Design Of A Super High Frequency (SHF) Extremely High Frequency (EHF) Satellite Communications (SATCOM) Terminal (SEST) For New Construction Naval Surface Ships Using the Systems Engineering Process

by

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(ABSTRACT)

Alternative means of satisfying the high bandwidth and protected communications requirements for New Construction Naval Surface Ships in the midst of conflicting reduced radar cross section (RCS) requirements were investigated using the systems engineering process. Various antenna, ranging from parabolic dish antennas to Luneberg lens antennas to phased array antennas, and feed and amplifier combinations were considered to provide a dual-band Super High Frequency (SHF) and Extremely High Frequency (EHF) Satellite Communications (SATCOM) Terminal (SEST).

Through the design of this hypothetical system, the various stages of the systems engineering process are considered-- definition of need, conceptual design, preliminary system design, production and installation, and utilization and support. Sample tasks are performed at each stage in the process (e.g., a system performance specification is prepared in the advanced system planning stage).

The set of technical solutions that remained in the preliminary design phase are compared based on life cycle costs. Two approaches are recommended -- one assuming lowest life cycle cost has highest priority and one assuming that the ability to communicate simultaneously on SHF and EHF has highest priority.

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1. Problem

New construction surface ship, such as the Surface Combatant 21 (SC 21), require large amounts of high bandwidth, real-time, two-way, over-the-horizon communications from both within and outside of the battlegroup. Such communications are used for command and control, force direction, surveillance relay, and targeting/retargeting of ordinances. High frequency (HF) and troposcatter communications are candidates to provide these communications, however, protection, reliability, bandwidth, and bit-error-rate limitations, to name a few, prevent these from being viable candidates. The best means of satisfying this over-the-horizon communications requirement is SATCOM. Commercial SATCOM is one alternative to providing these communications, however, technical problems such interference with radars and antenna size as well as policy problems such as landing rights and foreign nation access prohibit the complete effectiveness of commercial SATCOM. Therefore, Military SATCOM must provide these communications requirements. Existing Military SATCOM systems have not been procured for these new Naval surface ships. Furthermore, existing military SATCOM systems utilize outdated technology and do not address the radar cross section (RCS) requirements and limited topside space, weight, and moment of the new construction platforms. Therefore, a new Military SATCOM system must be designed which satisfies the new construction combatant's communications requirements in a single system.

2. Overview -- The Systems Engineering Process

This paper describes the application of the systems engineering process to design a flexible military satellite communications (SATCOM) terminal for new construction destroyers and other new construction naval surface ship. The terminal must operate in both the military Super High Frequency (SHF) and Extremely High Frequency (EHF) bands. This SHF EHF SATCOM Terminal (SEST) is required to begin installation on the aforementioned new construction ships by the year 2000.

The remainder of this section provides an overview of the stages of the systems engineering process -- definition of need, conceptual design, preliminary system design, production and installation, and utilization and support -- as an outline of the remaining analysis and tasks to be accomplished.

The sections that follow step through the stages of the systems engineering process as they specifically apply to the SEST.

2.1 System Flow Diagram

Figure 2.1 provides a graphical representation of the life cycle of the SEST system. This life cycle begins with defining the need for the new SEST system for new construction Naval ships. From there, the conceptual design of the system is performed. This phase includes such tasks as feasibility studies, needs anises, refinement of operational requirements and the maintainability concept. After conceptual design, the preliminary design phase will begin. This phase includes such tasks as allocating functional requirements down to system components and subcomponents, performing design alternative trade-offs and optimization, and development of detailed systems specifications. The next phase in the SEST life cycle is detailed design and development during which design reviews are conducted, the hardware and software design is becoming very detailed, and planning for production and testing is performed. During production and installation, the next phase in the SEST life cycle, the SEST is assembled, tested, and integrated for operational use. After production, the utilization and support phase includes the obviously operational use, but also includes a system integration test to demonstrate the system meets its operational requirements. Finally, when the system no longer meets the communications requirements of the new construction ships, it will be phased out and disposed of to make way for a new system.

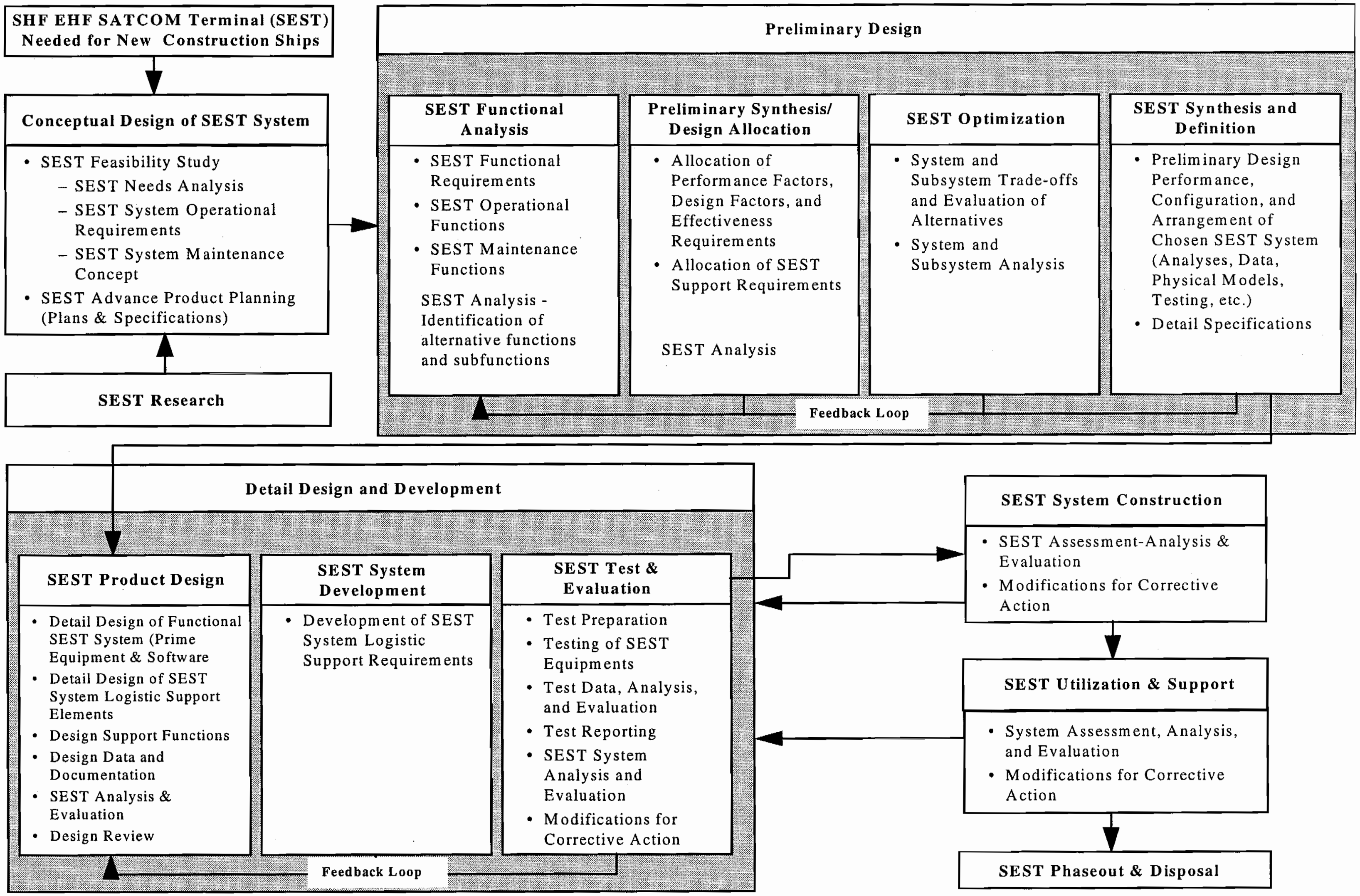

Figure 2.1- SEST and The Systems Engineering Process

2.2 System Management

Management is an important part of designing any system. The appropriate resources must be applied, through a structure, orderly approach and in a timely manner in order to deliver a cost effective system. With this in mind, a system organization or management structure should be developed. In addition, a realistic schedule highlighting critical milestones, such as operational need dates, must be prepared. Finally, in order to control costs from a life cycle perspective, a process and structure for preparing cost estimates should be developed.

2.2.1 System Organization

A critical part of designing and developing a system to meet a requirement is obtaining the required skills an disciplines and delegating roles and responsibilities to ensure that the system is designed, developed, constructed, and operated with the life cycle in mind. This includes such things as obtaining early design support to ensure the system will meet reliability and maintainability requirements and ensuring the design is logistically supportable. Figure 2.2 provides a graphical display of the organization chosen to design, develop, and produce the system requirements. The management approach selected for the SEST project is integrated product teams (IPTs). The concept of an IPT is two-fold. First, involving all participants early in the process where they can be effective before it is too late. For example, by the end of the system planning and conceptual design phase, approximately 60% of the projected life-cycle cost is committed even though actual project expenditures are minimal.[1] Therefore, it is important to include all of the appropriate disciplines early in the life cycle of the project to make the most informed, cost effective decisions. Second, IPTs delegate roles and responsibilities down to knowledgeable levels in an effort to instill ownership and obtain expediency instead of waiting for management to make late and potentially uninformed design decisions. The organization includes five focused IPTs -- research, engineering, design support, manufacturing, and test and evaluation -- as well as one higher order or executive IPT which is comprised of the overall manager, a cost estimating member, and the lead of the other five IPTs.

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[1] Blanchard, B.S., and Fabrycky, W.J., *Systems Engineering and Analysis*, Englewood Cliffs, NJ, Prentice Hall, 1990.

The systems engineering lead will provide high level focus to the engineering IPT and will interface with the design support IPT early in the system life cycle to design and develop a successful, cost effective, logistically supportable system.

2.2.2 System Schedule

In order to meet the Naval combatants requirements for a SEST, the schedule in Figure 2.3 must be met.

2.2.3 System Cost

In order to design and develop a successful, cost effective system, a cost breakdown structure and life cycle cost projections have been developed. The cost breakdown structure is shown in Figure 2.4 and is intended to highlight all major cost contributors to that accurate life cycle costs can be estimated and tracked. Initially, the life cycle cost projections are based on engineering estimates and the target development, unit production, and operations and maintenance objectives. As the system undergoes the system engineering process and trade-offs and optimizations occur, the life cycle cost projections will be updated. These projections are intended to give the developer and customer some insight into their future fiscal liabilities.

2.3 System Evaluation

System evaluation is an important part of a system throughout the life cycle of the system. Varying degrees of evaluation commensurate with the various stages of development will be accomplished throughout the program as shown in Figure 2.5.

2.3.1 Conceptual Design Phase Evaluation

During conceptual design, SEST evaluation will include market and product research to determine what systems are available and required to meet the system requirements as well as theoretical evaluation to determine derived requirements.

2.3.2 Preliminary Design Phase Evaluation

In preliminary design, cost-performance evaluations and trade-offs will be performed in an attempt to optimize the system design and increase the probability of meeting the system requirements in a cost effective fashion.

