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Reliability of Naval Radar Systems

[Unclassified Title]

D.F. Hemenway and B.N. Navid

Radar Techniques Branch
Radar Division

September 1978

NAVAL RESEARCH LABORATORY
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(U) This report relates the operational reliability of naval radar systems to the reliability achieved by other electronic systems. Representative naval radars are examined by their reliability and design concepts, stress levels and modes of operation. Additionally, there is a brief consideration of reliability-growth procedures and a projection of the operational reliability achievable with present day technology.

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RELIABILITY OF NAVAL RADAR SYSTEMS
(Unclassified Title)

INTRODUCTION

(U) Existing naval radar systems exhibit low mean time between failures (MTBF) and poor operational availability. Typically, operational MTBF's may range from 5 to 200 hours, and operational availabilities may range from 10 to 60%. (See Appendix A for definitions of acronyms and special terms.) As a consequence of such performance, in an age when satellites have electronics systems which operate with life times measured in years, and when space probes travel interplanetary distances to perform sophisticated experiments, questions are increasingly raised about the poor reliability of military electronic systems.

(U) This report provides a basis for relating operational reliability of naval radar systems to the reliability achieved by other electronics systems. Current naval radar systems are examined for their reliability, design concepts, stress levels, and modes of operation. Additionally, this report presents a brief consideration of reliability-growth procedures and projects the operational reliability achievable with present day technology.

OBJECTIVES

(U) The primary objective of this report is to document the operational reliability of representative radar systems. Additional objectives include:

(1) To document the growing complexity of military electronic systems and compare them with their approximate non-military equivalents.

(2) To indicate the design and development impact of such factors as: parts count, component quality, screening, de-rating, burn-in and redundance on the reliability of an electronic system.

(3) To document the growth in radar systems reliability achieved through reliability growth programs.

Note: Manuscript submitted August 28, 1978.

I. MAGNITUDE OF THE NAVY'S PROBLEM

A. General Factors

(U) Operational naval radars were chosen, representative of specific important functional categories. Examples are the selection of the AN/SPS-10 and the AN/SPS-55 as a representatives of shipboard, surface-surveillance radars, and the AN/SPN-43 as a representative of an aircraft approach control radar.

(U) For a variety of reasons, the compilation of credible data on the reliability of radar systems has been a difficult task. On some systems, the need for, and the value of, such data has been barely recognized; on other systems, financial and manpower constraints have precluded the adequate reporting of data; on still other systems the data may be extensive but of questionable value. An example is the reporting of a system MTBF for an aircraft approach control radar based on the number of hours the carrier is at sea, "steaming time," rather than on the number of hours the radar actually operating during this time.

(U) The sources of radar systems documentation data used in this report are varied. An effort has been made to incorporate only the most current data available and to credit the source. In some instances "official" Navy or company data is either unavailable or non-releaseable. When possible and appropriate, "official" sources are used. The several references to non-military electronics systems in this report are examples where "company" policy prohibits the release of MTBF data and a company authorized "parts count" is not published, yet credible information was available through personal communication and reference to schematics and service publications.

(U) The radar systems selected for documentation are shown in Table I. The non-military systems are included for purposes of reference and comparison. Each of the system listed in Table I is referred to in subsequent parts of this report. Photographs of systems and major sub-assemblies (hardware), block diagrams, tabular listing of system parameters and discussion is provided for each of the systems.

(U) TABLE I

Radar Systems Selected for Documentation (U)

Type of Radar	Nomenclature
Shipboard Surface Search	AN/SPS-10 AN/SPS-55
2-D Air Search	AN/SPS-40 AN/SPS-49
Point Defense	AN/SPS-65 TAS
3-D Air Search	AN/SPS-48
Missile Track/Illuminator	AN/SPG-51D
Fire Control	MK86
Search	AN/SPQ-9A
Track	AN/SPG-60
Air Traffic Control	
Carrier	AN/SPN-43
Land (Navy/FAA)	AN/FPN-59 (FAA ASR-8)
Airborne Early Warning	AN/APS-96 AN/APS-120 AN/APS-125
NASA Satellite Altimeter	GEOS-C

(U) The magnitude of the Navy's problem is not completely conveyed through the reference to any single statistical parameter such as the system MTBF. Important elements of the total problem include such factors as the stress levels, system complexity (or parts count), operating environment, operating modes, and mission requirements. In turn, each of these factors may be sub-divided into one or more categories. As an example, MIL-HDBK-217B identifies and describes 9 nominal environmental conditions, each of which results in a unique modifier to be applied in the determination of part failure rates.

(U) Table II lists these environmental conditions in increasing order of severity, with the least severe being "Ground, Benign" and the most severe being "Missile, Launch."

(U) Indicative of the impact of environmental conditions on a system, operational MTBF data can be cited for approximately the same system used in two different environmental situations. Technical Report ASD-TR-73-22[2] indicates that the AN/APQ-120 developed for Air Force use in F-4E aircraft had a predicted MTBF of 45 hours and a reliability demonstration of 4.3 hours. Essentially the same system with a more complex antenna pedestal and external cabinets to house the hardware instead of the F-4E fuselage is manufactured by Westinghouse Electric as the W-120, a shipboard radar currently rated at a 200 hour MTBF.

(U) Table II explains, in part, the difference between the reliability problems for naval radars and "long-lived" satellites. The respective modification factors are 4.0 and 0.2. Thus, in the absence of other considerations, a space radar has a 20 to 1 advantage in MTBF over a naval radar. The environmental factor, however, is only one of the reasons for the differences in system MTBF's. Other factors which will be developed are the differences in mission, power levels, stress, and costs allowed for the development and assurance of reliability.

(U) Table III provides further information which will help to develop appreciation for the interrelationships between system use or mission (including the environment), complexity (parts count), and stress (power, voltage, heat, shock, and vibration).

(U) As indicated earlier, one of the objectives of this report is to document the complexity of military systems and to compare them with non-military systems. The "parts count" of an electronic system is a common measure of system complexity. In its simplest form it is a count of the total number of discrete components which are connected together to form an operating system. Such parts are the resistors, capacitors, tubes, solid-state devices, coils, transformers, and other items typically in a schematic diagram of the system. In a real system, the parts count should include much more than the basic electronic components; i.e., the electrical, electromechanical, and mechanical hardware

(U) TABLE II

Environmental Classifications (U)

Environment	Nominal Environmental Conditions	Factor
Ground, Benign	Nearly zero environmental stress with optimum engineering operations and maintenance.	0.2
Space Flight	Earth orbital. Approaches Ground, Benign conditions without access for maintenance. Vehicle neither under powered flight nor in atmospheric re-entry.	0.2
Ground, Fixed	Conditions less than ideal to include installation in permanent racks with adequate cooling air, maintenance by military personnel and possible installation in unheated buildings.	1.0
Ground, Mobile (and Portable)	Conditions more severe than those for Ground, Fixed mostly for vibration and shock. Cooling air supply may also be more limited, and maintenance less uniform.	4.0
Naval Sheltered	Surface ship conditions similar to Ground, Fixed but subject to occasional high shock and vibration.	4.0
Naval, Unsheltered	Nominal surface shipboard conditions but with repetitive high levels of shock and vibration.	5.0
Airborne,	Typical cockpit conditions without environmental extremes of pressure, temperature, shock and vibration.	4.0
Airborne, Uninhabited	Bomb-bay, tail, or wing installations where extreme pressure, temperature, and vibration cycling may be aggravated by contamination from oil, hydraulic fluid, and engine exhaust. Classes I and Ia equipment of MIL-E-5400 should not be used in this environment.	6.0
Missile Launch	Severe conditions of noise, vibration, and other environments related to missile launch, and space vehicle boost into orbit, vehicle reentry and landing by parachute. Conditions may apply to installation near main rocket engines during launch operations.	10.0

* Table II is taken from MIL-HDBK-217B.[1]
** After a system failure rate has been calculated, it should be multiplied by the appropriate factor-value to reflect impact of environment.

(U) TABLE III

Reliability as a Function of Complexity and Stress (U)

System	No. of Parts	Power	Voltage	MTBF Hours
B & W TV Receiver	297	23 W	0.7 kV	2,500
Marine Radar	764	10 kW	6.2 kV	1,000
FAA Radar	18,700	1,600 kW	80 kV	365
Naval Radar	10,000	1,000 kW	30 kV	50

(U) necessary for the normal operation of an electronic system.

(U) The first system listed in Table III, is a foreign made, black-and-white solid state television receiver. The receiver is identified as having 297 series active elements (parts count), and an observed MTBF of approximately 2,500 hours. Stress factors are indicated by the input power to the receiver of 23 watts, and the peak operating voltage of 700 volts dc.

(U) The second system is a commercial marine radar with 764 parts and an MTBF of approximately 1,000 hours. Stress for this system is indicated by the peak pulse output power of the transmitter, 10 kW (6 watts average power output), and a peak pulse voltage of 6.2 kV.

(U) The third system is the Federal Aviation Agency's ASR-8. The ASR-8 has a parts count of approximately 18,000 elements, and an observed MTBF of approximately 300 hours. Peak power output for the transmitter is 1,000 kW (720 W average power output), and the peak system voltage is 80 kV.

(C) The fourth system is a naval radar, the AN/SPS-39A with a parts count of approximately 10,000 and an observed MTBF of about 50 hours. Power stress is indicated by the peak pulse output power of 1,000 kW (2 kW average power output). Peak voltage stress for this radar is 30 kV.

(U) The four data points from Table III are plotted as circles in Fig. 1. Note that a line can be drawn through three of the data points almost parallel to the lines identified for 1950 and 1960 systems. The latter lines are based on a General Electric Co. report and reflect the relationship between MTBF and system complexity for airborne electronic systems.[3] The slope of the line connecting the three data points, and the proximity of these points to the 1960 systems-line offers a degree of assurance that the first three systems of Table III are representative of the state of technology and engineering practice for this period.

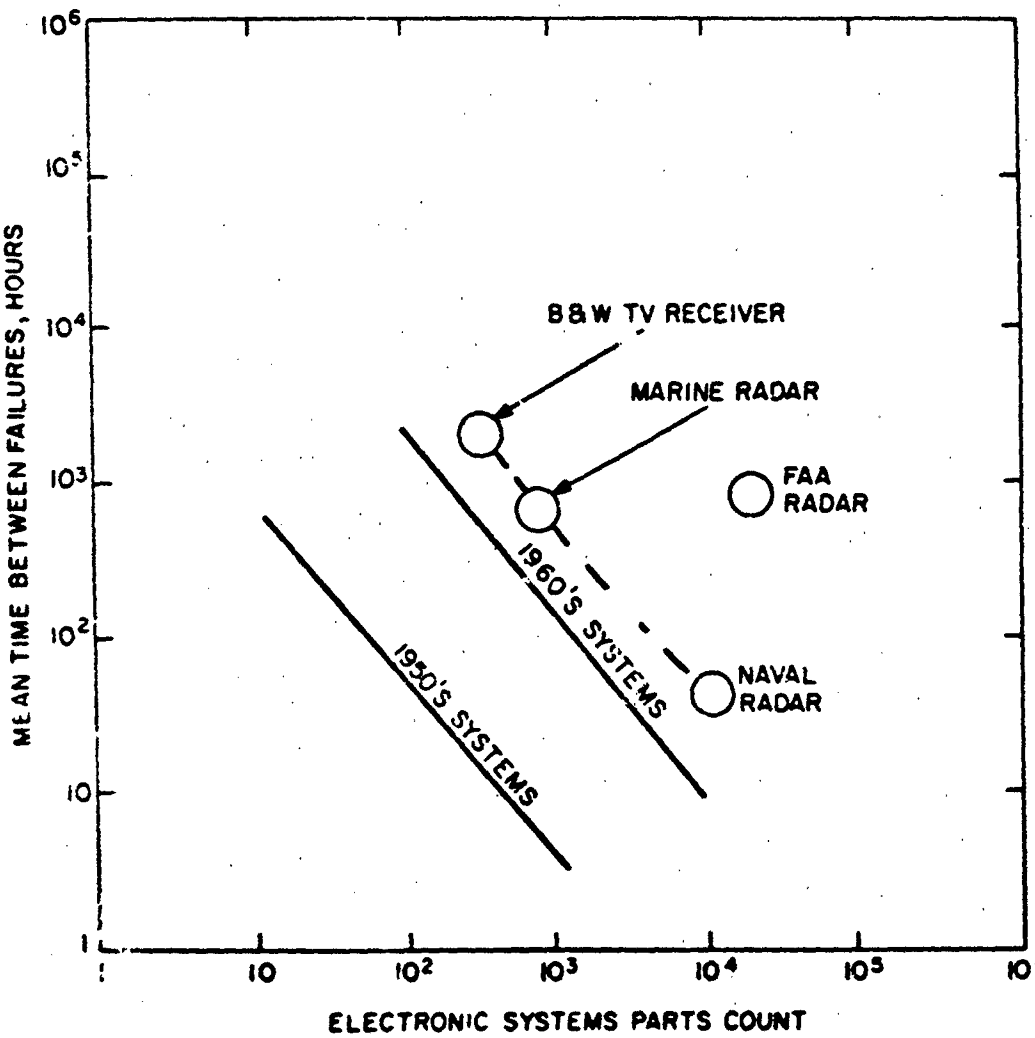

Fig. 1 (U) - Trends in systems complexity and MTBF (U)

(U) Several additional characteristics can be inferred from the curves shown in Fig. 1. First, there is an approximate log-log linear relationship between the MTBF and the parts count (complexity) of the electronics systems represented. Second, there is an indication that the type of electronics system is not critical so far as the relationships shown in Fig. 1 are concerned. In the example shown, a television receiver, a low-power marine radar, and a high-power naval radar, all exhibit the same parts count vs. MTBF relationship appropriate for 1960 era technology and engineering practice.

B. Reliability Growth

(U) The exception in Fig. 1, is the data point plotted for the FAA radar, the ASR-8. The ASR-8 is not representative of conventional radar engineering development for either the 1960's or the 1970's. The MTBF achieved, and indicated in Fig. 1, is the result of a significant and determined effort to achieve high availability. The ASR-8 data point serves to document that a determined reliability growth and development program can lead to an MTBF which is an order of magnitude or more above the MTBF achieved with system developed in a conventional manner. A similar superior MTBF resulting from determined reliability growth programs is documented in an Air Force study which compares a conventionally developed airborne radar with an approximately comparable system developed under a contract that stressed high reliability.[2] The two systems are the AN/APQ-120 with an MTBF, at the time of the study of approximately 4 hours, and an AN/APQ-113 with an MTBF of approximately 150 hours.

(U) Determined radar reliability growth programs have not been commonplace, but other examples are to be found in the AN/APQ-148 an air-to-ground attack radar the AN/APG-63, and the AN/APS-125.

(U) In Fig. 2, another important aspect of reliability growth is developed showing the relationship between MTBF and time for reliability test, analysis, and redesign.

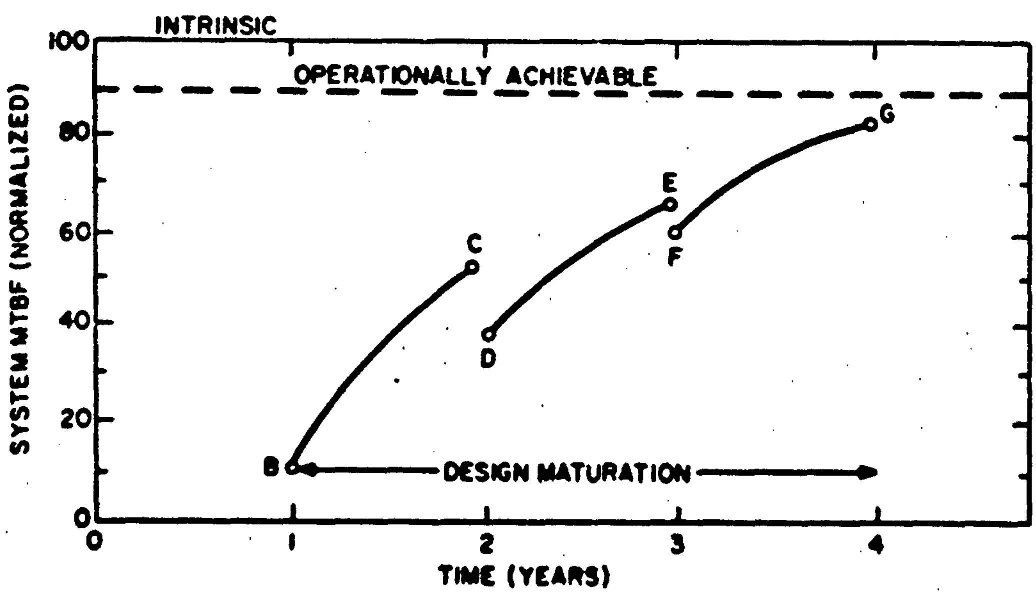

Fig. 2 (U) - The growth of reliability as a function of a time extended design and development process (U)

(U) In Fig. 2, the line at the top of the figure represents the operationally achievable system MTBF. Point B, represents the system MTBF achieved on initial operation. Typically, for large complex radars, the initial observed MTBF's are on the order of 1 to 10% of the intrinsic system value. The different values of the MTBF from 1 to 10% referred to above is indicative of "corporate memory" or design team experience. A company building a radar similar to one that it has manufactured recently with the same design team can reasonably expect to achieve the larger initial value, 10% of the system intrinsic MTBF.

(U) In contrast with the above, a company building a new radar with a new design team, does not have the same degree of "corporate memory." With less experience, this company would probably achieve the lesser value of 1% upon initial operation. Note, the reference to a new design team does not imply inexperience or incompetence. The point is that the reliability of a complex system is also to some degree the product of design team educational process.

(U) In Fig. 2, the curve plotted between points B-C represents growth in reliability as the first system constructed is tested, analyzed, and improved. The first system might be representative of a pre-production prototype. The system represented by the curve D-E might represent the first production run, and F-G a still further improved second year production run. The total growth in MTBF, from B to G represents the reliability improvement as a system matures. Page 13 of the Reliability Design Handbook, (Reference 4) has a brief description of a similar figure.)

C. Considerations for Achieving High Reliability in Electronics Systems

1. General

(U) The achievement of high reliability in electronics systems involves many diverse factors including: design; "corporate memory"; iteration or maturation; "screening"; "de-rating"; "burn-in"; together with a dedication of manpower, materials, and time, to a sustained effort for system reliability development. Systems reliability can be developed either before or after system production is initiated. It is to be emphasized that after the fact corrective action is much more costly, and generally much less effective than the reliability improvements that precede the release to production. These general ideas will be expanded upon briefly in the sections that follow.

2. Reliability Design

(U) There are numerous excellent texts and articles on the general topic of reliability and the interested reader is referred to these for more details and specifics (References 1, 4, 5, 6, and 7).

(U) General reliability theory introduces the concept of failure rate (λ). The time-history failure rate for a system is often represented by a characteristic curve similar to that shown in Fig. 3.

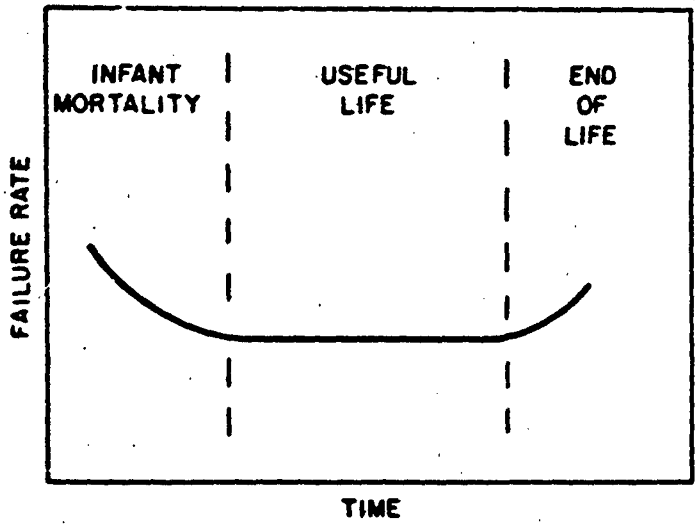

Fig. 3 (U) - Time-history failure characteristics (U)

(U) The initial high and decreasing failure rate is referred to as the "infant mortality" period. The operationally "useful life" period is characterized by the relatively constant failure rate shown in the center portion of the curve. The end-or-life period is characterized by an increasing failure rate as components fail from age and wearout.

(U) The failure rate of a component or a system is defined as the number of failures per unit time. The failure rate, as indicated in Fig. 3, is not constant for the entire life of the component or system. During that period of time indicated as useful life in Fig. 3, the failure rate is approximately constant. The approximately constant failure rate in the useful life period is the reciprocal of the MTBF. Alternatively, the MTBF of a component is the reciprocal of the constant failure rate for that item.

(U) As an example, from MIL-HDBK-217B a fixed composition resistor, type MIL-R-39008 operating at rated wattage, and a temperature of 20°C (68°F) has a base failure rate, λ_b of 0.0007 (failures per 10^6 hours). The MTBF of the item is then:

$$MTBF = 1/\lambda_b$$
$$= 1/(0.0007/10^6)$$
$$= 1.43 \times 10^9 \text{ hours}$$

(C) An example of a radar system, one which will be referred to later in the report would be the AN/APS-96, currently exhibiting a Mean Flight Hours Between Failures (MFHBF) of approximately 12.0 hours. The failure rate for the airborne AN/APS-96 radar system is then:

$$\lambda = 1/MFHBF$$
$$= 1/12$$
$$= 0.083 \text{ failures per flight hour}$$

(C) Reliability, R(t), is the probability that an item will continue to perform its specified functions up to and including time t, the equipment having been operable at time t = 0. For the AN/APS-96 in an E-2 aircraft with a 5 hour endurance, the probability of completing the mission is:

$$R(t) = e^{-t/MTBF}$$
$$= e^{-5/12}$$
$$R_{(5)} = .66$$

(C) There is, therefore, a 66% probability of an E-2 aircraft completing its 5 hour mission with its AN/APS-96 radar still operating.

3. Redundancy Considerations

(U) One common method of obtaining high reliability is the use of various forms of redundancy. The simplest form employs two identical components, modules or even whole systems in parallel (Fig. 4). There are two general operating modes: stand-by redundancy (Fig. 4a) and active redundancy (Fig. 4b).

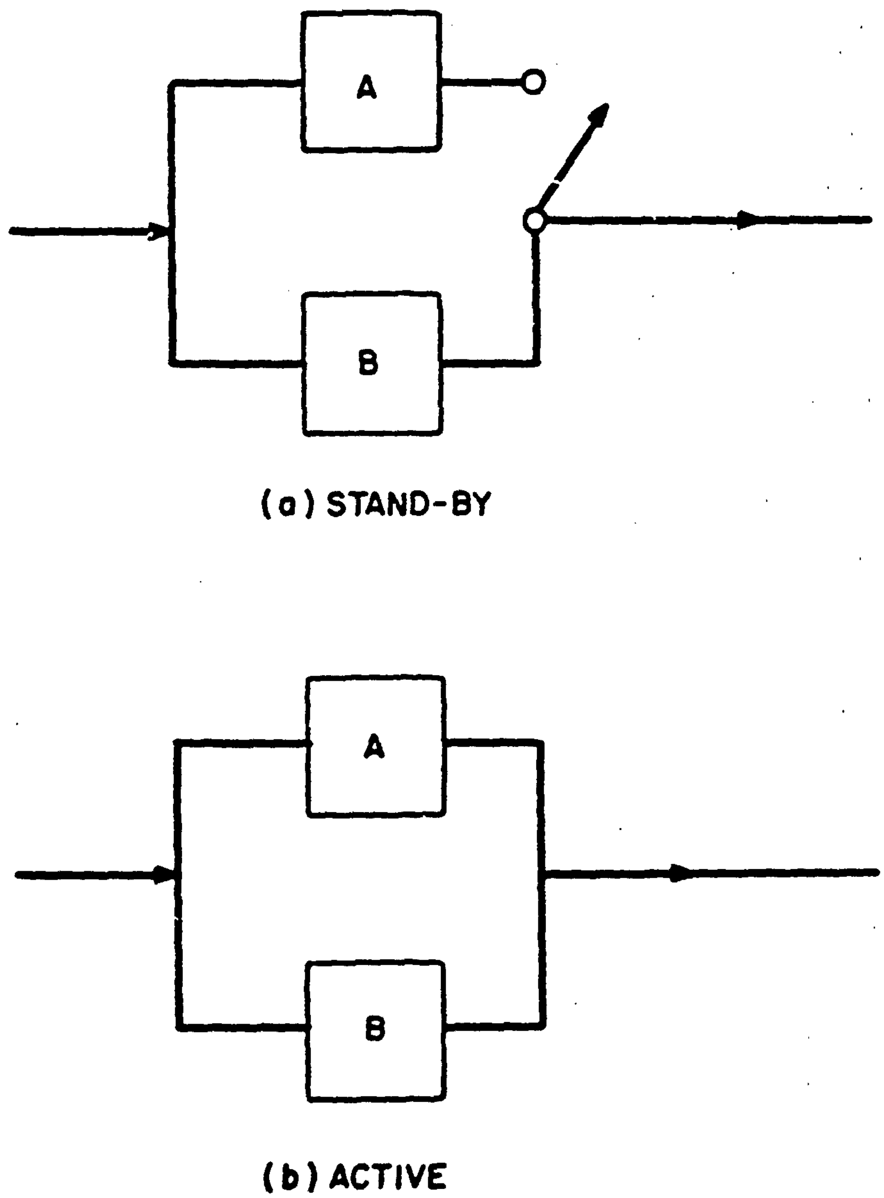

Fig. 4 (U) - Two basic parallel redundancy configurations (U)

(U) In the stand-by mode, if one unit fails, the failure is sensed and a replacement unit is energized; in the active redundancy mode both units operate simultaneously, although only one of the pair need be "good" for successful circuit operation. The problems associated with fault sensing or switching will not be considered in the subsequent discussions.

(U) A redundant system in either of these modes exhibits an MTBF greater than that of the corresponding non-redundant system. For a system with a constant failure rate the improvement factor in the active redundancy mode is 1.5 and in the stand-by mode the factor is 2.

(U) This does not indicate the full extra advantage of redundancy. When a system contains considerable redundancy, the overall MTBF, by itself, is not sufficient to characterize its reliability. Two systems with the same MTBF could have different reliabilities; one could have a greater MTBF than that of a second, yet its reliability could actually be less. Other seeming anomalies could be cited.

(U) The following example illustrates the principle involved:

(U) Let there be a requirement that a function be performed with a reliability of 0.9 for a 30 day (720 hours) period. Suppose a module, version A, has been manufactured to perform this function. After infant mortality failures have been eliminated, it is established that its MTBF is 1895 hours. This translates into a 30 day reliability of $\exp[-720/1895] = 0.68$. Thus, the module is unacceptable and must be rejected. The designer has at least two choices:

a. He could try to design a more reliable module, say version B, with an MTBF of 6,834 hours. This would satisfy the reliability requirement. If however, the original module were designed near the limit of present day technology, the 3.6 improvement factor in MTBF might be either unattainable or excessively costly.

b. Alternatively, a <u>pair</u> of the original, A version, modules could be connected in the active redundancy mode. The reliability of this package would be $[2\exp(-720/1895)-\exp(-1440/1895)]=0.9$ which would also meet the specifications. In this case the MTBF would be only 2843 hours (1.5 X 1895).

(U) Thus, two different systems have been exhibited with different MTBF's (6834 and 2843) but with the same reliability (0.9).

(U) If, further, a new module, say version C, with constant failure rate and MTBF of 2843 hours were constructed, its reliability for 90 days would be only 0.75. However, version C and the aforementioned pair of version A modules are two systems with the same MTBF (2843) but

(U) different reliabilities (0.75 and 0.9).

(U) There are two obvious conclusions from the foregoing argument:

a. A system specification should include both the reliability and the mission period for which it applies rather than simply the MTBF alone.

b. When the system design incorporates a degree of redundancy, using the MTBF alone, and incorrectly assuming a constant failure rate for the system, leads to a pessimistic assessment of the system's reliability.

D. Quality of Components

(U) In the design of a modern radar, there is a trade-off between the quality of parts used and the overall system procurement cost. For the Navy, this has meant specifying for example: Established Reliability (ER) level P for resistors and capacitors, JANTX level for transistors, and MIL-M-38510 Level B for Integrated Circuits. The present section considers the theoretical improvement attainable in system reliability if still higher quality components were used.

(U) To perform the analysis in a meaningful way, it seemed best to choose a particular representative radar and to perform detailed reliability prediction calculations based on this radar for each of two levels of component quality. The radar selected was the ASR-8, the FAA air terminal radar, which is being procured by the Navy in essentially the same version, designated as the AN/FPN-59. A particular advantage of this choice is that the detailed part-by-part system reliability data assembled by the manufacturer, Texas Instruments, was provided by the FAA.

(U) Although the radar was not procured under Navy specifications, the resistors and capacitors approximate N or P level Established (ER) components, the transistors are JANTX or even in some cases JANTXV and the manufacturer screens and "burn-in" IC's to a level equivalent to MIL-M 38510 Level B-2, or B-1. Thus, the ASR-8 is an example of a system with good quality parts, similar in quality to that recommended for present naval radars.

(U) Aside from the antenna and the central/data link subsystems the ASR-8 is capable of operating as a dual channel system (Fig. 5). The system includes two waveguide-transmitter-receiver-processor chains of equipment, operated in parallel. Even in those subsystems which are not paralleled (antenna assembly and controls) there is considerable internal redundancy. Moreover, the system is capable of performing its

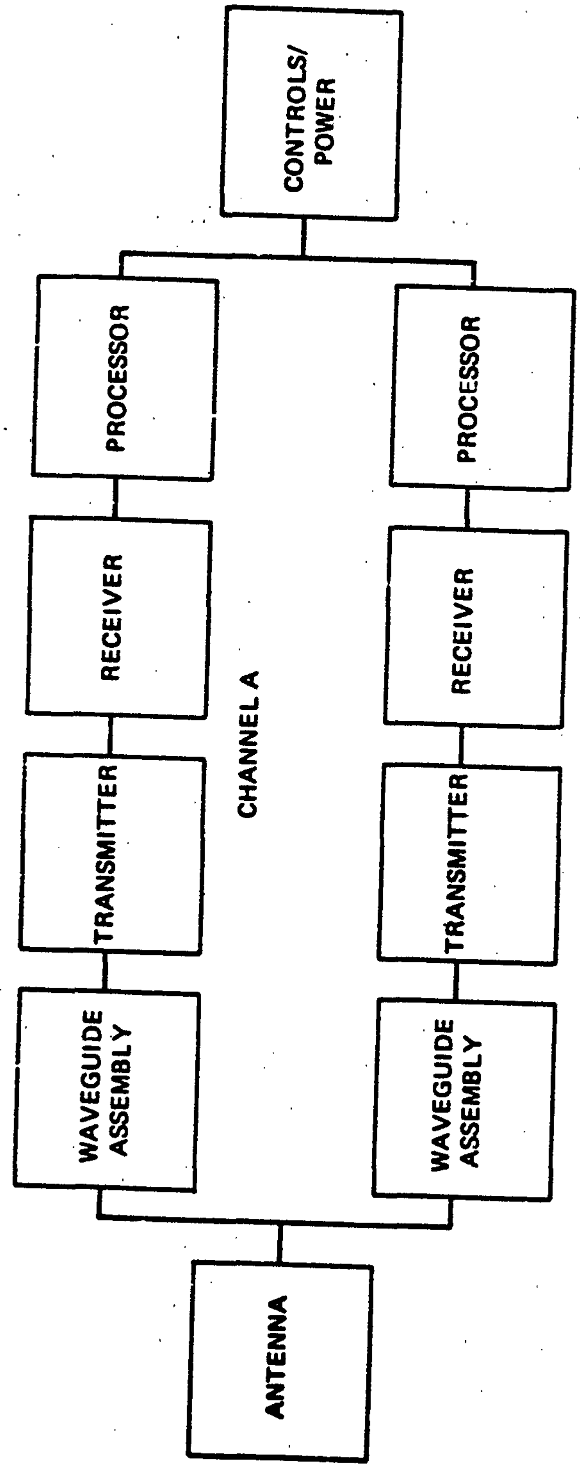

Fig. 5 (U) - Active, parallel (dual thread) reference radar (U)

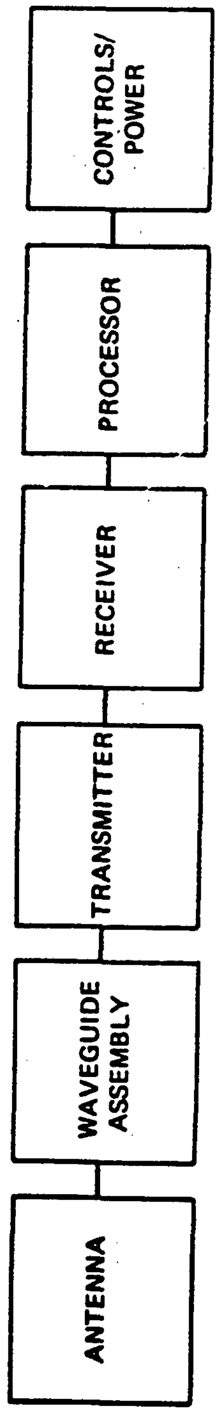

Fig. 6 (U) - Non-redundant (single thread) reference radar (U)

(U) mission with only one channel functioning (Fig. 6). In this mode its theoretical MTBF is approximately 635 hours. This is near the limits attainable from conventional design and manufacturing processes. A more detailed description of the system and its reliability implications appear in NRL Memorandum Report 3719.[8]

(U) A second reliability calculation was made for the ASR-8 assuming NASA-like components. Specifically, all resistors and capacitors were assumed to be S-Level, all transistors JANTXV quality and all IC's specified as belonging to MIL-M3510 Level A. DIP (dual-in-line package) switches, waveguide components, connectors and electro-mechanical devices such as motors, and fans were not changed. Whether these extremely high quality parts are commercially available, whether a manufacturer would be willing to produce the required quantity and what the price might be was not considered. Nor was the cost of the manufacturer's buying moderate level parts and screening to obtain the highest quality estimated.

