and steered to the right.

7. The amount of phase shift produced by a single ferrite core is determined by its

A. length.
B. width.
C. height.
D. location.

8. Digital commands for a ferrite core phase shifter originate in a

A. core driver.
B. three or four bit phase shift circuit.
C. system computer.
D. beam steering computer.

9. Which type of electronic scanning can only be used with an active element array?

A. Rotating feed horn
B. Phase scanning
C. Frequency scanning
D. Feed switching

10. The most advantageous line length. to use in a delay line phase shifting system are those with the relationship

A. 1,2,3,4.
B. 1, 2, 4, 8.
C. 1, 3, 6, 9.
D. 1, 2, 4, 6.

11. The maximum safe power level of a diode phase shifter is obtained when

A. peak current rating is reached.
B. peak voltage rating is reached.
C. either peak current or peak voltage rating is reached.
D. peak current and voltage ratings are reached simultaneously.

12. The computer determines that a possible target is in fact a genuine target after

A. one observation by the radar system.
B. several observations made during the normal search function.
C. a close scrutiny of the location of the possible targets.
D. a target track is initiated.

13. During the receive mode using an optically fed array, the transmit phase is

A. duplicated.
B. shifted 180 degrees.
C. shifted 90 degrees.
D. reversed.

14. Which is NOT necessarily a component of a phase shifting element?

A. Front radiator
B. Rear radiator
C. 3 or 4 bit circuitry
D. Phase shifting circuitry

15. Which four bit word will produce a phase shift of 202.5 degrees?

A. 1001
B. 1010
C. 1011
D. 1100

LESSON 2. SAFEGUARD

MMS Sub course No. 175	Future Air Defense Missile System
Credit Hours	One
Lesson Objective	To describe the Safeguard System, to explain the reasons behind establishing the

TEXT

1. INTRODUCTION.

a. No weapon system has caused more debate in recent years than the Safeguard anti-ballistic system. Because of a Strategic Arms Limitation Treaty (SALT) agreement signed with the Soviet Union, only two ABM sites may be constructed in the United States under treaty agreements: one near Washington, D. C., to protect the nation's decision making center; and the other near the town of Grand Forks, North Dakota, close to the sites of the 150 Minuteman Inter Continental Ballistic Missiles (ICBM's).

b. Only the site in North Dakota is under construction. Though allowed by the treaty, the site near Washington, D. C., has been scrapped by Congress as unnecessary. No complex will rise above the Maryland or Virginia country side to guard the White House, the Pentagon and the Capitol. North Dakota alone will own that spectacle.

c. The construction in North Dakota, over 90% completed as of calendar year 1972, will be finished by the end of 1974. It is of monstrous proportions. The Safeguard ABM complex has two major units, the Missile Site Radar (MSR) and the Perimeter Acquisition Radar (PAR). The Missile-Site Radars (MSR) concrete housing is 230 feet square at the base and is 125 feet high. Fifty of the 125 feet, including the firing level, are underground. Next to the missile-site radars housing is an underground power plant containing six huge generators each whose flywheel alone weighs 20-tons.

d. The MSR's 7- ft- thick steel reinforced concrete walls form shear cliffs as awesome as any a California mountain climber sight be proud to scale. Near the top, out of each side stares one round radar eye. There are four in all, one for each side**.** These radar support rings, as the eyes are called, are each 30 feet in diameter, and are able to track hundreds of incoming warheads from several hundred miles out and in all directions.

e. The MSR directs the launch of both the long range Spartan missiles, which have a range of over 400 nautical miles and the fast little Sprint missiles which have a range of 25 miles and can climb 50,000 feet before you can blink your eyes. There is a farm of 30 Spartans just to the West of the MSR. Scattered around are several smaller farms containing in all 68 Sprints

f. The MSR is designed to survive a near miss of even the most powerful Soviet warheads. The walls and flooring of the MSR required 221000 tons of reinforced steel encased in 180,000 cubic yards of concrete. Entrance doors are foot-thick metal and bomb-blast proof.

g. Outside the MSR site are the barracks, the administrative office, and the individual housing units. All are low, single-story buildings built primarily, not to withstand possible nuclear blast, but to withstand the certain winter gales coming down from Canada.

h. The Perimeter Acquisition Radar (PAR), the other major complex, is 35 miles from the MSR site. The PAR housing is even more massive and towering than the MSR. Shaped like a great granite block, this monolith is 200 feet square at the bat and towers up over 120 feet. One mammoth eye looks north ward. This radar support ring tracks moving warheads from up to about 2,000 miles away and assigns them, when they get near enough, to the MSR which then can send the Spartans and Sprints to greet them.