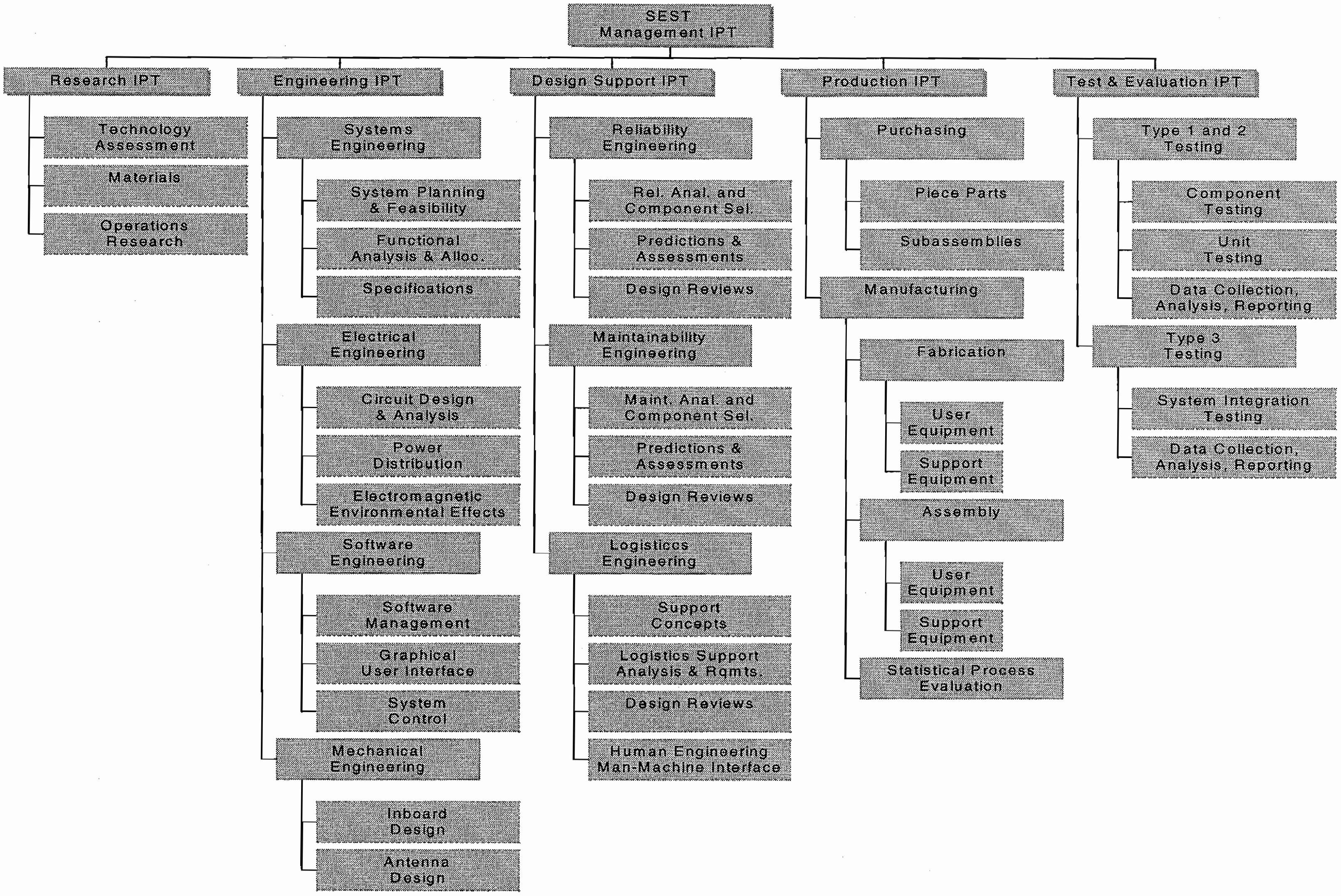


Figure 2.2 - System Organization

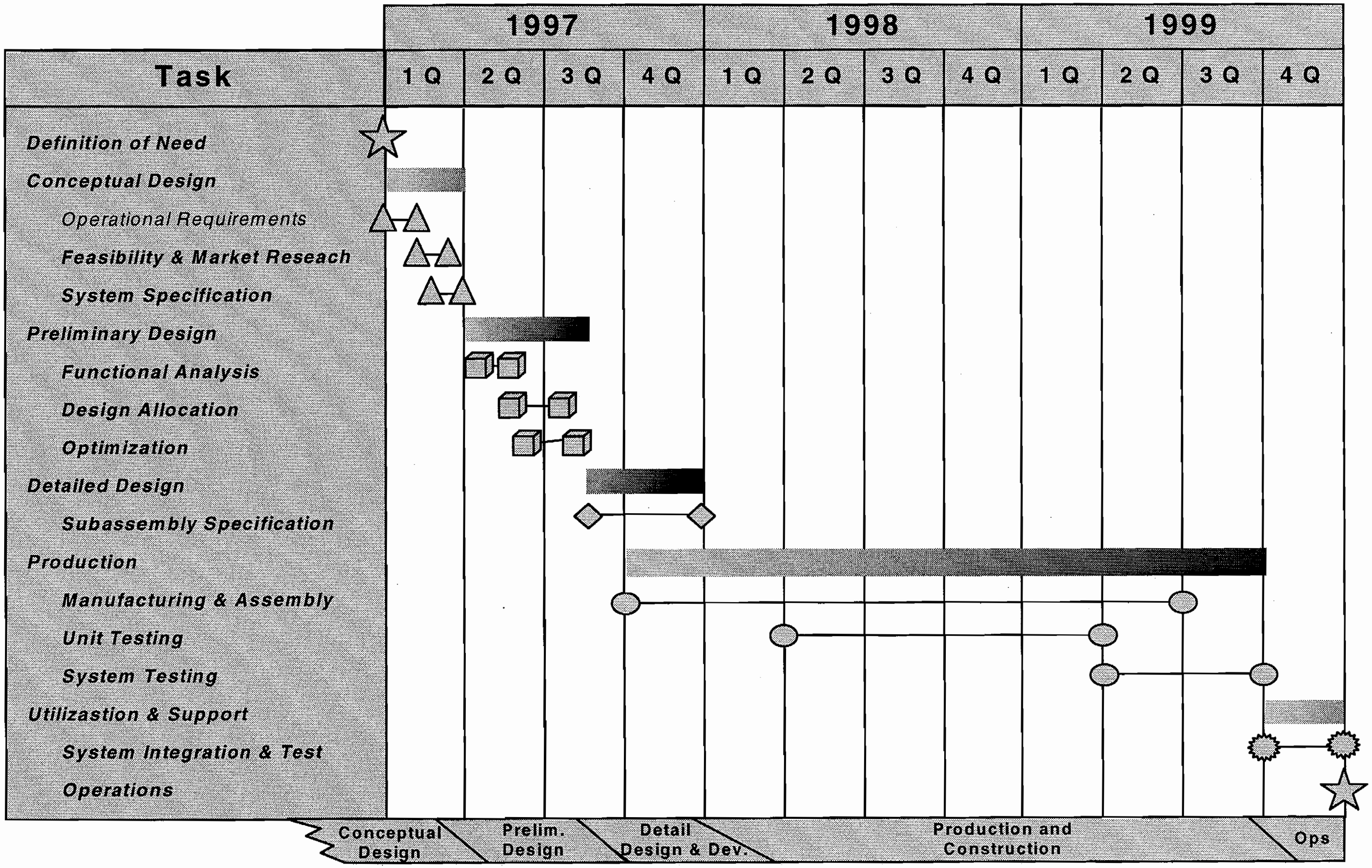


Figure 2.3 - SEST Schedule

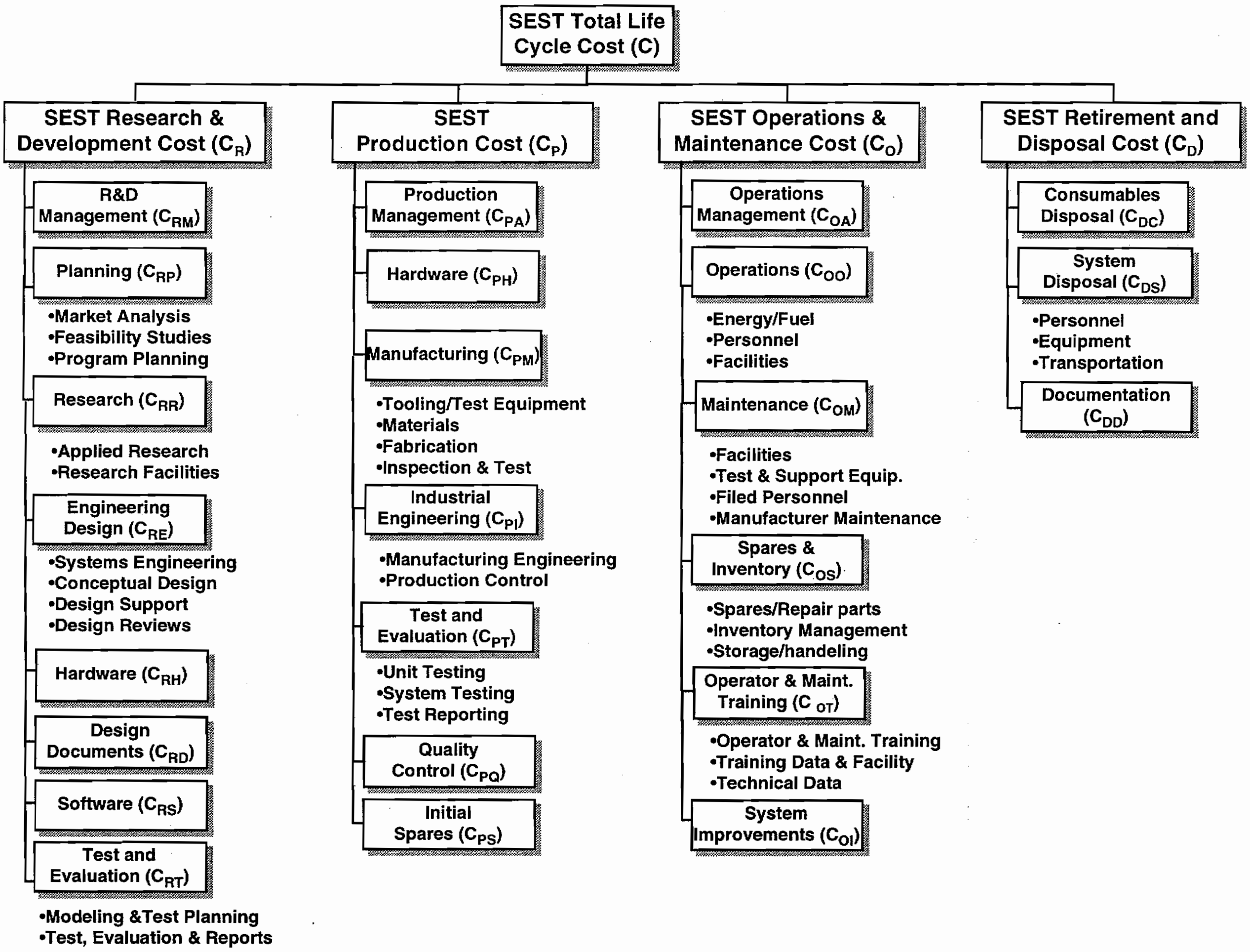


Figure 2.4 - SEST Cost Breakdown Structure

2.3.3 Detailed Design Phase Evaluation

During detailed design and development, models may again be used to help lower level system trade-offs. Particularly when the allocation of design requirements is being performed. For example, models may help determine the feasibility of meeting an MTBF in a subsystem in order to meet the overall system MTBF.

To help with some of the trade-offs during the detailed design phase, prototype subsystems may be fabricated and tested to determine if an approach warrants further consideration or if it can be ruled out for reasons of cost or performance.

2.3.4 Production Phase Evaluation

During the production phase, three types of evaluation will be performed: component testing; unit or subsystem testing; and system integration testing.

2.3.4.1 Component Testing

During fabrication and assembly, component testing will occur to ensure that the piece parts and subassemblies meet the respective requirements before it is integrated in a higher level of the system. This testing may include lot sampling or 100% verification depending on the history and criticality of the item.

2.3.4.2 Unit or Subsystem Testing

During assembly, unit testing will occur to ensure that the workmanship and assembly process was effective. This testing is conducted before system testing and helps improve the maturity of the system during system integration testing.

2.3.4.3 System Integration Phase Evaluation

System integration evaluation occurs at the finished system level and is conducted on the system in an environment that simulates the one the system is intended to operate in. This is the final level of verification before the system is put into its actual operational environment.

2.3.5 System Verification Process

The system verification process is comprised of three types of verification: analysis; inspection; and testing.

2.3.5.1 Analysis

Analysis is the review of design data, test data, or other data describing the design and/or function of the system, its subsystems, assemblies, and components. Analysis includes the review of engineering drawings, engineering reports, and test reports, including identification of National Standards and/or codes which an item meets. Analysis is the method of verification used when rigorous testing is impossible or impractical because of the required environment or other conditions needed to conduct a realistic test.

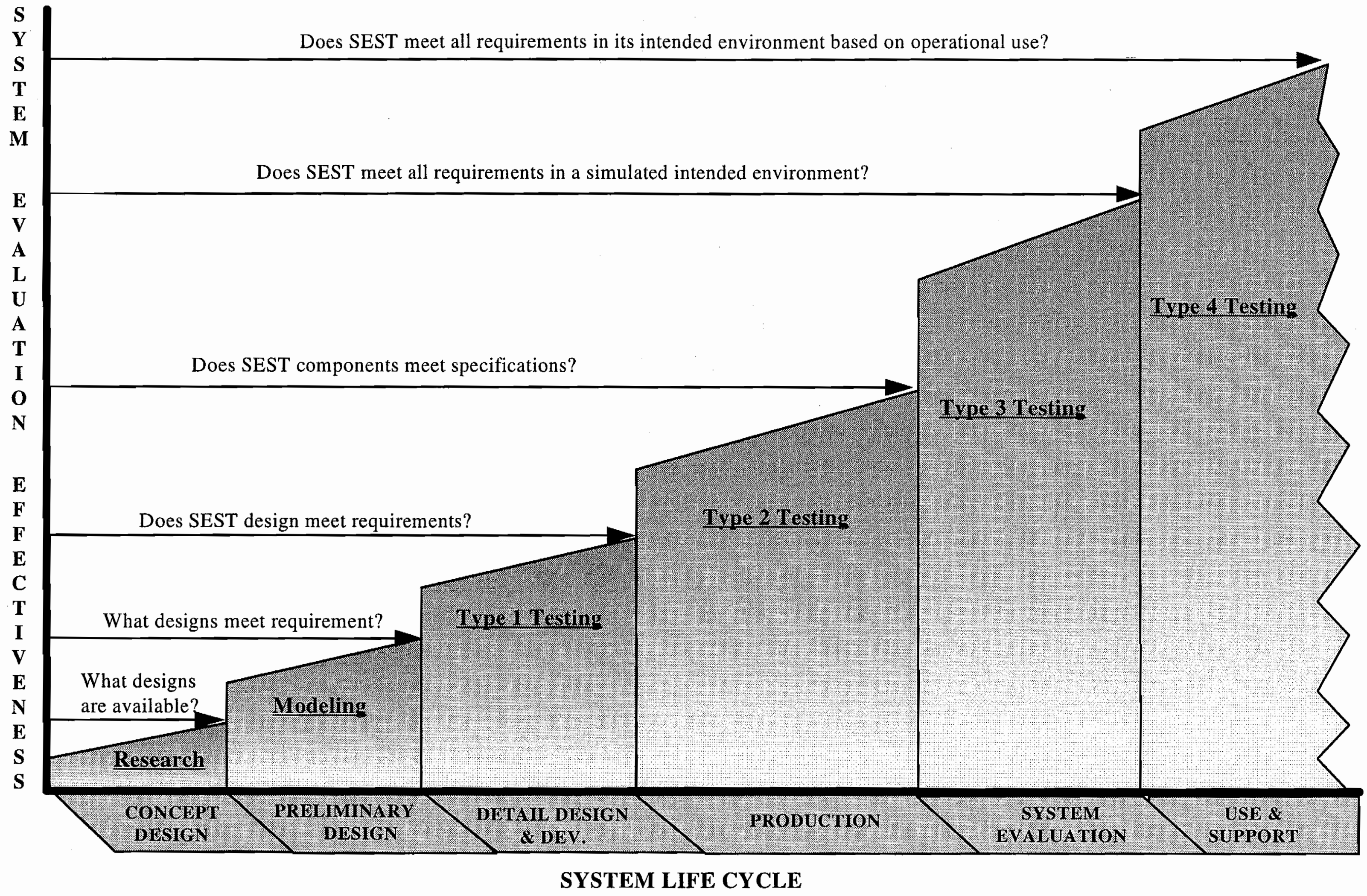


Figure 2.5 - SEST System Evaluation

2.3.5.2 Inspection

Inspection is the examination of specific physical elements of the system, its subsystems, assemblies, components and work underway. Inspection may include the taking of static measurements such as length, width, or height where simple measuring devices are used. In cases where physical inspection of specific assemblies or components is not possible because of manufacture or constructions, inspection is carried out by the review of reports of previously conducted inspections. Inspections may be carried out in combination with other verification methods, such as test, where visual observation as well as the taking of measurements is necessary to verify a particular requirement.

2.3.5.3 Test

Testing is the systematic evaluation of performance of the system, its subsystems, assemblies, and components. Performance parameters are measured using specific instrumentation and recording devices appropriate to that parameter or the employment of testing laboratories. All tests are conducted using previously developed procedures which are followed in a step-by-step fashion. Test data and results shall be formally recorded and evaluated for conformance to the requirements of the specifications an test procedures.

2.3.6 System Demonstration Process

The system demonstration process will verify that the SEST complies with its operational requirements. The system demonstration will involve operating the SEST in its intended operational environment by actual Navy personnel with the operational satellite systems.

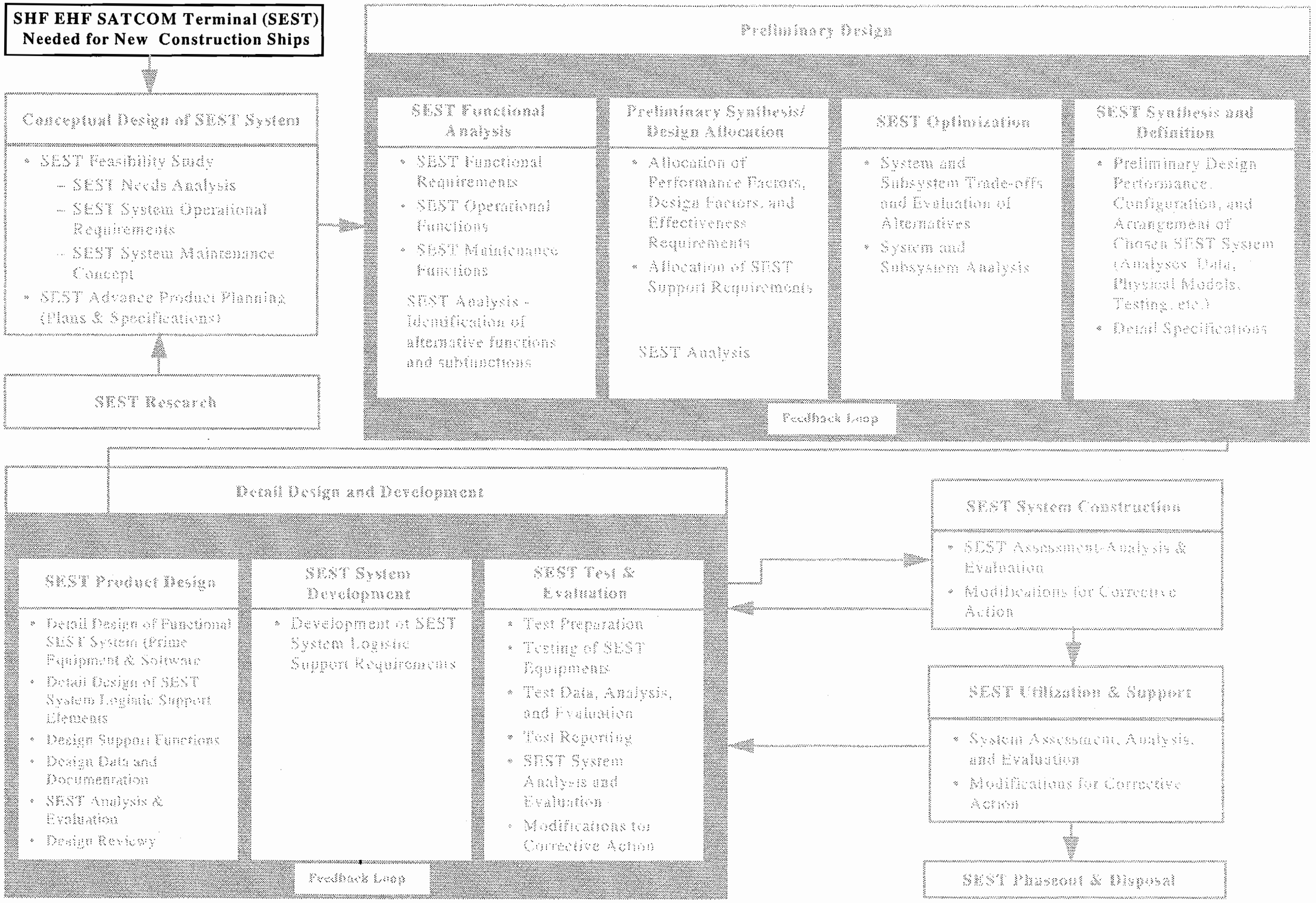
2.3.7 Other Demonstrations

Concurrent with the system test, other demonstrations such as a maintainability demonstration or a reliability growth test may be performed as the short period of testing may not be long enough to obtain a statistically significant sample size form an accurate maintainability evaluation.