(U) With these higher quality components, an ASR-8 in the single series chain (single thread) mode of operation would have a projected MTBF of 1319 hours if superior quality electronic parts were used (Table IV). In other words, the intrinsic MTBF of the present system can be improved by at most a factor of about 2, by resorting to NASA-like specifications. The failure rates and MTBF's for the basic subsystems are shown in Table V.

(U) There are additional but minor improvements possible. If all potentiometers were eliminated and replaced by fixed resistors, the MTBF would theoretically improve to about 1485 hours. Elimination of the DIP switches in the processor would raise the MTBF to a projected 1604 hours. Any further increase with the same design would require improved connectors, RF plumbing and electromechanical device in general. The results are summarized in Table IV.

(U) In its single channel mode of operation the ASR-8 is not a truly single thread system. There are two antenna drive motors where one would be sufficient and the control/power assembly has redundant pulse shapers, line compensators and DC power supplies. By removing these last vestiges of redundancy, a completely single thread "Reference radar" can be derived. The failure rates for the major subsystems are shown in Table V. It can be seen in Table IV that there is little difference between the MTBF's of the original ASR-8 single channel radar and the Reference radar. Subsequent analysis in this report will be based upon the latter radar, although data for the actual ASR-8 will be presented when appropriate.

(U) TABLE IV

IMPACT OF COMPONENT

QUALITY ON SYSTEM MTBF (U)

Component Quality	SYSTEM MTBF (HOURS) Single Channel ASR-8	Single Thread Reference Radar
Average Quality	635	609
High Quality	1319	1259
High Quality Without Potent.	1485	1409
High Quality Without Potent. and DIP Switches	1604	1516

(U) TABLE V

MTBF and Failure Rate for Each of the Major Sub-Units of the Single Chain Reference Radar (U)

Radar Sub-Units	Failure Rate(per hr)(X 10^6) Standard Components	High Quality Components	MTBF (Hrs) Standard Components	High Quality Components
Antenna	92	92	10,870	10,870
Wave Guide Installation	11	11	90,909	90,909
Transmitter	277	181	3,610	5,525
Receiver	200	120	5,000	8,333
Processor	905	322	1,105	3,106
Controls/Power/ Data Link	156	68	6,410	14,706
TOTAL SYSTEM			609	1,259

E. Maintenance Free (Unattended) Radar

(U) The MTBF of a system is merely one of a number of system parameters related to its average availability, i.e., the percentage of the time that a system is capable of performing its major functions.

(U) For a system that is fully operational at the start of a mission, the MTBF is the mean time to first failure. There is a statistical distribution of first failure times, however. During its useful life time, the probability of a system failing before a time equal to its MTBF is 0.632. There is as much as a 10% chance it will fail before it has operated 10% of its MTBF.

(U) The availability of a system A(t), is the probability that it is capable of being fully operational. Availability thus depends on both the maintainability (ease of repair and adequacy of logistics) as well as the reliability. As time increases from the initial installation of the system, the availability, A(t), tends toward a limiting value, A, independent of the time.

$$A = MTBF/MDT$$

or

$$A = MTBF/MTTR + MLT$$

where

MDT = mean down time

MTTR = mean time to repair

MLT = mean logistics time (mean time awaiting spares)

(U) It follows that system availability can be improved either by increasing the reliability (MTBF) or decreasing the down time (MDT). The Navy has struggled for years with the problem of maintaining increasingly complex equipment with less than adequately prepared personnel; the achievement of satisfactory logistics is an on-going and ever more difficult problem.

(U) Present and emerging technology in solid state transmitters, digital circuitry and fault-tolerant architectures suggest consideration of the concept of a maintenance free radar. Under this concept, there would be no maintenance for the duration of a prescribed mission. Although the initial acquisition system cost would increase, the total life cycle cost could be less and the system availability could increase dramatically.

(U) Mission periods of 30 days to a year have been suggested for the radar to operate with a reliability of 0.9. A 30 day mission would require an MTBF of 6834 hours, a 90 day mission an MTBF of 20,501 hours

(U) and a one year mission an MTBF of 83,143 hours—all for single thread systems. It should be noted that an unattended radar with a reliability of 0.9 for a given period of time, actually has an average availability of 0.95.

(U) Several studies have been made to study the feasibility of this concept. It appears that there is a potential for achieving a 90 day system (References 8, 9, 10, 11, 12, 13) with available technology.

(U) It is instructive to consider the actual probabilities for the Reference radar to survive 30 or 90 days. These are shown in Table VI; they vary from 0.31 to 0.63 for 30 days and 0.03 to 0.25 for 90 days. Clearly, surviving 30 days is unlikely and surviving 90 days is extremely unlikely.

(U) Finally, again assuming that a reliability of 0.9 is a goal for maintenance free operation, the maximum mission time for which this goal can be achieved is shown in Table VII. Thus, the present ASR-8 will be expected to operate failure-free for 2.8 days and even with the best of components could be expected to last no more than 7 days.

(U) It is evident from the preceding analysis that even one of the best of todays radars cannot become a maintenance free radar solely by replacing every component with a much higher quality equivalent. For a radar to have a 0.9 reliability of surviving 30 days without a failure, its MTBF must be 6834 hours and for 90 days its MTBF must be 20,501 hours. These are each far greater than the 1604 hours, the best extrapolated value for the present system.

(U) TABLE VI

Effect of Component Quality and System Reliability (Single Channel Operation) (U)

	System Reliability			
	30 Day Mission		90 Day Mission	
Component Quality	Present ASR-8	Reference System	ASR-8	Reference System
Standard Component	0.32	0.31	0.03	0.03
High Quality	0.58	0.57	0.19	0.18
High Quality-No Potent.	0.62	0.60	0.23	0.22
High Quality-No Potent.-No DIP Switches	0.64	0.63	0.26	0.25

(U) TABLE VII

Maximum Mission Time (Days) for which Reliability of System is 0.9 (Single Channel Operation) (U)

Component Quality	Present ASR-8	Reference System
Standard Component	2.8	2.7
High Quality	5.8	5.5
High Quality-No Potent.	6.5	6.2
High Quality-No Potent. No DIP Switches	7.0	6.7

F. Redundancy

(U) The present section considers the increased reliability a system can attain through redundancy. Again the reference radar derived from the ASR-8 will be considered. The approach will be based on the maintenance free concept; if one module of a redundant pair fails, it is not repaired during the mission of interest.

(U) Before proceeding, it is of interest to contrast this approach with that of the actual ASR-8 philosophy. When one of the two redundant channels does fail the operator takes it off-line, leaving the other channel to perform most of the relevant radar functions. Highly skilled maintenance technicians then work to repair the fault and return the subsystem to operation, with a MTTR of 1 hour. This redundancy-with-repair concept requires extremely good logistics and highly trained personnel. It has produced an availability for the ASR-8 of 0.999; the radar is off the air less than 1 hour in a whole year. The effective MTBF for the system is in excess of 440,000 hours.

(U) The Reference radar configured as a dual channel, system (Fig. 5), has a maintenance free reliability of 0.54 for a 30 day mission and a reliability of only 0.07 for a 90 day mission. Use of the High Quality components would increase the first figure to 0.80 and the second figure to 0.35 (Table VIII).

(U) In the present system, failure of a subsystem in one chain, e.g., the receiver means the whole waveguide-transmitter-receiver-processor chain must be replaced. A more efficient use of the same subsystem (in fact, with one less waveguide assembly is shown in Fig. 7. Here the

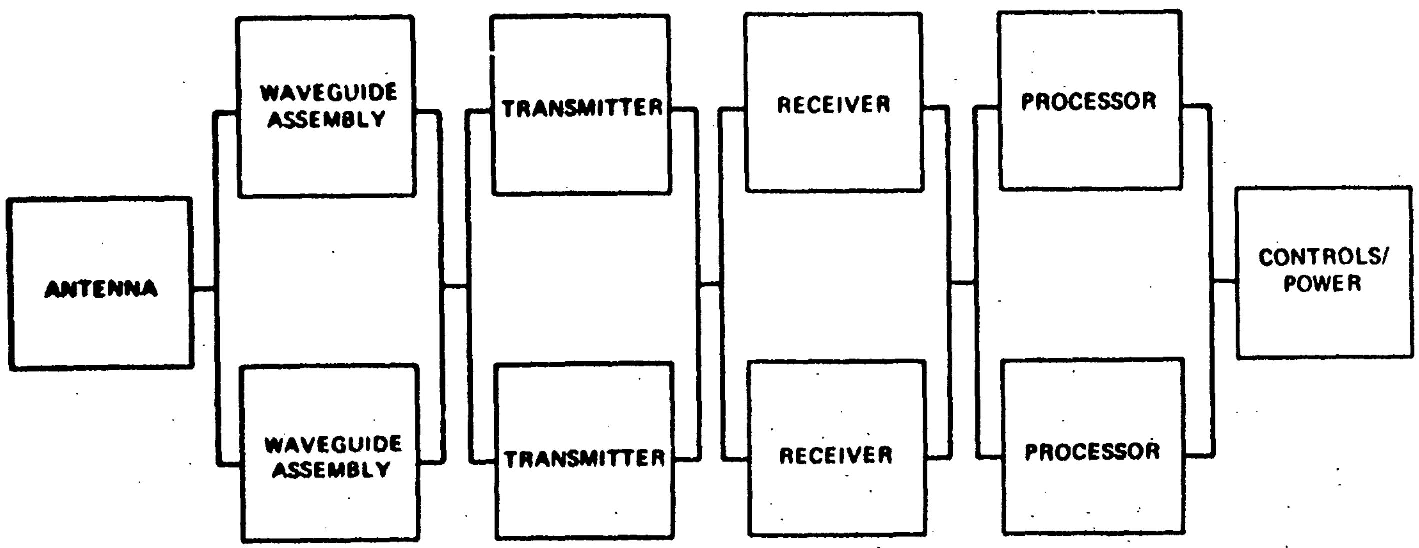

Fig. 7 (U) - Dual mode configuration of reference radar modified by cross-strapping four major sub-assemblies (U)

(U) two transmitters, the two receivers, the two processors are each connected in parallel to each other. This permits replacement of a single sub-assembly instead of a chain of four sub-assemblies. The reliability increases to 0.62 for a 30 day mission and to 0.11 for a 90 day mission. Further improvement is possible with the use of high quality components. The 30 day mission would have a reliability of 0.84 and the 90 day a reliability of 0.46 (Table VIII).

(U) TABLE VIII

Reliability for the Dual Channel Reference Radar with Various Degrees of Redundancy (U)

Radar Configuration	30 Day Mission		90 Day Mission	
	Standard Components	High Quality Components	Standard Components	High Quality Components
"Dual Channel" but with 1 Waveguide Assembly	0.54	0.80	0.07	0.35
Redundancy at Sub-System Level	0.62	0.84	0.11	0.46
Redundancy at Sub-Sub-System Level (1 Antenna)	0.89	0.90	0.62	0.70
Redundancy at Sub-Sub-System Level (2 Antennas Active)	0.93	0.95	0.72	0.73

(U) Still further reliability can be achieved by the incorporation of redundancy at a lower level, i.e., dualization of circuits within the major subsystems. It should be emphasized that it is not proposed that the following changes should be made in the present system; the analysis is made merely to indicate the credibility of a redundant approach to system reliability. Moreover there are other redundancy techniques applicable to a more modular radar that do not require 100% replication. Nevertheless, the calculations that follow are considered to lead to a reasonable bench mark.

(U) The reliability model of the ASR-8 consists of a serial chain of six basic subsystems, antenna, waveguide installation, transmitter, receiver, processor and controls/power including data link. In turn each of these is divided further into sub-subsystems. In all,there are 103 of

(U) these sub-subsystems. Some of these are already fully or partially dualized with provision for repairing a failed unit while the good unit is still operational. For the reference radar, no repair is permitted. Other assemblies can clearly be dualized, e.g., power supplies, RF drivers, PRF generators. Still other assemblies such as the duplexers, TR limiters, panel assemblies have been left as single threads.

(U) An example of a group of sub-subassemblies is shown in Fig. 8. Here the receiver is decomposed into its basic sub-subassemblies together with their failure rates. The redundancy model assumes active redundancy for 12 of the 18 shown. Only the Module Rack Assy., the COHO Crystal Assy, the TR Limiter, the Isolator, the Attenuator and the RF Switch remain as single thread items.

(U) Altogether in the anlysis 78 "units" were dualized (operating redundancy) and 25 "units" were left unchanged. Again, the reliability for two different mission periods, 30 days and 90 days and for the two quality levels of components previously defined were calculated. These results are also listed in Table VIII. Failure rates for the major subsystems are shown in Table IX and the corresponding reliabilities for 30 and 90 day missions are shown in Table XIII.

(U) For the 30 day mission, the reliability for the system with standard parts is 0.8. Use of highest quality parts would only increase the reliability to 0.90. For the 90 day mission the reliability using standard parts is 0.62 and is increased to 0.70 when high quality parts are used.

(U) This is in contrast to the results for single channel operation (Table VI) where the effect of high quality parts is to double the 30 day reliability (0.32 to about 0.6) and to increase the 90 day reliability sevenfold (0.03 to 0.20).

(U) It appears that a radar can be constructed to operate maintenance free for 30 days. A 90 day mission seems marginally achievable, using the preceding analysis.

(U) It should be recalled that the ASR-8 is, in fact, a dual channel system with approximately twice the number of parts of the single channel version. Thus the preceding hypothetical redundancy design would not lead to an unreasonably sized radar.

(U) Further, the results are consistent with the results of the "unattended" radar study by Raytheon.[13] In that study the base line single thread system has a theoretical MTBF of 1050 hours. It is a much more modular radar with 44 major functional items. The 90 day reliability model proposed does not have complete redundancy but does have redundant units for each functional item. Its probability of surviving 90 days without a failure is 0.896 as compared with 0.62 for the Reference radar. This is consistent with the difference in the two baseline MTBF's, i.e., the difference between 1050 hours and 609 hours.

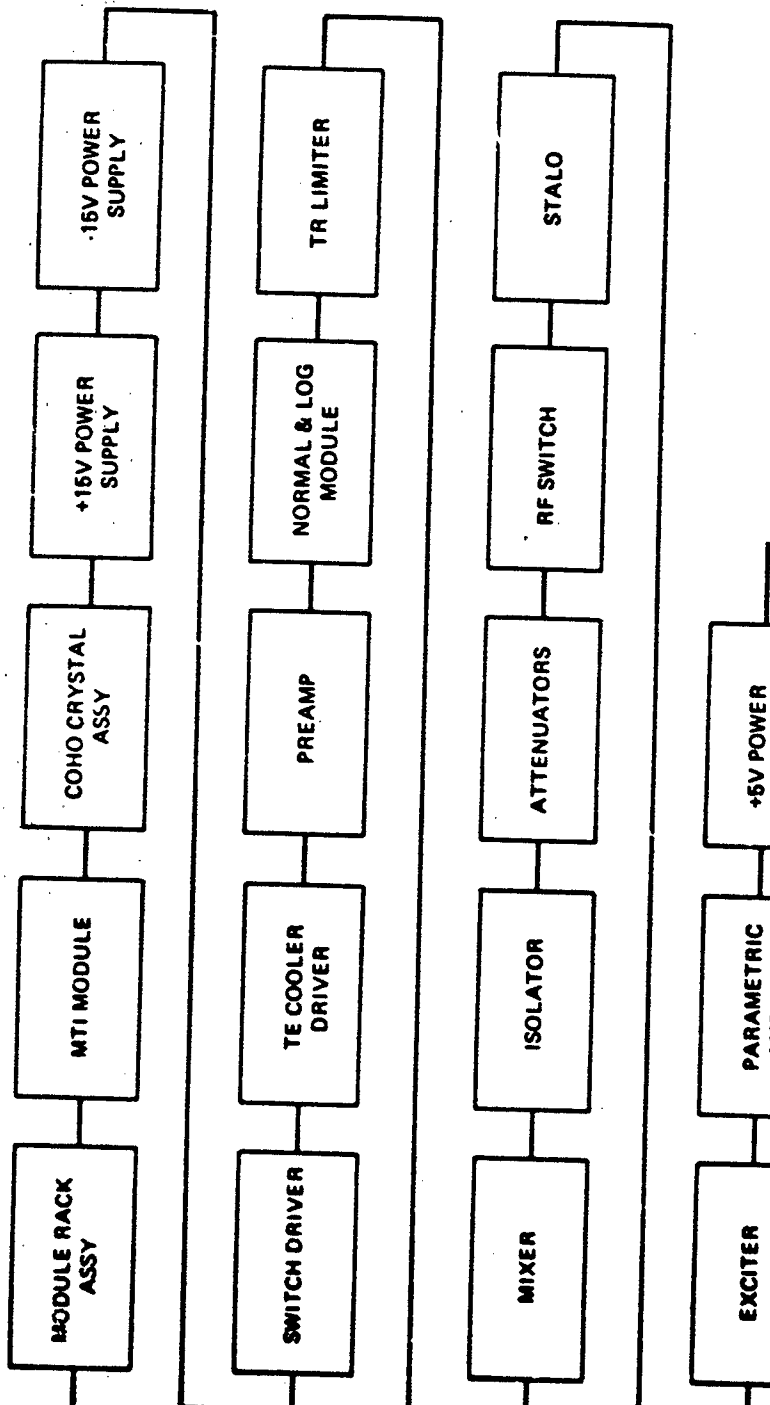

Fig. 8 (U) - Major subunits of Reference radar receiver (U)

(U) TABLE IX

Failure Rates for each of the Major Sub-Units of the Completely Redundant Reference Radar (U)

	Failure Rate Per Hr (X 10^6) of Equivalent Single Chain System			
	30 Day Mission		90 Day Mission	
	Standard Components	High Quality Components	Standard Components	High Quality Components
Antenna	69	69	69	69
Wave Guide Installation	11	11	11	11
Transmitter	31	23	40	28
Receiver	21	19	26	21
Processor	23	9	54	13
Controls/Power/ Data Link	12	7	17	8

(U) TABLE X

Reliability for each of the Major Sub-Units
of the Completely Redundant Reference Radar (U)

RADAR SUB-UNITS	RELIABILITY 30 Day Mission Standard Components	RELIABILITY 30 Day Mission High Quality Components	RELIABILITY 90 Day Mission Standard Components	RELIABILITY 90 Day Mission High Quality Components
Antenna	.9515	.9515	.8615	.8615
Wave Guide Installation	.9921	.9921	.9765	.9765
Transmitter	.9783	.9836	.9181	.9412
Receiver	.9850	.9862	.9449	.9553
Processor	.9833	.9935	.8895	.9729
Controls/Power Data Link	.9913	.9947	.9649	.9821

II. RADAR SYSTEMS

(U) General. In this section of the report, more detailed information will be presented on specific radars. The emphasis is on operational naval systems. For purposes of comparison, however, data is also provided for several nonmilitary systems. A total of sixteen radars are considered with at least one representative selected from each of the functional categories: Airborne Early Warning, Surface Search, Two Dimensional Air Search, Three Dimensional Air Search, Missile and Fire Control. In addition, one satellite radar altimeter is considered.

(U) Specific MTBF's are assigned to each radar together with the source of the estimate. It is difficult, however, to obtain a universally agreed upon definition of how to collect data for this parameter.

(U) Many radars do not have elapsed time meters throughout the system. It is difficult, in these cases, to determine the number of hours a radar has been operating. Even if there are meters, all are not always read. Further, not all parts of a complex system will operate at the same time.

(U) The usual MTBF for a system is calculated by assuming the system is "up" not only during the time it is energized, but also during the time it is in "stand-by". In this mode, it is only partially energized but believed capable of being placed in operation with little or no delay. If there are extended periods of stand-by, this method of calculation for the MTBF can lead to an overly optimistic value. Certainly, for example, the relatively failure prone high power sections of the transmitter are not stressed in this mode.

(U) Again, the definition of what constitutes a failure is a serious problem. Should all corrective maintenance actions be considered failures? If a limited life component fails after the contractor's recommended replacement time, is it a "failure"?

(U) It is not proposed to study the problems associated with data collection in this report. Where available, the reliability figures for shipboard radars have been obtained from FLTAC (Fleet Analysis Center) or NSWES (Naval Ship Weapon Systems Engineering Station) reports. The MTBF cited is the "mean time" between failure under continuous demand. "Continuous demand" assumes that all subsystems of an equipment operate with a 100% duty factor, normalized to the same time base as necessary. It does not necessarily represent the way the system operates in practice; it is, however, both useful in comparing systems and is believed especially relevant in determining equipment readiness.

(U) For airborne radars, 3-M (Maintenance and Material Management) and RISE (Readiness Improvement Status Evaluation) data are used. These sources are believed of comparable credibility to the aforementioned sources for ship radars.

(U) Finally, in a few cases, for either old or very new radars, estimates by project engineers have been included. These are educated judgments but of lesser credibility than that of the other sources.

A. Airborne Early Warning (AEW)

(U) The first systems to be presented are a series of Airborne Early Warning (AEW) radars. The radars are the AN/APS-96, the AN/APS-120, and the AN/APS-125. These radars are particularly appropriate for this report in that they demonstrate the advances that can be made in operational capability, reliability, and maintainability. The advances stem from a combination of factors including: years of reliability and maintainability (R&M) improvement programs; iterative and evolutionary design reinforced by a continuity within the radar design team that dates from approximately 1957 to the present date; and the incorporation of new technology.

(U) The oldest radar in the series, the AN/APS-96, with approximately 7,000 serial parts, evidenced MTBF's of 3.0 hours and less during Board of Inspection and Survey (BIS) trials. The system has been the subject of numerous R&M improvement programs, the first really major program being the Operational Improvement Program of 1964-1965. Current operational experience with the AN/APS-96 indicates MTBF's of approximately 12 hours are being experienced.

(U) The newer AN/APS-120, which has grown considerably in complexity, is currently evidencing MTBF's on the order of 18 hours.

(U) The newest radar in the series, the AN/APS-125 is not yet operational. The APS-125 is even more complex than the APS-120, with a serial parts count of approximately 25,000. The APS-125 in Corporation flight operations (not Navy operational use) is reported as indicating MTBF's in excess of 100 hours.

1. The AN/APS-96 Radar

(C) The AN/APS-96 is a search and height finding airborne early warning radar. The AN/APS-96 was developed for use in the E-2A (old W2F-1) twin engine, turbo-prop, carrier based aircraft. The aircraft carries a 5 man crew, two pilots, and three men in the Airborne Tactical Data System compartment. The aircraft typically operates at altitudes of 6.1 to 9.1 km (20,000 to 30,000 ft.) and has an approximate "on station" endurance capability of 5.0 hours.

(U) The AN/APS-96 radar together with the AN/APS-143 rotodome antenna were first flown on the aircraft as an operating weapons system in April 1961. In-flight the rotodome structure rotates at 6 rpm. For stowage on board carriers in the aircraft wings fold back and the rotodome structure retracts 0.6 m (2 ft.).

(U) During BIS trials conducted in 1963-4, unofficial records cited a radar system MTBF of 3.0 hours or less. More recent records covering the 1976 and 1977 operational experience are contained in the Airborne Section of the 3-M Program reports (3-M from Maintenance and Material Management) as well as Naval Air Systems Command RISE (Readiness Improvement Summary Evaluation) reports. Table XI contains representative data from the 3M and RISE reports.

(U) TABLE XI

AN/APS-96 RELIABILITY AND MAINTAINABILITY (U)

Source	Time Period	MFHBF*	MMH/MA**
3-M	Jan 76 - Jun 77	12.8	8.1
RISE	Mar 77	9.9	9.8
RISE	Aug 77	12.9	7.7

* MFHBF - Mean Flight Hours Before Failure

**MMH/MA - Maintenance Man Hours per Maintenance Action

(U) Table XI data indicates that the system reliability as represented by the MFHBF data, and the maintainability as represented by the MMH/MA data varies, and is a function of the chronological date of data acquisition and the time interval over which the data acquisition process takes place. In approximate terms, the AN/APS-96 evidences a MFHBF of about 12 hours and a MMH/MA of about 8 hours.

(U) There has been a continuing change in the types of maintenance actions and in the types of failure as a result of varying degrees of success in R&M improvement programs. In the 1961 to 1965 time period some of the major problems were:

(a) inoperative auto-tune mechanisms for the final power amplifier

(b) pulse compression circuit stability

(c) antenna sidelobe clutter response

(d) arcing and breakdown in final output cavity

(e) failures of the output power meter

Most of the cited problems have been eliminated by redesign and new technology. Major antenna sidelobe problems were initially relieved by the combination of raising the rotodome antenna to a more elevated

(U) position relative to the fuselage of the aircraft and by replacing the metal (upper-half) vertical stabilizers of the aircraft tail with fiberglass-plastic material. The auto-tune problem was relieved through incorporation of broad-band input circuitry for the final power amplifier.

(U) In 1977 AN/APS-96 problems for which improvements are being evaluated or implemented are:

(a) trigger pulse amplifier

(b) a modulator and set controls

(c) matched filter improvement

(d) provision of a solid state synchronizer and trigger beam

(U) Table XIa is a general listing of the AN/APS-96 operating parameters, characteristics, and general information.

(U) A block diagram of the radar is shown in Fig. 9, and the external appearance of the aircraft is shown in Fig. 10.

2. The AN/APS-120 Radar

(C) The AN/APS-120 is a search and height finding airborne early warning radar. The AN/APS-120 was developed by essentially the same General Electric design team responsible for the predecessor AN/APS-96 and AN/APS-111 (XN-1) AEW radar systems. The AN/APS-120 incorporates many of the techniques and features demonstrated in the experimental AN/APS-111(XN-1) flight test program. Differences between the AN/APS-120 and the older, operational AN/APS-96 are: incorporation of a coaxitron power amplifier for stability, reliability and elimination of the electro-mechanical tuning actuators; and AN/APS-171 Antenna Group with sum and difference channels; and a linear, quartz, dispersive delay line for matched filter pulse expansion and compression.

(C) The advanced design features incorporated in the AN/APS-120 permit the detection of targets at longer ranges and in more severe clutter. In spite of the greatly increased system complexity, 19,000 parts vs. 7000 for the AN/APS-96, the reliability and maintainability of the AN/APS-120 has been improved significantly over that of the AN/APS-96. Recent RISE data indicates that in operational service the AN/APS-120 is averaging MFHBF's of about 18 hours, and MMH/MA's of about 7 hours.

(U) Table XII lists major operating parameters, performance data, and other technical information of the AN/APS-120.

(C) TABLE XIa

AN/APS-96 Radar Parameters (U)

FUNCTION: search and height finding for airborne early warning.

FREQUENCY RANGE (MHz): 406 - 450

PEAK POWER (kW): 1000

AVERAGE POWER (W): 3840

TRANSMIT PULSE LENGTH (μs): 12.8

COMPRESSED PULSE LENGTH (μs): 0.2

PULSE RATE (pps): 300

TRANSMITTER TYPE: coherent master oscillator, power amplifier

OUTPUT TUBE: 6952 (4605V2), coaxial beam power tetrode

EMISSION BANDWIDTH (kHz): 6000

WAVEFORM: pulsed, linear FM(stepped)

IF FREQUENCY (MHz): 122.5, 30

IF BANDWIDTH (kHz): 5000

SENSITIVITY (dBm): -115

NOISE FIGURE (dB): 4

OUTPUT DATA: PPI, Headset

SPECIAL SIGNAL PROCESSING: pulse compression, AMTI

ANTENNA TYPE: retarded wave endfire

ANTENNA SIZE: 0.76M x 73M (2.5'x 24')

ANTENNA GAIN (dB): 21.5

POLARIZATION: horizontal

BEAMWIDTH (deg): HORZ. 7
VERT. 20

ANGLE COVERAGE (deg): HORZ. 360
VERT. 20

SCAN RATE: HORZ. 6 rpm
VERT. N/A

SECTOR SCAN RATE: N/A

ANTENNA WEIGHT (kg): 1044 (2300 lbs.)

BEAM POSITIONING TECHNIQUES:
HORZ. mechanical
VERT. fixed

LOBING TYPE: N/A

LOBING RATE (Hz): N/A

CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): 85 (157km)

ANGULAR ACCURACY: N/A

GROSS WEIGHT (kg): 1701 (3750 lb)

MANUFACTURER: General Electric

NUMBER (mfg/oper): 60/60

NAVY COGNIZANT CODE: NAVAIR 5333D3

TECHNICAL MANUALS: NAVAIR 01-85, WBA-76.1

NOMENCLATURE ASSIGNMENT DATE: 1957

NUMBER OF ELECTRONIC PARTS USED: 7000[(1)]

MTBF (theo/oper): /12.8[(2)]

MTTR: 8.1[(2)]

HIGH FAILURE RATE ITEMS: receiver, signal comparator, delay line, trigger pulse amplifier

MAXIMUM VOLTAGE: 30kV

A.C. POWER CONSUMPTION: 19kVA

(1) General Electric estimate
(2) 3-M data for Jan 76 through June 76

3. The AN/APS-125 Radar

(C) The AN/APS-125 is the third and latest in a series of General Electric Company radars developed for use in the Grumman Aerospace Corporation E-2 carrier based aircraft. The AN/APS-125 is not yet operational, and reliability data is based on General Electric and Grumman operating experience. The AN/APS-125 incorporates recent advanced technology features such as an improved pulse compression device, auxiliary sidelobe cancelling antennas and receivers, and significantly improved reliability and maintainability. The AN/APS-125 is the first in this series of Naval AEW radars to include a contractural requirement for a minimum 100 hour MTBF capability. The AN/APS-125 is also the first of the series for which each production system must pass a 100 hour system burn-in under cycled vibration, temperature, and operate periods.

(U) The MTBF and maintainability data shown in Table XIII are not of the same category as cited for the AN/APS-96 and AN/APS-120. The AN/APS-125 data is based on three systems, only one of which is operating in an E-2 aircraft, and in each case the systems are operated and maintained by contractor personnel.

(C) The block diagrams for the AN/APS-120 and the AN/APS-125 are essentially identical with that for the AN/APS-96. There is also no difference in external appearance of the aircraft fitted with the three radars. A photograph of the APS-125 in its factory test position is shown in Fig. 11.