2. HISTORY.

a. During the last decade, there have been several names attached to what is now the Army's Safeguard Ballistic Missile Defense System. The program was born with the name Nike—Zeus. It later became Nike-X. And, with a decision to actually produce and deploy the system, it was given name Sentinel. The final witch from the term Sentinel to the new term Safeguard, promoted by a change in government, also denoted a change in deployment planning away from urban center defense and toward Minuteman missile site and key government personnel defense.

b. Of course, while the name was changing through its multiplicities, there were also industrially gratifying changes in hardware. This often lead to confusion among old-timers in the various missile programs, consternation the tax payer, and opportunity for debate among duly elected representatives this republic.

c. The original need to provide a defense against ballistic missiles became very clear to England in the 1940's with the introduction of the German V-2 short-range ballistic rocket.

d. The early state-of-the art, being primitive, led to the first argument against anti-ballistic missile systems, "Is it possible for a bullet to hit a bullet?" This controversy passed, first when calculations showed the feasibility of such an intercept and, later and most definitely, when success ful intercepts of actual ICBM targets fired from Vandenburg AFB were accomplished by the old Mike Zeus System in 1962 and 1963. Out of 14 attempted intercepts, 10 were successful. What Daniel Boone could do with the ball from a Kentucky rifle, so could modern science with a missile.

e. However, the old Nike Zeus System as good as it was, had two major defects. One was that of the Zeus missile reaction time, too slow to permit waiting until atmospheric re-entry of the targets took place. Hence, discrimination between real warheads and decoys could not be aided by atmospheric filtering. The second defect was that it used what are now considered to be old-fashioned, mechanical radars which had to be mechanically controlled or pointed at each target in turn. A radar for each target was almost a necessity.

f. An improvement was made in 1963 by the initiation of the Nike-X Program. Phased array radars which steer their beams electronically in a few millionths of a second were introduced to replace the older Nike Zeus radars . The traffic-handling capability of the system was thus vastly improved .

g. Also, the Sprint missile, a very high acceleration interceptor, was added. Sprint launches could be delayed until after the cloud of objects had re-entered the atmosphere . The atmosphere slowed down the pieces of chaff and balloons, and the radar could discriminate them from the warheads which did not slow down until much lower altitudes.

h. In 1965, the PAR (perimeter acquisition radar) was added and the missile's name changed from Zeus to Spartan. Because of its long range, the Sparta can protect a large area.

i. In November 1967, the name changed from Nike-X to Sentinel. Thus, the Sentinel System was initiated as an anti-ICBM system designed for defense of the United States against a intercontinental ballistic missile attack. At this time, plans envisioned an aggregate of sites numerous enough to provide coverage to all of the contiguous United States .

j. Incidental to this concept, it was reasoned that deployment of the Anti-ICBM would increase the defense of our Minuteman sites against either Chinese or Soviet attack, adding greater effectiveness to our offensive missile force and maintaining our retaliatory capability. In March 1969, the name was changed to Safeguard and the primary objective became not area defense of all U. S. cities but the area defense of our land based missile sites, with a yearly evaluation of the threat to determine the need for possible expansion to 12 bases in the Continental U. S.

k. The October 1972 SALT agreement with Russia limited the ABM System to No sites, one at Grand Forks, North Dakota, and the other in the Washington, D. C. area. The only site that will be constructed is the one at Grand Forks which was completed in October 1974.

3. SYSTEM DESCRIPTION.

a. The four principle components used in Safeguard are two radars and No missiles. The first radar is a perimeter acquisition radar called PAR, and the second is a missile site radar, MSR (figure 1). interceptors are the Spartan and Sprint.