2.3.8 Utilization and Support Phase Evaluation

During the use and support phase, the final level of system evaluation can be accomplished -- actual operations in the systems intended operational environment over time. During this phase, a Failure Reporting, Analysis and Corrective Action System (FRACAS) program should be implemented as well as true reliability, maintainability, and availability evaluations. Also, system upgrades, as required, may be incrementally evaluations throughout this phase.

3. Phase 0 -- Definition of Need



3.1 Need Statement

New construction surface ship, such as the Surface Combatant 21 (SC 21), require large amounts of high bandwidth, real-time, two-way, over-the-horizon communications from both within and outside of the battlegroup. Such communications are used for command and control, force direction, surveillance relay, and targeting/retargeting of ordinances. High frequency (HF) and troposcatter communications are candidates to provide these communications, however, protection, reliability, bandwidth, and bit-error-rate limitations, to name a few, prevent these from being viable candidates. The best means of satisfying this over-the-horizon communications requirement has been SATCOM. Commercial SATCOM is one alternative to providing these communications, however, technical problems such interference with radars and antenna size as well as policy problems such as landing rights and foreign nation access prohibit the complete effectiveness of commercial SATCOM. Therefore, Military SATCOM must provide these communications requirements.

Historically, Ultra High Frequency (UHF) SATCOM (225-400 MHz) has been the backbone of Naval SATCOM providing effective low to medium data rate communications on-the-move with the Fleet Satellite (FLTSAT) and UHF Follow-On (UFO) satellites. In addition, SHF SATCOM (7.9-8.4 GHz) has augmented Naval communications with medium to high data rate point-to-point communications via the Defense Satellite Communications System (DSCS) II and III satellites. Most recently, Extremely High Frequency (EHF) SATCOM (43.5-45.5 GHz on the uplink and 20.2 to 21.2 GHz on the downlink) has been added to the Naval arsenal of communications with protected (jam resistant, low probability of intercept, nuclear scintillation resistant, etc.) low and medium data rate communications via the Milstar satellite system and the EHF communications packages on the UFO satellites.

Each SATCOM 'band' provides its own unique strengths and weaknesses that are exploited by the Navy on Carriers, Flagships, and Amphibious Ships. However, on the smaller combatants such as the Destroyers, topside space limitations and cost hinder the installation of each type of Military SATCOM system. As the current backbone of Naval communications, a UHF system is undoubtedly required. Likewise, as the core wartime communications system, EHF SATCOM is required. As these terminals likely require dual antennas to counteract the blocking effects of a ship's superstructure and, thus, provide a full hemispherical view to a given satellite from the ship, there is little topside space remaining for an SHF SATCOM system.

Likewise, declining military budgets make it difficult to afford UHF, EHF, and SHF communications systems on every Navy platform. Finally, a new emphasis on reducing the radar cross-section of the ships makes it difficult to continue to add additional sets of large parabolic dish antennas for the SHF SATCOM terminal. And yet, the addition of an SHF SATCOM terminal would provide additional flexibility to the Naval warfighter.

Thus, new construction Destroyers and other planned new construction surface ship, such as the SC 21 require SATCOM system(s) that enable access to all of the MILSATCOM attributes and capabilities in the UHF, SHF, and EHF spectrums while simultaneously limiting the number of topside antennas and not adding significantly to the radar cross-section of the ships.

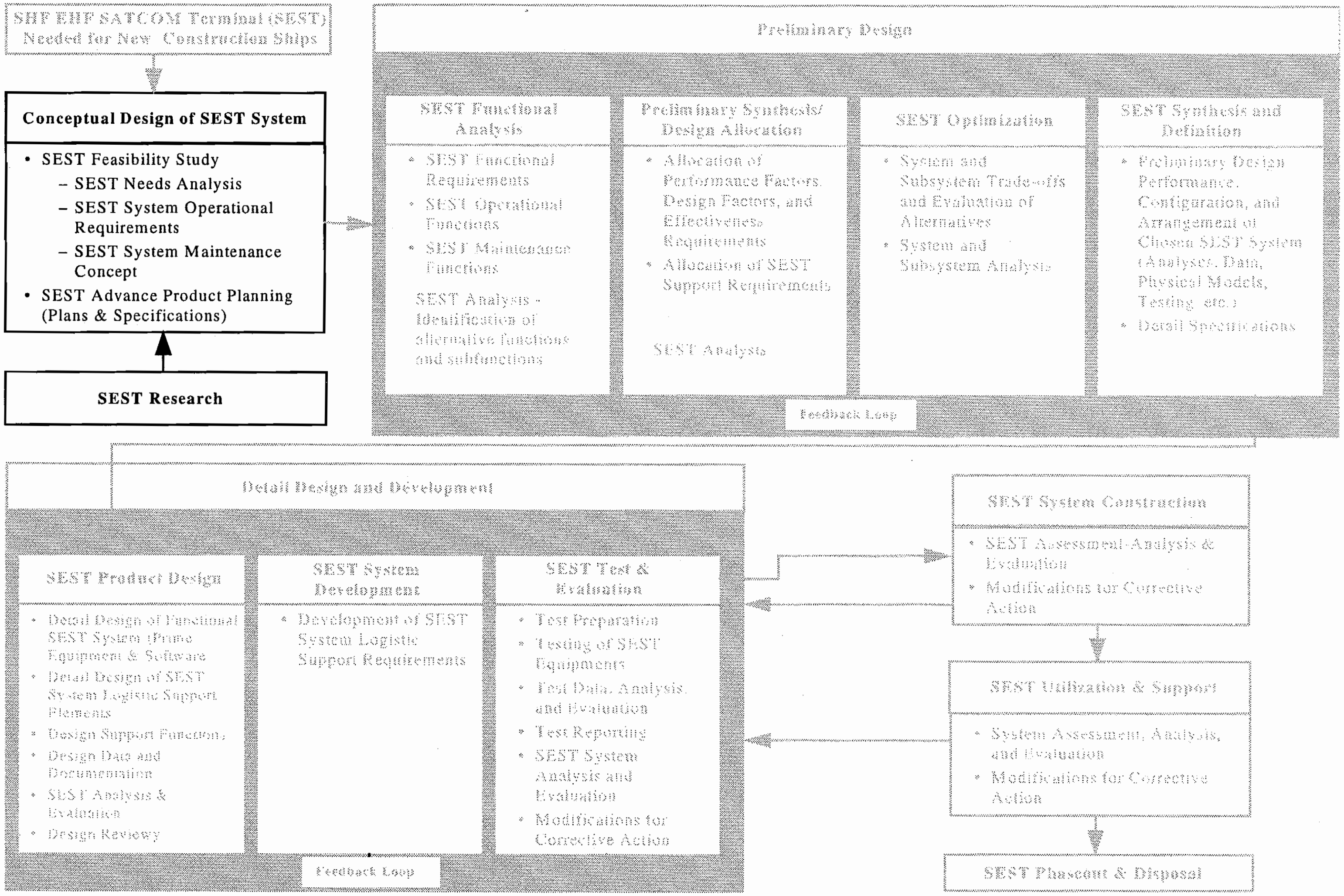
3.2 Deficiency of Existing Systems

While the Navy currently has SATCOM terminals that provide UHF, SHF, and EHF communications, several deficiencies exist with these systems. First, each system was designed independently of the other. Therefore, potential synergism, such as common electronics chassis or common antenna pedestals, have not been realized within either the inboard equipment or the outboard antennas. This contributes to the second deficiency which is size.

Because each of the existing systems has its own unique equipment and antenna, each places a burden of volume and weight on the platform on which they are being installed. On many of the smaller Naval combatants, topside space cannot be found to install two separate UHF, SHF, and EHF antenna given the radars, electronic warfare, and munitions that must occupy the same topside space and or compete for optimum locations to increase hemispherical coverage or reduce interference. In addition, these antennas add topside moments to platforms which are already moment critical. Therefore, these smaller ships are forced to make a decision as to which SATCOM services it will have. Since each band provides its own set of unique strengths, it is a difficult decision. In addition to the space and weight restrictions, these multiple sets of antenna add to the radar signature of a ship which is currently being emphasized on new ships such as the arsenal ship. While a panacea which eliminates all of these problems it unlikely, by eliminating even one set of parabolic dish antennas, the radar cross-section of the ship is reduced.

The third and final deficiency of existing systems is that, as they exist today, they utilize somewhat outdated technology and are primarily implemented in a closed architecture as opposed to an open architecture which allows future growth and flexibility to allow cost effective improvements and upgrades such as new modulation techniques and coding schemes.

4. Phase 1 -- Conceptual Design



4.1 System Requirements

4.1.1 System Operational Requirements

The SEST shall have the following system operational requirements:

4.1.1.1 Performance Requirements

It is desired that the SEST operate simultaneously in EHF and Military SHF SATCOM modes; however, this is not an essential requirement.

4.1.1.1.1 EHF

4.1.1.1.1.1 Simultaneous LDR and MDR

The SEST shall be capable of supporting simultaneous EHF low data rate (LDR) and medium data rate (MDR) communications. In addition, the system shall be designed with growth to minimize the effects of adding the advanced EHF waveform and multiple downlinks.

4.1.1.1.1.2 LDR

The SEST shall be capable of supporting 4 - 2400 bps LDR channels in the Milstar Spot Antennas A, B, and C as well as the Agile Beam antennas using the least robust uplink and downlink modulation modes.

4.1.1.1.1.3 MDR

The SEST shall be capable of supporting 1- 256 kbps MDR channel into either the Milstar Distributed User Coverage Antenna (DUCA) or Narrow Spot Beam (NSB) antennas using the DPSK 4+64 modulation mode on the uplink and the DPSK 6+128 modulation mode on the downlink.

4.1.1.1.1.4 Data Quality

The SEST shall have an EHF bit error rate of 10^{-5}.

4.1.1.1.2 SHF

On a DSCS III multibeam receive and transmit antenna to a 40 foot hub station, the SEST shall provide a minimum of 128 kbps in a full duplex configuration using no more that 2W of transponder power with a bit error rate of 10^{-5}.

4.1.1.2 Physical Requirements

4.1.1.2.1 Shock and Vibration

The SEST shall be shock and vibration hardened in accordance with MIL-S-901, Grade A, Type A, Class 1.

4.1.1.2.2 Radar Cross Section

The SEST shall contribute minimally to the radar cross-section (RCS) of the platform on which it is installed. In order to reduce the RCS of the SEST, the antennas and any corresponding radome shall be no larger than 56" in diameter.

4.1.1.2.3 Weight

The inboard equipment of the SEST shall not weigh more than 600 lbs. The antennas of the SEST shall not weigh more than 1000 lbs including radome.

4.1.1.2.4 Size

The inboard equipment of the SEST shall fit within one standard 19" rack. The antennas and any required radome of the SEST shall be less than or equal to 54" in diameter.

4.1.1.3 Suitability Requirements

4.1.1.3.1 Operational Availability

The system operational availability (A_O) shall be ≥ 0.94.

4.1.1.3.2 Maintainability

The system mean time to repair MTTR shall be $\leq$ 2 hours to isolate, repair and test not including baseband devices and platform interfaces.

4.1.1.3.3 Reliability

The SEST system mean time between failure (MTBF) is calculated using the following equation assuming a mean logistics down time (MLDT) of 78 hours:

$$A_o = \frac{MTBF}{MTBF+MTTR+MLDT}$$

The above equation is solved for MTBF using the required A_o yielding an MTBF of 1250 hours. From this figure, it can be seen that the system MTBF shall be $\geq$ 1250 hours not including baseband devices and platform interfaces.

4.1.1.4 Cost Requirements

As a goal, the system cost shall be less than $1 Million. In addition, the system shall be designed to minimize life cycle costs.

4.1.2 System Maintenance Concept

4.1.2.1 Maintenance Planning

4.1.2.1.1 Organizational Level (O-level)

Corrective maintenance will be performed on the inboard and outboard equipment group as a line replaceable unit (LRU) remove and replace function.

4.1.2.1.2 Intermediate Level (I-level)

There is no I-level repair planned for the SEST system.

4.1.2.1.3 Depot Level (D-level)

The depot will be responsible for repair of SEST LRUs including pierce part replacement.

4.1.2.1.4 Support Equipment

Removing and replacing the antennas may require special handling equipment. Likewise, maintenance may require special electronic test equipment (SPETE). For O-level maintenance, the SEST will incorporate provisions to isolate system and LRU malfunctions. Built-in-test (BIT) and BIT equipment (BITE) will be provided to identify inboard equipment and outboard equipment malfunctions.

4.2 Preliminary System Analysis

4.2.1 Link Availability

Link availability is an important part of a SATCOM system. In systems above about 2-5 GHz, link availability tends to be driven by weather, or rain, induced outages. To counter act the effects of weather induced outages, the system is designed with transmit and receive margin above the minimum required to communicate. However, it should be kept in mind that 100% availability is unachievable at microwave frequencies. In general, this can be done by increasing output power of an amplifier (or, conversely, by decreasing losses) or by increasing antenna gain and efficiency. However, neither of these techniques come without a cost. In the case of increasing amplifier output power, the required margin may drive the system design to a more costly type of amplifier. In the case of antennas, increasing the size of the antenna may not be practical given the installation requirements of the platform on which the antenna will be installed. In this particular design, the increased amplifier output power or the increased antenna size or efficiency may be offset by the inefficiencies of a multi-band antenna. Therefore, it is important to not over estimate the margin requirements in order to keep down system cost.

The approach to determine the required link margin is to specify a required link availability for the SHF and EHF systems and then estimate the required margin to provide that link availability. Figure 4.1[2] provides a world map which divides the world into climatological regions or regions characterized by distinct one-minute surface rain rate distributions.