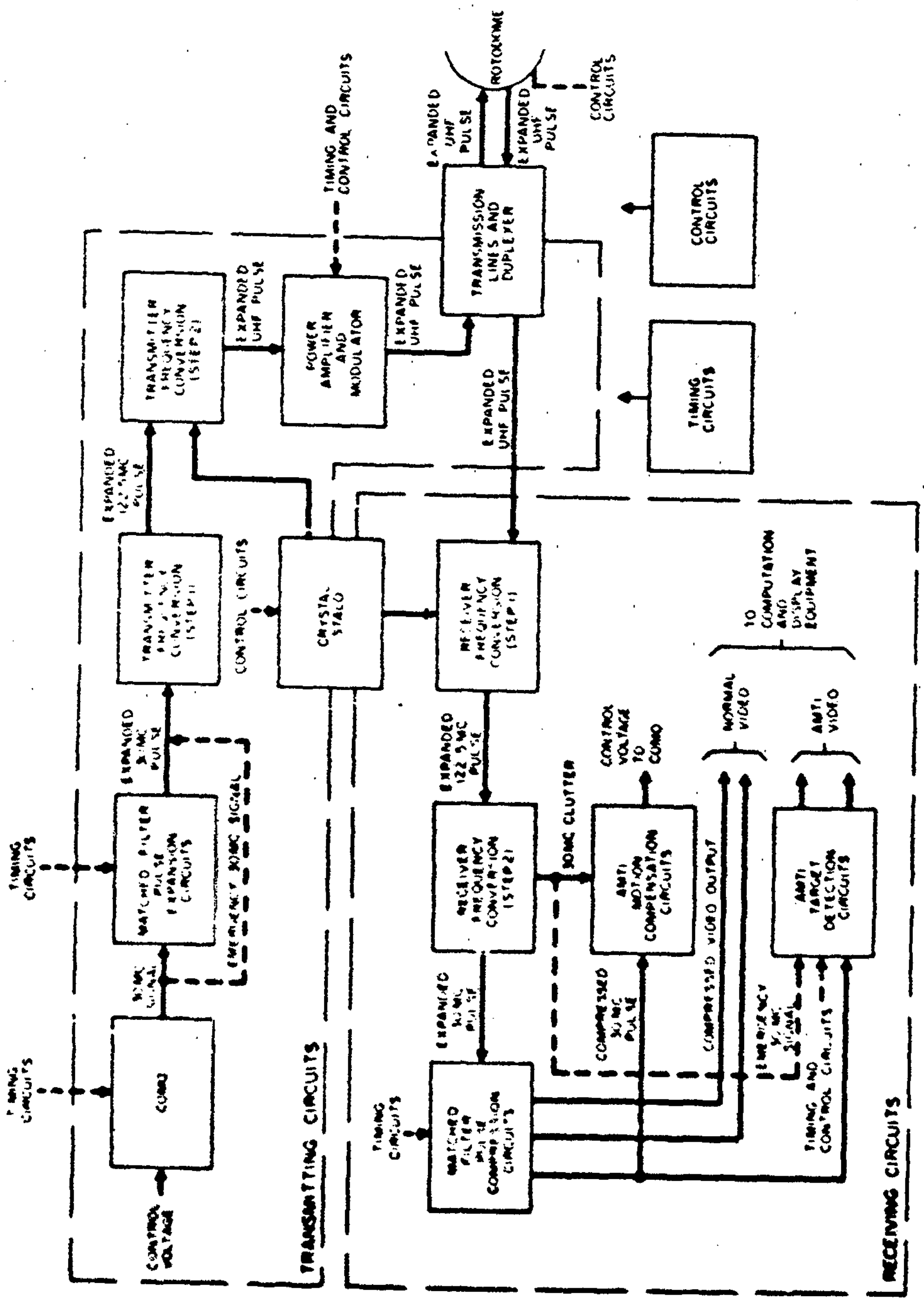

Fig. 9 (C) - AN/APS-96 block diagram (U)

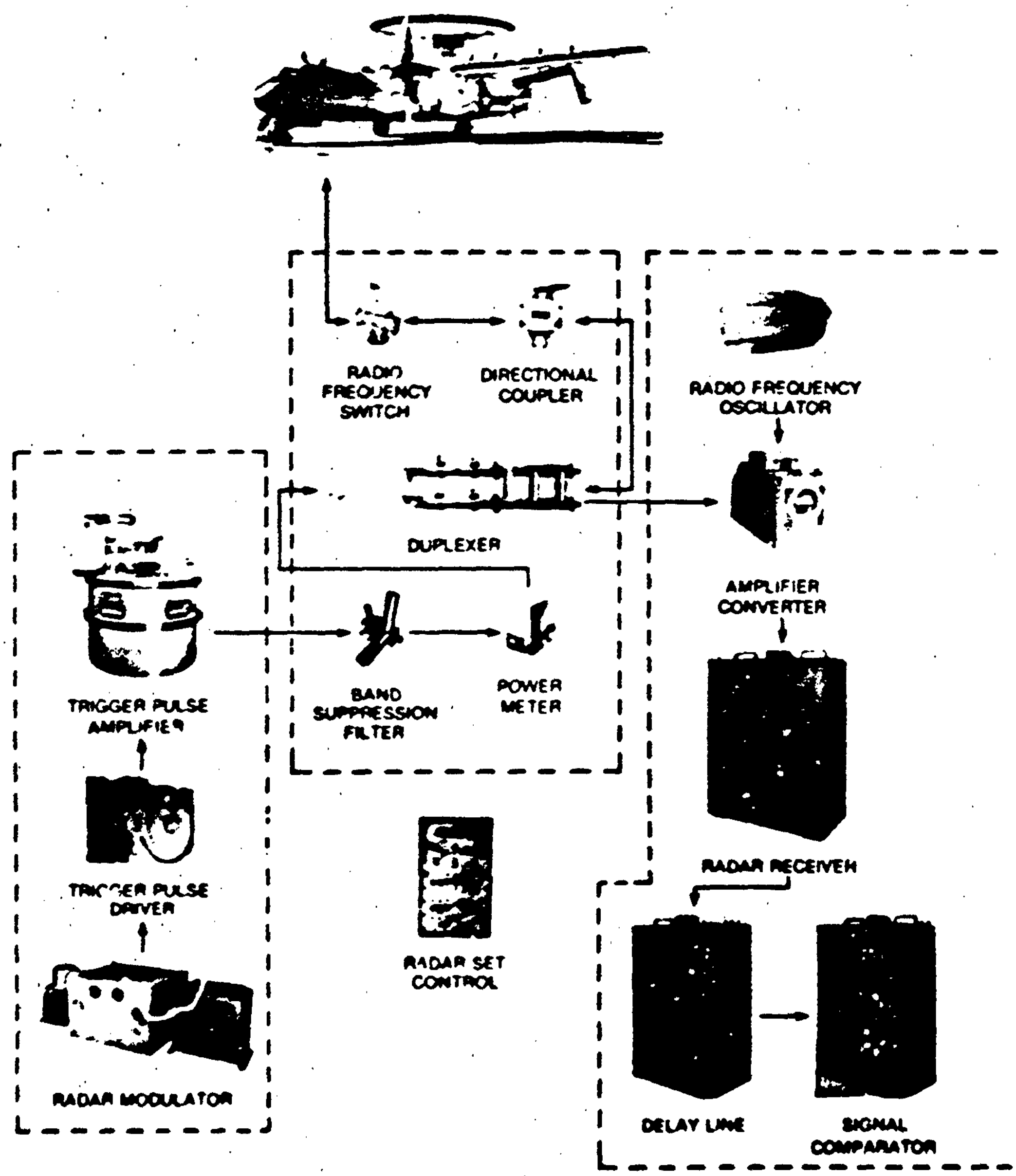

Fig. 10 (U) - AN/APS-96 radar (U)

(C) TABLE XII

AN/APS-120 Radar Parameters (U)

FUNCTION: search and height finding for airborne early warning

FREQUENCY RANGE (MHz): 406-450

PEAK POWER (kW): 1000

AVERAGE POWER (W): 3840

TRANSMIT PULSE LENGTH (μs): 12.8

COMPRESSED PULSE LENGTH (μs): 0.2

PULSE RATE (pps): 298-303.5

TRANSMITTER TYPE: coherent master oscillator, power amplifier

OUTPUT TUBE: coaxitron

EMISSION BANDWIDTH (kHz): 6250

WAVEFORM: pulsed, linear FM

IF FREQUENCY (MHz): 30

IF BANDWIDTH (kHz): 6250

SENSITIVITY (dBm): -121 (manual mode)

NOISE FIGURE (dB): 4

OUTPUT DATA: video for PPI display, automatic detection

SPECIAL SIGNAL PROCESSING: pulse compression, AMTI, displaced phase center antenna, staggered PRF

ANTENNA TYPE: Yagi array

ANTENNA SIZE: 0.76M x 73M (2.5'x 24')

ANTENNA GAIN (dB): 22

POLARIZATION: horizontal

BEAMWIDTH (deg): HORZ. 6.6
VERT. 20

ANGLE COVERAGE (deg): HORZ. 360
VERT. 20

SCAN RATE: HORZ. 6 rpm
VERT. N/A

SECTOR SCAN RATE: N/A

ANTENNA WEIGHT (kg): 1044 (2300 lbs.)

BEAM POSITIONING TECHNIQUES:
HORZ. mechanical scan
VERT. fixed

LOBING TYPE: N/A

LOBING RATE (Hz): N/A

CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): 120 (222km)

ANGULAR ACCURACY: N/A

GROSS WEIGHT (kg): 1952 (4300 lbs.)

MANUFACTURER: General Electric

NUMBER (mfg/oper): 34/34

NAVY COGNIZANT CODE: PMA 231

TECHNICAL MANUALS: GAC

NOMENCLATURE ASSIGNMENT DATE: 1969

NUMBER OF ELECTRONIC PARTS USED: 19,000[(1)]

MTBF (theo/oper): 77/17.5[(2)]

MTTR: 8.0[(2)]

HIGH FAILURE RATE ITEMS: signal comparator, receiver, pulse generator

MAXIMUM VOLTAGE: 25kV

A.C. POWER CONSUMPTION: 25kVA

(1) General Electric estimate
(2) 3-M data for Jan 76 through June 76

(C) TABLE XIII

AN/APS-125 Radar Parameters (U)

FUNCTION: overland and overwater search and height finding for airborne early warning

FREQUENCY RANGE (MHz): 406 - 450

PEAK POWER (kW): 1000

AVERAGE POWER (W): 3840

TRANSMIT PULSE LENGTH (μs): 12.8

COMPRESSED PULSE LENGTH (μs): 0.2

PULSE RATE (pps): 298 - 303.5

TRANSMITTER TYPE: coherent master oscillator, power amplifier

OUTPUT TUBE: coaxitron

EMISSION BANDWIDTH (kHz): 6250

WAVEFORM: pulsed, linear FM

IF FREQUENCY (MHz): 30

IF BANDWIDTH (kHz): 6250

SENSITIVITY (dBm): -121

NOISE FIGURE (dB): 4

OUTPUT DATA: video for PPI, automatic detection

SPECIAL SIGNAL PROCESSING: side lobe cancellation, coherent 3 pulse digital AMTI, 16 pulse FFT, scan to scan target processing

ANTENNA TYPE: Yagi array

ANTENNA SIZE: 0.76m x 73m (2.5' x 24')

ANTENNA GAIN (dB): 22

POLARIZATION: horizontal

BEAMWIDTH (deg): HORZ. 6.6

VERT. 20

ANGLE COVERAGE (deg): HORZ. 360

VERT. 20

SCAN RATE: HORZ. 6 rpm

VERT. N/A

SECTOR SCAN RATE: N/A

ANTENNA WEIGHT (kg): 1058 (2331 lbs.) excluding pedestal(1)

BEAM POSITIONING TECHNIQUES:

HORZ. mechanical scan

VERT. N/A

LOBING TYPE: N/A

LOBING RATE (Hz): N/A

CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): 135

ANGULAR ACCURACY: 0.38° to 1°

GROSS WEIGHT (kg): 2022 (4454 lbs.)

MANUFACTURER: General Electric

NUMBER (mfg/oper): 10/5

NAVY COGNIZANT CODE: PMA 231

TECHNICAL MANUALS:

NOMENCLATURE ASSIGNMENT DATE:

NUMBER OF ELECTRONIC PARTS USED: 24,243

MTBF (theo/oper): 109/22.6(1)

MTTR: 12.2(2)

HIGH FAILURE RATE ITEMS: no pattern

MAXIMUM VOLTAGE: 25kV

A.C. POWER CONSUMPTION: 25kVA

(1) Antenna pedestal weights 506kg (1115 lbs.)
(2) NMESA Report - May-June 1977. (Mean Flight Hours Between Maintenance Action)

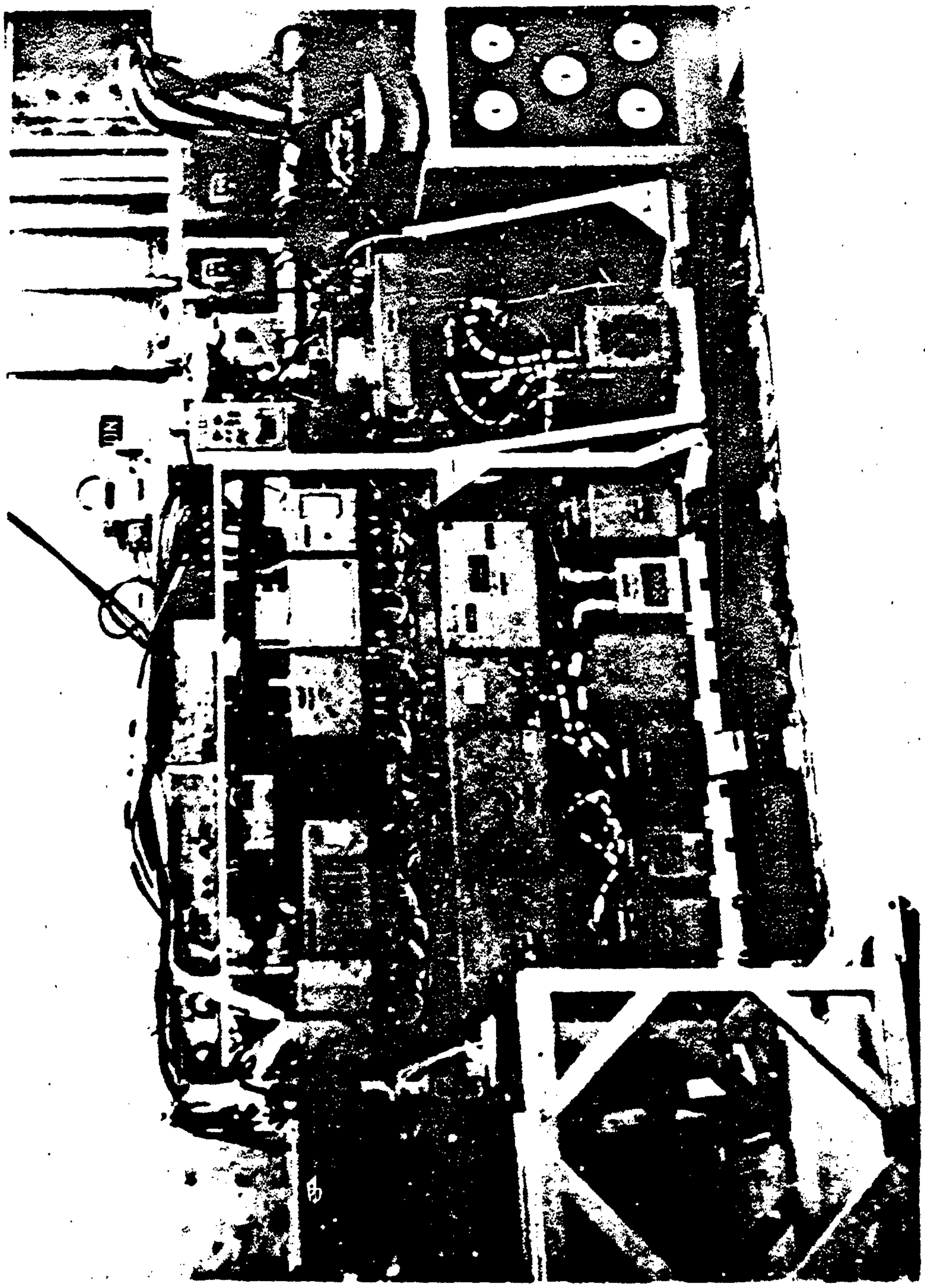

Fig. 11 (U) - AN/APS-125 radar (test position) (U)

B. Surface Search

(U) The surface search function of the Navy is handled principally by the SPS-10 and the SPS-55. The SPS-10 is a conventional C band magnetron radar of a type that has been on many naval ships throughout the world since the 1940's. The SPS-55 is an outgrowth of civilian and coast guard radars built within a weight constraint and with a low level of complexity. Transmitters of this group are generally based on a magnetron tube since good MTI performance is usually not required to distinguish large ships from the sea, and since a magnetron design minimizes cost, weight, and the required peak pulse voltage. The radars of the SPS-55 type have traditionally been quite reliable, because they are of modest power, low complexity and of a well proven design. The more recent versions such as the Decca commercial radar are virtually all solid-state, the magnetron itself being the principle exception.

1. AN/SPS-10

(U) The AN/SPS-10 is a surface search radar that operates over the C-band frequencies of 5450 to 5825 MHz. The antenna is an open mesh truncated parabolic reflector illuminated by a feed horn supported by a boom that extends from beneath the lower edge of the reflector, see Fig. 12. Typically, the transmitter and receiver for the system are mounted below decks, so that the weight of equipment mounted at the top of the mast is minimized.

(U) Fig. 13 is a block diagram of the radar, and Table XIV lists pertinent operating parameters and performance data.

(U) It is difficult to get current reliability data on the SPS-10. FLTAC (Fleet Analysis Center) does not follow the system and the 3-M data, developed for logistics purposes, is not ideally structured for reliability analyses. Informal conversation with the program managers, reveals that reasonable radar reliability has been obtained considering the age of its design and the length of time the systems have been operational. Currently, there is a problem obtaining replacement transmitting tubes since the original tube type is no longer in production.

(U) High failure rate items for the SPS-10 have included the pulse forming network, the pulse transformer, the AFC, and the problems associated with the aging of system components. The system reliability in terms of operational MTBF is estimated to be 180 hours. The same source, (NAVSEA 65242) estimates current MTTR as between 5 and 6 hours.

(U) In 1977 a program was initiated to build a modern version of the SPS-10, the SPS-XX. This is the so-called "solid state" version, although it should be understood that the output device is still a tube, a magnetron. The magnetron is of the coaxial type, and not similar to the types originally used with the SPS-10. One of the principal objectives of the program is to develop a radar making maximum use of the Standard Electronic Modules (SEM) developed by the Naval Avionics Facility, Indianapolis (NAFI). Since these conform to a form, fit, and function concept, an individual chassis can generally be replaced by a more modern design as new components become available.

2. AN/APS-55

(C) The SPS-55 is a modern surface search and navigation radar developed as a replacement for the SPS-10 radar. The antenna is a slotted waveguide. With the exception of the transmitter magnetron, the SPS-55 is a solid-state radar. The system operates in X-band, 9.05 to 10 GHz. The original system was developed by Raytheon, and a subsequent production contract was awarded to Cardion Electronics. A total of 36 systems have been manufactured. To date only 18 of these systems are in operation in the fleet. Even though the radars are equipped with elapsed time meters, gross MTBF data is not readily available. The most readily available reliability data on this radar is that compiled on a system at the Cardion plant. The Cardion operating data seems to confirm the 700 hour MTBF predicted for the radar by MIL-HDBK-217B computations. The factory environment is, of course, benign, and the radar is maintained by Cardion engineers and technicians. The best estimate by the NAVSEA project office is for an MTBF of 600 hours with the operational radars but there is still little analysis of the data.

(U) A block diagram of the SPS-55 is shown in Fig. 14. Fig. 15 is a photograph of the various SPS-55 sub-system units. Table XV is a listing of operating and performance parameters, together with other pertinent and appropriate information.

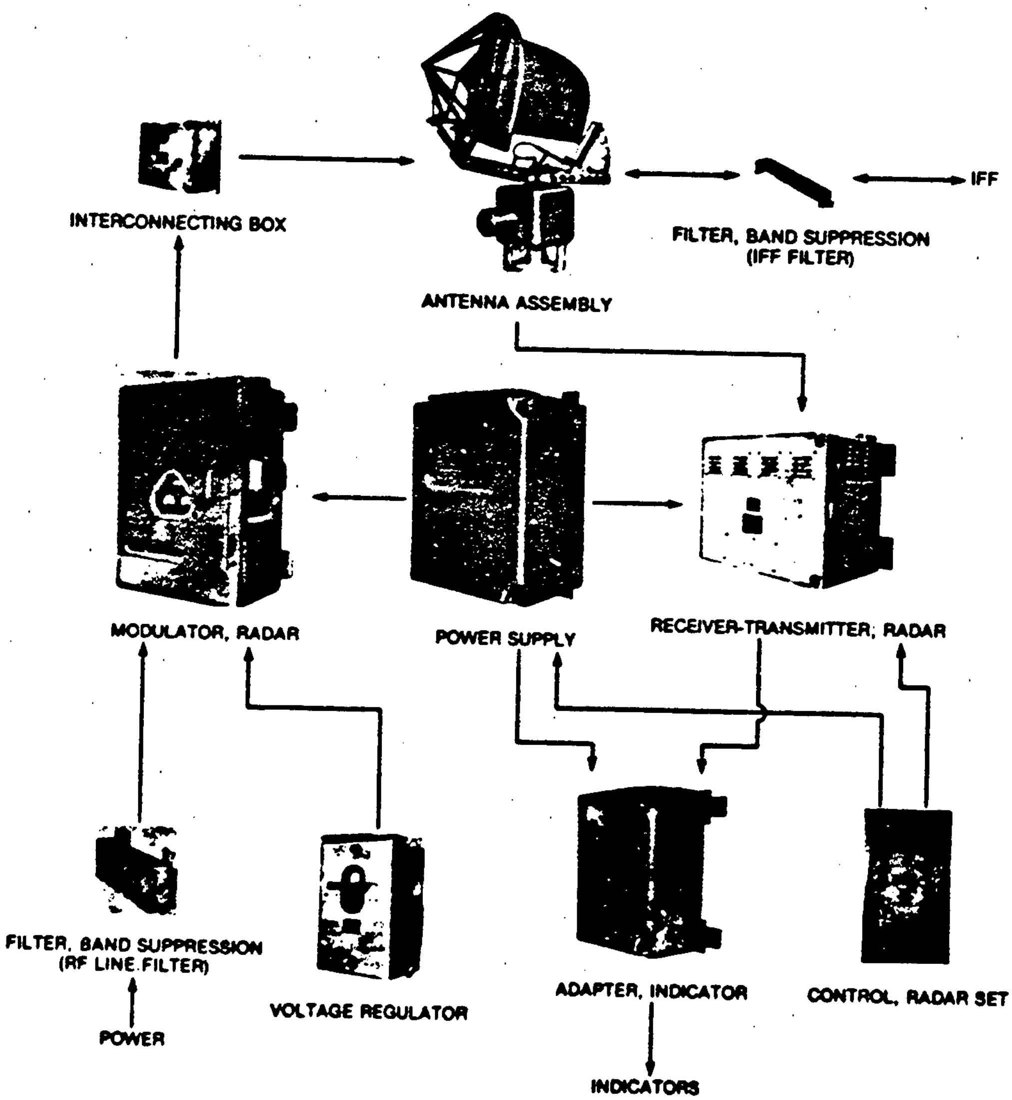

Fig. 12 (U) - AN/SPS-10 radar (U)

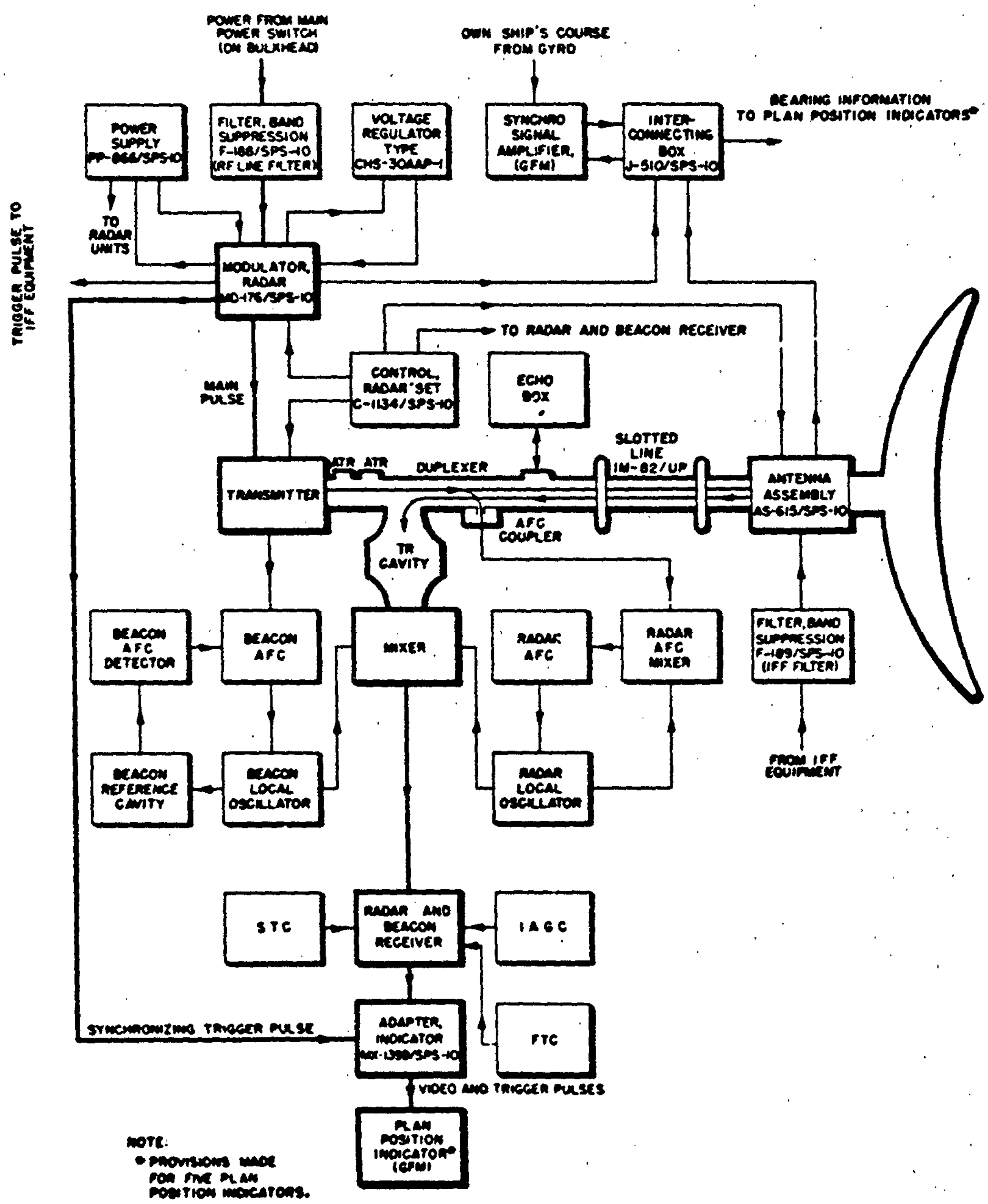

Fig. 13 (U) - Block diagram of AN/SPS-10 radar (U)

(U) TABLE XIV

AN/SPS-10 Radar Parameters (U)

FUNCTION: surface search radar

FREQUENCY RANGE (MHz): 5450 - 5825

PEAK POWER (kW): 285

AVERAGE POWER (W): 50 - 241

TRANSMIT PULSE LENGTH (μs): 0.25 - 1.3

COMPRESSED PULSE LENGTH (μs): N/A

PULSE RATE (pps): 625 - 650

TRANSMITTER TYPE: magnetron

OUTPUT TUBE: QK 235

EMISSION BANDWIDTH (kHz): 5000

WAVEFORM: pulsed carrier

IF FREQUENCY (MHz): 30

IF BANDWIDTH (kHz): 1000, 5000

SENSITIVITY (dBm): -96, -103

NOISE FIGURE (dB): 14

OUTPUT DATA: video to PPI

SPECIAL SIGNAL PROCESSING:

ANTENNA TYPE: truncated parabolic reflector

ANTENNA SIZE: 0.8m x 3.2m (2.5'x 10')

ANTENNA GAIN (dB): 32

POLARIZATION: horizontal

BEAMWIDTH (deg): HORZ. 1.5
VERT. 5

ANGLE COVERAGE (deg): HORZ. 360
VERT. 5

SCAN RATE: HORZ. 15
VERT. N/A

SECTOR SCAN RATE: N/A

ANTENNA WEIGHT (kg): 190 (420 lbs.)

BEAM POSITIONING TECHNIQUES:
HORZ. mechanical
VERT. N/A

LOBING TYPE: N/A

LOBING RATE (Hz): N/A

CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): 19.2 Swerling 0

ANGULAR ACCURACY: N/A

GROSS WEIGHT (kg): 624 (1375 lbs.)

MANUFACTURER: Sylvania, Weston[(1)]

NUMBER (mfg/oper): 400/400[(2)]

NAVY COGNIZANT CODE: NAVSEA - 65242

TECHNICAL MANUALS:

NOMENCLATURE ASSIGNMENT DATE: 1960

NUMBER OF ELECTRONIC PARTS USED: 2106[(1)]

MTBF (theo/oper): /80[(2)]

MTTR: 5.5[(2)]

HIGH FAILURE RATE ITEMS: pulse forming network, pulse transformer, AFC, and accumulated aging of system components

MAXIMUM VOLTAGE: -20kV

A.C. POWER CONSUMPTION: 3500 W

(1) There are about 175 of the B version manufactured by Sylvania, 175 of the F version manufactured by Weston, and the rest of by various manufacturers.
(2) NAVSEA estimate.