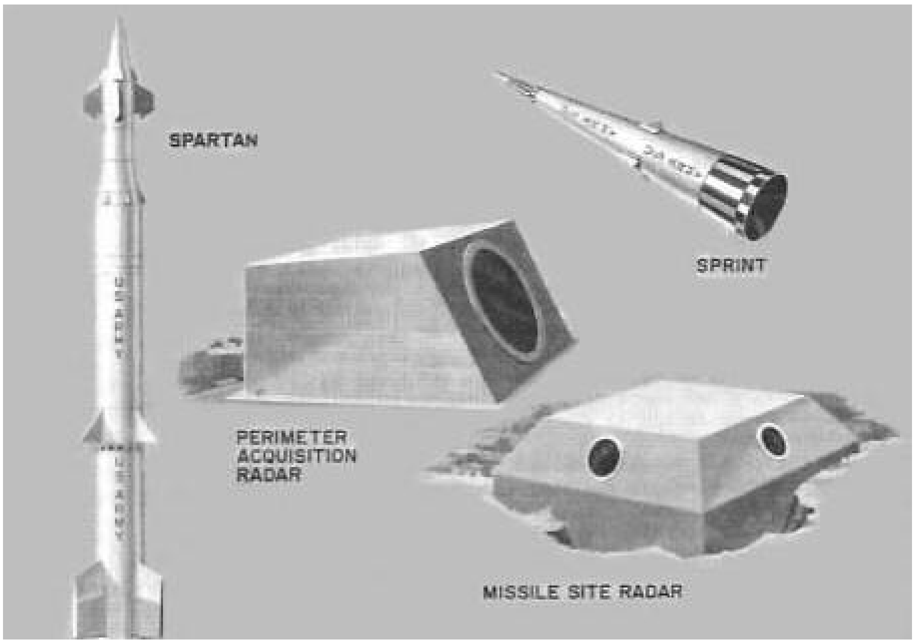

Figure 1. Safeguard Components.

b. Perimeter acquisition radar. The PAR (figure 2) pointing northward is used for long—range target detection, acquisition, and tracking. It is a large, phased array radar, transmitting a beam which can be moved from one direction in the sky to another in a few millionths of a second. A large concrete building houses the transmitter, receiver, and associated electronic components. The antenna elements are embedded in, and actually form part of, the walls of the buildings. The PAR will operate at a relatively low frequency and is capable of long-range detection and tracking. The PAR installation require. about 300 acres . The PAR building is over 120 feet high and 200 feet square at the base . By comparison, this makes the PAR about as large as two football fields placed side by side, and as tall as a 13 story building. This radar has its own integral data processing system which is linked to the data processor in the MSR. The detection capability of the PAR is on the order of 2000 nautical miles against a single intercontinental ballistic missile.

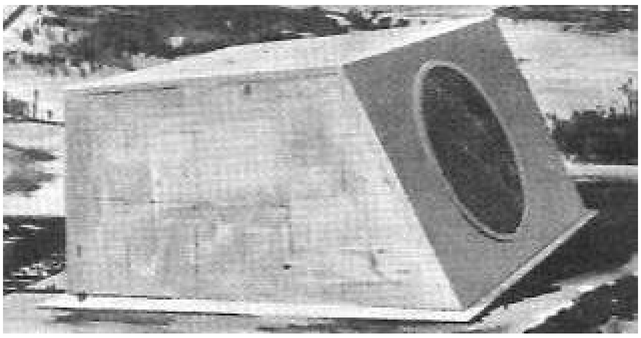

Figure 2 . Perimeter Acquisition Radar .

c. Missile site radar. A cut-away view of the missile site radar (MSR) is shown in figure 3. This phased array radar operates at a higher frequency than the PAR and is designed for precision target tracking. It is also used to track and guide the Sprint or Spartan missiles to the intercept point. Because of its electronic scanning capability, the MSR can handle a large number of intercepts simultaneously with a intercept capability in the order of 400 nautical miles range . Figure 3 shows that most of the missile site radar installation is underground with only the radar arrays and necessary electronic equipment above the ground . The building housing this radar is tout 230 feet square and 125 feet tall. However, the above ground portion which can be seen on site is only about 125 feet square and even though so much of it is buried, still is an imposing monolith. The operations control center for the Safeguard sits is located below ground in the hardened MSR building. This building is actually the nerve center for a Safeguard site.

d. Safeguard site. Figure 4 is a model of a missile site radar Installation with the associated Spartan and Sprint missile farms and support facilities . The site has its own underground power plant and above-ground offices and living quarters . This installation requires between 220 and 250 acres of land. This picture shows a site on barren land in order to make the items of equipment stand out. However, after the North Dakota site is constructed equipped, and manned, it will be landscaped to bland as nearly as possible with the surrounding countryside. This won't be difficult.