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[2] N. E. Feldman, *Rain Attenuation Over Earth-Satellite Paths*, 1979

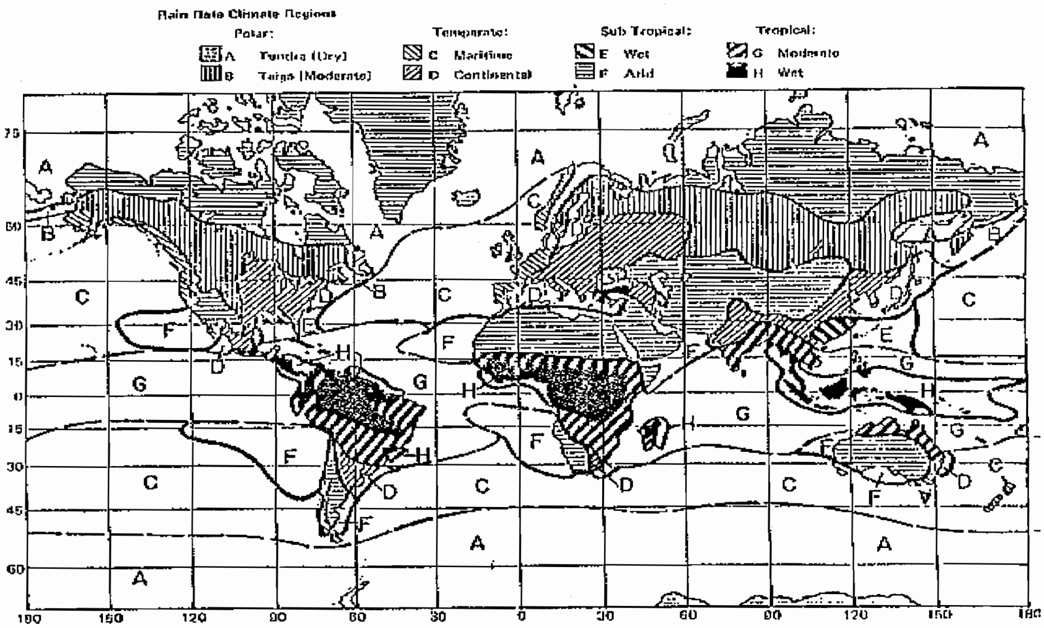
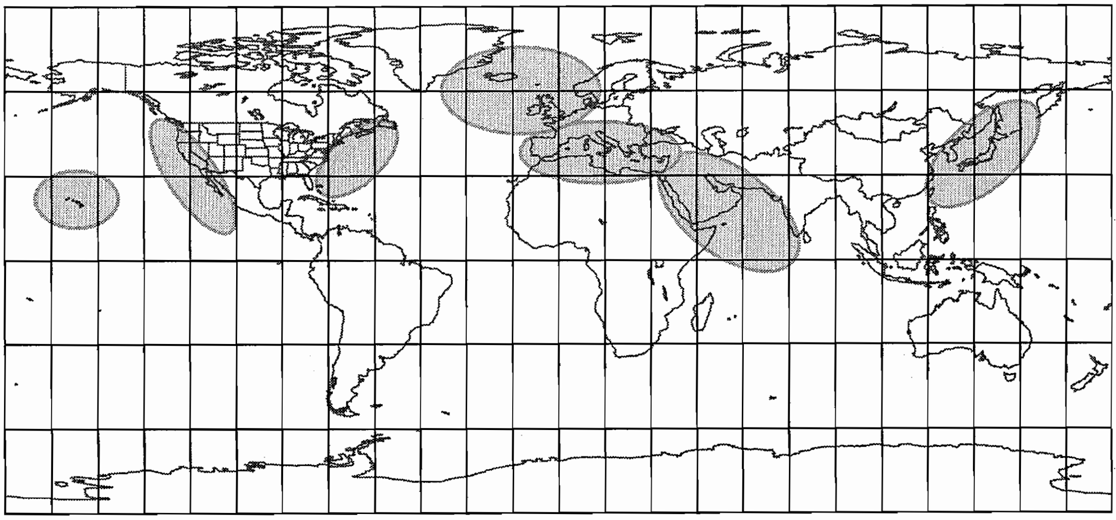


Figure 4.1 - World Climatological Regions

The significance of Figure 4.1 is to determine in which climatological regions the new construction surface combatants must operate. Based on nominal ship operating locations during deployments, it is assumed that the ships routinely operate in regions A through D and F as shown Figure 4.2. While transiting through regions E, G, and H is expected, extended operations in these regions are unlikely. Therefore, these regions will be neglected. This assumption is a cost versus link availability trade-off as these regions experience the greatest amounts of rainfall and would drive up the required link margin, and subsequently the cost, for a given availability.



AREAS OF CONCENTRATED, EXTENDED NAVAL OPERATIONS

Figure 4.2 - Planned SEST Deployment Locations

Table 4.1[3] provides the percent of the year that a given rain rate is exceeded for the different climatological regions. Given the aforementioned assumption regarding climatological regions, region D represents the worst case operating climatological region. Therefore, the rain rate for that region for the given availability will be used.

The fist step in calculating the required link availability is to calculate the attenuation caused by the given rain rate using the following equation

$$A = aR^{b}L \text{ dB}^{4} \qquad \text{(Equation 4.1)}$$

where the aR^b is the specific attenuation having units of dB/km -- with the coefficients being approximated by the following equations

$$a = 4.21 \times 10^{-5}(f)^{2.42}, \qquad 2.9 \leq f \leq 54 \text{ GHz}^{1} \qquad \text{(Equation 4.2)}$$

$$= 4.09 \times 10^{-2}(f)^{0.699}, \qquad 54 \leq f \leq 180 \text{ Ghz}$$

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[3] N. E. Feldman, *Rain Attenuation Over Earth-Satellite Paths*, 1979

[4] T. Pratt, C. W. Bostian, *Satellite Communications*, John Wiley & Sons, New York, 1986.

Table 4.1- Revised Rain Rate Distributions (mm/hr)

	Rain Rate Climate Regions (mm/hr)							
% of Year	A	B	C	D	E	F	G	H
0.001	28.0	54.0	80.0	102.0	164.0	66.0	129.0	251.0
0.002	24.0	39.0	62.0	86.0	144.0	51.0	109.0	220.0
0.005	19.0	26.0	41.0	64.0	117.0	34.0	85.0	178.0
0.01	15.4	19.0	28.0	48.0	98.0	23.0	67.0	147.0
0.02	12.0	14.0	19.0	35.0	77.0	14.0	51.0	115.0
0.05	8.0	9.5	11.0	22.0	52.0	8.0	33.0	77.0
0.1	5.8	6.8	7.2	15.0	35.0	5.5	22.0	51.0
0.2	4.1	4.8	4.8	9.8	21.0	3.8	14.0	30.0
0.5	2.5	3.0	2.8	5.2	8.6	2.4	7.0	13.0
1.0	1.7	2.1	1.9	3.1	4.0	1.7	4.0	6.4
2.0	1.1	1.4	1.3	1.8	2.0	1.2	2.2	3.0

$$b = 1.41(f)^{-0.0779}, \qquad 8.5 \leq f \leq 25 \text{ GHz}^{[2]} \qquad \text{(Equation 4.3)}$$

$$= 2.63(f)^{-0.272}, \qquad 25 \leq f \leq 164 \text{ GHz}$$

-- and L is the path length through the precipitation in km and is given by

$$L = \frac{FH^{[5]}}{\sin(El)} \qquad \text{(Equation 4.4)}$$

FH is the freezing height, or the point in the atmosphere where all precipitation is frozen and, therefore, does not have the same attenuating effect on the RF signal and El is the elevation angle of the satellite communications terminal to the satellite.

The relationship of L and FH are represented graphically in Figure 4.3 below.

The freezing height is a function of latitude, Λ, and is given by

$$FH = 4.8, \qquad |\Lambda| \leq 30^{\circ\,[6]} \qquad \text{(Equation 4.5)}$$

$$= 7.8 - 0.1|\Lambda|, \qquad |\Lambda| \geq 30^{\circ};$$

Further, for a given location on the earth, the freezing height is also a function of the season. In the summer, the freezing height is highest. In the winter, the freezing height is lowest. However, as conservative assumptions, the freezing height will always be assumed to be 4.8 km regardless of the season or the latitude.

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[5] T. Pratt, C. W. Bostian, *Satellite Communications*, John Wiley & Sons, New York, 1986.

[6] T. Pratt, C. W. Bostian, *Satellite Communications*, John Wiley & Sons, New York, 1986.

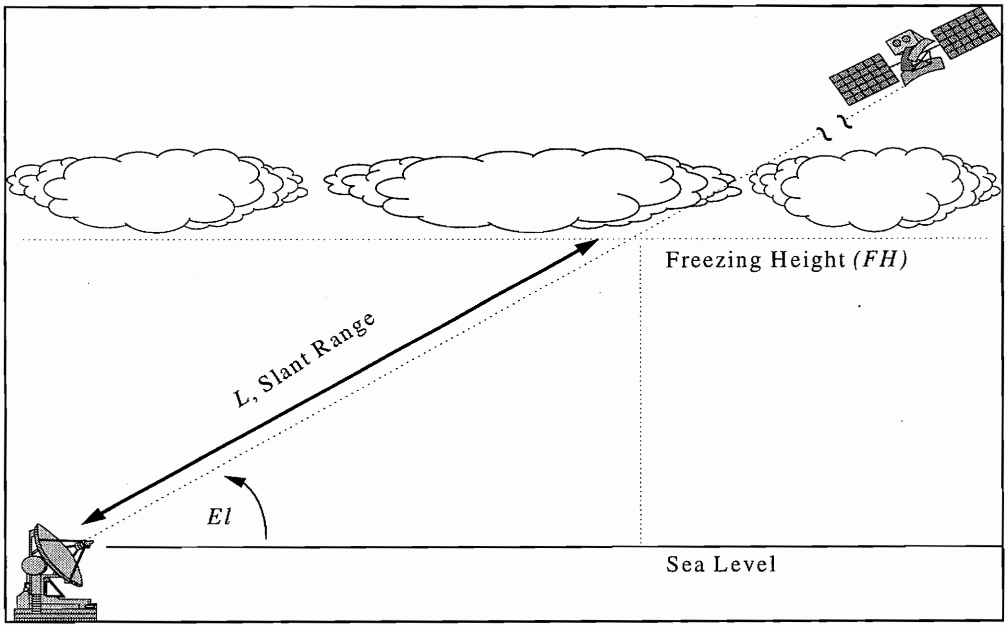
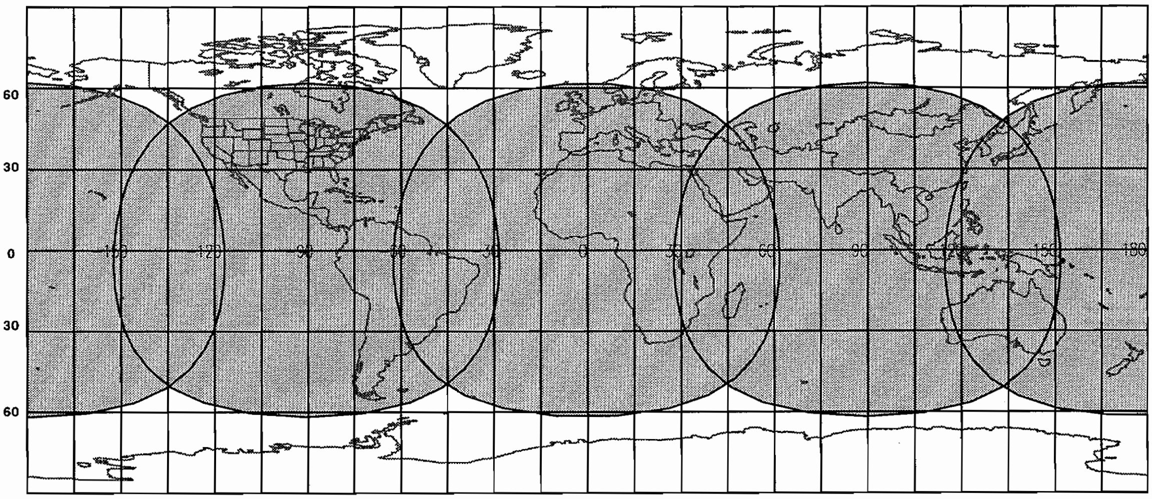


Figure 4.3 - Relationship Between Freezing Height, Elevation Angle, and Slant Range

The assumption regarding El is that it will always be ≥ 20°. The reason for this assumption is three-fold. The first is based on the satellite constellations. The Milstar constellation includes four geosynchronous satellites and the DSCS constellation includes five geosynchronous satellites as three geosynchronous satellites cannot provide sufficient coverage at the higher latitudes. Based on current and planned locations of these satellites, a ground terminal never requires an elevation angle to the satellite of less than 20° as shown in Figure 4.4 below for the four Milstar satellites (the minimum elevation angle improves with the five DSCS satellites).



20° ELEVATION ANGLE COVERAGE CONTOURS
FROM 4° INCLINED MILSTAR SATELLITES AT 90° W, 4° E, 90° E, AND 177° E

Figure 4.4 - Planned Milstar Constellation Coverage

The second is based on the fact that requirements for EHF SATCOM include protection from downlink jamming. In order to help defeat a downlink jammer, the elevation angle to the satellite is maintained above 20° in order to place the jamming signal well down on the sidelobes of the antenna. The third reason is cost. The difference in slant range between a 20° and 10° elevation angle is approximately a factor of two or nearly 3 dB and the difference in slant range between a 20° and 5° elevation angle is approximately a factor of four or nearly 6 dB as shown below

$$\sin(20) / \sin(10) = 1.97$$
$$10 \log(1.97) = 2.94 \text{ dB}$$

$$\sin(20) / \sin(10) = 3.92$$
$$10 \log(3.92) = 5.94 \text{ dB}$$

These factors are a direct multiple in the slant range calculation above and double or quadruple the amount of margin required to mitigate the effects of precipitation. While this may not be a driving factor at SHF, it is an important consideration at EHF where 6 dB may be the difference between a lower cost solid state amplifier and a traveling wave tube amplifier.

Next the attenuation for each of the four frequencies (EHF uplink and downlink and SHF uplink and downlink) are calculated. As the EHF and SHF uplink and downlinks vary over a range of frequencies, the highest frequency is selected. As a sample, the calculation for 2% outage in region D at 45.5 GHz, the highest frequency in the EHF uplink band, is shown below

$$R = 1.8 \text{ mm/hr}$$

$$L = 4.8/\sin(20) = 14.03 \text{ km}$$

$$a = 4.21 \text{ x } 10^{-5}(f)^{2.42} = 0.433181$$

$$b = 2.63(f)^{-0.272} = 0.931058$$

$$A = (0.433181) \text{ x } \{(1.8)^{0.931058}\} \text{ x } (14.03) = 10.5 \text{ dB}$$

Table 4.2 below shows the results for all the calculations. Figure 3.5 below plots the results for all the calculations. (Except for those with an answer ≥ approximately 50 dB of the which are the entries in the gray shaded cells. These values are not plotted in order to keep the scale of the graph meaningful.)

Table 4.2 - Percent Outage vs. Weather Margin (dB)

	Frequency			
% Outage	45.5 GHz[7]	21.2 GHz[8]	8.4 GHz[9]	7.75 GHz[10]
2.0	10.5	1.8	0.2	0.1
1.0	17.4	3.4	0.4	0.3
0.5	28.2	6.0	0.7	0.5
0.2	50.9	12.1	1.6	1.1
0.1	75.7	19.4	2.6	1.9
0.05	108.1	29.7	4.1	3.0
0.01	166.5	49.8	7.1	5.2
0.02	223.5	70.8	10.4	7.7
0.005	292.1	97.4	14.7	10.9
0.002	384.6	135.3	20.9	15.5
0.001	450.8	163.6	25.6	19.1

* Inverted cells indicate the uplink or downlink margin selected to achieve the corresponding availability.
** Gray cells indicate points that are not graphed in Figure 3.5 below.

The selected values for EHF uplink and downlink and SHF uplink and downlink margin appear in the black cells and coincide with the highlighted values on the graph. The EHF values

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[7] Uses the equation $a = 4.21 \text{ x } 10^{-5}(f)^{2.42}$ and $b = 2.63(f)^{-0.272}$

[8] Uses the equation $a = 4.21 \text{ x } 10^{-5}(f)^{2.42}$ and $b = 1.41(f)^{-0.0779}$

[9] Uses the equation $a = 4.21 \text{ x } 10^{-5}(f)^{2.42}$ and $b = 1.41(f)^{-0.0779}$

[10] Uses the equation $a = 4.21 \text{ x } 10^{-5}(f)^{2.42}$ and $b = 1.41(f)^{-0.0779}$

were selected based on the location at the knee in the curve. For example, to decrease the 21.2 GHz availability by 0.3%, the margin would have to be quadrupled from 6 dB to just over 12 dB. This does not seem to be worth the additional power and cost to obtain the marginal 0.3%. The SHF values were selected based on the fact that it achieve a high availability of 99.9% and the objective requirement is satisfied.