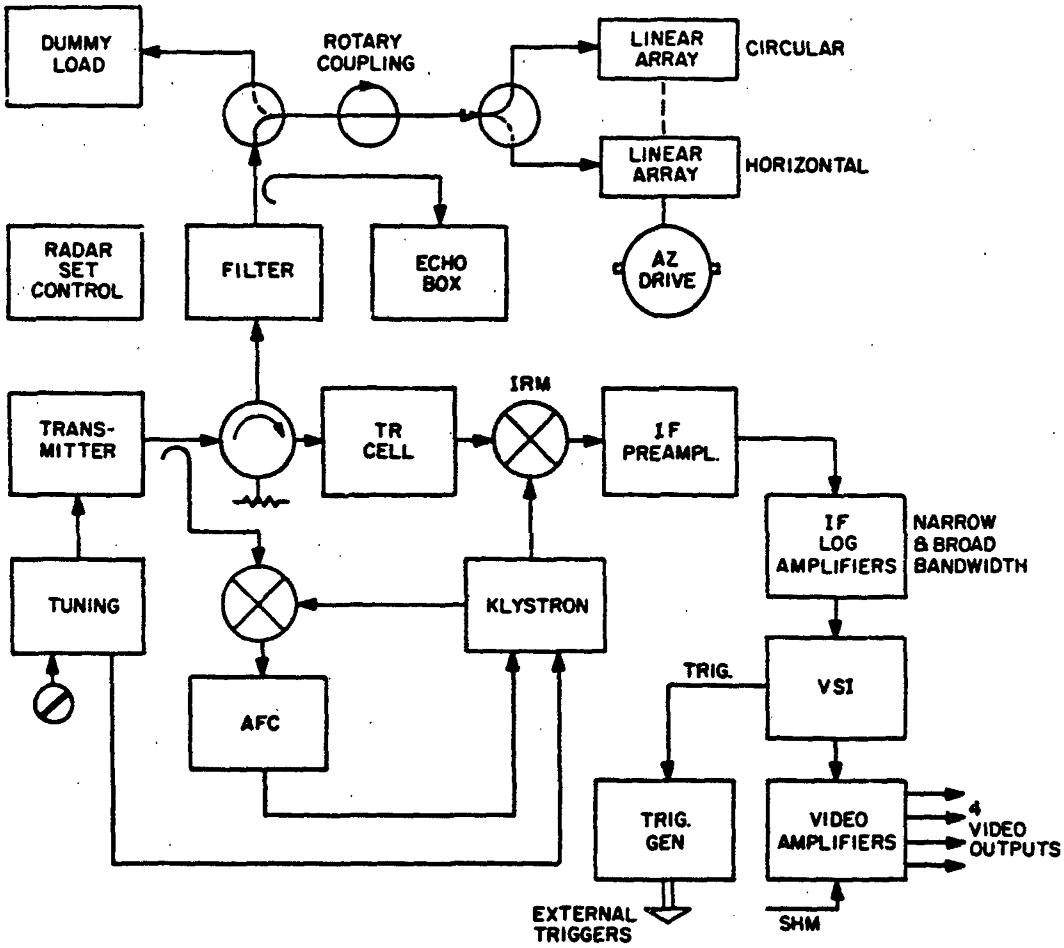

Fig. 14 (U) - AN/SPS-55 block diagram (U)

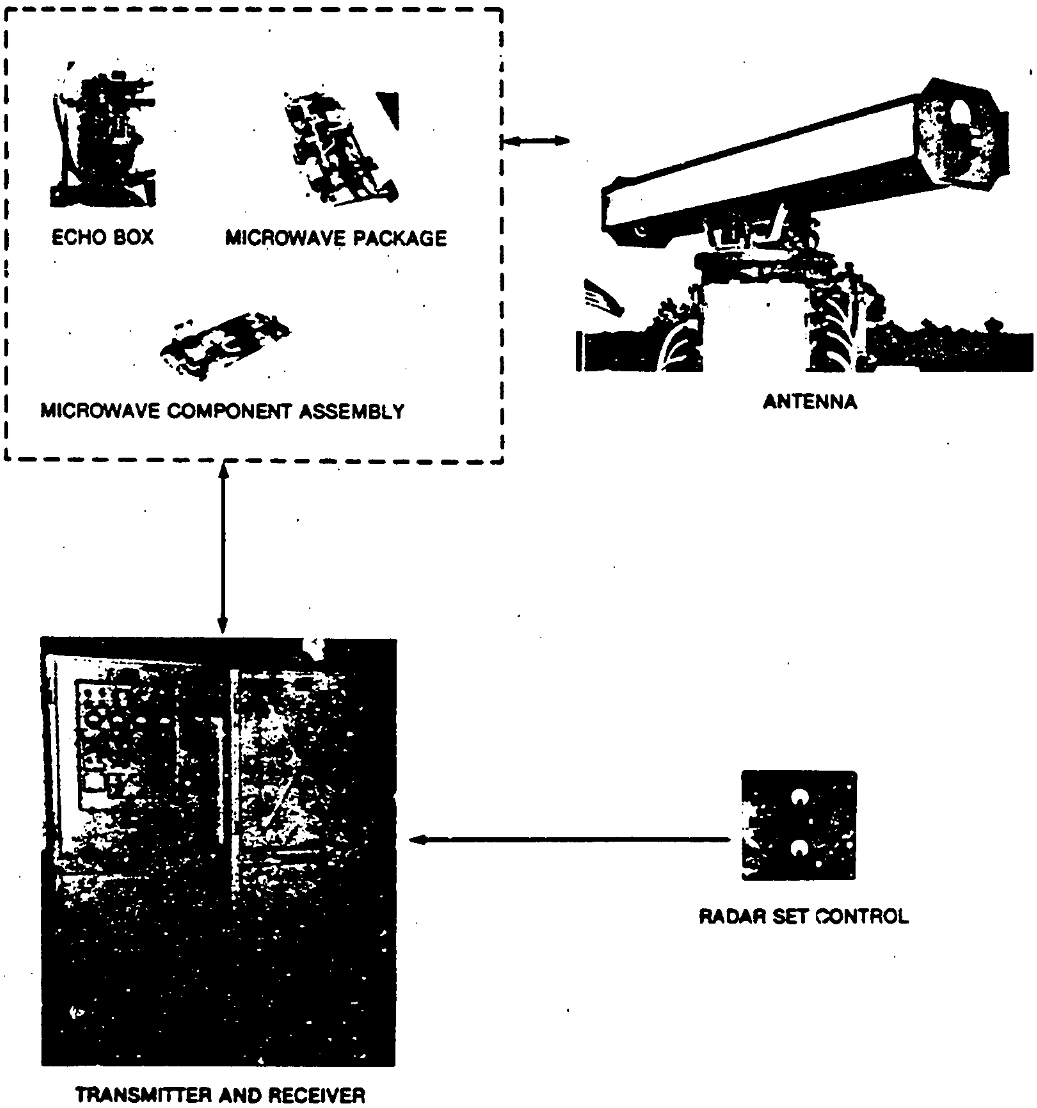

Fig. 15 (U) - AN/SPS-55 radar (U)

(C) TABLE XV

AN/SPS-55 Radar Parameters (U)

FUNCTION: surface search radar

FREQUENCY RANGE (MHz): 9050 - 10,000

PEAK POWER (kW): 130

AVERAGE POWER (W): 67/225

TRANSMIT PULSE LENGTH (μs): 0.1, 1

COMPRESSED PULSE LENGTH (μs): N/A

PULSE RATE (pps): 2250/750

TRANSMITTER TYPE: tuneable magnetron

OUTPUT TUBE: QKM 1792

EMISSION BANDWIDTH (kHz): 12,000

WAVEFORM: pulsed carrier

IF FREQUENCY (MHz): 60

IF BANDWIDTH (kHz): 12,000

SENSITIVITY (dBm): -102, -93

NOISE FIGURE (dB): 10

OUTPUT DATA: video

SPECIAL SIGNAL PROCESSING: STC, FTC, LOG, LIN LOG

ANTENNA TYPE: back-to-back, end-fed, linear arrays

ANTENNA SIZE: 1.9m x 0.2m (6' x 0.5')

ANTENNA GAIN (dB): 31

POLARIZATION: horizontal, circular

BEAMWIDTH (deg): HORZ. 1.2 to 1.5°
VERT. 20°

ANGLE COVERAGE (deg): HORZ. 360
VERT. 20

SCAN RATE: HORZ. 16 ± 1 rpm
VERT. N/A

SECTOR SCAN RATE: N/A

ANTENNA WEIGHT (kg): 27.2 (60 lbs.)(1)

BEAM POSITIONING TECHNIQUES:
HORZ. N/A
VERT. N/A

LOBING TYPE: N/A

LOBING RATE (Hz): N/A

CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): 8.3 (15.4 km) swerling type 1

ANGULAR ACCURACY: 1°

GROSS WEIGHT (kg): 526 (1134 lbs.)

MANUFACTURER: Cardion Electronics

NUMBER (mfg/oper): 36/18 as of Jun 77

NAVY COGNIZANT CODE: NAVSEA - 65242

TECHNICAL MANUALS: NAVSEA 0967-LP-531-5010

NOMENCLATURE ASSIGNMENT DATE: 1967

NUMBER OF ELECTRONIC PARTS USED: 2717(2)

MTBF (theo/oper): 714/600(2)

MTTR: 0.33(2)

HIGH FAILURE RATE ITEMS: TR tube, thyratron

MAXIMUM VOLTAGE: 20kV

A.C. POWER CONSUMPTION: 2.875 kVA

(1) With pedestal antenna weight = 88.5kg (195 lbs.)
(2) Estimate of project engineer.

C. 2D Radars

(C) The two dimensional (range and bearing), 2D radars are the primary systems for air target acquisition by the Navy. They were among the earliest radars developed for use at sea, and still the first line of defense against attacking aircraft. The SPS-40, in its various versions, is being used on a great majority of the larger naval ships. It is a 400 MHz radar using tetrodes to generate its microwave power. Originally it did not have an MTI capability but throughout a long series of modifications by many different vendors, has progressed to a coherent canceller with 30 dB of cancellation. Even though the radar is a relatively simple one it has not had a history of being reliable. Part of the problem was caused by the use of a considerable number of vacuum tubes and devices such as mechanical relays, that may have relatively short lives. The original design was performed in a very different climate with respect to reliability, than prevails today. No reliability projections were made and apparently little was done to assure that either the MTBF was large or the MTTR small. The principle factors that the radar has in its favor are a relatively straightforward design, a moderate level of complexity, and a long history of modifications that have tended to remove many of the more troublesome circuits and components.

(C) The replacement for many of the SPS-40's will be the SPS-49. This is a radar that uses the high UHF band frequencies, 850 to 942 MHz. The development of this radar started in the early 1960's but the commitment and funding were uneven. In the early 1970's after two or three years of being somewhat ignored, the development cycle was accelerated. An almost completely new design evolved in which many of the analog circuits were replaced by digital circuits, and substantial changes were made in the antenna, pedestal, etc.

1. AN/SPS-40

(C) The AN/SPS-40 series radars (40, 40A, 40B, 40C, 40D) are designed as lightweight, high power, early warning, two-dimensional, air search radars for use on naval vessels varying in size from destroyer escorts to the smaller aircraft carriers. The system operates in the UHF frequency region (400-450 MHz) with a peak power of 200 KW and an average power of 3600 W. Fig. 16 is a photograph of the subsystems of the SPS-40; a block diagram is shown in Fig. 17; Table XVI lists pertinent operating parameters and performance data. These radars are capable of free space ranges up to 90 nmi, have 10 operational channels, and MTI (moving target information). Target range information is displayed on an A-scope, and video signals are provided for presentation of target range and bearing on associated PPI units.

(U) The AN/SPS-40B, 40C, and 40D radars have a LFDM (low flying detection mode) that uses an uncompressed short pulse as an alternate mode of operation to the compressed pulse LRM (long range mode). The LFDM is designed to provide a close-in detection capability against fast, small, low altitude air targets in a heavy clutter environment. The AN/SPS-40C radar is a field change conversion of the AN/SPS-40 radar to the AN/SPS-40B configuration; the AN/SPS-40D radar is a field change conversion of the AN-SPS-40A radar to the AN/SPS-40B configuration.

(U) The radar is normally operated from a control and range indicator located in the CIC (combat-information-center). In addition, remote-local switching permits operation of the radar set from the equipment room.

(U) A common IFF and radar feed illuminates an antenna reflector, thereby eliminating the requirement for the attachment of a separate IFF antenna.

(U) The pulse compression is by analog techniques and uses a steel line.

(U) The AN/SPS-40B, 40C and 40D sets will contain a digital MTI thus providing improved target discrimination against clutter from sea or shore returns.

(U) In its early years the AN/SPS-40 had a poor reliability record. The cost of maintaining this equipment to achieve an acceptable availability level was high, and the down time was excessive. Four basic causes for the various failures of the AN/SPS-40 were:

1) Inadequate heat dissipation

2) Part overstress

3) Inadequate personnel training

4) Inadequate equipment design

(U) The system has been the subject of numerous and extensive "get well" and improvement programs. The present AN/SPS-40B version has an improved MTBF of 200 hours.

2. AN/SPS-49

(U) The first production model of the AN/SPS-49 program is just being completed (Mar. 1978). It will be put through temperature cycling and a one g sinusoidal vibration. This radar differs from the ones tested in Tech. Eval. and OP Eval. by the incorporation of 15 to 20 ECP's that were the result of a major improvement program. There has also been a large number of minor changes, e.g., a larger resistor to reduce a stress level, or a better cable combined with a rounding of a chassis so that it will not fray.

(C) The system operates in the high UHF-band (850-942 MHz) with a peak power of 280 KW and an average power of 10,000 W. Fig. 18 is a photograph of its various subsystems; a block diagram is shown in Fig. 19; Table XVII lists pertinent operating parameters and performance data.

(U) There has been a reliability demonstration, where three to five relevant failures were experienced. All but one were the result of a design or manufacturing deficiency. All the problems have been corrected with ECP's. Only one failure could have been considered to come under the random failure designation. In addition to the 3 to 5 relevant failures, other failures occurred that were in areas where improvements had already been initiated. These were scored as non-relevant since, in each case, an ECP had been initiated but had not yet been implemented.

(U) The major area attacked by the improvement program, and the one in which a majority of the costs were occurring, was the antenna. The jack screw mechanism in the stabilization platforms was changed from a parallel set of jack screws to a single larger screw.

(U) Earlier in the program twenty critical chasses were examined to see if any component exceeded 50% of the maximum allowable stress level. A few did and ECP's were initiated to replace those components with ones of higher ratings. This program has continued and other areas have been designated, from time to time, for such a stress level study. These areas are chosen by the reliability engineer in the Navy's AN/SPS-49 program office. It is not planned to encompass all of the electronics in such studies, but the mechanism exists for doing an additional study just as soon as a chassis or board becomes suspect.

(U) Reliability data, in this system, is limited to that acquired on the land based test site and that acquired during Tech. Eval., OP Eval. and subsequent experience on the U.S.S. DALE. The radar has been used on the DALE for 3,000 radiating hours and an

(U) additional 8,000 stand-by hours. All of the radiating hours have been with the one transmitter tube of the prototype design. Just as in the reliability test, failures are ruled relevant only if both of the following conditions hold:

1) They prevent the radar from acquiring data.

2) They are not in an area in which an ECP is pending.

(U) For this limited data sample, the MTBF appears to lie between 350 and 600 hours; the former figure is exact in that it includes all "events", i.e., both relevant and non-relevant failures. It is to be emphasized that this figure has been computed by lumping together the data from both radiation and stand-by modes, because the project office feels that the stand-by mode, in some sense, produces as much stress as the radiation mode. The high-power modulator and, to some extent, the transmitter tube are clearly exceptions to this position.

(U) As noted above, a prototype tube was used in the development program. A slightly modified version of it was used in the Tech. Eval., Op. Eval and all subsequent tests conducted on the U.S.S. DALE. Varian has now been given substantial funding to improve the tube, make it ready for production, and to build the required test equipment for a production line. Six or eight tubes of this latest version have now been built and tested. They appear to be satisfactory.

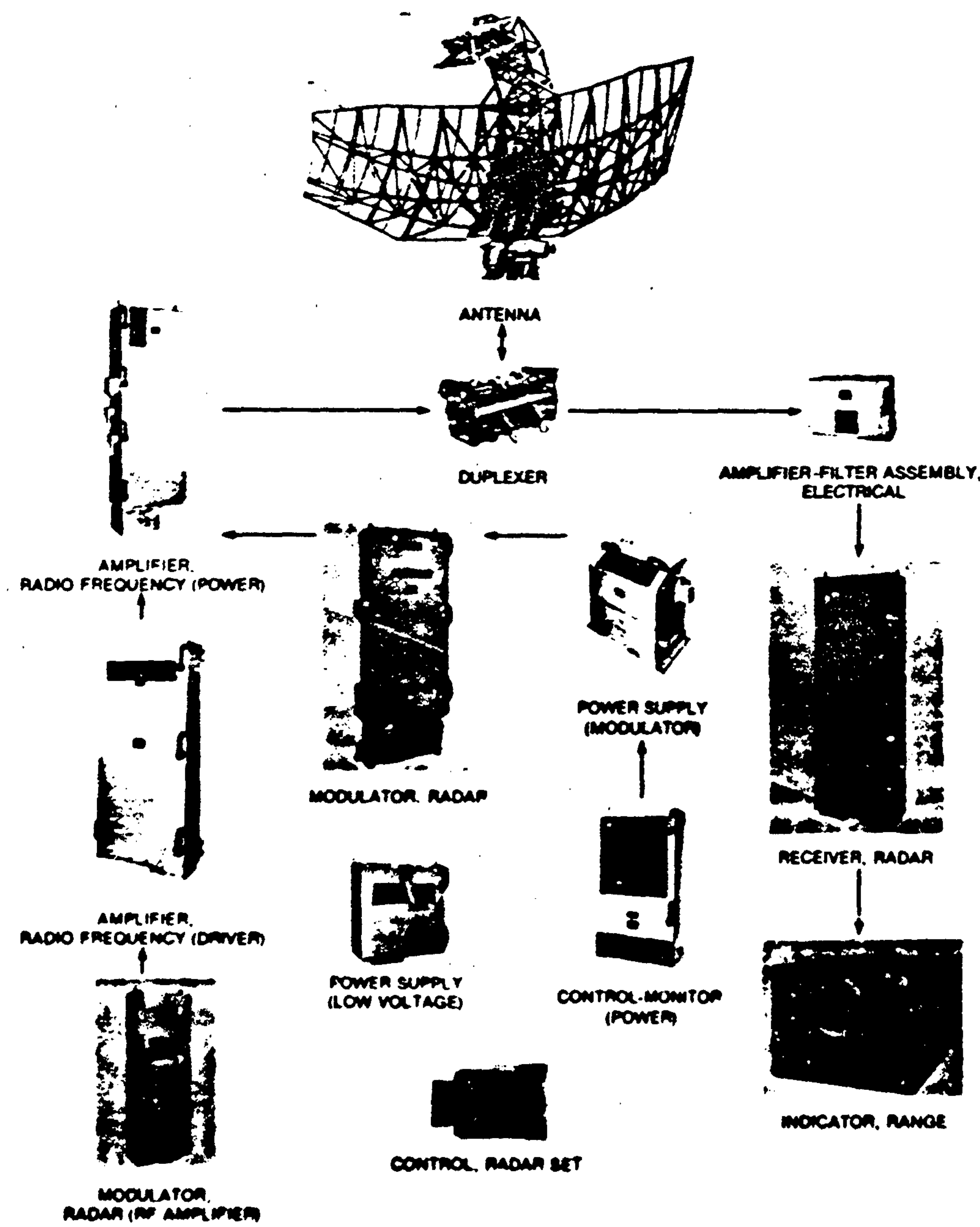

Fig. 16 (U) - AN/SPS-40 radar (U)

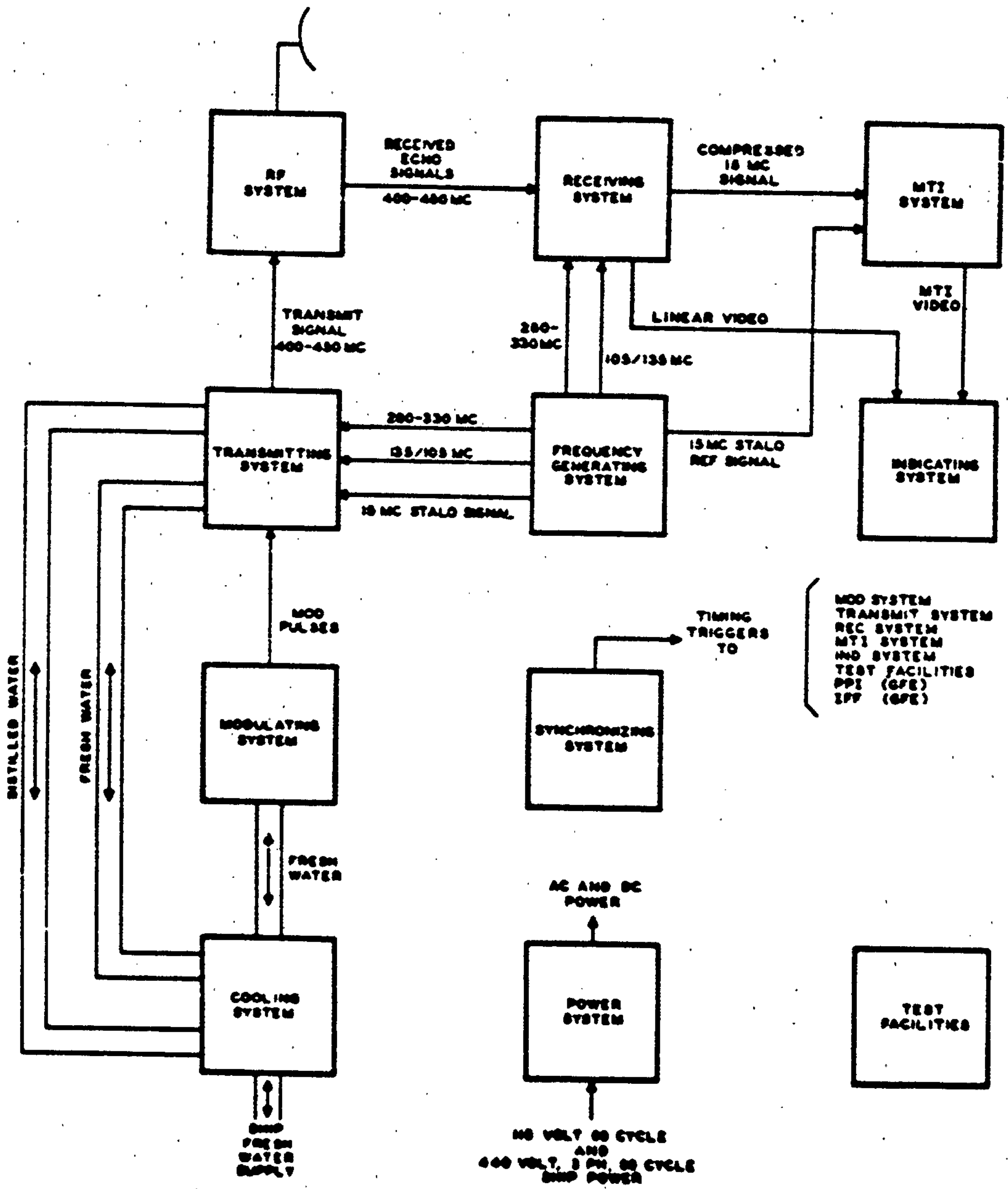

Fig. 17 (C) - AN/SPS-40 block diagram (U)

(C) TABLE XVI

AN/SPS-40B Radar Parameters (U)

FUNCTION: air search, early warning with range up to 200 nautical miles

FREQUENCY RANGE (MHz): 400-450

PEAK POWER (kW): 200

AVERAGE POWER (W): 3600

TRANSMIT PULSE LENGTH (μs): 60

COMPRESSED PULSE LENGTH (μs): 0.6

PULSE RATE (pps): 300

TRANSMITTER TYPE: master oscilator, power amplifier

OUTPUT TUBE: 8932

EMISSION BANDWIDTH (kHz): 1670

WAVEFORM: frequency coded rectangular pulse

IF FREQUENCY (MHz): 15

IF BANDWIDTH (kHz): 1670

SENSITIVITY (dBm): -120

NOISE FIGURE (dB): 5.2

OUTPUT DATA: linear video, MTI video, composite video

SPECIAL SIGNAL PROCESSING: pulse compression, digital MTI, coherent canceller

ANTENNA TYPE: truncated paraboloid

ANTENNA SIZE: 5.42m x 3.56m(17'9½" x 11'8")

ANTENNA GAIN (dB): 21

POLARIZATION: horizontal; IFF vertical

BEAMWIDTH (deg): HORZ. 10.5
VERT. 20

ANGLE COVERAGE (deg): HORZ. 360
VERT. N/A

SCAN RATE: HORZ. 7.5, 15rpm
VERT. N/A

SECTOR SCAN RATE: N/A

ANTENNA WEIGHT (kg): 783(1725 lb.)

BEAM POSITIONING TECHNIQUES:
HORZ. mechanical
VERT. N/A

LOBING TYPE: N/A

LOBING RATE (Hz): N/A

CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): 200 (with resolution of 100 yards)

ANGULAR ACCURACY:

GROSS WEIGHT (kg): 1589 (3500 lbs.)

MANUFACTURER: Dynel Electronics Corp.

NUMBER (mfg/oper): 150/90

NAVY COGNIZANT CODE: NAVSEA 6524

TECHNICAL MANUALS: NAVSHIPS 0967-441-9010

NOMENCLATURE ASSIGNMENT DATE: 1971

NUMBER OF ELECTRONIC PARTS USED: 10,000(1)

MTBF (theo/oper): 200/195(2)

MTTR: 0.75,(2) 11(2)

HIGH FAILURE RATE ITEMS: transmitter antenna, HV power supply tank

MAXIMUM VOLTAGE: 18kV

A.C. POWER CONSUMPTION: 30,000kW

(1) Furnished by manufacturer.

(2) Fleet Analysis Center, Confidential Report Number 861-02-77. "Radar Set AN/SPS-40B, C, and D Readiness During First Half CY 1976 (U)."

Fig. 18 (U) - AN/SPS-49 radar (U)

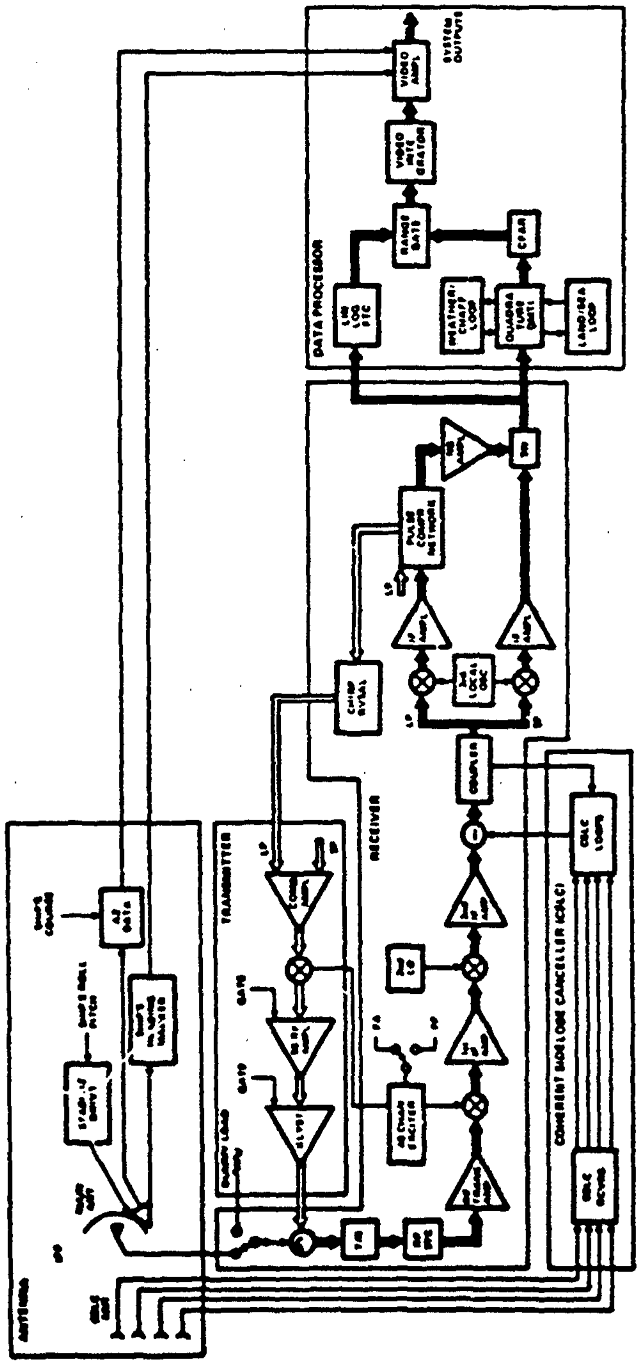

Fig. 19 (U) - AN/SPS-49 block diagram (U)

(C) TABLE XVII

AN/SPS-49 Radar Parameters (U)

FUNCTION: long range air search

FREQUENCY RANGE (MHz): 850-942
PEAK POWER (kW): 280
AVERAGE POWER (W): 10,000
TRANSIT PULSE LENGTH (μs): 125 or 2[1]
COMPRESSED PULSE LENGTH (μs): 1.6[2]
PULSE RATE (pps): 270/285 or 833/100[3]

TRANSMITTER TYPE: klystron
OUTPUT TUBE: VA 889A
EMISSION BANDWIDTH (kHz): 1000

WAVEFORM: pulsed linear coded FM or pulsed uncoded
IF FREQUENCY (MHz): 601, 42, .4
IF BANDWIDTH (kHz): 380 or 800
SENSITIVITY (dBm): -115
NOISE FIGURE (dB): 4.5
OUTPUT DATA: visual
SPECIAL SIGNAL PROCESSING: pulse compression, adaptive digital MTI, coherent side lobe canceller, digital CFAR
ANTENNA TYPE: parabolic
ANTENNA SIZE: (25') radius
ANTENNA GAIN (dB): 28.4
POLARIZATION: horizontal
BEAMWIDTH (deg): HORZ. 3.5
VERT. 11

ANGLE COVERAGE (deg): HORZ. 360
VERT. csc^2 to 20

SCAN RATE: HORZ. 6 or 12 rpm
VERT. N/A
SECTOR SCAN RATE: N/A
ANTENNA WEIGHT (kg): 1611 (3,550 lbs)
BEAM POSITIONING TECHNIQUES:
HORZ. mechanical scan
VERT. line-of-sight stabilization
LOBING TYPE: N/A
LOBING RATE (Hz): N/A
CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): 219[4] (Swerling 0)
ANGULAR ACCURACY: N/A

GROSS WEIGHT (kg): 7823 (17,232 lbs)
MANUFACTURER: Raytheon
NUMBER (mfg/oper): /2
NAVY COGNIZANT CODE: NAVSEA 65241
TECHNICAL MANUALS: NAVSEA 0967-LP-584-8010
NOMENCLATURE ASSIGNMENT DATE: 1960
NUMBER OF ELECTRONIC PARTS USED: 1,300[5]
MTBF (theo/oper): 300/600[6]
MTTR: 1.5/
HIGH FAILURE RATE ITEMS:

MAXIMUM VOLTAGE: 50 kV
A.C. POWER CONSUMPTION:
85 kVA, 3 phase @ 440 Hz
10 kVA, single phase @ 115 Hz

(1) There are three operational modes: two long range and one short range
 a. the long range modes interlace long and short pulses
 b. the short range mode uses only uncoded short pulses
(2) Only the long pulse is compressed
(3) The symbol "/" indicates that pulse rates can alternate on successive scans
(4) $P_D = 0.5$. $P_{FA} = 10^{-6}$
(5) Primarily a count of system modules rather than individual components
(6) Since data has been accumulated on only 1 ship, this figure is influenced by judgment of relevant failures

D. Point Defense

(C) The need to extend 2D radar technology to a role in the point defense against cruise missiles and low flying aircraft became apparent after the sinking of the Israeli destroyer ELAT. The first radar, developed for this role was the AN/SPS-58. This is an L-band radar with 250 watts of average power, and some of the first fielded digital signal processing. A few copies of an alternate version of the radar were built with a different antenna (AN/SPS-62). At present the program has been directed toward the AN/SPS-65 version, one that shares the AN/SPS-10 antenna. It is planned to modify all the earlier versions to the AN/SPS-65 configuration. All future radars will probably be of this type.

(U) The development cycle has allowed adequate time for a thorough reliability prediction study. The output tube is a particularly well proven design, since it was used in great quantities on the DEW LINE. The same tube was used as the driver, but that design yielded a cumbersome and inefficient package that required considerable time to tune when changing channels. A cost effectiveness study initiated by Dr. Waterman, formerly ASNRD, pinpointed the driver as the first item to be considered for improvement and a new design for an all solid-state driver is now under contract.

(C) The newest radar developed for point defense is the TAS. It is an L band radar with a uniform antenna coverage up to nearly 75 degrees. The original impetus was to aid in the defense against cruise missiles, but the requirements were extended, during the design phase, to include high elevation missiles as well. The radar has been through Tech. Eval. and Op. Eval. and at present is being prepared for production. Some redesign is being done in the modulator, but the principle change is to remove a special purpose computer, built by the radar developer, and to substitute one of the standard AN/UYK-20. The output tube is a slight modification of a design that was produced in large quantities by Raytheon for the Bell Telephone Laboratories and under their guidance. It had a very good reliability history in the original Bell version.

1. AN/SPS-65

(C) The AN/SPS-58, 63, 65 radars are all basically of the same family with different antennas. The radar operates in the L band of frequencies (1215-1365 MHz) with a peak power of 12 kW and an average power of 250 W. Fig. 20 is a photograph of the subsystems of the SPS-65, a block diagram is shown in Fig. 21. Table XVIII lists pertinent operating parameters and performance data.

(U) As noted, the transmitter is a solid state STAMO amplified first by a driver klystron and then by a final klystron. The two klystrons are identical, but the driver uses as much prime power to produce a few watts as the output tube does to produce several kilowatts. Large klystrons, such as the ones used, have a lower efficiency with a lower drive level since more of the input beam power has to show up as heat. Originally it was a slow procedure to tune each of the klystrons because tuning screws, on a total of six cavities, had to be individually adjusted. Moreover, the process was iterative in that the final tune on the driver could not be accomplished until the first-cut tune on the output had been completed. This has been changed to a micrometer tuning arrangement on the screws with a calibrated dial, marked in channels. Only a final "tweeking" against the power meter is now required. The replacement of the klystron driver by a wideband solid state driver, as previously mentioned, will simplify the process even further, since only the output will have to be tuned and there will be no iteration. In addition, the demand on the high voltage power supply will be halved. This derating should greatly improve its reliability; at present it is one of the more failure prone items.

(U) The receiver for the AN/SPS-58 family grew out of IR&D work accomplished at Westinghouse in the early 1960's. They were one of the first companies to demonstrate a successful digital MTI, and this work was extended in the building of the first AN/SPS-58s. An elliptic filter, at the I.F. frequency, shapes the samples so that there is essentially only one filter in each range bin. After transfer to base band, the filter output is read by the A/D converter for the MTI processing which is accomplished by a recursive five-pulse design. The recursive design permits much sharper filter slopes for the same number of delays at the cost of a poorer transient response. This is acceptable in the AN/SPS-58 since the PRF's are relatively low and when switched, second time around clutter is not usually present to cause transients.

(C) The receiver has the reliability expected from a first, and in some portions, second generation digital design. A principle problem is logistics, which has kept many radars inoperative for an extended period of time. This was aggravated by an overly optimistic approach to the allotment of spares, and by an inaccurate estimate of the types of spares that would be required. Since the radar was represented as one with a 600 hour MTBF, the spares were proportioned accordingly. When it turned out that the MTBF was closer to 123 hours, the logistic system virtually collapsed. A new table of spares has now been prepared, but it will be several more months before the stock is bought and delivered. In the meantime the radar is acquiring a very bad reputation. When the part must be secured from external sources, the average logistic delay is 840 hours. Unfortunately, it is the design of the radar that is being taken as the culprit.

2. TAS

(C) The TAS radar is a recent radar developed for the Navy and as such has the advantage of the newest solid state technology. The development was directed by a group of Navy radar engineers assembled from the staffs of NOSC, NEWSES, China Lake, Dahlgren, etc. The present system has 200 kW peak power and an average power of either 2400 or 5600 W, depending on the mode of operation. The frequency range is also in the L band, from 1268 to 1400 MHz. Fig. 22 is a photograph of the system. A block diagram is shown in Fig. 23. Table XIX lists pertinent operating parameters and performance data.