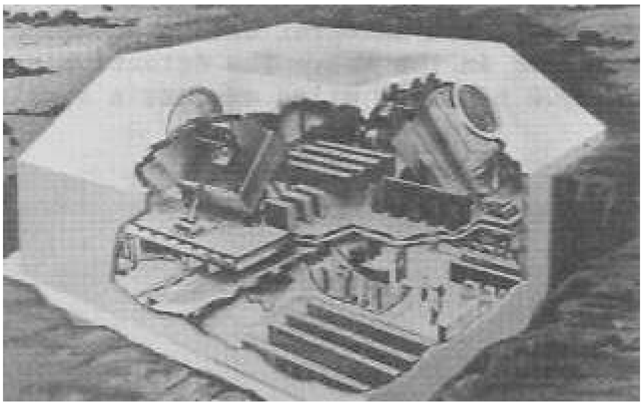

Figure 3. Missile Site Radar.

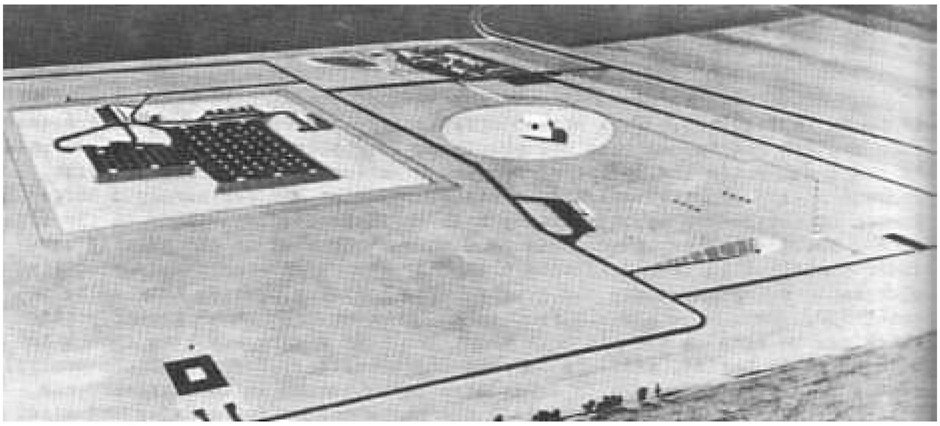

Figure 4. Missile Site Radar Installation

e. Spartan missile. The Spartan missile (figure 5) can operate out ranges of several hundred miles and is designed to intercept outside the earth's atmosphere. This missile has three stages, uses solid propellant engines, and is launched vertically from an underground storage silo. It will carry a nuclear warhead having a yield in the megaton range. Spartan test launches have been conducted at the Pacific Missile Test Range.

Figure 5. Spartan Missile.

f. Sprint missile. The Sprint missile (figure 6) is smaller but a very high performance inteceptor. It has two stages, also uses solid propellant engines, and is also launched from an underground silo. The Sprint is launched using a technique called "pop-up ejection." The missile is ejected by a "hot gas generator" placed under it in the cylindrical cell. The gas generator creates enough pressure beneath the missile to pop it out like a dart from a blowgun. This action overcomes the force of inertia and permits using all the on-board solid propellant to produce tremendous acceleration. Sprint's high acceleration allows it to climb thousands of feet in a few seconds. Because of its limited range, compared to Spartan, it is essentially a terminal defense component and is, therefore**,** particular well adapted to defending point targets such as Minuteman silos or radars. The Sprint carries a nuclear warhead, but because it is designed to make intercepts within the earth's atmosphere, the yield is low in the kiloton range. A number of very successful launch tests of the Sprint missile have been conducted at White Sands Missile Range and at the Pacific Missile Test Range.

Figure 6. Sprint Missile

4. DATA PROCESSOR. A data processor of modular design will be associated with the perimeter acquisition radar and missile site radar, to process and evaluate the vast amount of information accumulated by the radars . The hardware of the data processing system is composed of computer processors, memory banks, displays, tapes, and discs. Software consists of a completes set of computer programs. These are controlling programs that go into the computer. The computers are programmed to receive data outputs of the PAR and MSR, convert them to missile firing and direction data to guide either of the missiles to target intercept. The digital computers used by the Safeguard System are new to air defense and are now being produced. A developmental data processing system has been installed and tested at the Bell Laboratories, Whippany, New Jersey. The MSR portion of the Data Processing System has been installed at the Pacific Missile Test Range and is being tested there.

Go to Part 3