While 98% availability does not seem very appealing (i.e., 98% availability translates to almost 29 minutes of outage per day), it should be considered that the rainfall required to produce such attenuation usually occurs in small, relatively rapid moving cells. As such, the spatial diversity of the ships in a battlegroup is on the order of 3-5 miles and provides some measure of availability improvement, at the network level, over single terminal availability.

4.2.2 Link Budgets

The next step in the preliminary analysis process is to determine the effective isotropic radiated power (EIRP) and receive gain to system noise temperature (G/T) required to support the communications requirements.

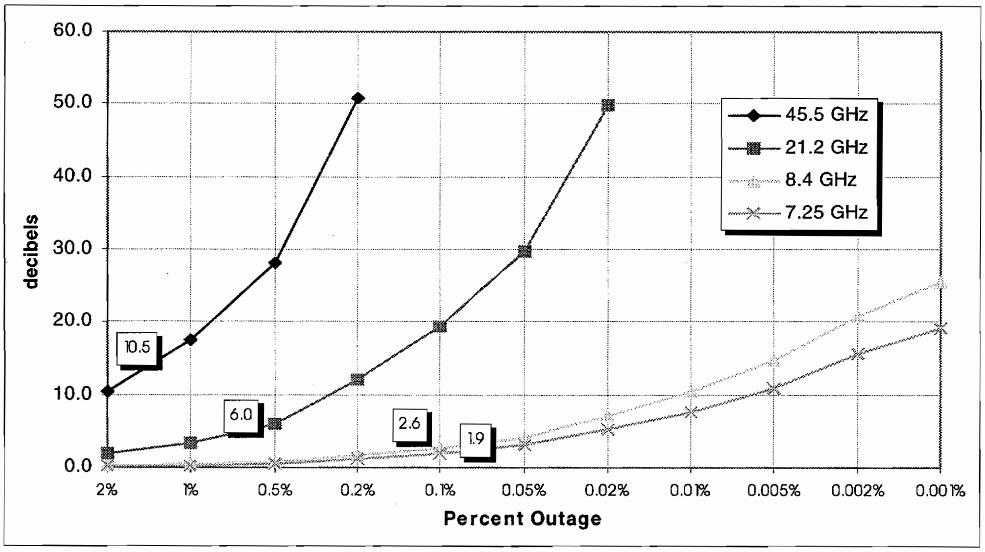

Figure 4.5 - Percent Outage vs. Weather Margin (dB)

4.2.2.1 EHF[11]

EHF operates at both LDR and MDR. LDR is more robust in that it employs data chip redundancy to ensure the information is received. In some cases, the modes may be so robust that multiple downlink hops must be received and integrated to decipher a single data chip. MDR is less robust in that there are usually multiple data chips per hop. For accuracy, independent LDR and MDR link budgets should be performed. However, it will be assumed that the LDR EIRP and G/T requirements are automatically satisfied when the MDR EIRP and G/T requirements are satisfied due to the chip redundancy. Therefore, only the MDR link budgets will be performed.

4.2.2.1.1 EIRP

Since EHF is a processing satellite, the uplink and downlink are independent. First, the uplink link budget will be performed determining the terminal EIRP in order to meet the satellite Receive Incident Power (RIP) requirement for a given EHF uplink modulation mode.

Working from the required BER, the probability of chip error (P_c) or chip error rate (CER) can be found to be 0.0175 from the equation

$$P_b = 16900 \times P_c^{5.25} \qquad \text{(Equation 4.6)}$$

Then from the CER, the required Ec/No is calculated to be 3.354 or 5.3 dB from the equation

$$P_c = ½e^{-Ec/No} \qquad \text{(Equation 4.7)}$$

From Ec/No, the Pr/No required at the satellite demodulator input can be calculated by subtracting demodulator implementation, adjacent channel interference, and timing error losses and subtracting the chip duration in dBsec. This results in a required Pr/No of 73.2 dBHz from which required RIP can be calculated by subtracting the satellite antenna G/T, 10 dB/K, and adding Boltzmann's constant resulting in -166.4 dBW. This is summarized in Table 4.3.

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[11] Modes, BER, EIRPs, G/Ts, RIPs, P_r/N_o, and other elements of the EHF link budget are contrived to avoid classification

Table 4.3 - Required EHF RIP at Satellite Antenna

Link Budget Element	**Equations**	**Value**
Required BER		1×10^{-5}
CER	$P_c = 10^{\{\log(Pb/16900)\}/5.25}$	0.0175
Ec/No	Ec/No = - $\ln(2\,P_c)$	5.3 dB
- Demodulator Implementation Loss		2.5 dB
- Adjacent Channel Interference Loss		1.5 dB
- Timing Error Loss		1.5 dB
Hop Rate		20000 hops/sec
Hop Duration		5×10^{-5}
Synthesizer Settling Time		1×10^{-6}
Usable Hop Duration		4.9×10^{-5}
Chips/Hop		68
- Chip Duration		-61.4 dBsec
Required Pr/No		**72.2 dBHz**
- Satellite Antenna G/T		**- 10 dB/K**
Boltzmann's Constant		**- 228.6 dBW/K/Hz**
Required RIP at Antenna		**-166.4 dBW**

Second, the terminal EIRP required to obtain the -166.4 dBW RIP will be calculated. To do this, transmission path losses, such as free space loss, atmospheric losses, wet radome losses, and weather margin, are added to the required RIP value to get the receive isotropic power (RIP) at the satellite antenna. The free space loss is calculated at 45.5 GHz to be 217.6 dB, atmospheric loss is assumed to be 1.0 dB, wet radome loss is allocated to be 2.0 dB, and the EHF uplink weather margin calculated earlier is 10.5 dB for a total transmission path loss of 231.1 dB. Subtracting the transmission path losses from the required RIP at the satellite antenna provides the required terminal EIRP of 65.2 dB. This is summarized in Table 4.4 below.

Table 4.4- Required EHF Terminal EIRP

Link Budget Element	**Equations**	**Value**
Required RIP at Antenna		**-166.4 dBW**
- Free Space Loss	$L = (4\pi R/\lambda)^2$	217.6 dB
- Atmospheric Loss		1.0 dB
- Wet Radome Loss		2.5 dB
- Weather Margin		10.5 dB
- Transmission Path Losses		**231.6 dB**
Required Terminal EIRP		**65.2 dBW**

From these calculations, it can be seen that the required terminal EIRP to meet the required modulation mode, which in EHF SATCOM equates to the required data rate, is 65.2 dBW. Note that this EIRP value includes pointing errors.

4.2.2.1.2 G/T

Essentially, the inverse of the calculations for EHF EIRP are performed to determine the require terminal G/T. Starting with the satellite EIRP, which is 56.1 dBW for the worst case satellite antenna at the edge of beam and end of the satellite life, we can determine the RIP available at the terminal. Next, the free space loss is calculated at 21.2 GHz to be 210.9 dB, atmospheric loss is assumed to be 1.0 dB, wet radome loss is allocated to be 1.0 dB, and the EHF downlink weather margin calculated earlier is 6.0 dB for a total transmission path loss of 218.9 dB. Subtracting the transmission path losses from the available EIRP at the satellite provides the available terminal RIP of -166.0 dBW. This is summarized in Table 4.5 below.

Table 4.5 - Available EHF RIP at Terminal

Link Budget Element	Equations	Value
Available Satellite EIRP		**53.9 dBW**
Free Space Loss	$L = (4\pi R/\lambda)^2$	- 210.9 dB
Atmospheric Loss		- 1.0 dB
Wet Radome Loss		- 2.0 dB
Weather Margin		- 6.0 dB
Transmission Path Losses		**- 219.9 dB**
Available RIP at Terminal		**-166.0 dBW**

Next, starting with the RIP available at the terminal, the required terminal G/T can be determined by subtracting Boltzmann's constant and the Pr/No required at the terminal demodulator input similar to the satellite calculations above. The Pr/No required is calculated at 76.6 dBHz, which when subtracted from the available RIP along with Boltzsmann's constant, provides a required terminal G/T of 13.0 dB/K. This is summarized in Table 4.6 below.

Table 4.6 - Required Terminal EHF G/T

Link Budget Element	Equations	Value
Available RIP at Terminal		**-166.0 dBW**
- Boltzmann's Constant		**228.6 dBW/K/Hz**
Required BER		1×10^{-5}
CER	$P_c = 10^{\{\log(Pb/16900)\}/5.25}$	0.0175
Ec/No	$Ec/No = -\ln(2\,P_c)$	5.3 dB
Demodulator Implementation Loss		2.5 dB
Spurious Signal Loss		2.0 dB
Timing Error Loss		1.5 dB
Hop Rate		20000 hops/sec
Hop Duration		5×10^{-5}
Synthesizer Settling Time		1×10^{-6}
Usable Hop Duration		4.9×10^{-5}
Chips/Hop		134
Chip Duration		64.4 dBsec
- Required Pr/No		**- 75.6 dBHz**
Required Terminal G/T		**13.0 dB/K**

From these calculations, it can be seen that the required terminal G/T to meet the required modulation mode is 13.0 dB/K. Note that this G/T value includes pointing errors.

4.2.2.2 SHF

SHF is a transponded satellite system. Therefore, the link budgets must be solved simultaneously to obtain the overall C/N of the link. Since the DSCS satellites use gain states to vary the transponder output power, a U.S. Government developed spreadsheet based link budget calculating tool will be used. In using this tool, the earlier assumptions regarding link margin will be included in the tool.

4.2.2.2.1 EIRP

The following assumptions will be made in calculating the required SEST EIRP:

- DSCS III satellite
- Gain state 3
- 3 foot SEST antenna communicating to a 40 foot hub
- The satellite uplink is the multi-beam receive antenna
- The satellite downlink is the multi-beam transmit antenna
- The required Pr/No is 5.1 dB using 1/2 rate encoding
- The uplink weather margin is 2.6 dB
- The downlink weather margin is 1.9 dB

- 10^{-5} BER
- 3 dB backoff
- The elevation angle is 20°.

Using these assumptions, the SEST terminal EIRP is varied until the link budget tool indicates that the link is supportable in the required operational scenario or 128 kbps with no more than 2 W of transponder power.

The results of the model indicate that the SEST can support at 128 kbps link to and from a 40 foot hub station with a SEST EIRP of 50.6 dB or greater. This configuration requires approximately 12 mW of transponder power. Given the gain of a 3 foot antenna, 41 W of amplifier output power are required. Assuming 3 dB backoff of the transmitter, the SHF amplifier must be at least 82 W. Given the proximity to commercially available 100W amplifiers, a 100W will be assumed.

4.2.2.2.2 G/T

Also using the U.S. Government link budget tool, the required G/T to receive the return link from the 40 foot hub is determined using similar assumptions. In order to support the 128 kbps link from the hub station without using more than 2 W of transponder power, the SEST SHF G/T must be 10.5 dBi or greater. This requires 1.968 W of transponder power. Combined with the transponder power required for outbound link, 1.98 W of transponder power is required.

4.3 Hardware configuration

For life cycle cost considerations, an open system architecture approach, such as a Versa Module Eurocard (VME) chasis and cards, will be used. The advantage of such an approach is three-fold. First, utilizing an open system architecture opens up the list of available commercial products that can be used to develop the system. Second, with more commercially available products and subassemblies, the cost of the system should be reduced. And third, a VME architecture is largely software driven enabling future growth and flexibility through increased software functionality without redesigning hardware.

4.4 Feasibility Studies and Market Survey

During the conceptual design phase, one task to be undertaken includes antenna feasibility studies of meeting the SEST requirements. Based on market and product research, the three types of antennas that are being investigated are: a non-simultaneous multi-band parabolic dish with electronic switchable feed assembly; a simultaneous multi-band Luneberg lens antenna; and a simultaneous multi-band phased array antenna. The Luneberg lens and phased array antennas have the advantage of providing simultaneous EHF and SHF communications, but not without considerable added complexity and/or risk. The following sections discuss the three antenna alternatives in greater detail.

4.4.1 Non-Simultaneous Multi-Band Parabolic Dish Antenna with Electronic Switchable Feed

This approach is a proven, practical approach to satisfy the SEST antenna requirements. A three axis pedestal would be used to avoid keyhole effects at zenith. The same aperture (reflector) can support operations at both frequencies. The feed design may be accomplished in a number of means such as:

a. concentric SHF and EHF feeds;
b. offset dual rotating SHF and EHF feeds;
c. dual SHF and EHF feeds with a dichroic subreflector; and
d. dual SHF and EHF feeds with a hinged window in subreflector.

Antennas in a shipboard environment typically utilize a radome in order to make the antennas lighter, avoid icing requirements, better tolerate wind effects, etc. Therefore, only Cassegrain or ring-focus antenna approaches with parabolic (or eliptical) reflectors are being considered in order to maximized the aperture within the space available inside the radome. With an offset feed type antenna, the main reflector size may have to be reduced to allow clearance for the feed and structures within the radome.

4.4.1.1 Concentric SHF and EHF feed Multi-Band Parabolic Dish Antenna.

A graphical representations of this design is contained in Figure 4.6.

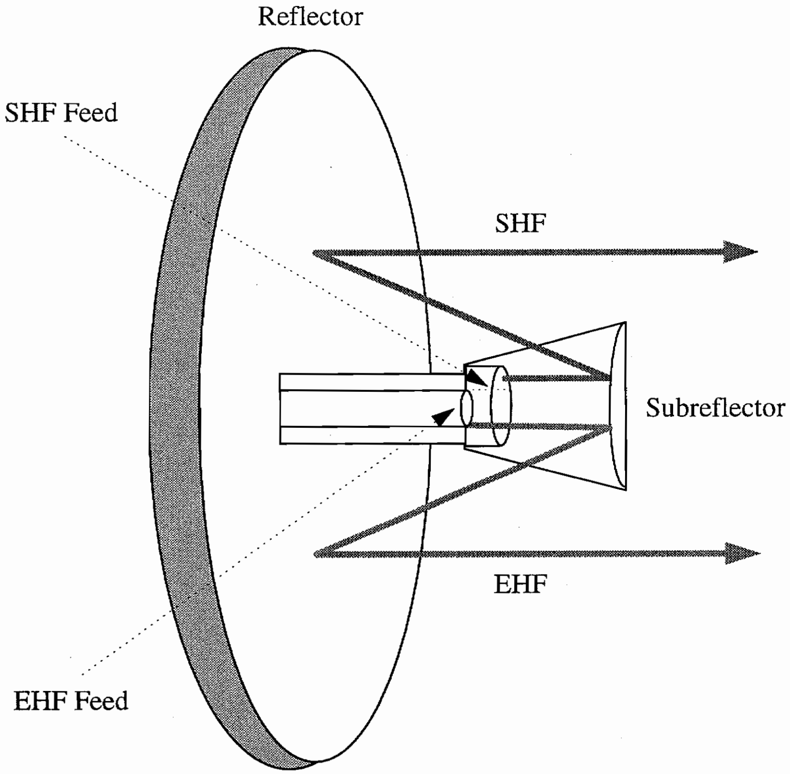

Figure 4.6 - Concentric SHF and EHF Feed Multi-Band Parabolic Dish Antenna

The advantages and disadvantages of this design are contained in Table 4.7 below.

Table 4.7- Advantages and Disadvantages of Concentric SHF and EHF Feed Multi-Band Parabolic Dish Antenna

Advantages	Disadvantages
No moving parts	EHF feed blocks SHF feed
No support strut blockage	
Costs less than phased array	

4.4.1.2 Offset Dual Rotating SHF And EHF Feed Multi-Band Parabolic Dish Antenna.

A graphical representations of this design is contained in Figure 4.7.