(C) The tube chosen was a Bell Laboratory-Raytheon TWT that originally had a 175 kW peak. The decision was made to try to increase this to 300 kW. The attempt was not successful. A three dB improvement could have been achieved in this area by other techniques with far less risk than was taken by altering the design of an eminently successful TWT.

(C) The demand of power was pressed because of the added requirement to see the high elevation missile. This implied not only high angle coverage but such coverage without any cosecant shaping. The result was an extremely low antenna gain 21 dB, with a requirement to see a missile with a small radar cross section. It appears that the added requirement has now been met - but the whole system can stand very little derating. This always has an impact on reliability.

(U) For reason of logistics, and perhaps cost, the successful special purpose computer, built by the radar's manufacturer and tested during the Tech. Eval. and Op. Eval. phase, is to be replaced by a Univac. These general purpose computers have not shown the reliability that is predicted by a projection from Mil. Stand. 217B. There is no way of knowing whether the special purpose computer might have been more reliable, since the statistics on it during Tech. Eval. and Op. Eval. are not extensive enough to be conclusive. All that can be stated is that reliability is seldom improved by testing one device and deploying another.

(U) The only substantial reliability problem that showed up during the limited testing of Tech. Eval. and Op. Eval. was, as might have been anticipated, in the power supplies of the transmitter. They are currently being redesigned and there is always hope that they will be

(U) better. Since the TWT is gridded, the design of the pulse waveform should not present the problems it does for an ungridded klystron or amplitron. There is every reason to expect that the receiver design will cause only those problems associated with the relatively high complexity of pulse doppler circuitry. Since integrated components are used extensively and since they normally exceed the figures given for them in Mil. Stand. 217B by substantial margins, the receiver circuitry should have a high MTBF in spite of its relative complexity. Moreover, the use of BITE is extensive and this should reduce substantially the MTTR.

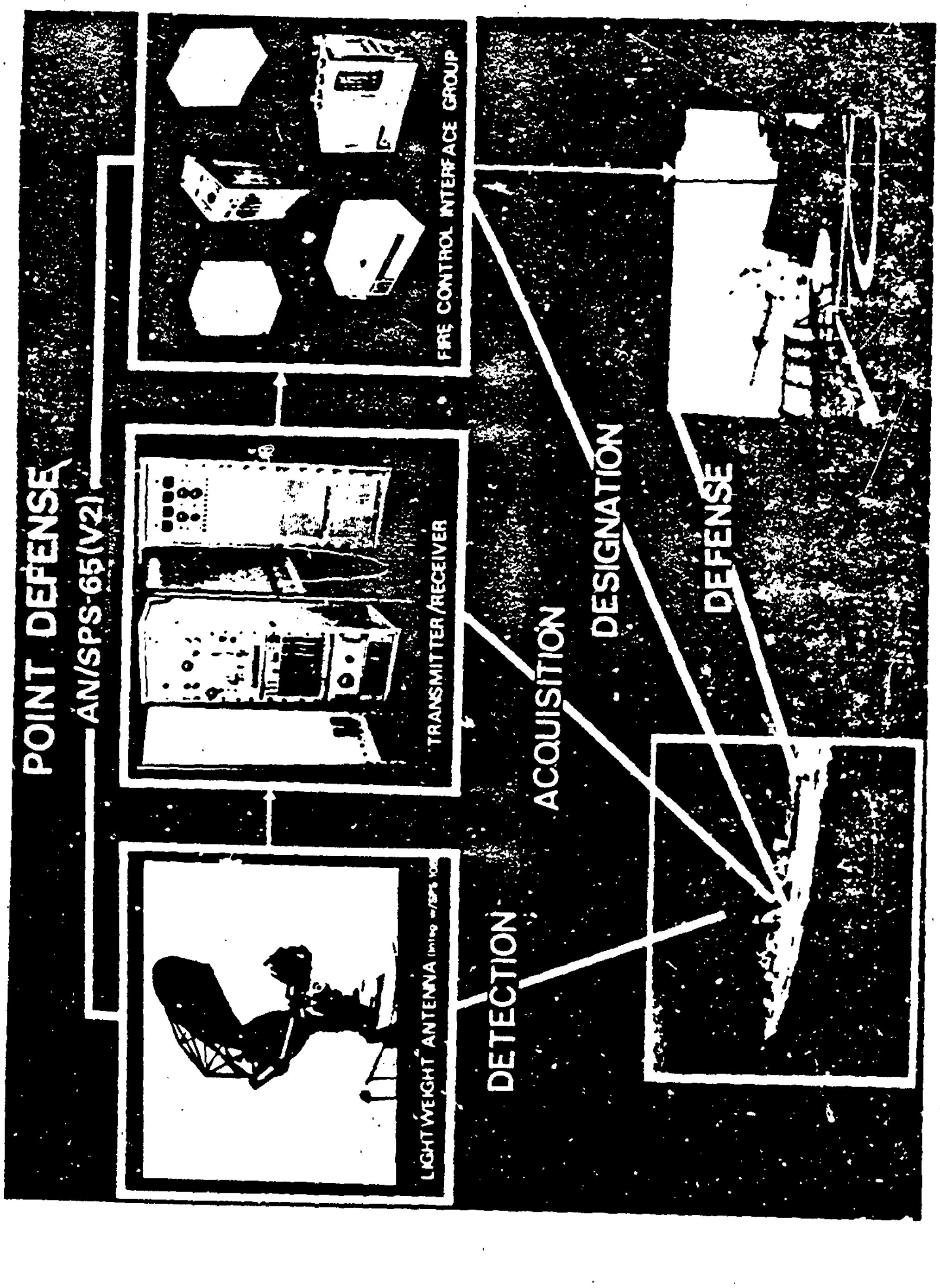

Fig. 20 (U) - AN/SPS-65 radar (U)

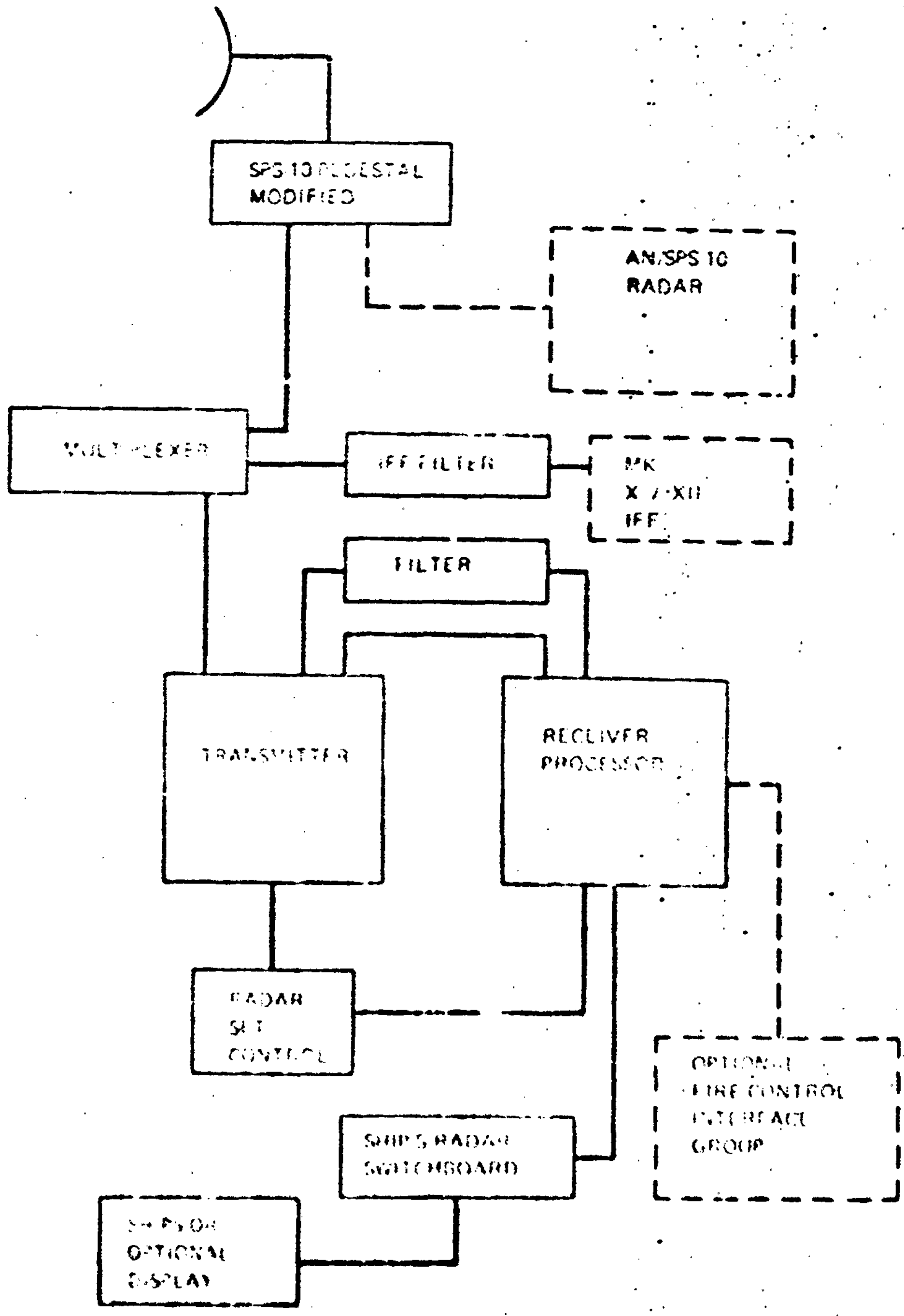

Fig. 21 (U) - AN/SPS-65 block diagram (U)

(C) TABLE XVIII

AN/SPS-65 Radar Parameters (U)

FUNCTION: acquisition radar for point defense

FREQUENCY RANGE (MHz): 1215 - 1365

PEAK POWER (kW): 12

AVERAGE POWER (W): 250

TRANSMIT PULSE LENGTH (μs): 7

COMPRESSED PULSE LENGTH (μs): N/A

PULSE RATE (pps): 2288 to 3049

TRANSMITTER TYPE: klystron

OUTPUT TUBE: SAL0893

EMISSION BANDWIDTH (kHz)

WAVEFORM: rectangular pulsed carrier

IF FREQUENCY (MHz):

IF BANDWIDTH (kHz): 130

SENSITIVITY (dBm): -118

NOISE FIGURE (dB): 6

OUTPUT DATA: range, azimuth, doppler

SPECIAL SIGNAL PROCESSING: digital gated MTI, 7 pulse canceller, log FTC

ANTENNA TYPE: shares antenna with SPS-10

ANTENNA SIZE: 3M x 1M (10ft x 3ft)(1)

ANTENNA GAIN (dB): 23

POLARIZATION: vertical

BEAMWIDTH (deg): HORZ. 5.6
VERT. 19

ANGLE COVERAGE (deg): HORZ. 360°
VERT. ± 9.5

SCAN RATE: HORZ. 15 rpm
VERT. N/A

SECTOR SCAN RATE: N/A

ANTENNA WEIGHT (kg):

BEAM POSITIONING TECHNIQUES:
HORZ. mechanical
VERT. fixed

LOBING TYPE: N/A

LOBING RATE (Hz): N/A

CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): 22.5

ANGULAR ACCURACY: N/A

GROSS WEIGHT (kg): 639 (1400 lbs.)

MANUFACTURER: Westinghouse

NUMBER (mfg/oper):

NAVY COGNIZANT CODE: PMS 404-50

TECHNICAL MANUALS:

NOMENCL RE ASSIGNMENT DATE:

NUMBER OF ELECTRONIC PARTS USED: 5100

MTBF (theo/oper): 400/123(2)

MTTR:

HIGH FAILURE RATE ITEMS: transmitter power supplies, receiver STC amplifier

MAXIMUM VOLTAGE: 14,000 V

A.C. POWER CONSUMPTION: 8 kVA

(1) Uses AN/Sps-10 antenna with modified L/C band feed.

(2) FLTAC Report No. 061-24-76. This is FLTAC's first report on this system.

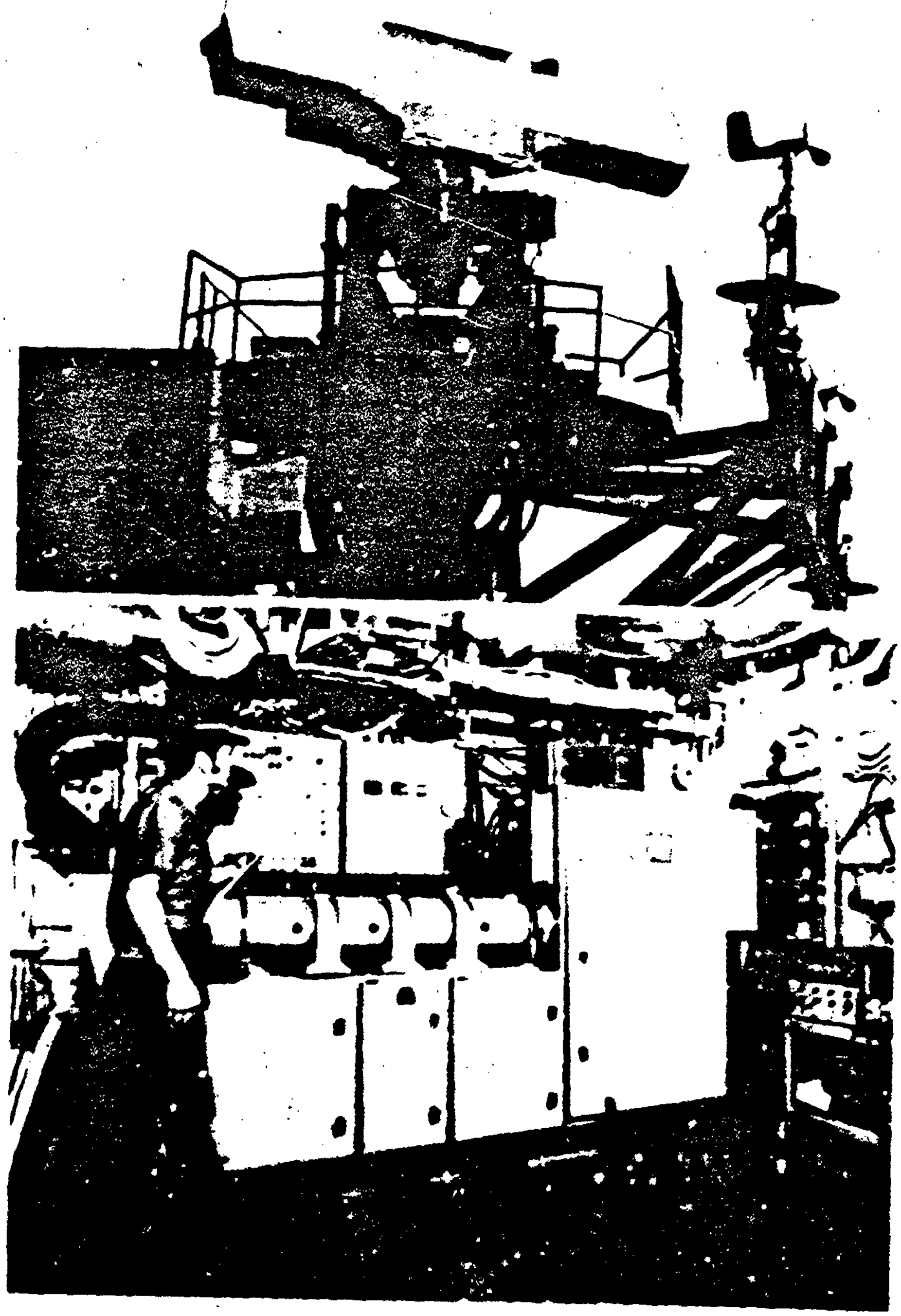

Fig. 22 (U) - TAS radar (Mk 23 point defense/target acquisition system (U)

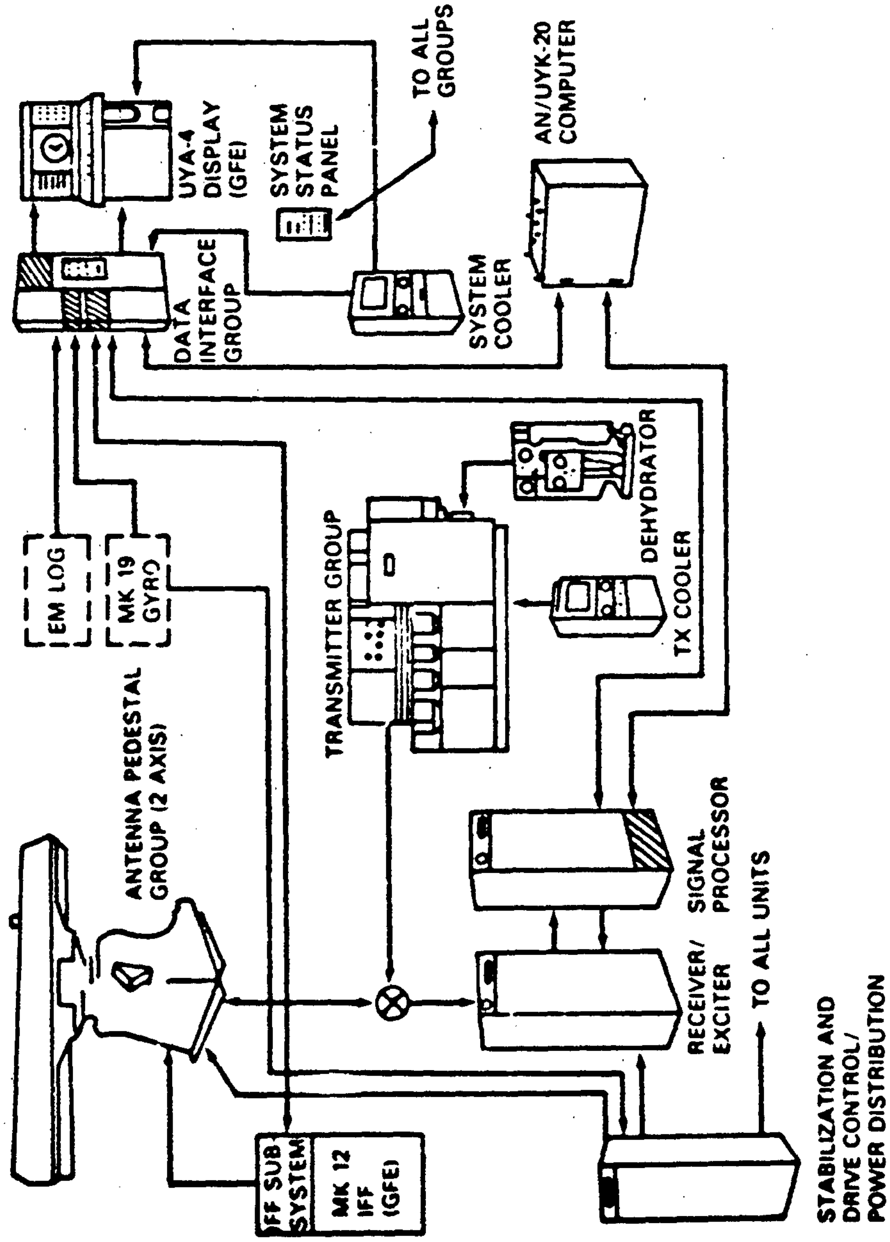

Fig. 23 (U) - TAS (Mk 23) block diagram (U)

(C) TABLE XIX

IFD/TAS MARK 23 Radar Parameters (U)

FUNCTION: automatic target acquisition, tracking and designation to point defense weapons(1)

FREQUENCY RANGE (MHz): 1268 - 1400

PEAK POWER (kW): 200

AVERAGE POWER (W): 2400 or 5600(2)

TRANSMIT PULSE LENGTH (μs): 3.8 or 42

COMPRESSED PULSE LENGTH (μs): 3.8

PULSE RATE (pps): 2660/3570 or 635/750(3)

TRANSMITTER TYPE: high power grid pulsed TWT

OUTPUT TUBE: QKW 17071

EMISSION BANDWIDTH (kHz):

WAVEFORM: pulsed uncoded (normal), pulsed linear FM (long range)

IF FREQUENCY (MHz): 1st: 270, 2nd: 30

IF BANDWIDTH (kHz): 220

SENSITIVITY (dBm): -117, -122, -125(3)

NOISE FIGURE (dB): 2.9

OUTPUT DATA: range, azimuth, doppler, and video

SPECIAL SIGNAL PROCESSING: digital, double MTI in cascade with 8 range-gated doppler filters, two-pulse non-coherent integrator

ANTENNA TYPE: 26 element linear array

ANTENNA SIZE: 4.27m X 0.61m (14' x 2')

ANTENNA GAIN (dB): 21.8

POLARIZATION: vertical

BEAMWIDTH (deg): HORZ. 3.4
VERT. 75

ANGLE COVERAGE (deg): HORZ. 360
VERT. 90

SCAN RATE: HORZ. 30 (normal, mixed), 15 long range
VERT. N/A

SECTOR SCAN RATE: up to eight 10° sectors per scan

ANTENNA WEIGHT (kg): 906 (1995 lbs.) including pedestal

BEAM POSITIONING TECHNIQUES:
HORZ. roll stabilization (up to 30°)
VERT. N/A

LOBING TYPE: N/A

LOBING RATE (Hz): N/A

CALCULATED DETECTION RANGE ON 1-m² TARGET (nmi): 21.3, 59.3

ANGULAR ACCURACY: N/A

GROSS WEIGHT (kg): 4120 (9075 lbs.)

MANUFACTURER: Hughes Aircraft Co.

NUMBER (mfg/oper): 43/2

NAVY COGNIZANT CODE: PMS 404-50

TECHNICAL MANUALS: NAVSEA OP 4199 (PMS/SMS)

NOMENCLATURE ASSIGNMENT DATE:

NUMBER OF ELECTRONIC PARTS USED: 19,569

MTBF (theo/oper): 200/365

MTTR: 1.6

HIGH FAILURE RATE ITEMS: power supplies transmitter deck, IC's, transistors, aluminum oxide capacities

MAXIMUM VOLTAGE: 38 KV

A.C. POWER CONSUMPTION: 53KW @ 60Hz
20KW @ 400Hz

(1) Three operating modes exist - a normal mode instrumented to 25nmi, a long range mode instrumental to 110nmi and a mixed mode which is a sequential combination of two short range and one long range.

(2) For any parameter in which two numbers are given separated by "or" the first number applies to the normal mode or short range scans of mixed mode and the second number applies to the long range mode or long range scans of mixed mode.

(3) The pulse rate in each mode alternates from scan to scan.

E. Air Traffic Control

(U) The Navy air traffic control function is performed on carriers by the AN/SPN-37 and the AN/SPN-43 and will be done at many of the naval airfields by the newly acquired AN/FPN-59. These radars differ from the 2D search radars in two particulars: they have a considerably less stringent long range requirement, and skin track of targets is not of prime importance since most of the tracked planes respond via beacon.

(U) This report concentrates on the AN/SPN-43 rather than the AN/SPN-37 since it is the newer version of the Gilfillan technology.

(U) The FPN-59 is not a Navy development but a radar bought by the Navy to an FAA Specification. It has been the subject of an extensive report just published, NRL Memorandum Report 3719. Documentation of the reliability of the equipment is particularly complete since each copy of the radar is bought by the FAA with a one year warranty a process that keeps the developer and the project office highly aware of the performance of the fielded radars. Moreover, the radar runs 24 hours a day at each site and some of the sites have been in operation over two years so the data is extensive.

1. SPN-43

(C) The AN/SPN-43 was a replacement for the Raytheon-built AN/SPN-6 and was first delivered in 1969. A newer version with a new pedestal and antenna appeared in 1972. The radar has a peak power of 850 kW and an average power of 861 W. It operates in the S-band of frequencies (3590-3700 MHz). Fig. 24 is a photograph of the system antenna; a block diagram of the radar is shown in Fig. 25, a listing of the pertinent operating parameters and performance data appears in Table XX.

(U) There are fifteen radars at sea, all on carriers, plus two on shore: one at the training school and the other at NESTEF (Naval Electronics Systems Test and Evaluation Facility).

(U) The original stabilization brakes were mechanically unacceptable and the redesign for new brakes proved satisfactory when tested at NESTEF. The only pair of these that have actually been replaced on a carrier were those on the Forrestal's radar. She, however, has been laid up and the project office is unwilling to modify the brakes on all the other ships until at least one set has been tested at sea. There are also servo motor problems, especially on those carriers where the servos operate in a stack gas environment.

(U) The only major electronic problem has been with the magnetrons.

There has been an operational problem with the capture of the flag halliards by the rotating antenna. One suggested solution has been to shut down rapidly whenever this occurs. An alternative approach, suggested by NESTEF, is to design the halliards so they will not interfere. A restraining loop or a spring loaded continuous loop similar to one used on a draw drape should suffice.

2. FPN-59

(U) The FPN-59 is identical to the FAA's airport terminal radar, the ASR-8 and is just being procured by the Navy. It is land based, operating in the S-band of frequencies (2700-2900 MHz) with a range up to 70 nautical miles. Its peak power is 1 Megawatt with an average power of 720 watts.

(U) The antenna is an open mesh parabola sixteen feet wide and nine feet high. (See Fig. 26.) Fig. 27 is a block diagram of the radar and Table XXV lists pertinent operating parameters and performance data.

(U) The ASR-8 radar is a dual system with two transmitters, two receivers and two synchronizer/processors, feeding and fed by a large, common, continuously- rotating antenna. There are two separate and independent drive motors on the bull ring gear either of which is capable of maintaining the rotation. Normally, both radar chains operate in the so-called "frequency diversity" mode. One of the synchronizers is designated as master and the other becomes the slave. The second radar channel pulses about 1.5 microseconds after the first and on a different microwave frequency.

(U) The two returns to the two channels are realigned by the processor to bring them into synchronization. The resulting signals are summed in the various modes and are passed via cabling to the switchboard that feeds the displays. Should one channel fail or be under test or maintenance such that it is inoperable, then the data to the interface is provided solely by the other channel. This leads to some loss in the ability to detect aircraft, due both to the 3 dB loss in average power and a target fluctuation described by a less favorable Swerling model.

(U) Since the radar is bought with a warranty clause, failed parts are returned to the contractor for repair and failure analysis. There is, thus, extensive data available on single thread reliability (i.e., the reliability of the individual channels). These data have been compiled by counting total returned parts under the warranty and assuming that the channels have been operating continuously.

(U) This is a reasonable assumption since the frequency diversity mode is employed 24 hours a day except during repair or maintenance actions.

(U) These data have been reduced to arrive at two different MTBF figures for the individual channels. One figure, the "gross" MTBF, was obtained by dividing the total number of operating hours by the total number of returned parts. The only exceptions are those parts known to have failed in secondary modes. This "gross" value, cumulated over all the field experience to Spring 1977, is 365 hours. A second value, the "refined" MTBF, is also calculated. This figure, cumulative as well, is 650 hours. In the "refined" value both secondary failures and failures that the manufacturer has been unable to duplicate are removed from the data.

(U) Originally the returned circuit boards were tested only in a circuit tester, but more recently, boards that pass the tester have been further tested in whatever radar is undergoing checkout tests on the factory floor. The "refined" data tends to lag the "gross" data by some two months since it takes longer to prepare. The real cumulative MTBF would be somewhere between the two figures, probably closer to the "refined". In all of this, it is to be emphasized that only failures are considered in the MTBF data. Adjustments, and the FAA's technicians make them frequently, are not charged against MTBF.

(U) The FAA is little concerned with single thread reliability. As long as one channel is operating, the system is available so far as they are concerned. Careful records are kept, however, of the total time any installation has both channels down. This has been less than one hour per year per installation.

(U) The extremely high availability of the ASR-8 is achievable by the FAA, not only through radar redundancy, but also because of their particular site, logistics and personnel policies. The radars are located at commercial airports, readily accessible to the main supply base at Oklahoma City. The radars are maintained by GS-12, GS-13 technicians, who work on this equipment exclusively. When one channel fails, repair starts immediately. There is no waiting for outside technical assistance.

(U) The original radar installation contains an extensive set of spare parts almost equivalent to that needed for an additional channel. Should there be parts needed that are not available on the site, they can be flown in directly from the central spare parts depot at Oklahoma City.

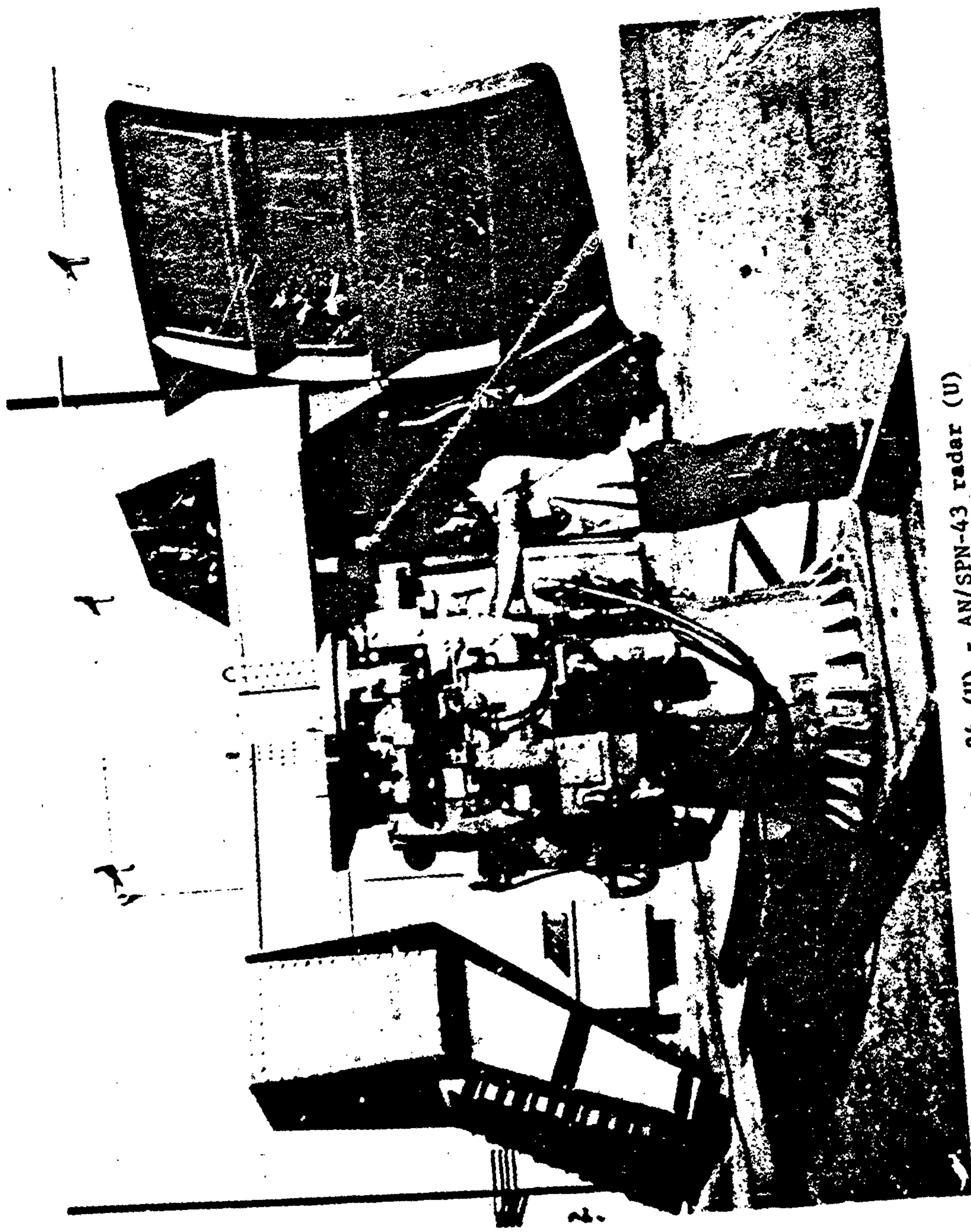

Fig. 24 (U) - AN/SPN-43 radar (U)

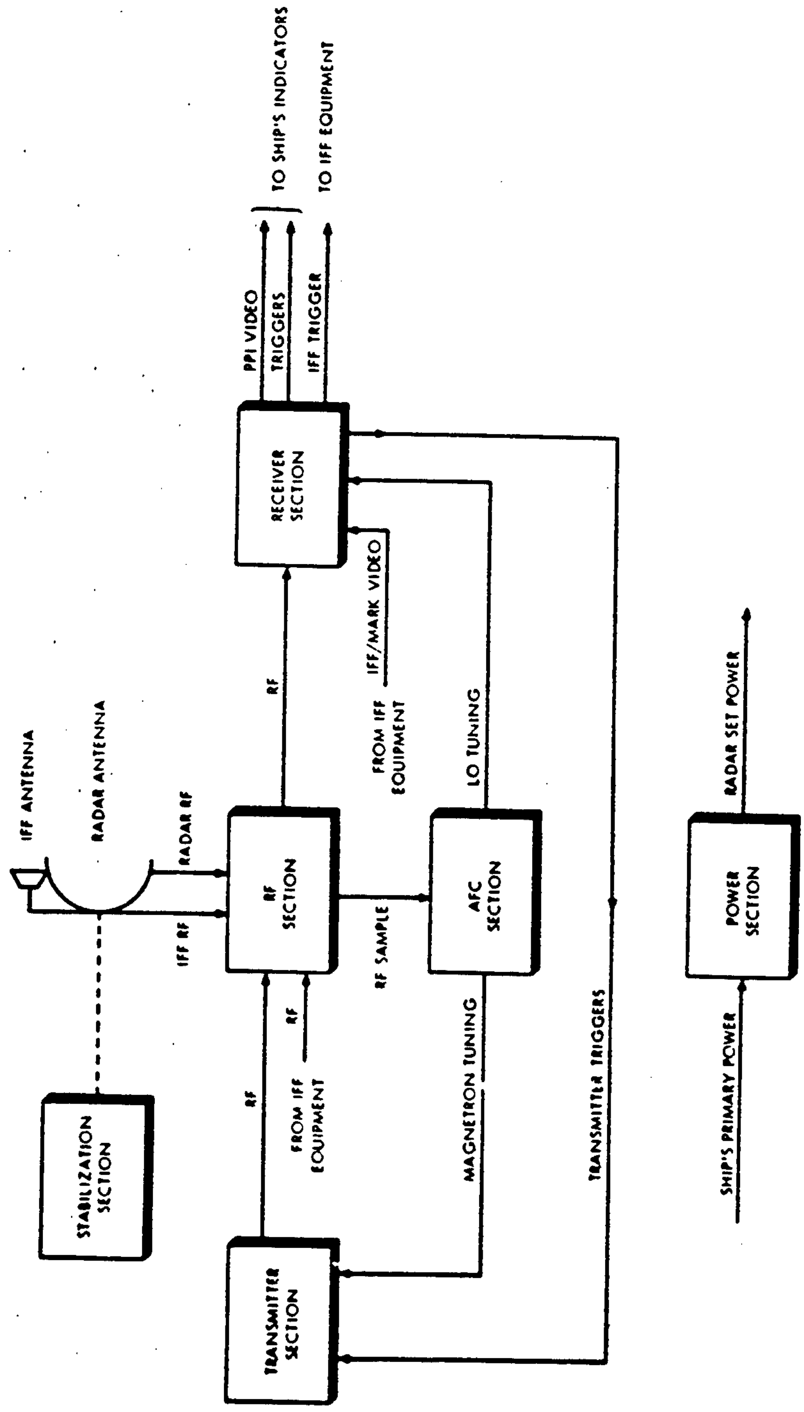

Fig. 25 (U) - AN/SPN-43 block diagram (U)

(U) TABLE XX

AN/SPN-43A Radar Parameters (U)

FUNCTION: air traffic control radars for aircraft carriers

FREQUENCY RANGE (MHz): 3590-3700

PEAK POWER (kW): 850

AVERAGE POWER (W): 861

TRANSMIT PULSE LENGTH (μs): 0.9

COMPRESSED PULSE LENGTH (μs): N/A

PULSE RATE (pps): 1125

TRANSMITTER TYPE: magnetron

OUTPUT TUBE: 125132

EMISSION BANDWIDTH (kHz):

WAVEFORM: pulsed carrier

IF FREQUENCY (MHz): 30

IF BANDWIDTH (kHz): 2500

SENSITIVITY (dBm): -100, -109 (1)

NOISE FIGURE (dB): 3.5

OUTPUT DATA: radar and IFF video

SPECIAL SIGNAL PROCESSING: STC, FTC, LIN-LOG receiver

ANTENNA TYPE: foil-fiberglass reflector CSC^2 elevation shape control

ANTENNA SIZE: 2.1m x 3m (7'x10')

ANTENNA GAIN (dB): 32

POLARIZATION: horizontal

BEAMWIDTH (deg): HORZ. 1.5
VERT. 4.2 CSC^2 to 45

ANGLE COVERAGE (deg): HORZ. 360
VERT. 4.2

SCAN RATE: HORZ. 15 rpm
VERT. N/A

SECTOR SCAN RATE: N/A

ANTENNA WEIGHT (kg): 1543 (3400)

BEAM POSITIONING TECHNIQUES:
HORZ. N/A
VERT. N/A

LOBING TYPE: N/A

LOBING RATE (Hz): N/A

CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): 55 (100km)

ANGULAR ACCURACY: 1.5 deg.

GROSS WEIGHT (kg): 2719 (5990 lbs.)

MANUFACTURER: ITT-Gilfillan

NUMBER (mfg/oper): 19/15

NAVY COGNIZANT CODE: NAVELEX-52011B

TECHNICAL MANUALS: NAVELEX-0967-436-3010

NOMENCLATURE ASSIGNMENT DATE:

NUMBER OF ELECTRONIC PARTS USED: 4323 (2)

MTBF (theo/oper): 83/77 (3)

MTTR: 3 (3)

HIGH FAILURE RATE ITEMS: stabilization brake, stabilization servo motor, azimuth bull gear bearing, magnetrons

MAXIMUM VOLTAGE: -50kV

A.C. POWER CONSUMPTION: 21kVA

(1) Sensitivity with parametric amplifier "off" = -100 dBm, "on" = -109dBm.

(2) ITT-Gilfillan.

(3) ITT-Gilfillan estimate as of 1976.

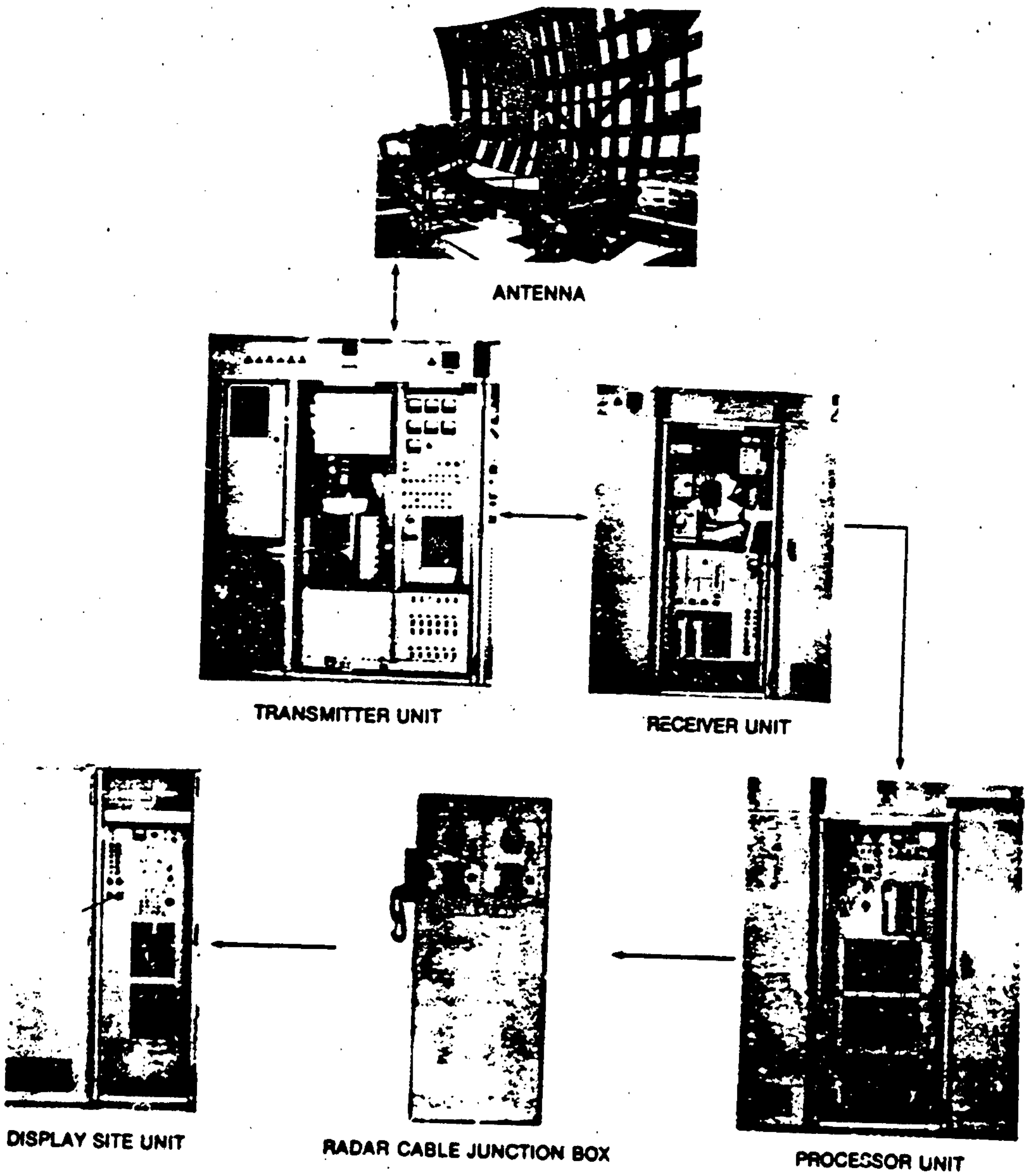

Fig. 26 (U) - AN/FPN-59 radar (U)

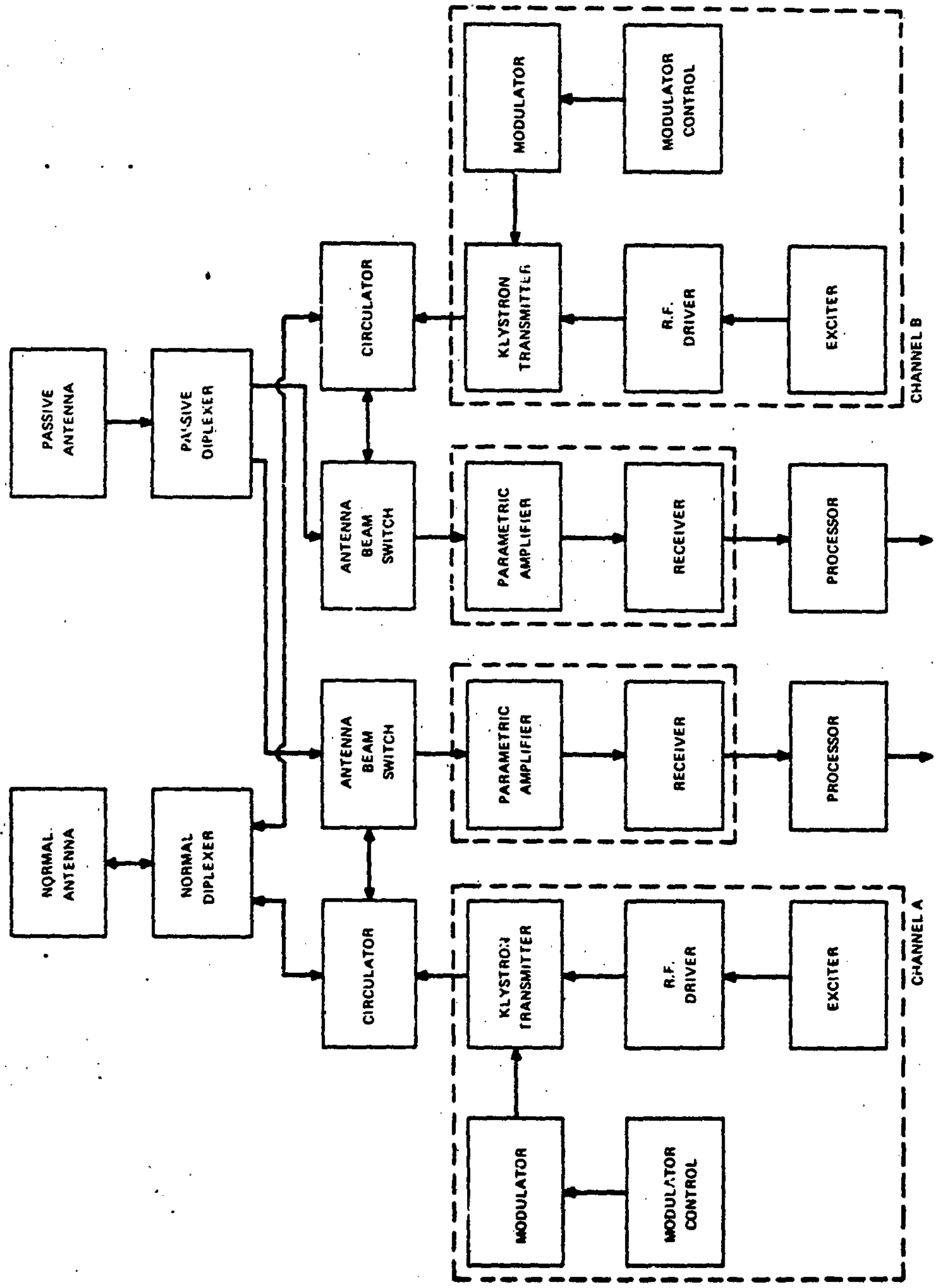

Fig. 27 (U) - AN/FPN-59 radar block diagram (U)

(U) TABLE XXI

AN/FPN-59 Radar Parameters[1] (U)

FUNCTION: air traffic control in terminal area

FREQUENCY RANGE (MHz): 2700 - 2900

PEAK POWER (kW): 1000

AVERAGE POWER (W): 720

TRANSMIT PULSE LENGTH (μs): 0.6

COMPRESSED PULSE LENGTH (μs): N/A

PULSE RATE (pps): 1040

TRANSMITTER TYPE: klystron

OUTPUT TUBE: VA 87E

EMISSION BANDWIDTH (kHz): 2000

WAVEFORM: pulsed carrier

IF FREQUENCY (MHz): 30

IF BANDWIDTH (kHz): 2000

SENSITIVITY (dBm): -110 (-108 MTI mode)

NOISE FIGURE (dB): 4

OUTPUT DATA: to displays

SPECIAL SIGNAL PROCESSING: digital MTI, log FTC, 2 or 3 pulse canceler

ANTENNA TYPE: open mesh parabolic reflector

ANTENNA SIZE: 2.7m x 4.9m (9' x 16')

ANTENNA GAIN (dB): 33.5

POLARIZATION: linear vertical or circular, remotely selectable

BEAMWIDTH (deg): HORZ. 1.4

VERT. 30

ANGLE COVERAGE (deg): HORZ. 360

VERT. modified CSC

SCAN RATE: HORZ. 12.5 rpm

VERT. N/A

SECTOR SCAN RATE: N/A

ANTENNA WEIGHT (kg): 908 (2000 lbs.) without pedestal

BEAM POSITIONING TECHNIQUES:

HORZ. N/A

VERT. slight mechanical adjustment

LOBING TYPE: N/A

LOBING RATE (Hz): N/A

CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): 75

ANGULAR ACCURACY: N/A

GROSS WEIGHT (kg): 9080 (20,000 lbs.) per channel [2]

MANUFACTURER: Texas Instruments

NUMBER (mfg/oper): 8 to be delivered in late 1977

NAVY COGNIZANT CODE: NAVELEX 520

TECHNICAL MANUALS:

NOMENCLATURE ASSIGNMENT DATE: 1976

NUMBER OF ELECTRONIC PARTS USED: 18,700[3]

MTBF (theo/oper): 663/300[4]

MTTR: 0.5 hour

HIGH FAILURE RATE ITEMS: paramp, modulator, klystron assembly

MAXIMUM VOLTAGE: 80 kV

A.C. POWER CONSUMPTION: 10 kW per channel

(1) First radars of series are identical to FAA's ASR-8.
(2) Weight includes shelter delivered for FAA type installation.
(3) NRL parts count.
(4) Single channel, manufacturer's data as October 1976.

F. 3-D

(U) Most of the three dimensional (range, height, and bearing) radars in the fleet are an outgrowth of the frequency scan radars developed by Hughes Aircraft in the 1950's.* The Hughes models, currently at sea, are the AN/SPS-39 and the AN/SPS-52. They employ a single pencil beam that is scanned in elevation by frequency changes of the transmitter, and in bearing by mechanical rotation of the antenna. Under the instigation of the Naval Research Laboratory, ITT Gilfillan developed a variant of the basic design, the AN/SPS-48, which radiates nine elevation beams by use of a long pulse containing nine different frequency segments.

(U) In this study we have concentrated on the SPS-48 and the later SPS-48A since these radars are recent representative of the class, and the reliability data on them has been particularly extensive.

SPS-48

(C) The AN/SPS-48, an S-band radar (2900-3100 MHz), can operate in any one of three power modes, low, medium and high power. These correspond, respectively, to transmissions through the second (TWT), driver (first amplitron), or final stage (second amplitron) of the radar transmitter. In the high power mode, the peak power is 2,200 kW, with an average power of 15,000 W. Fig. 28 is a photograph of the major subsystems; a block diagram is shown in Fig. 29. A listing of pertinent operating parameters and performance data appears in Table XXII.

(C) As indicated above, the radiated signal is coded with 9 distinct carrier frequency segments. The return signal is sorted by nine filters, one around each carrier, and given to nine different receivers. Thus, at the cost of a ninefold increase in receiver complexity, there are effectively nine times as many radiated pulses as in the SPS-52. This overcomes one of the basic problems of a 3D radar having only a single beam, i.e., how to locate long range targets unambiguously and still get enough hits to assure detection and perhaps even MTI processing. In essence, the AN/SPS-48 has nine times as many beams to process during each revolution as the AN/SPS-39 or AN/SPS-52. All three radars stabilize the beam with respect to ship roll and pitch by electronic means. The transmitted frequency is modified to change the elevation skew angle of the beam relative to the antenna face.

---

* (U) There are a few AN/SPS-30 stacked beam radars still on carriers but they are slated for replacement. There are also two or three prototype phase-scan radars, but nothing exists in quantity using this technique.

(U) The SPS-48 radar has a very high parts count for several reasons: (1) it was designed in an era when there were not many integrated circuits -- so that a simple device like a flip-flop will have a high parts count; (2) there are nine totally distinct receiver chains behind the wideband circuitry; (3) there is an elaborate plot extractor in the newest version; (4) the requirement for electronic stabilization of the beam adds a computer parts count burden to the system; (5) a complex synchronizer is required to program the large number of frequencies for the electronic scan.

(C) There are, however, some basic design advantages in frequency scan that reduce the sensitivity of adjustments and matching requirements. For example, one wideband STC can be used in either the microwave chain or the first I.F. amplifier. This makes the channels track in amplitude with STC - something that is difficult, if not impossible, to achieve in a stacked beam 3D radar. In the AN/SPS-48A the MTI is achieved in the wideband circuitry for all nine beams simultaneously. Again, this aids in matching but this time at a considerable reliability price in using quartz lines. The match is needed for interpolation between beams by some form of amplitude comparison. In the AN/SPS-48A this process is made easier by the close spacing of the beams. Since the AN/SPS-48 works with 9 beams at a time, one can afford to space them close together. A stacked beam radar is severely limited in the number of beams and in minimum beam spacing; it would be difficult physically to place the horns close enough together to get an overlap greater than the 3 dB points of the beams.

(C) Partially due to the relaxed tolerances of the frequency scan design and partially due to the better reliability of low power solid-state circuitry (even if not highly integrated), the nine complex receivers are reasonably reliable. There are problems, however, in the high power portions of the transmitter. The reported data clearly demonstrate this. The reliability of the radar decreases as the radiated power increases. The MTBF for low power radiation (under condition of continuous demand) is 84 hours, while the MTBF for high power radiation is only 31 hours.

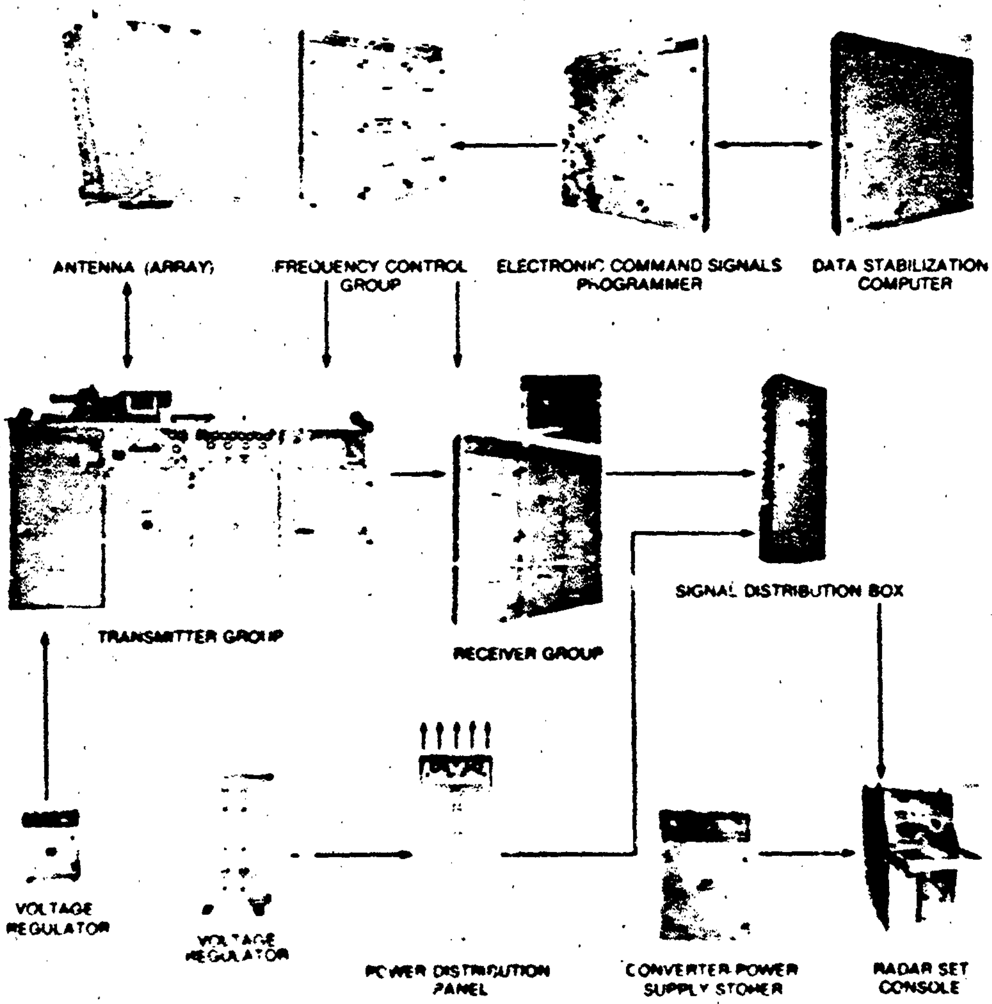

Fig. 28 (U) - AN/SPS-48 radar (U)

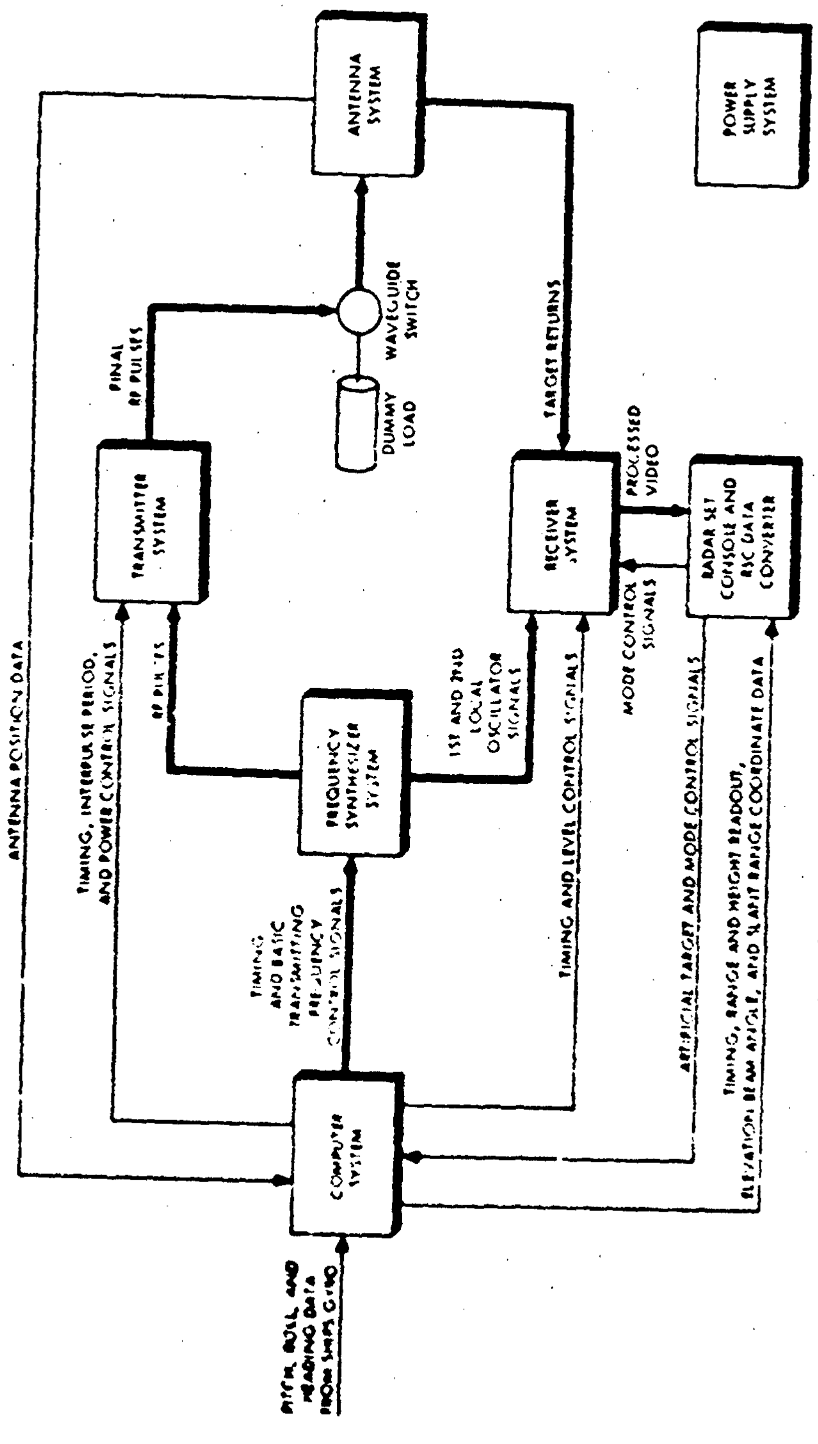

Fig. 29 (U) - AN/SPS-48 block diagram (U)

(C) TABLE XXII

AN/SPS-48 RADAR PARAMETERS (U)

FUNCTION: long range height finding air search

FREQUENCY RANGE (MHz): 2900-3100

PEAK POWER (kW): 2200

AVERAGE POWER (W): 15,000

TRANSMIT PULSE LENGTH (µs): 26.5

COMPRESSED PULSE LENGTH (µs):

PULSE RATE (pps): 161 to 1318

TRANSMITTER TYPE: frequency synthesizer power amplifier

OUTPUT TUBE: amplitron OKS-1541

EMISSION BANDWIDTH (kHz): 350

WAVEFORM: pulsed carrier

IF FREQUENCY (MHz): multiple IF frequencies(1)

IF BANDWIDTH (kHz): 350

SENSITIVITY (dBm): -102

NOISE FIGURE (dB): 5.5

OUTPUT DATA: video to PPI and range-height indicator

SPECIAL SIGNAL PROCESSING: MTI, automatic acquisition

ANTENNA TYPE: phased array

ANTENNA SIZE: 4.9m x 4.5m (16' x 15')

ANTENNA GAIN (dB): 38.5

POLARIZATION: horizontal

BEAMWIDTH (deg): HORZ. 1.5
VERT. 1.6

ANGLE COVERAGE (deg): HORZ. 360
VERT. 0-45

SCAN RATE: HORZ. 7.5, 15 rpm
VERT. computer programmed

SECTOR SCAN RATE: N/A

ANTENNA WEIGHT (kg): 2038 (4495 lbs.)

BEAM POSITIONING TECHNIQUES:
HORZ. mechanical
VERT. programmed incremental frequency change

LOBING TYPE: N/A

LOBING RATE (Hz): N/A

CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): 220

ANGULAR ACCURACY: 1/16°

GROSS WEIGHT (kg): 9189 (20,259 lbs.)

MANUFACTURER: ITT Gilfillian

NUMBER (mfg/oper): 62162

NAVY COGNIZANT CODE: NAVSEA 65231

TECHNICAL MANUALS: NAVSHIPS 6967-186-1010

NOMENCLATURE ASSIGNMENT DATE:

NUMBER OF ELECTRONIC PARTS USED: 250,000

MTBF (theo/oper): /84, 58, 32 (2)

MTTR: 7.5 (2)

HIGH FAILURE RATE ITEMS: Duplexer ATR Tube (W604218), Dry Air, Thyratron (V-75903), (V-79502), & (V-79501), Second Stage Amplitron, 400 Hz Fine Synchro Frequency Synthesizer TWT (V-63401)

MAXIMUM VOLTAGE: 60-70 kV

A.C. POWER CONSUMPTION: 111.4 kVA

(1) Multiple IF frequencies: 303-324, 25, 26.5, 28, 29.5, 31, 32.5, 34, 35.5, & 37.

(2) Fleet Analysis Report 041-132-. MTBF under condition of continuous demand for low, medium, and high power.

G. Missile

(U) The original semi-active missile system was the Sparrow, developed by the Navy's Bureau of Aeronautics. The Army, under the Hawk program, developed a missile system with greater detection and acquisition range. The Navy in turn built on the Hawk technology to produce a version of the Terrier which had the first semi-active guidance for use in a ship-to-air version.

(C) The tracking and illuminating radars used for the modern Tartar, Terrier and Standard Missiles are of the AN/SPG-51 and the AN/SPG-55 families. Each contains two radar transmitters, a pulse transmitter used in conjunction with a conical scan or monopulse receiver for target tracking and a CW transmitter for target illumination. This report has chosen the AN/SPG-51D as typical of the family, since it is the newest of these radars and the only one built in a reliability conscious era.

AN/SPG-51D

(C) The AN/SPG-51D is an update of the AN/SPG-51C. The principal change is in the pulse transmitter. The klystron was replaced by a TWT to permit the transmission to be chosen from a much wider bandwidth. The new system is frequency agile over 8 channels chosen from 32. In addition, the more recent design has permitted the incorporation of a much larger percentage of integrated circuits and of modern digital circuitry.

(C) Data on the radar have been gather principally from three ships (a total of 10 radar sets - 4 each on two ships and 2 on the third). Supposedly, the data is not typical of what the future reliability will be since there has been an extensive reliability improvement program conducted by the manufacturer under the direction of NAVSEA. For example, between 1 July 76 and 30 June 77, the pulse transmitter failed 87 times for an MTBF of 71.6 hours. The CWI transmitter (which is used much less) failed 26 times for a MTBF of 46.6 hours. The mean repair times were exceptionally long because of the relative inexperience of the crew with the new equipment, the incompleteness of the manuals, and the large proportion of transmitter failures. Transmitter failures usually take longer to repair than failures in the receiver or processor.

(C) In addition to the poor reliability of the output sections of the transmitters there has been a low MTBF in the STAMO that drives the CWI (627 hours). A STAMO should not constitute this much of a problem and another vendor for this component might be indicated. Problems have shown up in the cooling system, particularly, in the hoses and in their connectors. There is some redesign required to

(C) improve the monitoring of a TWT driver power supply. At present, excessive repair time is spent in determining whether it is the TWT or its power supply that is faulty.

(U) Reading the problem status report on the radar confirms that the reliability improvement program was urgently required. Every newly fielded system has its share of problems unless it has been through a test procedure similar to the one described for the airborne radars above. The AN/SPG-51D should have been more reliable since it is only a minor modification of the AN/SPG-51C. Reliability was not stressed appropriately in the initial phases of the design.

(U) A photograph of the major subsystems appears in Fig. 30; a block diagram is shown in Fig. 31. Pertinent operating parameters and performance data appears in Table XXIII and XXIV.