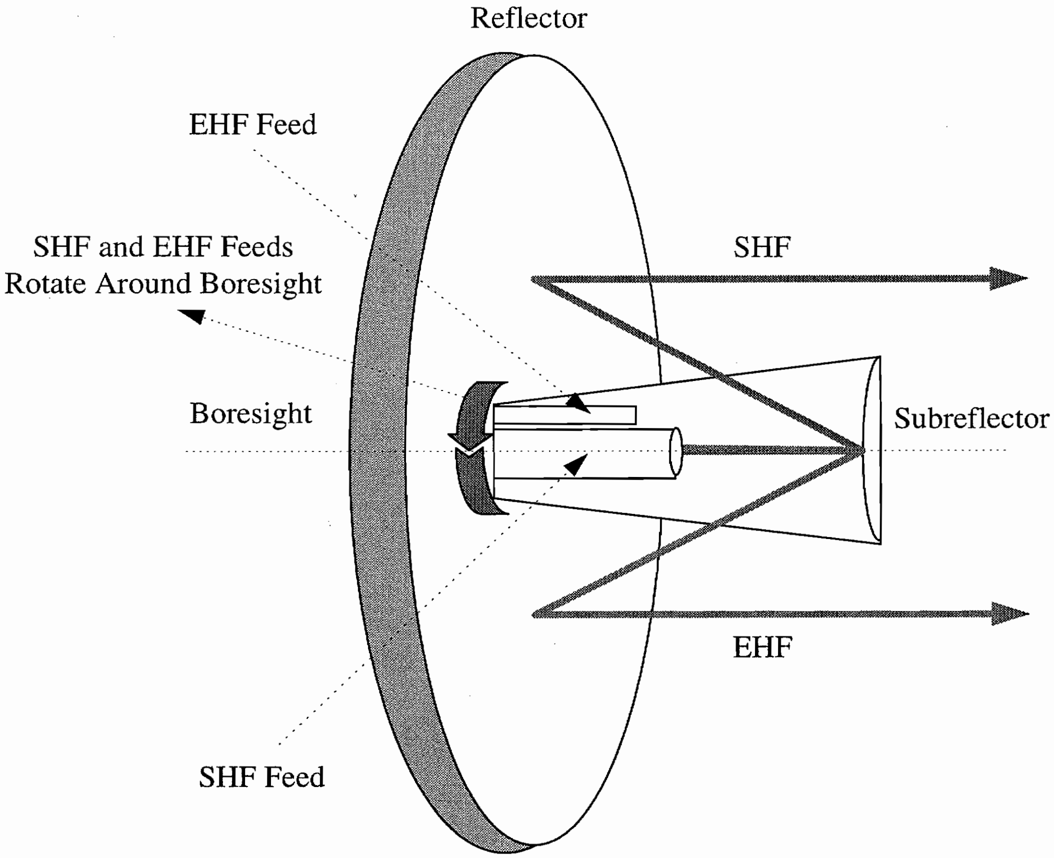

Figure 4.7 - Offset Dual Rotating SHF and EHF Feed Multi-Band Parabolic Dish Antenna

The advantages and disadvantages of this design are contained in Table 4.8 below.

Table 4.8 - Advantages and Disadvantages of Offset Dual Rotating SHF and EHF Feed Multi-Band Parabolic Dish Antenna

Advantages	Disadvantages
Costs less than phased array	Reliability of moving parts
	Alignment accuracies of moving parts
	Non-operating feed blocks operating feed

4.4.1.3 Dual SHF And EHF Feeds With A Dichroic Subreflector Multi-Band Parabolic Dish Antenna.

A graphical representations of this design is contained in Figure 4.8.

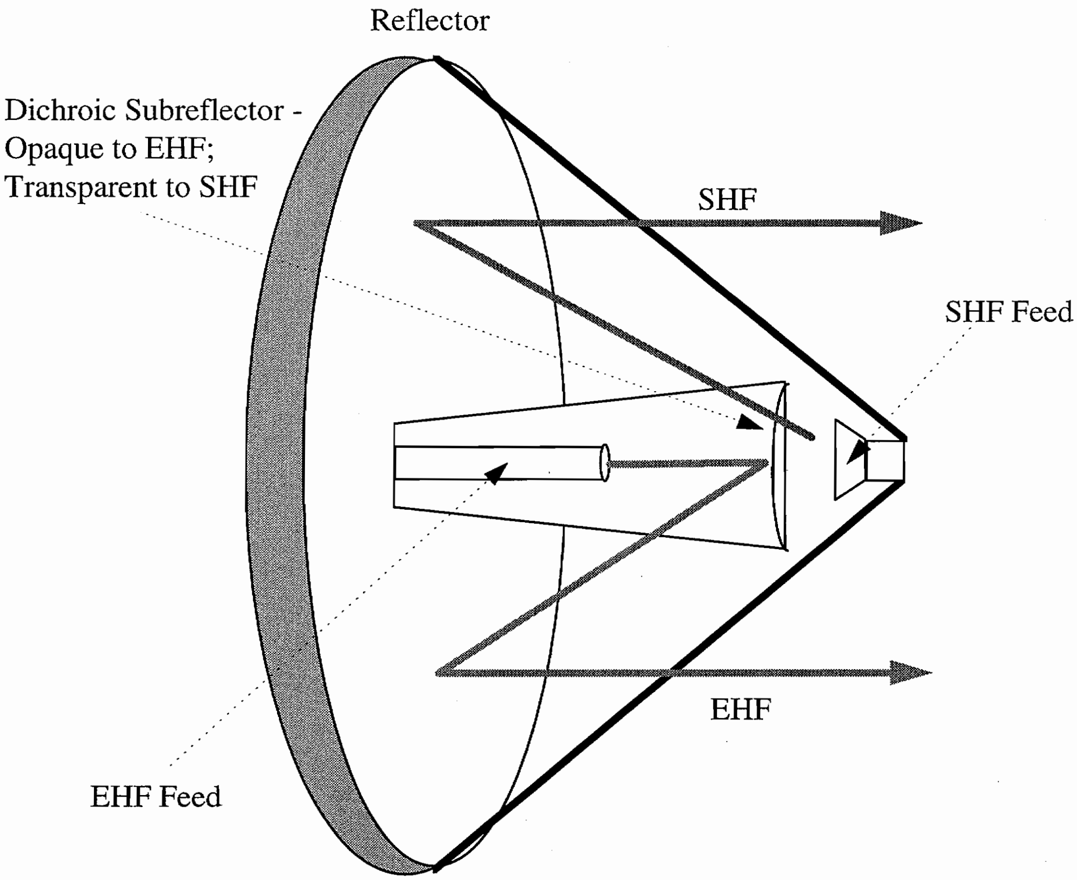

Figure 4.8 - Dual SHF and EHF Feeds With a Dichroic Subreflector Multi-Band Parabolic Dish Antenna

The advantages and disadvantages of this design are contained in Table 4.9 below.

Table 4.9 - Advantages and Disadvantages of Dual SHF and EHF Feeds With a Dichroic Subreflector Multi-Band Parabolic Dish Antenna

Advantages	Disadvantages
Reduced blockage from feeds	Subreflector struts increase blockage
No moving parts	Reliability of moving parts
Costs less than phased array	Alignment accuracies of moving parts
	Sophisticated dichroic development

4.4.1.4 Dual SHF And EHF Feeds With A Hinged Window In Subreflector Multi-Band Parabolic Dish Antenna.

A graphical representations of this design is contained in Figure 4.9.

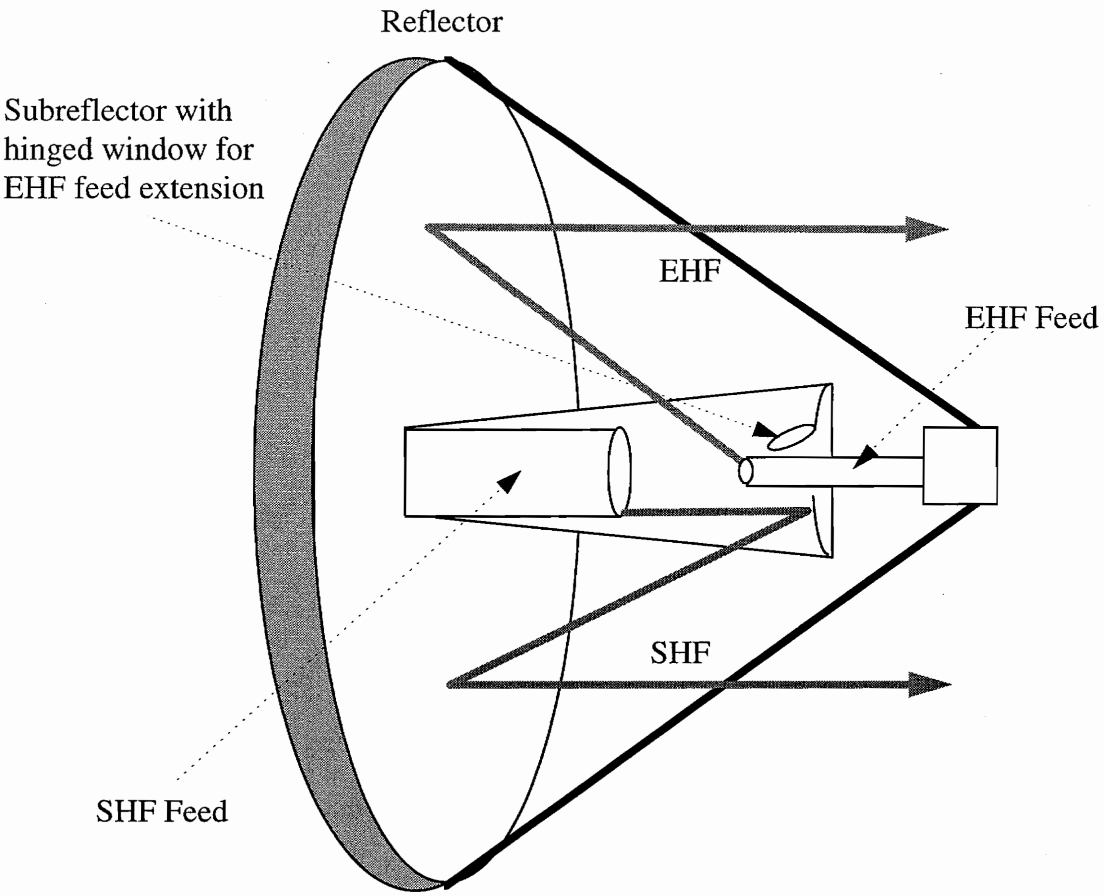

Figure 4.9 - Dual SHF and EHF Feeds with a Hinged Window in Subreflector Multi-Band Parabolic Dish Antenna

The advantages and disadvantages of this design are contained in Table 4.10 below.

Table 4.10 - Advantages and Disadvantages of Dual SHF and EHF Feeds with a Hinged Window in Subreflector Multi-Band Parabolic Dish Antenna

Advantages	Disadvantages
Reduced blockage from feeds	Subreflector struts increase blockage
Costs less than phased array	Reliability of moving parts and hinge
	Alignment accuracies of moving parts
	Hinge reduces efficiency

Table 4.11 below provides a summary of some of the advantages and disadvantages of a non-simultaneous multi-band parabolic dish antenna with electronic switchable feed approach.

Table 4.11 - Advantages and Disadvantages of Non-Simultaneous Multi-Band Parabolic Dish Antenna

Advantage	Disadvantage
Low risk, well understood technology	Dual-band reduces efficiency
Dual-band antenna eliminates one set of antennas thereby reducing the RCS	Structures independent of ships superstructure contributes to RCS and/or add to structures requiring RCS reduction techniques
Demonstrated accurate pointing under shipboard motion	Non-simultaneous dual-band
Relatively low risk approach to dual-band	

4.4.1.5 Conclusions

From the above market survey of each of the non-simultaneous multi-band parabolic dish antenna with electronic switchable feed approaches, the concentric SHF and EHF feed approach has been selected based on the advantages and disadvantages considered. This approach results in superior performance based on reduced aperture blockage with acceptable risk s while minimizing the reliability risks or moving parts. Therefore, the concentric SHF and EHF feed approach to non-simultaneous multi-band parabolic dish antenna will be considered further in the conceptual design phase.

4.4.2 Simultaneous Multi-Band Luneberg Lens Antenna

A Luneberg lens antenna is a solid or staggered shell lens with a circular cross section having an index of refraction varying only in the radial direction such that a feed located on or near a surface or edge of the lens produces a major lobe, or main beam, diametrically opposite the feed. Figure 4.10 presents the electrical properties of a Luneberg lens antenna. In this figure, the lens is receiving light and coupling it into a fiber optic cable.

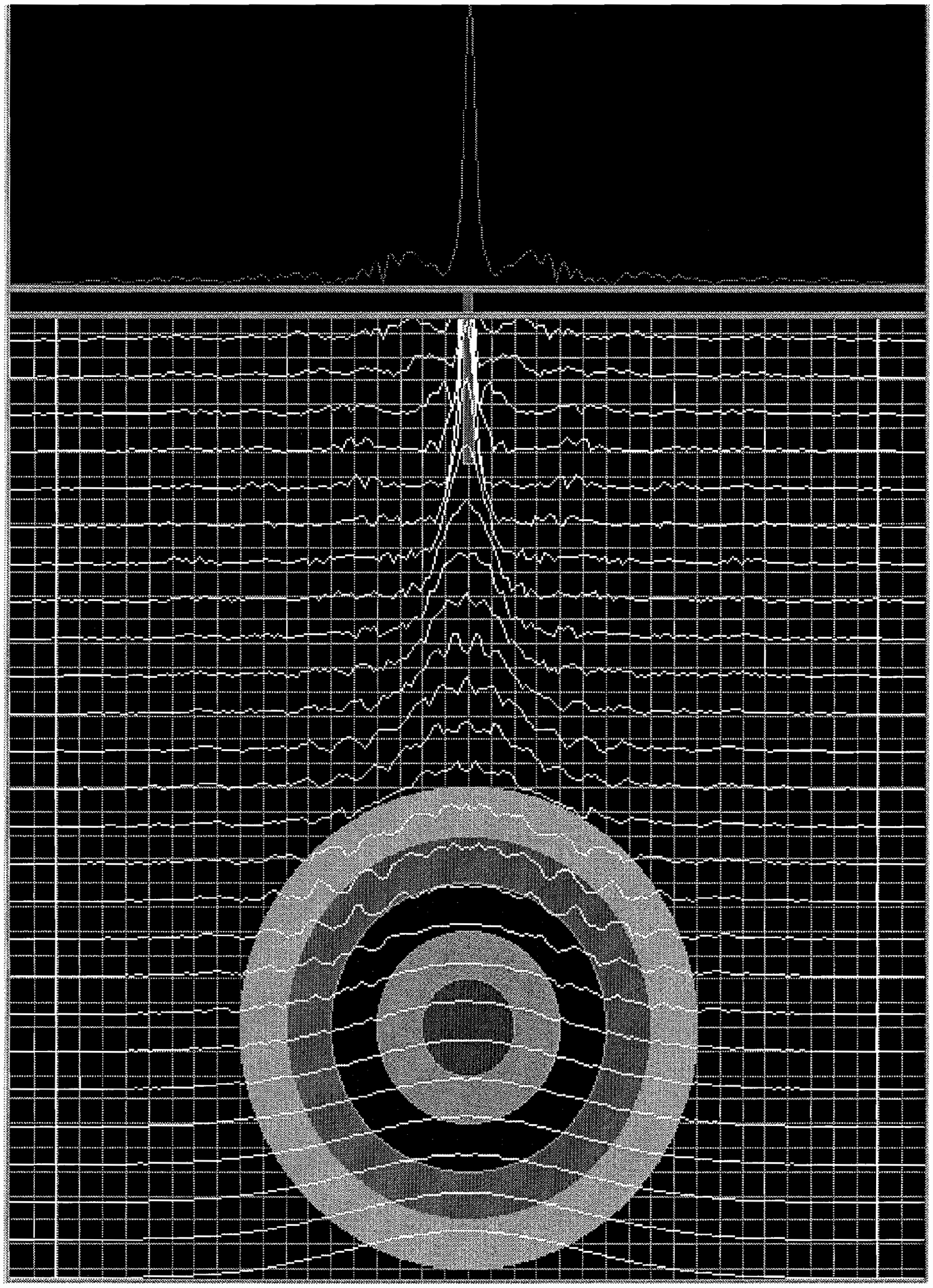

Figure 4.10 - The Electrical Properties of a Luneberg Lens Antenna

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Graphic Courtesy of the University of California