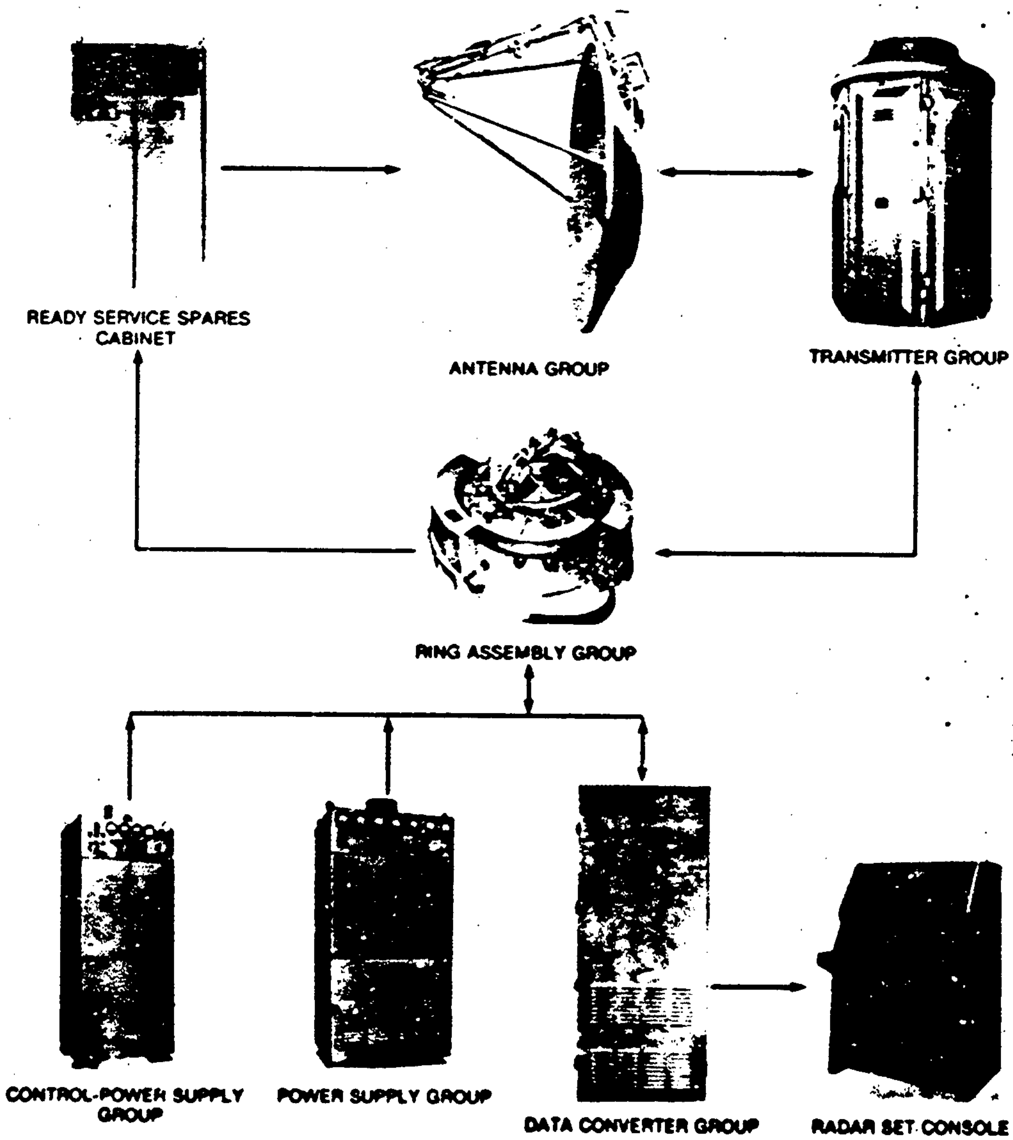

Fig. 30 (U) - AN/SPG-51 radar (U)

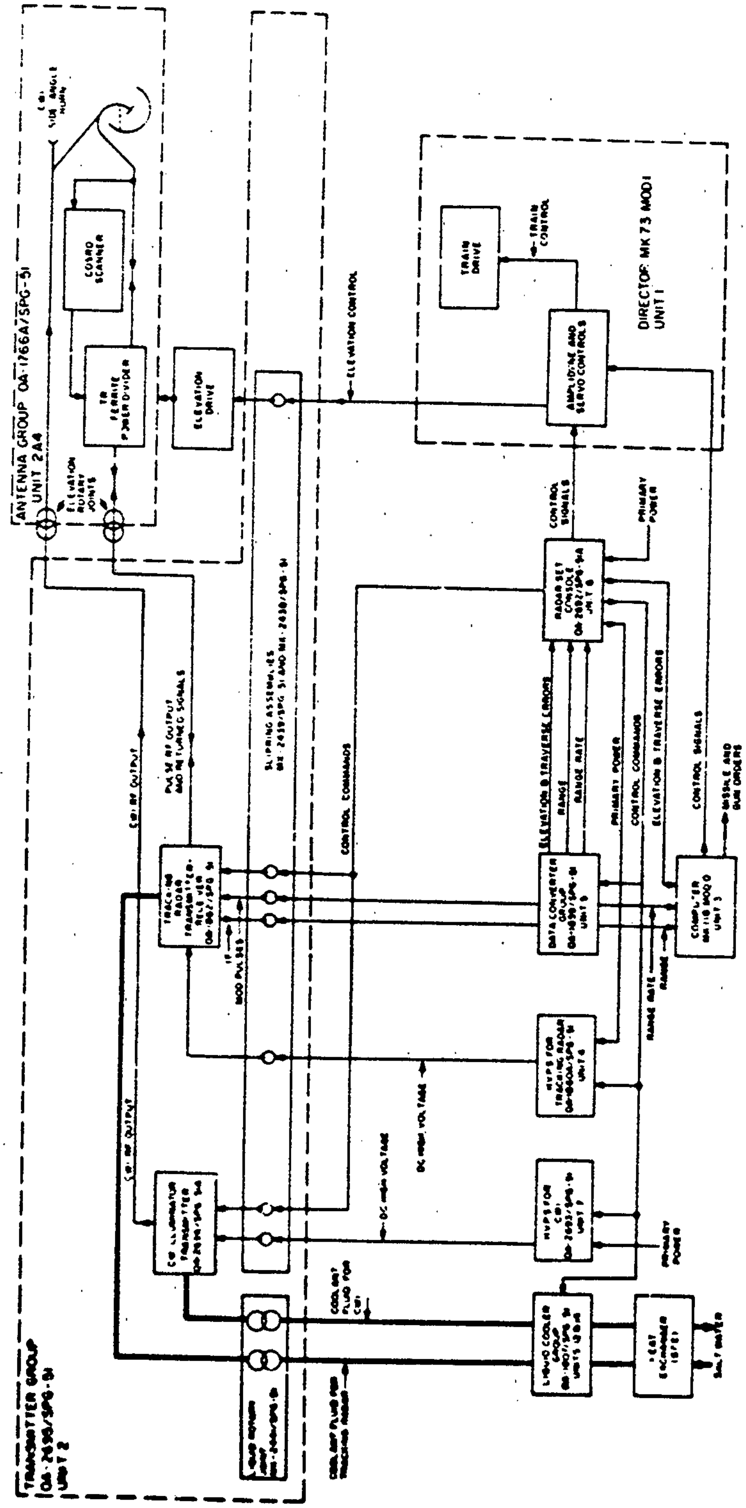

Fig. 31 (C) - AN/SPG-51 radar block diagram (U)

(C) TABLE XXIII

AN/SPG-51D Radar Parameters (U)
(Target Illuminator)

FUNCTION: an X-band target illuminator combined with an S-band acquistion, tracking radar

FREQUENCY RANGE (MHz): 10250-10500

PEAK POWER (kW): 6

AVERAGE POWER (W): 4000

TRANSMIT PULSE LENGTH (μs): N/A

COMPRESSED PULSE LENGTH (μs): N/A

PULSE RATE (pps): N/A

TRANSMITTER TYPE: master oscillator, power amplifier

OUTPUT TUBE: klystron - VA828

EMISSION BANDWIDTH (kHz):

WAVEFORM: CW or modulated CW

IF FREQUENCY (MHz): N/A

IF BANDWIDTH (kHz): N/A

SENSITIVITY (dBm): N/A

NOISE FIGURE (dB): N/A

OUTPUT DATA: N/A

SPECIAL SIGNAL PROCESSING: N/A

ANTENNA TYPE: dual purpose parabolic reflector

ANTENNA SIZE: 2.5m diam (7.7')

ANTENNA GAIN (dB): 45

POLARIZATION: vertical

BEAMWIDTH (deg): HORZ. 0.9
VERT. 0.9

ANGLE COVERAGE (deg): HORZ. 0.9
VERT. 0.9

SCAN RATE: HORZ.
VERT.

SECTOR SCAN RATE: N/A

ANTENNA WEIGHT (kg): 254 (560 lbs.)

BEAM POSITIONING TECHNIQUES:
HORZ. via S-band radar
VERT. function

LOBING TYPE: N/A

LOBING RATE (Hz): N/A

CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): N/A

ANGULAR ACCURACY: N/A

GROSS WEIGHT (kg): 10,670 (23,500 lbs.)

MANUFACTURER: Raytheon

NUMBER (mfg/oper): 5/5

NAVY COGNIZANT CODE: NAVSEA 6242

TECHNICAL MANUALS: NAVSEA OP 3541 (PMS/SMS) Vol 1-3

NOMENCLATURE ASSIGNMENT DATE:

NUMBER OF ELECTRONIC PARTS USED: 31,000[1]

MTBF (theo/oper): 75[2]/ 90[3]

MTTR: 8[3]

HIGH FAILURE RATE ITEMS: CWI transmitter, CWI power supply, director control

MAXIMUM VOLTAGE: 15kV

A.C. POWER CONSUMPTION: 340kVA

(1) Raytheon estimate includes tracking radar.
(2) Design specification.
(3) NSWSES Preliminary Report, 14 Dec 1977.

(C) TABLE XXIV

AN/SPG-51D Radar Parameters (U)
(Tracking Radar)

FUNCTION: target acquisition and tracking radar function combined with a CW target illuminator.

FREQUENCY RANGE (MHz): 5450-5825

PEAK POWER (kW): 81

AVERAGE POWER (W): 1600

TRANSMIT PULSE LENGTH (μs): 2.1 - 3.2

COMPRESSED PULSE LENGTH (μs): N/A

PULSE RATE (pps): 4100 (surface)
9600 - 16700 (air)

TRANSMITTER TYPE: master oscillator, power amplifier

OUTPUT TUBE: TWT 608H

EMISSION BANDWIDTH (kHz): 20,000 at -65dB point

WAVEFORM: pulsed carrier

IF FREQUENCY (MHz): 660, 30

IF BANDWIDTH (kHz): 1200

SENSITIVITY (dBm): -115

NOISE FIGURE (dB): 8

OUTPUT DATA: tracking error signals in bearing, elevation, and range

SPECIAL SIGNAL PROCESSING: CFAR in doppler domain with 15 filters, STC

ANTENNA TYPE: dual purpose parabolic reflector

ANTENNA SIZE: 2.5m diam (7.7')

ANTENNA GAIN (dB): 39.5

POLARIZATION: horizontal

BEAMWIDTH (deg): HORZ. 1.6
VERT. 1.6

ANGLE COVERAGE (deg): HORZ. [1]
VERT.

SCAN RATE: HORZ.
VERT.

SECTOR SCAN RATE: N/A

ANTENNA WEIGHT (kg): 254 (560 lbs.)

BEAM POSITIONING TECHNIQUES:
HORZ. zero error tracking, closed loop
VERT.

LOBING TYPE: conical scan or receive only

LOBING RATE (Hz): 16 to 110

CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): 100 (185km)

ANGULAR ACCURACY: N/A

GROSS WEIGHT (kg): 10,670 (23,500 lbs.)

MANUFACTURER: Raytheon

NUMBER (mfg/oper): 10/10

NAVY COGNIZANT CODE: NAVSEA 6242

TECHNICAL MANUALS: NAVSEA OP 3541 (PMS/SMS) Vol 1-3

NOMENCLATURE ASSIGNMENT DATE:

NUMBER OF ELECTRONIC PARTS USED: 31,000[2]

MTBF (theo/oper): 75[3]/90[4]

MTTR: 8[4]

HIGH FAILURE RATE ITEMS: pulse transmitter, antenna

MAXIMUM VOLTAGE: 51kV

A.C. POWER CONSUMPTION: 340kVA

(1) Angle coverage with 3D designation, beam spirals out to 1.8° with 2D designation.
(2) Raytheon estimate (includes illiminator).
(3) Design specification.
(4) [illegible] Preliminary Report, 14 Dec 1977.

H. Fire Control

(C) The last group of shipboard radars considered in this report are elements in the gun control systems. The newest are the radars for the Mark 86 and the Mark 92 systems. The Mark 86 system was chosen for this analysis because it has been in the fleet for some time and it has been well documented. There are two radars used in the system, an AP/SPQ-9A which performs the search function and an AN/SPG-60 which performs the tracking function. Both are relatively low powered radars, with the AN/SPQ-9A having an average power of 75 watts and the AN/SPG-60 having an average power that varies, depending on the mode of operation, between 30 and 900 watts.

(U) A photograph of the major subsystems of each radar in the Mark 86 configuration is shown in Fig. 32. A block diagram of the Mark 85 system appears as Fig. 33. A separate block diagram for the SPG-60 occurs as Fig. 34 and a block diagram for the SPQ-9A radar occurs as Fig. 35. Finally, pertinent operating parameters and performance data for the SPG-60 and the SPQ-9A are listed in Tables XXV and XXVI respectively.

(C) The AN/SPQ-9A is somewhat unusual in that it employs an optical system to produce a non-linear chirp waveform. Non-linear chirps have the property that they do not have to be preceded by weighting in order to have acceptable range sidelobes. (An unweighted linear chirp has the usual 13 dB sinx/x sidelobes.) The elimination of weighting saves 2-3 dB of S/N. Unfortunately, the full saving is only realized on the slowest targets. The higher dopplers produced by the faster (and the usually more important) targets are mismatched in a non-linear dechirp process and this results in a loss of most of what was gained by the elimination of weighting.

(C) The AN/SPG-60 is a conventional monopulse tracking radar. It is coherent with a set of high prfs that individually have no blind speeds for the targets of interest. In acquisition, the blind ranges are avoided by the computer choosing from the set of prfs on the basis of range information available either from the AN/SPQ-9A or from another shipboard radar. In track the computer uses the information coming from the AN/SPG-60 itself to avoid the blind ranges. The whole Mark 86 system, including the radars, the optical tracker for clear weather, and the guns, is controlled by a UYK-7 master computer.

1. SPQ-9A

(U) The reliability of the AN/SPQ-9A has been improving rather consistently over the past two years since the system was fielded. The optical pulse compression system depends on an arc lamp which has a limited life. The manufacturer originally promised 750 hours MTBF

(U) and has exceeded this by 30-50%. Unfortunately, the crews are reluctant to replace the lamp as long as it is working; the replacement requires somewhat elaborate refocusing adjustments, and since the logistic system is seldom more than one arc lamp ahead of the demand on each ship they hate to use the last spare. The result is the identification of a "low reliability" item when, in fact, a limited life item is involved. It is like faulting a diesel engine for running out of oil.

(U) In addition to the arc lamp, the optical system has also had problems with the ultra-sonic light modulator, with the photo tube, and with the power supply for the lamp. The first problem appears to be caused by human error since there is a suspicion that the technicians do not replace the water as it evaporates. The second is again a limited life item. An ECP is now in on the lamp power supply.

(U) Lockheed expects that eventually an ECP will be generated to replace the whole optical chirp system with a surface acoustic wave line. (At the time the optical system was chosen, the SAW lines were in a much earlier development phase.)

(U) The shaft encoders, on both the AN/SPQ-9A and AN/SPG-60, are supplied by the same vendor and neither meets its reliability specifications. They have been improving and at present are at about 50% of the required MTBF's i.e., they now last 6,000 and 12,000 hours. This is certainly not ideal but cannot be considered a really critical item since even the lowest figure is 10 times the theoretical MTBF of the radar it serves.

(U) Finally, the AN/SPQ-9A has suffered from an output TWT that is still at only 25% of its theoretical MTBF. Some of the TWT power supplies and protective circuitry were also unsatisfactory but ECPs have corrected most of these problems. The driver TWT is also not yet delivering the expected reliability.

2 SPG-60

(U) The AN/SPG-60, being more conventional, has had fewer unusual problems. There has been an issue with the klystron's screen supply but this has occurred only when the equipment was installed in a particular ship yard - so operator error is suspected. There is limited life switch tube in the klystron modulator; it should be replaced periodically and probably is not. As mentioned above, the shaft encoder still needs further improvement.

(U) Most of the other failures in both the AN/SPQ-9A and AN/SPG-60 are well within the levels derived from MIL Stand 217B projections. In a few cases some component has failed more frequently than anticipated, but in this event an ECP has been generated either to alter

(U) the circuit or to replace the unsatisfactory component. Generally the majority of such failures occur in the solid state circuit boards and the alteration or replacement of a board is accomplished relatively easily. It is only in the transmitters, in the optical chirp, or in the mechanical elements, that extensive redesign may be required to implement an ECP.

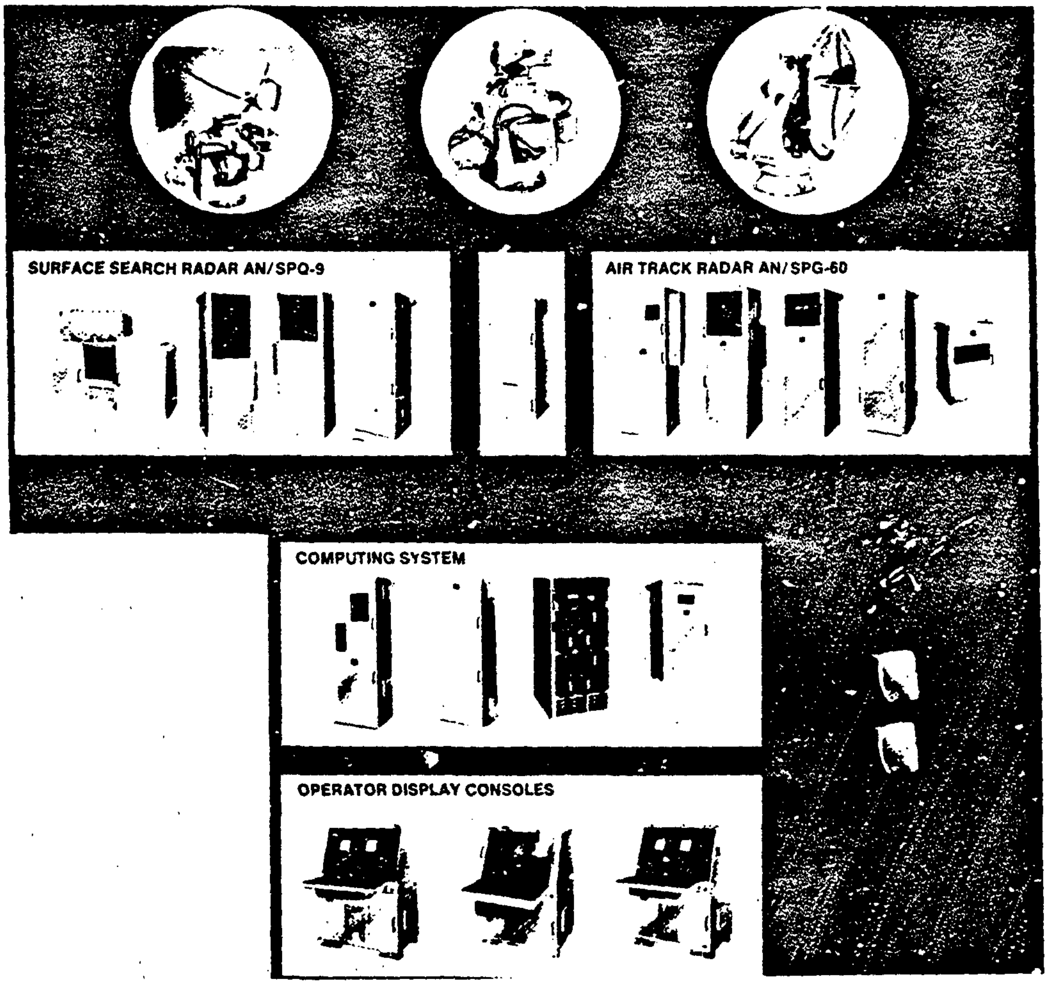

Fig. 32 (U) - Mark 86 gun control system (AN/SPQ-9A and AN/SPQ-60 radars) (U)

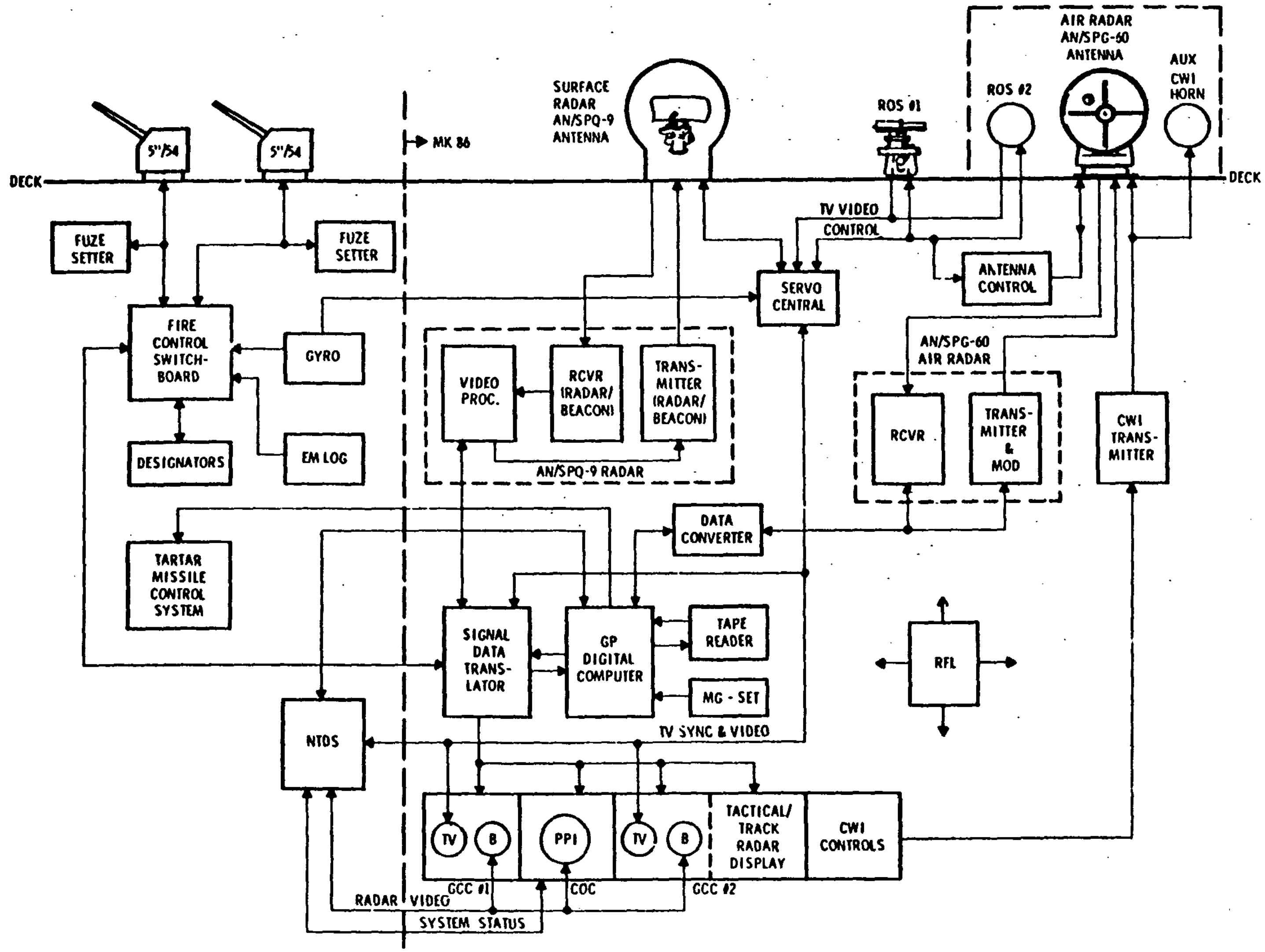

Fig. 33 (C) - Mark 86 gun control system (AN/SPQ-9A and SPQ-60 radars) block diagram (U)

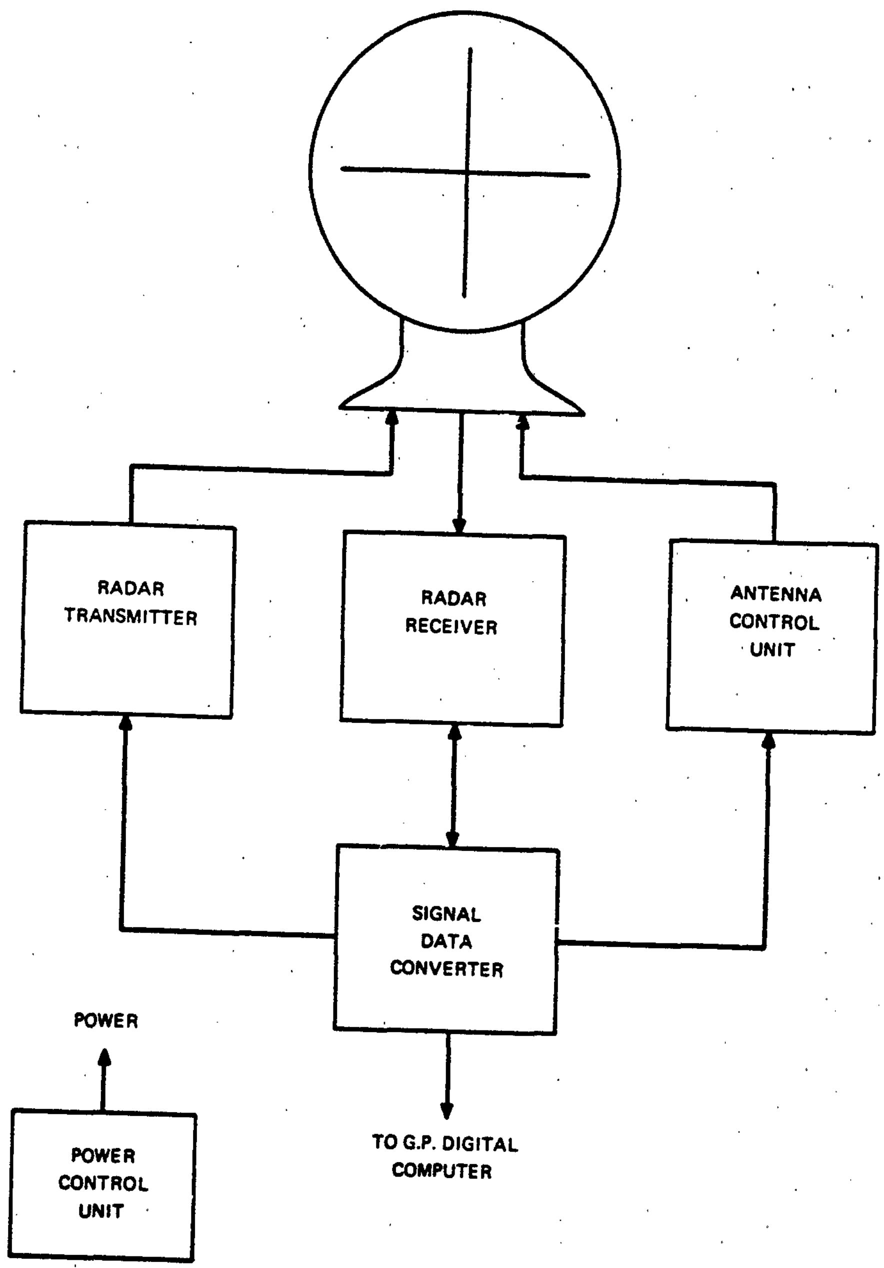

Fig. 34 (U) - AN/SPQ-60 block diagram (U)

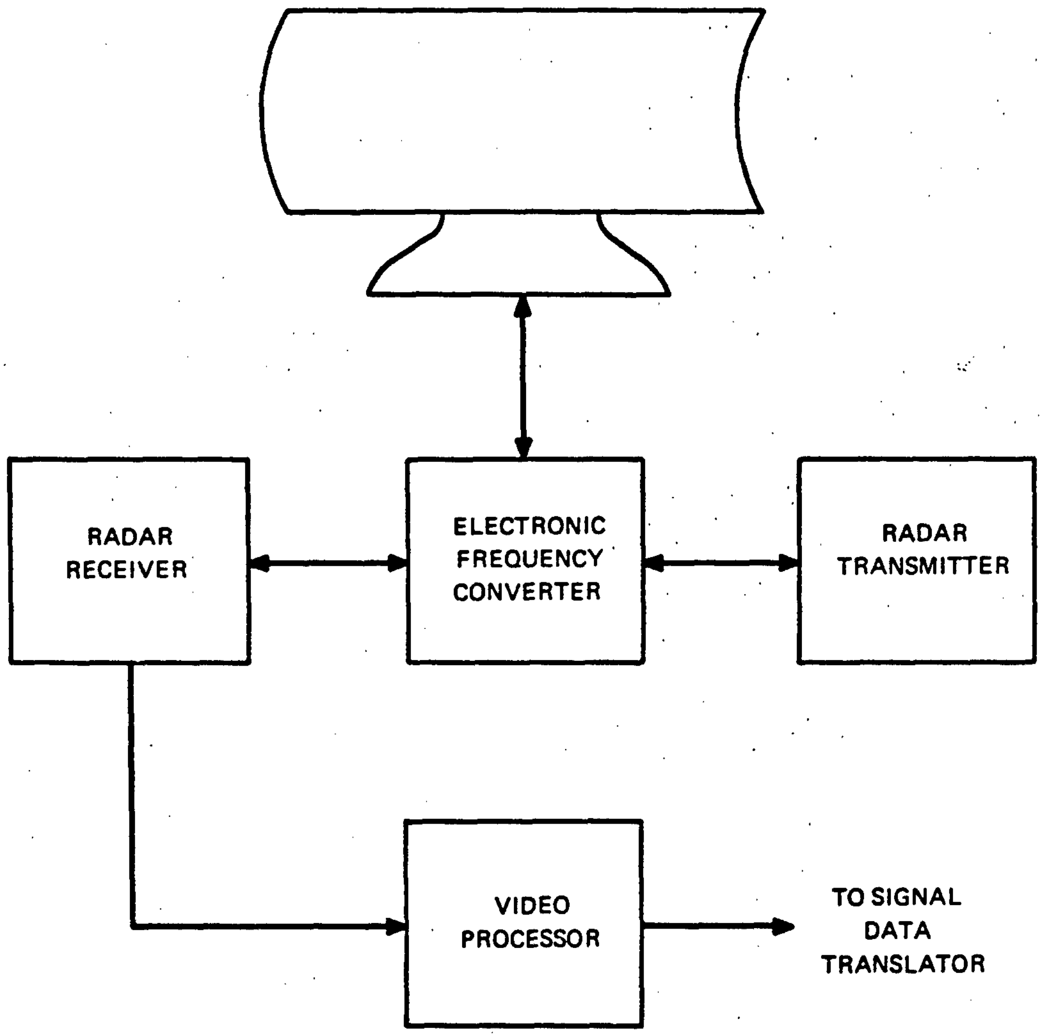

Fig. 35 (U) - SPQ-9A radar block diagram (U)

(C) TABLE XXV

AN/SPG-60 Radar Parameters (U)

FUNCTION: fire control

FREQUENCY RANGE (MHz): 8500-8709

PEAK POWER (kW): 5

AVERAGE POWER (W): 1000

TRANSMIT PULSE LENGTH (μs): 0.25, 1, 6

COMPRESSED PULSE LENGTH (μs):

PULSE RATE (pps): 25,000 to 35,000

TRANSMITTER TYPE: klystron

OUTPUT TUBE: VA 956A

EMISSION BANDWIDTH (kHz): 9000

WAVEFORM: rectangular pulse

IF FREQUENCY (MHz): 60

IF BANDWIDTH (kHz): .01522

SENSITIVITY (dBm): -99

NOISE FIGURE (dB): 14.5

OUTPUT DATA: analog, digital

SPECIAL SIGNAL PROCESSING: analog pulse doppler with 5 range gates(1)

ANTENNA TYPE: parabolic

ANTENNA SIZE: 2M diam (7')

ANTENNA GAIN (dB): 41

POLARIZATION: horizontal

BEAMWIDTH (deg): HORZ. 1.2
VERT. 1.2

ANGLE COVERAGE (deg): HORZ. N/A
VERT. -30 to +85

SCAN RATE: HORZ. N/A
VERT.

SECTOR SCAN RATE: N/A

ANTENNA WEIGHT (kg): 1823 (4015)

BEAM POSITIONING TECHNIQUES:
HORZ. 2-axis director
VERT.

LOBING TYPE: N/A

LOBING RATE (Hz): N/A

CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): N/A

ANGULAR ACCURACY: 0.3 milliradians for 15dB S/N

GROSS WEIGHT (kg): 4030 (8975 lbs.)