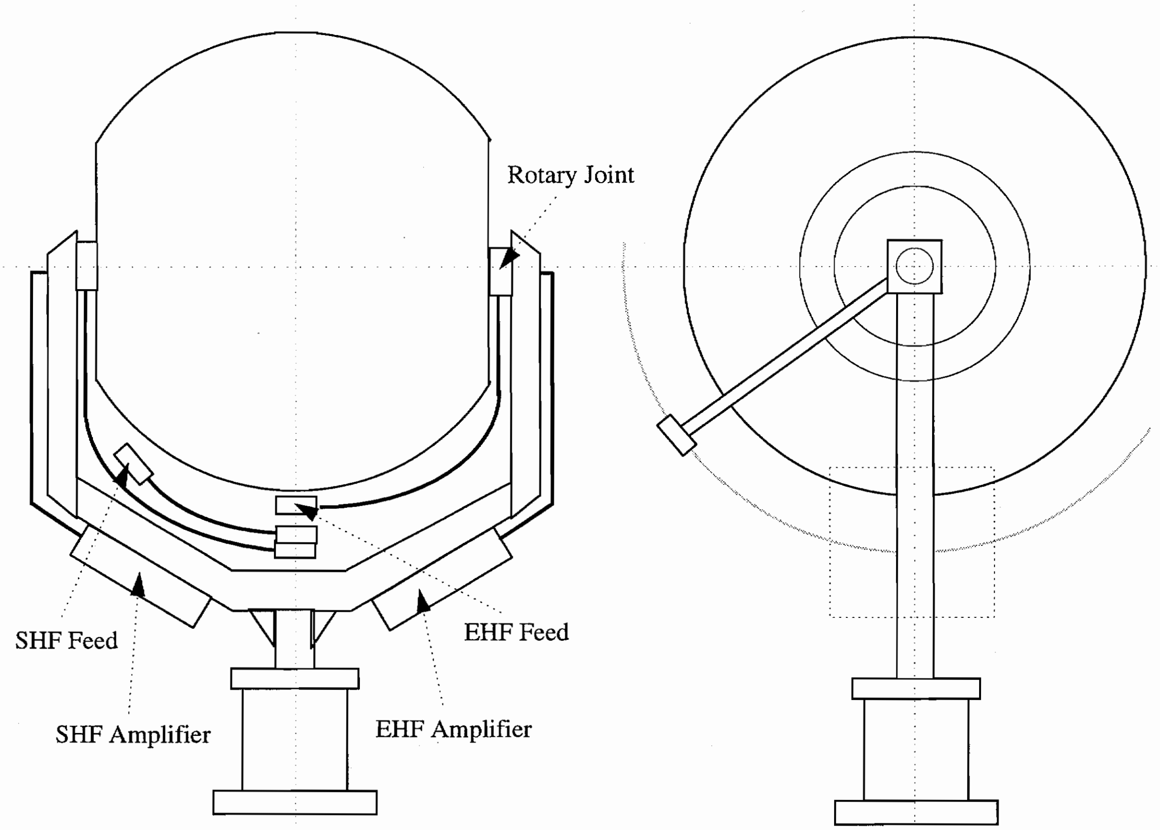


Figure 4.11 - Graphical Representation of a Simultaneous Multi-Band Luneberg Lens Antenna

From this figure it can be seen that the difficulty in producing this multi-band antenna is having feeds with multiple degrees of freedom. Another difficulty in producing a Luneberg lens antenna is the need for materials research. As Luneberg lens' have not enjoyed widespread use for communications, the materials and fabrication processes for lens antennas is not as sophisticated as with parabolic dish type antenna. Table 4.12 summarizes the advantages and disadvantages of a simultaneous multi-band Luneberg lens antenna.

Table 4.12 - Advantages and Disadvantages of Simultaneous Multi-Band Luneberg Lens Antenna

Advantages	Disadvantages
Simultaneous dual-band communications	Pointing accuracy under shipboard dynamics
Costs less than phased array	Lens materials and fabrication processes
	Azimuthal degrees of freedom
	Blockage from other feed
	Structures independent of ships superstructure contributes to RCS and/or add to structures requiring RCS reduction techniques
	Dielectric lenses are lossy
	Weight of lenses

4.4.2.1 Conclusion

Due to the promise of providing simultaneous dual-band communications capabilities, a Luneberg lens antenna approach will be further investigated. However, the risks associated with a lens type antenna do not warrant considering a Luneberg lens antenna approach if simultaneous multi-band communications can not be provided.

4.4.3 Simultaneous Multi-Band Active Phased Array Antenna

The basic principal behind the an active phased array antenna is many small transmitters and/or receivers which are combined in phase to produce a EIRP or G/T greater than the individual elements. For purposes of this project, only solid state active phased arrays will be considered. In general, phased array antennas require a large number of these individual transmit and receive modules which, depending in the operating frequency, can be relatively expensive on a per unit basis. In addition, the transmitters and receivers are often used to shift the phase of the beam, effectively 'steering' the antenna in the appropriate direction. However, the greater reliance on phase shift beamsteering increases the number of phased array elements required to steer the beam off boresight and, consequently, increases cost. In fact, by only phase shifting beamsteering one axis and mechanically steering the other, the number of elements required can be reduced by 10-15 times fewer. The following phased array approaches are considered:

a. Phase shift beamsteering in elevation and mechanical steering in azimuth; and
b. Phase shift beamsteering in elevation and azimuth.

4.4.3.1 Simultaneous Multi-Band Active Phased Array Antenna With Phase Shift Beamsteering In Elevation And Mechanical Steering In Azimuth.

A graphical representations of this design is contained in Figure 4.12.

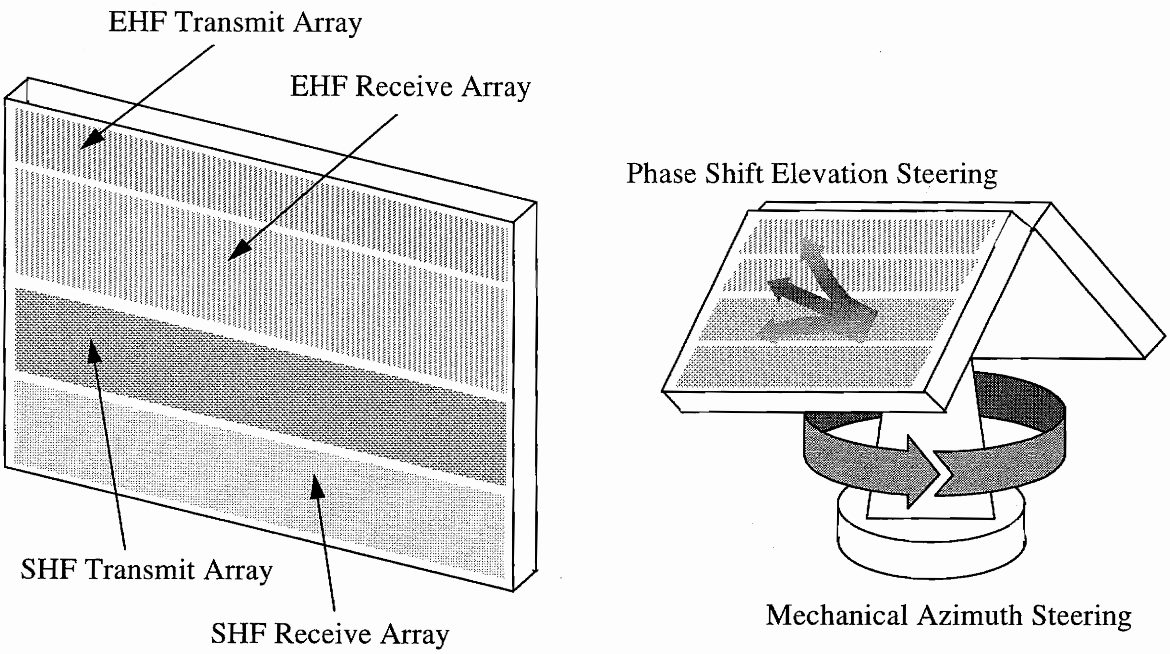


Figure 4.12 - Simultaneous Multi-Band Active Phased Array Antenna With Phase Shift Beamsteering In Elevation And Mechanical Steering In Azimuth

Table 4.13 summarizes the advantages and disadvantages of a Simultaneous Multi-Band Active Phased Array Antenna with Phase shift beamsteering in elevation and mechanical azimuth steering.

Table 4.13 - Advantages And Disadvantages Of Simultaneous Multi-Band Phased Array Antenna With Elevation Phase Shift Beamsteering And Mechanical Azimuth Steering

Advantages	Disadvantages
Simultaneous dual-band communications	Cost of elements and arrays
Costs less than full phase shift beamsteering	Two pedestals and four arrays required per ship due to superstructure blockage
Reliability	Structures independent of ships superstructure contributes to RCS and/or add to structures requiring RCS reduction techniques
	Depending on the frequency of the threat radar, the phased array element reflectivity may contribute to RCS
	Potential pointing conflicts between EHF and SHF satellites
	Poor sidelobe performance (compared to parabolic dish antennas).
	Restricted coverage in elevation.

4.4.3.2 Simultaneous Multi-Band Active Phased Array Antenna with Phase shift beamsteering in elevation and azimuth.

A graphical representations of this design is contained in Figure 4.13.

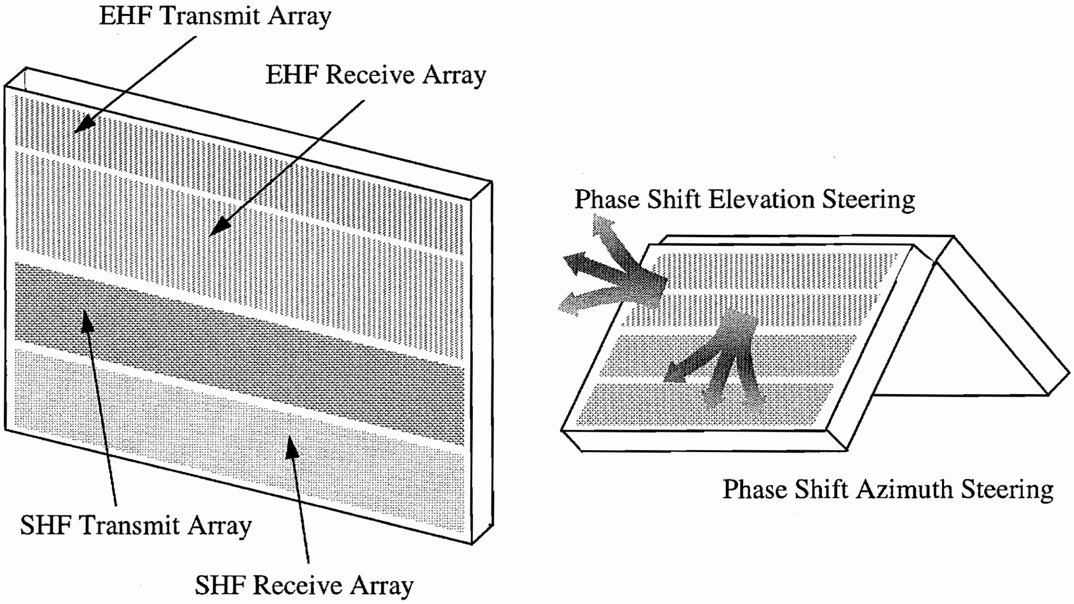


Figure 4.13 - Simultaneous Multi-Band Active Phased Array Antenna With Phase Shift Beamsteering In Elevation And Azimuth

Table 4.14 summarizes the advantages and disadvantages of a Simultaneous Multi-Band Active Phased Array Antenna with Phase shift beamsteering in elevation and azimuth.

Table 4.14- Advantages And Disadvantages Of Simultaneous Multi-Band Active Phased Array Antenna With Phase Shift Beamsteering In Elevation And Azimuth

Advantages	Disadvantages
Simultaneous dual-band communications	Cost of elements and arrays
Structures can be integrated with the ships superstructure reducing RCS	Depending on the frequency of the threat radar, the phased array element reflectivity may contribute to RCS
No pointing conflicts between EHF and SHF satellites	Poor sidelobe performance (compared to parabolic dish antennas).
Reliability	Restricted coverage in elevation and azimuth.

4.4.3.3 Conclusions

A phased array antenna approach offers strengths for providing simultaneous multi-band communications. An approach which uses phase shift beamsteering in elevation and azimuth is better in terms of advantages and disadvantages; however, these advantages are not without a cost. For example, increasing the phase shift scanning requirements on a phased array antenna reduces the gain of the antenna (as can be seen later in equation 4.4). Also, increasing the scanning angle increases the required number of elements which increases cost. Finally, covering 360° in azimuth without overly large scanning angles requires multiple faces of the phased array antenna which also increases cost. Therefore, only the approach which utilizes phase shift beamsteering in elevation and mechanical steering in azimuth will be further considered.

4.5 Advanced System Planning

Advanced system planning in this concept development phase includes the preparation of the system performance specification below.

4.5.1 System Performance Specification

4.5.1.1 System description

The SEST system shall provide satellite communications in the SHF and EHF bands from one antenna group.

4.5.1.2 Major components

Major components of the SEST system include the inboard equipment group, the amplification group, and the antenna group. The amplification group and the antenna group may be contained within the same group depending on the design.

4.5.1.2.1 Inboard Equipment Group

The inboard equipment group shall be the communications support group and the antenna controller and shall have the following performance characteristics.

4.5.1.2.1.1 Communications Support Group

The communications support group shall provide the transmission, reception, modulation/demodulation, and baseband interfaces required for EHF and SHF satellite communications. The equipment groups of the communications support group are the EHF equipment group and the Defense Satellite Communications System (DSCS) equipment group.

4.5.1.2.1.1.1 EHF Equipment Group

The EHF equipment group shall consist of the equipment required to communicate with Navy and Joint EHF terminals and shall be compatible with various EHF satellite packages (Milstar I, Milstar II, FEP, UFO/E, UFO/E enhanced and Interim Polar). The EHF equipment group shall provide a capability for both EHF low data rate (LDR) and EHF medium data rate (MDR) communications.

4.5.1.2.1.1.2 DSCS Equipment Group

The DSCS equipment group shall have the capability to communicate with Navy and Joint SHF terminals and shall be compatible with DSCS X-band satellites. The DSCS equipment group shall include an internal modem (or modems) which supports the required waveforms and shall provide a baseband interface. The DSCS equipment group shall provide an intermediate frequency (IF) interface for use with external modems. The terminal shall be capable of being switched between the internal modem and the external IF interface.

4.5.1.2.1.2 Antenna Controller.

The antenna controller shall consist of the hardware and software required for frequency band selection, control of antenna pointing and tracking, and interface to the communications support group and the Advanced Digital Network System (ADNS).

4.5.1.2.2 Amplifier Group.

The amplifier group shall provide the RF amplification at the EHF and SHF bands.

4.5.1.2.3 Antenna Group.

The antenna group shall include a multi-band antenna and RF transmission and reception equipment.