MANUFACTURER: Lockheed Electronics

NUMBER (mfg/oper): 46/4 as Jun 1976

NAVY COGNIZANT CODE: NAVSEA 65322

TECHNICAL MANUALS: OP 3646

NOMENCLATURE ASSIGNMENT DATE: 1971

NUMBER OF ELECTRONIC PARTS USED: 13,137(2)

MTBF (theo/oper): 325(2)/308(3)

MTTR: 7.7(3)

HIGH FAILURE RATE ITEMS: transmitter power resistors, servo amplifiers, encoder, klystron (4)

MAXIMUM VOLTAGE: 5kV

A.C. POWER CONSUMPTION: 30kVA

(1) And 8 doppler sub-filters in each gate, early-late gates plus a monopulse track gate.
(2) Lockheed Electronics estimate.
(3) Fleet Analysis Center Tech Memo 841-1471 of 16 Sep 1976.
(4) ECP's are being implemented for the power resistors and the encoder.
(5) May temp vise in transmitter cabinet is 22°C and 10°C elsewhere.

(C) TABLE XXVI

AN/SPQ-9A Radar Parameters (U)

FUNCTION: fire control search radar

FREQUENCY RANGE (MHz): 8500 - 9600

PEAK POWER (kW): 1.6

AVERAGE POWER (W): 75

TRANSMIT PULSE LENGTH (μs): 16

COMPRESSED PULSE LENGTH (μs): 0.112

PULSE RATE (pps): 3,000

TRANSMITTER TYPE: TWT

OUTPUT TUBE: Litton 44382

EMISSION BANDWIDTH (kHz): 20,000

WAVEFORM: rectangular pulse, linear FM

IF FREQUENCY (MHz): 1640, 193, 35

IF BANDWIDTH (kHz): 20,000

SENSITIVITY (dBm): -119

NOISE FIGURE (dB): 10.5

OUTPUT DATA: digital, and video

SPECIAL SIGNAL PROCESSING: non-linear optical pulse compression

ANTENNA TYPE: parabolic

ANTENNA SIZE: 2.1m x 0.8m (6.7'x 2.5')

ANTENNA GAIN (dB): 38

POLARIZATION: vertical

BEAMWIDTH (deg): HORZ. 1.52
VERT. 4 modified for CSC^2 to 2000' altitude

ANGLE COVERAGE (deg): HORZ. 360
VERT. -3 to +4

SCAN RATE: HORZ. 60 rpm
VERT. N/A

SECTOR SCAN RATE: N/A

ANTENNA WEIGHT (kg): 533 (1175 lbs.)

BEAM POSITIONING TECHNIQUES:
HORZ. N/A
VERT. N/A

LOBING TYPE: N/A

LOBING RATE (Hz): N/A

CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): 15

ANGULAR ACCURACY: N/A

GROSS WEIGHT (kg): 1,067 (2351 lbs.)

MANUFACTURER: Lockheed Electronics

NUMBER (mfg/oper): 46/4 as of Jun. 1976

NAVY COGNIZANT CODE: NAVSEA 65322

TECHNICAL MANUALS: OP 3855

NOMENCLATURE ASSIGNMENT DATE: 1970

NUMBER OF ELECTRONIC PARTS USED: 7969[1]

MTBF (theo/oper): 400/378[2]

MTTR: 3.9[2]

HIGH FAILURE RATE ITEMS: arc lamp[3] encoder, HV subassembly in the frequency converter, TWT[4]

MAXIMUM VOLTAGE: 12kV

A.C. POWER CONSUMPTION: 7kVA

(1) Lockheed Electronics.
(2) Fleet Analysis Center Tech Me.o 841-1471 of 16 Sep 1976.
(3) Failure to replace is an operational problem for a limited life item (arc lamp life = 1,000 hrs.).
(4) ECP's are being implemented for the shaft encoder and the TWT power amplifier.
(5) Max. temp rise under 10°C.

I. The GEOS-C Radar

(U) The GEOS-C radar is a precision satellite radar altimeter developed primarily to measure ocean surface topography and sea state. Although it is a non-military system, it is included in this section to serve as a reference system.

(U) The GEOS-C was designed, developed, manufactured, tested, and qualified by the General Electric Aerospace Electronic Systems Department, Utica, New York, under contract with the Applied Physics Laboratory, The Johns Hopkins University. The contract covered the period September 1972 to November 1974. Three systems were produced: an engineering model, a rototype model, and a flight model.

(U) It is a multimode radar system with two distinct operating modes: the Global Mode and the Intensive Mode. The key performance requirements are: in the Global Mode, to provide satellite-to-ocean surface height measurements to a precision of 50 centimeters and in the Intensive Mode, to provide satellite-to-ocean surface height measurements to a precision of 20 centimeters.

(U) The GEOS-C was launched 9 April 1975, and as of 15 November 1977 was in earth orbit, functional, and had not sustained any failures. The only failure experienced by the satellite system was the loss of a single diode in the command chain. Normal operation was restored through the use of an alternate command routine.

(U) The GEOS-C radar has two transmitters: the one for the Global Mode (a power conservation mode) uses a magnetron, L-5497; the other for the Intensive Mode uses a traveling wave tube, 852HA.

(U) The major subsystems of the GEOS-C are: (1) the Intensive Mode transmitter (power supplies, chirp generator, up-converter, 1-watt driver TWT, and a 2-W output TWT); (2) the Global Mode transmitter (power supply, modulator, and magnetron); (3) Microwave (RF switches, waveguide, and calibration attenuators); (4) the receiver front-end (down-converter and preamplifier); (5) the IF receiver (IF amplifiers, pulse compressor and detectors); (6) the signal processor; (7) the frequency synthesizer; (8) Mode control circuitry and (9) the calibrate-test circuitry.

(U) As of 15 November 1977, the accumulated operating time was approximately 60 hours in the Global Mode and 1,350 hours in the Intensive Mode. The total "operate" time was 1,685 hours of which 335 hours was warm-up and calibration time.

(U) Significant features of the GEOS-C which affect the reliability of the system are:

(a) The parts count is 6,000 parts. This is modest and is comparable to the parts count of the simpler 2-D naval radars.

(b) The power radiated, the power consumed, and the maximum voltages are all significantly less than those of naval radars. (Maximum average output power, Global Mode, is 0.78 watts and maximum system power consumption is 126 watts.)

(c) Parts and systems are subjected to a degree of rigorous and extensive "burn-in" and acceptance testing, that would be economically unfeasible for a production naval radar system.

(d) The system operates in a benign environment.

(e) The "in-orbit-accumulated operate time" as of 15 November 1977 was 1,685 hours. This is approximately 6% of the 22,000 hours that the satellite has been in orbit.

(U) Photographs of the system appear in Figs. 36 and 37. A block diagram is shown in Fig. 38 and pertinent operating parameters and performance data are listed in Tables XXVII and XXVIII for the Intensive and Global Modes, respectively.

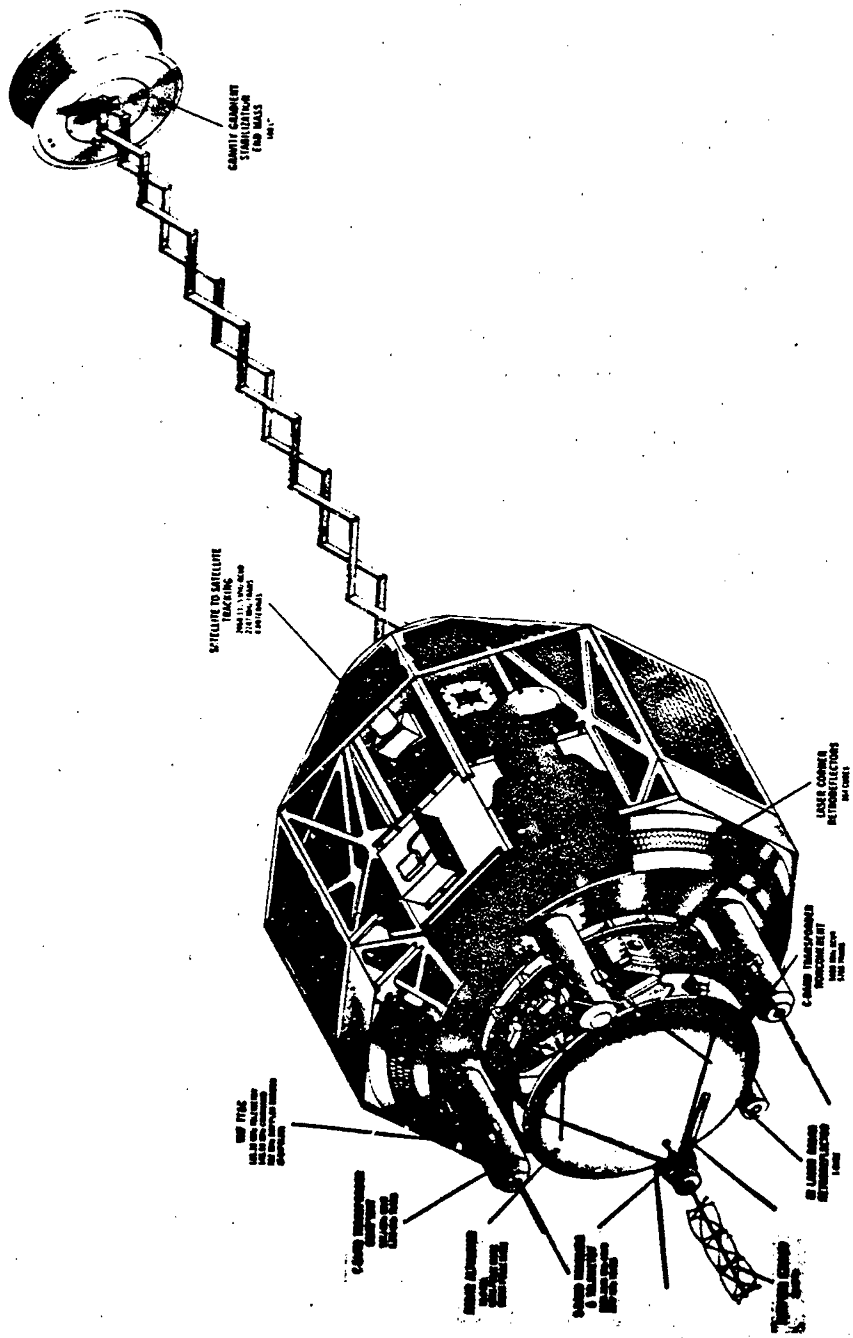

Fig. 36 (U) - GEOS-C satellite (U)

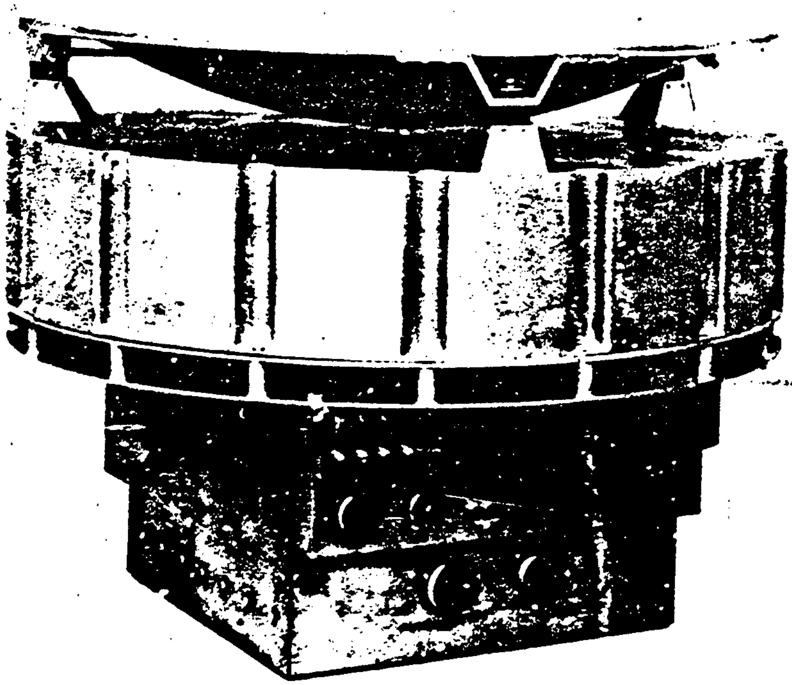

Fig. 37 (U) - GEOS-C altimeter (U)

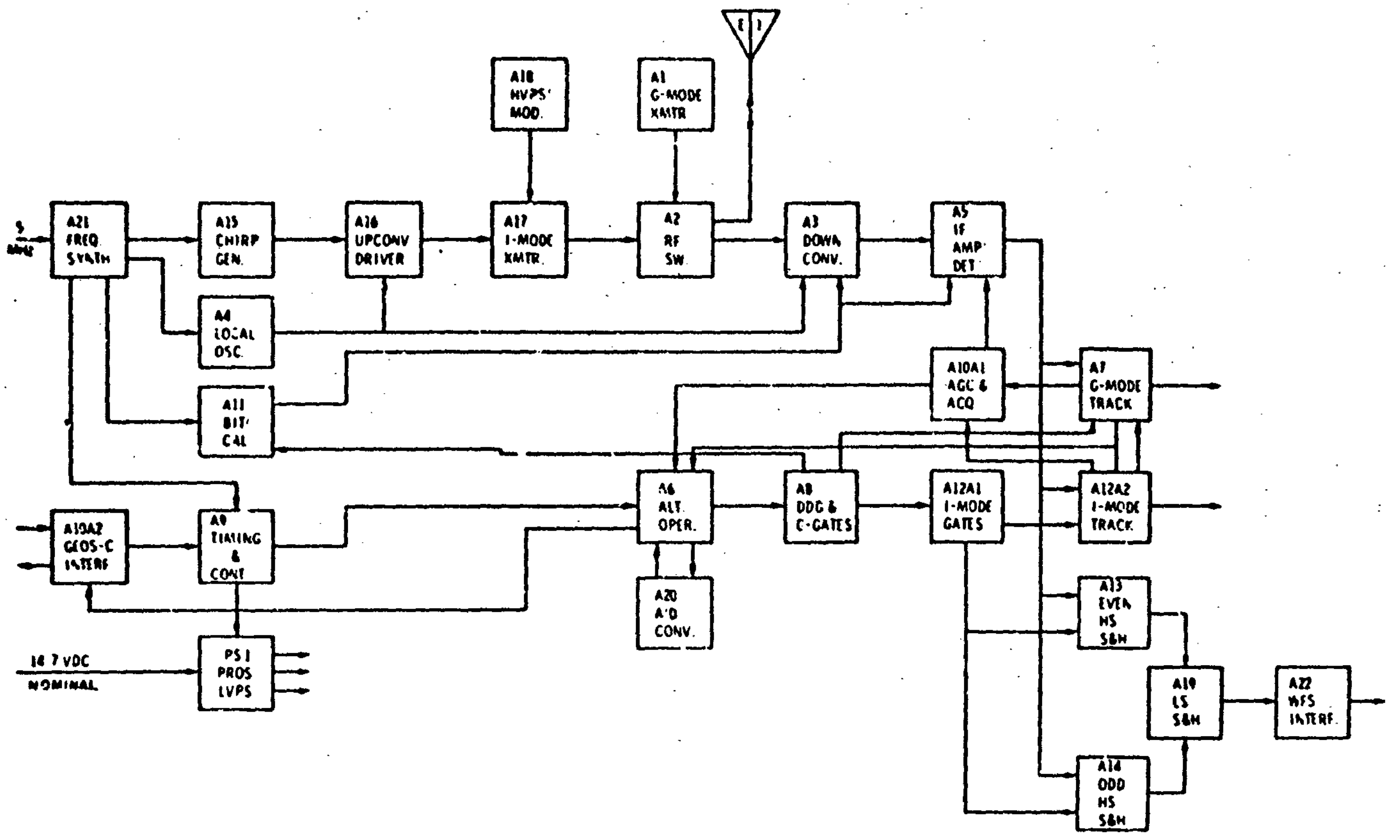

Fig. 38 (C) - GEOS-C radar altimeter block diagram (U)

(U) TABLE XXVII
GEOS-C Radar Parameters (U)
(Intensive Mode)

FUNCTION: earth satellite, radar altimeter (Intensive Mode - for high data rate and increased precision)

FREQUENCY RANGE (MHz): 13,900

PEAK POWER (kW): 2.5

AVERAGE POWER (W): 0.3

TRANSMIT PULSE LENGTH (μs): 1.25

COMPRESSED PULSE LENGTH (μs): 0.0125

PULSE RATE (pps): 100

TRANSMITTER TYPE: coherent, frequency synthesizer, power amplifier

OUTPUT TUBE: TWT, 852HA

EMISSION BANDWIDTH (kHz): 576,000

WAVEFORM: pulsed, linear FM

IF FREQUENCY (MHz): 300

IF BANDWIDTH (kHz): 100,000

SENSITIVITY (dBm): -82

NOISE FIGURE (dB): 7

OUTPUT DATA: digital - status and altitude, analog scientific and engineering pulse

SPECIAL SIGNAL PROCESSING: pulse compression

ANTENNA TYPE: parabolic reflector

ANTENNA SIZE: 0.6m diam (24")

ANTENNA GAIN (dB): 36

POLARIZATION: linear

BEAMWIDTH (deg): HORZ. 2.6
VERT. 2.6

ANGLE COVERAGE (deg): HORZ. 2.6
VERT. 2.6

SCAN RATE: HORZ. orbital velocity
VERT.

SECTOR SCAN RATE: N/A

ANTENNA WEIGHT (kg): 23 (5 lbs.)

BEAM POSITIONING TECHNIQUES:
HORZ. N/A
VERT. N/A

LOBING TYPE: N/A

LOBING RATE (Hz): N/A

CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): N/A

ANGULAR ACCURACY: N/A

GROSS WEIGHT (kg): 68 (150 lbs.)

MANUFACTURER: General Electric

NUMBER (mfg/oper): 3/1

NAVY COGNIZANT CODE: N/A(1)

TECHNICAL MANUALS: N/A

NOMENCLATURE ASSIGNMENT DATE: N/A

NUMBER OF ELECTRONIC PARTS USED: 6000

MTBF (theo/oper): 14,937/(2)

MTTR: N/A

HIGH FAILURE RATE ITEMS: N/A

MAXIMUM VOLTAGE: 12 kV

A.C. POWER CONSUMPTION: 126W

(1) NASA Project - NAS 6-2619 and APL 372165.
(2) No failure has been reported in Space use as of 15 Nov 1977 except for 1 diode in the command system which was by-passed by an alternate command routine. Total data transmission time in Intensive Mode was 1350 hours. Total "on" time was 1685 hours including 335 hours of warm-up and calibration. (Source - General Electric)

(U) TABLE XXVIII

GEOS-C Radar Parameters (U)
(Global Mode)

FUNCTION: earth satellite, radar altimeter (Global Mode - power conservation mode)

FREQUENCY RANGE (MHz): 13,900

PEAK POWER (kW): 2.5

AVERAGE POWER (W): 0.78

TRANSMIT PULSE LENGTH (μs): 1, 0.2

COMPRESSED PULSE LENGTH (μs): N/A

PULSE RATE (pps): 100(1)

TRANSMITTER TYPE: magnetron

OUTPUT TUBE: L 5497

EMISSION BANDWIDTH (kHz): est. 6000

WAVEFORM: pulsed carrier

IF FREQUENCY (MHz): 300

IF BANDWIDTH (kHz): 40,000

SENSITIVITY (dBm): -90

NOISE FIGURE (dB): 6.5

OUTPUT DATA: digital - status and altitude
analog - scientific and engineering

SPECIAL SIGNAL PROCESSING:

ANTENNA TYPE: parabolic reflector

ANTENNA SIZE: 0.6M diam (24")

ANTENNA GAIN (dB): 36

POLARIZATION: linear

BEAMWIDTH (deg): HORZ. 2.6
VERT. 2.6

ANGLE COVERAGE (deg): HORZ. 2.6
VERT. 2.6

SCAN RATE: HORZ. orbital velocity
VERT.

SECTOR SCAN RATE: N/A

ANTENNA WEIGHT (kg): 23 (5 lbs.)

BEAM POSITIONING TECHNIQUES:
HORZ. N/A
VERT. N/A

LOBING TYPE: N/A

LOBING RATE (Hz): N/A

CALCULATED DETECTION RANGE ON 1-m^2 TARGET (nmi): N/A

ANGULAR ACCURACY: N/A

GROSS WEIGHT (kg): 68 (150 lbs.)

MANUFACTURER: General Electric

NUMBER (mfg/oper): 3/1

NAVY COGNIZANT CODE: N/A(2)

TECHNICAL MANUALS: N/A

NOMENCLATURE ASSIGNMENT DATE: N/A

NUMBER OF ELECTRONIC PARTS USED: 6000

MTBF (theo/oper): 27,284/ (3)

MTTR: N/A

HIGH FAILURE RATE ITEMS: N/A

MAXIMUM VOLTAGE: 4kV

A.C. POWER CONSUMPTION: 71W

(1) PRF = 100pps for 1.0μs transmitted pulse and 100pps for pulse burst of 16 0.2μs pulses.
(2) NASA Project - NAS 6-2619 and APL 372165.
(3) No failure has been reported in Space use as of 15 Nov 1977 except for 1 diode in command system which was by-passed by an alternate command routine. Total data transmission time in Global Mode was 60 hours, including warm-up and calibration times.

III. SUMMARY

(C) This introduction to the magnitude of the Navy's radar reliability problem is summarized in the following two tables. In Table XXIX radar systems are ranked according to the parts count/complexity, and in Table XXX the radar systems are ranked according to system MTBF's.

(C) TABLE XXIX

Rank by Complexity

Radar	No. Parts	MTBF
AN/SPS-49	1,300 (1)	600
AN/SPS-10	2,106	180
AN/SPS-55	2,717	600
AN/SPN-43	4,323	77
GEOS-C	6,000	NONE (2)
AN/SPS-65(VI)	5,100	123
AN/APS-96	7,000	12.8
AN/SPQ-9A	7,969	378
AN/SPS-40B	10,000	195
AN/SPG-60	13,137	308
AN/FPN-59 (3)	18,700	365
AN/APS-120	19,000	17.5
TAS	19,569	365
AN/APS-125	24,243	22.6
AN/SPG-51D	31,000	90
AN/SPS-48	250,000	75

(1) Primarily a count of system modules rather than individual components
(2) Satellite Radar Altimiter, no failures in earth orbit
(3) A Navy version of the FAA's ASR-8 Radar

(C) TABLE XXX

Rank by MTBF (U)

Radar	No. Parts	MTBF
AN/APS-96	7,000	12.8
AN/APS-120	19,000	17.5
AN/APS-125	24,243	22.6
AN/SPS-48	250,000	75
AN/SPN-43	4,323	77
AN/SPG-51D	31,000	90
AN/SPS-65(VI)	5,100	123
AN/SPS-10	2,100	180
AN/SPS-40B	10,000	195
AN/SPG-60	13,137	308
AN/FPN-59	18,700	365
TAS	19,569	365
AN/SPQ-9A	7,569	378
AN/SPS-49	1,300	600
AN/SPS-55	2,717	600
GEOS-C	6,000	None

(C) In Table XXXI the Referenced radars are ranked according to the "systems average parts failure rate," with sub-divisions to distinguish between shipboard, airborne and the miscellaneous systems.

(C) TABLE XXXI

SYSTEM	System Failure Rate, X 10^3 hours	Average Systems Parts Failure Rate, X 10^6 hours
AN/SPS-48	13.3	0.05
TAS	2.7	0.14
AN/SPG-60	3.2	0.25
AN/SPQ-9A	2.6	0.33
AN/SPS-51D	11.1	0.36
AN/SPS-40B	5.1	0.51
AN/SPS-55	1.7	0.61
AN/SPS-49	1.7	1.3
AN/SPS-65 (VI)	8.1	1.6
AN/SPS-10	5.6	2.6
AN/SPN-43	13.0	3.0
AIRBORNE SYSTEMS		
AN/APS-125	44.2	1.8
AN/APS-120	57.1	3.0
AN/APS-96	78.1	11.2
MISCELLANEOUS		
GEOS-C	0.06 (1)	0.09
AN/FPN-59	2.7	0.15

(1) This is obtained from the theoretical design as the failure rate of the exponential system with the same reliability for the same mission time. In actual operation, there were no failures and therefore, the sample failure rate was 0.

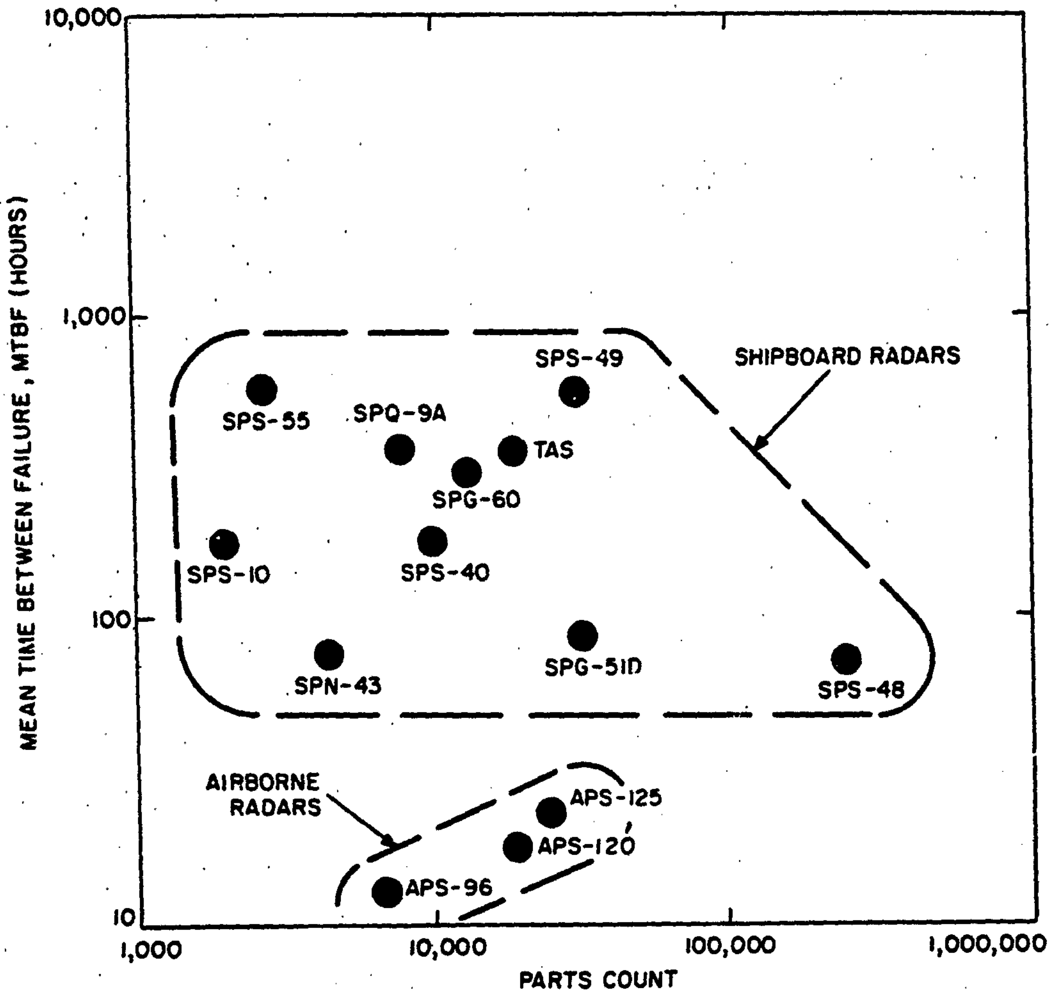

Fig. 39 (U) - MTBF vs parts count for selected naval radars (U)

(U) The graphical plot in Fig. 39 is based on the data presented in Tables IV and V. The grouping of the AEW Radar Sub-set of data in Fig. 39 is indicative of severity of the airborne enviornment vs. the environment for shipboard system. The grouping of the shipboard sub-set of data suggests a "rule of thumb" such as the following: "The probable upper limit of shipboard radar system MTBF, based on 1970 technology, for a "single thread" system is on the order of 1,000 hours."

(U) In the preceding tables it may be seen that the magnitude of the Nâvy's radar reliability problem is considerable. The problem is compounded by a variety of factors, such as multiple mission requirements, and stress levels that are infrequently experienced by commercial and non-military electronic systems.

(U) From Fig.39, it appears that an "average" current Navy radar would exhibit an MTBF of about 200 hours. This means there would be a 10% chance that the average radar would fail within 20 hours of "turn-on" and a 25% chance that it would fail within 58 hours. Conceivably, ... the logistic delay and repair times were sufficiently small, the operational availability might still be acceptable.

(C) This is not necessarily true. For example, according to FLTAC, the MTBF (under continuous operation) for the SPS-40 series radars was 195 hours in 1976. The operational availability, A_o, was only 0.64, since the mean down time was 110 hours.

(U) An increase in availability to an interim goal of 0.75 could be achieved with the same hardware if the mean down time were decreased to 65 hours; a goal of 0.95 could be reached with a system down time of 10 hours. These improvements imply major changes in training of maintenance personnel and logistics support programs.

(U) An alternative approach is to improve the hardware. Thus, assuming the same down time of 110 hours, a 0.75 availability is achievable with an MTBF of 330 hours and 0.95 with an MTBF of 2,090 hours.

(U) A major redesign would be necessary to reach either of these figures. Moreover, there would still remain the problems of personnel performance and logistics support a maintenance free approach, if feasible, would by-pass the maintenance problems.

ACKNOWLEDGMENT

(U) The authors wish to thank Mr. D. C. Rohlfs and Dr. W. K. Saunders for their editorial assistance and generous aid in collecting the data.

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APPENDIX A

List of Acronyms

ACQ: acquisition system

AEW: airborne early warning

AFC: automatic frequency control

AGC: automatic gain control

AMTI: airborne moving target indicator

B & W: black and white

BITE: built in test equipment

CFAR: constant false alarm rate

CIC: combat information center

COC: control officer console

COHO: coherent oscillator

COMO: coherent master oscillator

COSRO: comical scan rotator

CSLC: coherent sidelobe canceller

CWI: continuous wave illuminator

DEW: distant early warning

DIP: dual in-line package

ECP: engineering change proposal

ER: established reliability

FAA: Federal Aviation Administration

FLTAC: Fleet Analysis Center

FTC: fast time constant

GFE: government furnished equipment

GP: general purpose

HSS & H: high speed sample and hold

HVPS: high voltage power supply

IAGC: instantaneous automatic gain control

IR: infra-red

IRM: image rejection mixer

LFDM: low flying detection mode

LINLOG: linear-logarithmic

LO: local oscillator

LRM: least replaceable module

LSS & H: low speed sample and hold

LVPS: low voltage power supply

MDT: mean down time

MFHBF: mean flight hours between failure

MG: motor generator

MLT: mean logistics time

MMH/MA: mean man hours per/maintenance action

MTBF: mean time between failure

MTI: moving target indicator

MTTR: mean time to repair

NA: not applicable

N/A: not applicable

NAFI: Naval Avionics Facility Indianapolis

NASA: National Aeronautics and Space Administration

NAVELEX: Naval Electronics Systems Command Headquarters

NESTEF: Naval Electronics Test and Evaluation Facility

NOSC: Naval Ocean Systems Center

NRL: Naval Research Laboratory

NSWES: Naval Ship Weapon Systems Engineering Station

NTDS: Naval Tactical Data System

Op. Eval: Operational Evaluation

RAM: reliability, availability and maintainability

RISE: Readiness Improvement Status Evaluation

ROS: remote optical sight

SEM: standard electronic module

STALO: stabilized local oscillator

STAMO: stabilized master oscillator

STC: sensitivity time control

SHM: superheterodyne mixer

Tech.Eval: Technical Evaluation

TWT: traveling wave tube

VSI: video sweep integrator

WFS: wave form sample

2-D Radar: two dimensional radar

3-D Radar: three dimensional radar

3-M: Maintenance and Material Management

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UNITED STATES GOVERNMENT

memorandum

DATE: February 6, 1996

REPLY TO ATTN OF: Code 5304

SUBJECT: Revised Distribution Statement for NRL Memo Report 3867

AD-C016 190

TO: Code 1221 (Charles Rogers) 2-6-96

1. NRL Memorandum Report 3867 "Reliability of Naval Radar Systems," by D. F. Hemenway and B. N. Navid was declassified December 31, 1984.

2. As the principal author of the subject NRL Memorandum Report, I see no reason why the previous limitation on distribution should any longer apply. I recommend that the distribution statement be changed to "Approved for public release: distribution is unlimited."

D. F. Hemenway

D. F. Hemenway, Code 5304

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