4.5.1.2.3.1 Multi-Band Antenna(s).

The multi-band antenna(s) shall provide the required gain, polarization, efficiency, sidelobe levels, and frequency response to meet the performance requirements.

4.5.1.2.3.2 RF Transmission and Reception Equipment.

The RF transmission and reception equipment shall consist of those components necessary to meet EIRP and G/T requirements. The RF equipment consists of such components as: RF low noise amplifiers (LNAs), RF power amplifiers and frequency upconverters and downconverters.

4.5.1.3 Interface Definition

4.5.1.3.1 External Communications Interface

4.5.1.3.1.1 EHF

The SEST system shall interoperate with Navy, Army, and Air Force EHF SATCOM terminals using Milstar satellites (Milstar I LDR and Milstar II LDR/MDR) and EHF communications packages on existing (FEP, UFO/E, UFO/E Enhanced) and future (Interim Polar) satellites.

4.5.1.3.1.2 DSCS

The SEST system shall interoperate with Navy, Army, Air Force, and Allied SHF terminals using the DSCS satellite constellation (DSCS II, DSCS III) and shall support the SHF waveforms specified in MIL-STD-188-164 and MIL-STD-188-165.

4.5.1.3.2 Platform systems interface

4.5.1.3.2.1 Baseband Interfaces

Baseband interfaces shall be in accordance with either MIL-STD-188-114, EIA/TIA 530, EIA 422, and EIA 423, as appropriate. All baseband input/output (I/O) ports shall be unclassified, shall be capable of both full-duplex (FDX) and half-duplex (HDUX) operation, and shall support operation of standard shipboard baseband voice, data, imagery, and cryptographic equipment. The system shall be capable of baseband port configuration and baseband equipment connection using a local operator interface and remotely from the ADNS operator console. Baseband I/O ports shall be provided as specified below.

4.5.1.3.2.1.1 EHF Equipment Group

The EHF equipment group shall meet the terminal to baseband equipment interface requirements specified below. The number and type of EHF baseband ports shall be as shown in TABLE X. EHF baseband ports shall be interoperable and directly interfaceable with the following standard shipboard baseband equipment as specified in the baseband interface appendix (Appendix D) of SR-2300.

a. KG-84A/C, KG-194A, KY-58, and KY-68 (DSVT) cryptographic equipment
b. STU III telephone and facsimile equipment via STEL 9610/9620 modem
c. Advanced narrowband digital voice terminal (ANDVT) secure voice unit
d. AN/UGC-136AX, BX, and CX teletype
e. STU III multi-media terminal
f. Radio wire interface (RWI)
g. Navy EHF communications controller (NECC)

The 12 LDR and 14 MDR communication ports shall meet the electrical characteristics specified in MIL-STD-188-114 except for those noted in NSA 82-2A.

The MDR DSVT (secure voice) port shall be 4 wire, conditioned diphase and shall conform to the requirements of NSA 79-20.

The MDR T1 asynchronous port shall support bipolar AMI signaling in accordance with ANSI T1.403-1989.

LDR primary, secondary, and receive only baseband communication port operation shall be synchronous and shall be capable of full-duplex (FDX) and half-duplex (HDX) operation. Signal lines shall have the capability to be configured as balanced or unbalanced and shall allow external inversion of the signal sense. LDR baseband ports shall have the capability to be configured to operate at data rates specified in Table 3.15. The SEST system shall provide the capability to multiplex/demultiplex LDR primary or receive-only communications ports to achieve data rates of 4800 bps or 9600 bps. Transmit and receive epoch time markers shall be provided, when using the system transmit data clock, to permit time synchronization between the SEST system and baseband time division multiplex (TDM) slot assigned to that I/O port.

The Auxiliary TTY baseband port shall be able to interface with low level (+ or -6 VDC) interface signals. Port operation shall be asynchronous with data transfer rates of 75 bps and 1200 bps. This port shall provide ITA-5 (ASCII) and Baudot interface capability, both for input and output. An AN/UGC-136CX or equivalent teletype device will typically be used for auxiliary TTY functions. In the auxiliary TTY mode the port shall be used to output a log of system activity/status and checkpoint system data (for example black KGV-11 crypto variables, ephemeris data or adaptation data) to a teletype device and to input unique adaptation data, ephemeris data, black KGV-11 cryptographic variables and checkpoint system data from a teletype device. Checkpointed system data shall be stored on magnetic media by the auxiliary TTY device in a format that does not require editing before it can be input. Checkpointed cryptographic variables for a selected satellite constellation shall be output and stored in a single file. Initial loading of system data shall be from magnetic media via the auxiliary TTY interface.

Table 4.15 - EHF baseband I/O requirements

Port Type	Quantity	Data Rates Supported
LDR Primary Communications (Tx/Rx)	4	75, 150, 300, 600, 1200, and 2400 bps
LDR Secondary Communications (Tx/Rx)	4	75, 150, and 300 bps
LDR Receive-Only Communications	4	75, 150, 300, 600, 1200, and 2400 bps
Auxiliary TTY	1	75 and 1200 bps
MDR Communications	14	2.4*, 4.8, 9.6, 16, 19.2, 32, 64, 128, 256, 512, 1024, and 1544 kbps
MDR Digital Secure Voice Terminal (DSVT)	1	16 kpbs
MDR Asynchronous T1	1	1544 kbps
* Note: 2.4 kbps at baseband level double sampled for 4.8 kbps at the network level		

Baseband voice and data security shall be provided by external cryptographic equipment within the various voice and data systems which interface to the SEST system. Baseband voice and data interfaces shall be black digital.

MDR baseband port operation shall be synchronous for all data rates. Transmit and receive epoch time markers shall be provided by the system, when using the system transmit data clock, to permit synchronization between the system and baseband time division multiplex (TDM) slot assigned to that I/O port. A dedicated port shall provide asynchronous T1 operation. SEST system design shall be such that the communications data delay requirements of SR-2000 are satisfied.

4.5.1.3.2.1.2 MDR Baseband Iinterface Signals

The system shall support time division multiple access (TDMA) usage of forced timeslot services. The system interface shall provide the control signals necessary to support this requirement. At a minimum, the system shall provide the following signals on fourteen of the sixteen baseband ports. Other control/clock/data signals may be provided as required by system design. All signals shall be balanced voltage digital interface circuits in accordance with MIL-STD-188-114 and shall be in conformance with the requirements of 4.5 (Relationship With Other Digital Interface Standards), 5.2 (Balanced Voltage Digital Interface Circuit), and 5.3 (Terminated Voltage Digital Interface Circuit) of MIL-STD-188-114 and all subparagraphs thereof. With respect to MIL-STD-188-114 requirements, the terminal shall provide Type I balanced generators for all control signals and either Type I or Type II balanced generators for all data and clock signals. All input signals shall have an input termination impedance of not less than 120 ohms. All output signals shall allow for termination at the user end. Clock and control signal sense shall be in accordance with Table II of MIL-STD-188-114 (for example, negative: 1, MARK, OFF - positive: 0, SPACE, ON). The system shall be able to operate with all output signals of all ports terminated simultaneously with 100 ohm resistors and/or not terminated.

4.5.1.3.2.1.2.1 Transmit Data (TXDATA)

Transmit data will be a balanced serial synchronous data signal input to the EHF equipment. This signal is used by the baseband user system to transfer data into the system for transmission. BIT transitions on the TXDATA line nominally occur coincident with the OFF to ON transitions of the transmit clock (TXCLK or EXTTXCLK) signals.

4.5.1.3.2.1.2.2 Transmit Clock (TXCLK)

Transmit clock shall be a balanced clock signal output by the system. If selected, this signal is used by the baseband user system to synchronize output of data on the TXDATA signal line. The clock rate depends on the port data rate selected by the operator. The TXCLK duty cycle shall be between 48 percent and 52 percent of the bit time. The timing of this signal may vary over time depending on satellite range and Doppler conditions. TXCLK activity shall be configurable by the operator, on a port by port basis, as either a constant clock or a gated clock. If configured as constant clock, it shall be active (present at all times) on a particular port whenever that port is enabled. If configured as a gated clock, it shall be active on a particular port only if a net or point-to-point (PTP) call is active and the clear to send (CTS) signal is also active.

4.5.1.3.2.1.2.3 External Transmit Clock (EXTTXCLK)

The EXTTXCLK will be a balanced clock signal input to the system. The system shall provide the capability to accept the EXTTXCLK as an external clock source for accepting TXDATA for transmission. This signal is used by the baseband user system to synchronize output of data on the TXDATA signal line. The clock rate depends on the port data rate selected by the operator and will have a duty cycle between 48 and 52 percent of the bit time. The system operator shall have the capability to select on a port by port basis whether the EXTTXCLK or the TXCLK signal shall be used as the transmit data clock. The system shall provide data buffering for each port configured by the operator to use the EXTTXCLK as the transmit data clock. The system shall provide data buffering to preclude loss of bit count integrity at the receiver site over any 24-hour period due to worst case satellite range variations and variations in the bit rate of the data input to the system. The bit rate of the input data will be stable to two parts in 10^{11}. The amount of data buffering shall not exceed 36 hours. Buffer sizes shall be determined by the selected port data rate and peak satellite delay variation. Data buffer sizes shall be selected to ensure that the Communications Data Delay requirements of SR-2000 are satisfied by the SEST system. To minimize data loss, the system shall automatically recover from a data overrun or underrun condition (for example recentering the buffer).

4.5.1.3.2.1.2.4 Receive Data (RXDATA)

RXDATA shall be a balanced serial synchronous data signal output by the system. This signal is used to output data received by the system on a net or PTP call. This signal is not active unless a net or PTP call is active on the port and the receiver ready signal is also active. Bit transitions on the RXDATA line shall occur coincident with the OFF to ON transitions of the RXCLK signal.

4.5.1.3.2.1.2.5 Receive Clock (RXCLK)

RXCLK shall be a balanced clock signal output by the system. The signal is used by the baseband user system to input the synchronous receive data stream. The baseband user system should clock in the data on the RXDATA line using the ON to OFF transition of the RXCLK signal. This signal is active on a particular port whenever a net or PTP call is active. The clock rate depends on the port data rate selected by the operator. The RXCLK duty cycle shall be between 48 and 52 percent of the bit time. RXCLK activity shall be configurable by the operator, on a port by port basis, as either a constant clock or a gated clock. If configured as a constant clock, it shall be active (present at all times) on a particular port whenever that port is enabled. If configured as a gated clock, it shall be active on a particular port only if a net or PTP call is active and the receiver ready signal is active.

4.5.1.3.2.1.2.6 Request to send (RTS)

RTS shall be a balanced control signal input to the system. This signal is used by the baseband user system to request permission to input data for transmission. System responses to activation of RTS depend upon current system and satellite status. A particular user service can be set up to use either transmit over receive (XOR) or receive over transmit (ROX) protocol. Under the following circumstances, the system shall not act on a change in state of the RTS command line, unless executing non-operational loop-back tests:

a. No service is active on the port
b. The service is set up as receive-only
c. The service is set up as full duplex and the port is configured for 'no RTS required'
d. The service is set up using ROX protocol, and the current state of the receiver ready (RR) control line is high.

If none of the above apply, the system shall act upon the change of state in RTS, and one of the following shall apply:

a. If the service requires satellite coordination (for example, satellite configuration, half-duplex PTP call), the system shall first request service parameters from the satellite (for example, frequency channel, time slot, hops) and then activate the CTS control line after it is received and upon completion of any internal processing necessary to accept data for transmission.
b. If no satellite coordination is required (for example, forced time slot nets, full duplex PTP calls), the system shall activate CTS upon completion of internal processing necessary to accept data for transmission.

Once the Clear to Send (CTS) is granted, RTS shall be held ON until after the last data character is transferred to the EHF equipment. If RTS is dropped for any length of time, any data input during that period may be ignored by the system, even though CTS remains ON.

The operator shall have the capability to configure the port with respect to whether an RTS signal is required for full duplex circuits. If it is configured for 'no RTS required,' the terminal shall continuously transmit the data on the TXDATA signal line. If the service is half-duplex or the port is configured for 'RTS required', the terminal shall accept the RTS signal.

4.5.1.3.2.1.2.7 Clear To Send (CTS)

CTS shall be a balanced control signal output by the system. This signal indicates to the baseband user system whether the system will accept data for transmission. If CTS is OFF or RTS is OFF, the system may ignore all data input on the TXDATA line. If CTS is ON and RTS is ON, the system shall transmit all data input on the TXDATA line. If the service is full duplex and the port is configured for 'no RTS required', then the system shall assume continuous transmission is desired by the user equipment, request permission to transmit from the satellite as soon as the service is activated, and set CTS ON after receiving transmission permission from the satellite.

4.5.1.3.2.1.2.8 Receiver Ready (RR)

RR shall be a balanced control signal output by the system. This signal indicates to the baseband user system whether the system is outputting data on the RXDATA line. The RR signal shall be capable of being initialized by the operator to be either always high (ON) or toggled with respect to whether the system detects valid data on that service (QM TOGGLE). If RR is initialized for ON, a constant stream of data will be output on the RXDATA line. If RR is initialized QM TOGGLE, data will be output on the RXDATA line only when RR is HIGH. The system shall provide a quality monitor algorithm to determine the state of the RR control line. The RR signal shall transition from ON to OFF after a channel error rate of 1.4×10^{-1} or worse has been detected for one block of data. A block of data is defined as 100 ms of data at 4.8 kbps decreasing to 20 ms at 1544 kbps. The RR signal shall transition from OFF to ON after a channel error rate of 8.7×10^{-2} or less has been detected for one block of data, where the block size varies from 60 ms at 4.8 kbps to 20 ms at 1544 kbps.

4.5.1.3.2.1.2.9 Signal Ground/Common Return (SIGND)

A SIGND shall be provided to allow the interface to be cabled as an unbalanced interface for low speed data in accordance with MIL-STD-188-114 recommendations. If the user equipment connections use balanced drivers and receivers, this line will not be used.

4.5.1.3.2.1.2.10 Chassis Ground (CHGND)

A chassis ground shall be provided.

4.5.1.3.2.1.3 LDR Baseband Iinterface Signals

The LDR communication ports shall have the signal electrical characteristics as specified in Table 3.16. All input signals shall have an input termination impedance of not less than 120 ohms. All output signals shall allow for termination at the user end. Clock and control signal sense shall be in accordance with Table II of MIL-STD-188-114 (for example, negative: 1, MARK, OFF - positive: 0, SPACE, ON). The system shall be able to operate with all output signals of all ports terminated simultaneously with 100 ohm resistors and/or not terminated.

Table 4.16 - EHF LDR Baseband I/O Port Interface Characteristics

Signal			
1.	CLEAR TO SEND-P CLEAR TO SEND-N	Modem Ready for Data	O
2.	RECEIVER READY-P RECEIVER READY-N	Carrier Being Received	O
3.	REQUEST TO SEND-P REQUEST TO SEND-N	Baseband Ready to Send Data	I
4.	XMT CLOCK-P XMT CLOCK-N	Timing for Transmit Data	O
5.	XMT DATA-P XMT DATA-N	75 bps - 2.4 Kbps Transmit Data	I
6.	RCV CLOCK-P RCV CLOCK-N	Timing for Receive Data	O
7.	RCV DATA-P RCV DATA-N	75 bps - 2.4 Kbps Receive Data	O
8.	EXT XMT CLOCK-P EXT XMT CLOCK-N	Transmit Phase Correction Timing	I
9.	RCV TDMA CLOCK-P RCV TDMA CLOCK-N	Downlink Timing for Time Division Multiple Access (TDMA) Controller	O
10.	XMT TDMA CLOCK-P XMT TDMA CLOCK-N	Uplink Timing for TDMA Controller	O
11.	Signal GND		
12.	CHASSIS GND		

* Note: The electrical characteristics for items 1 through 10 are all MIL-STD-188-114 (inverted) low level + or - 6 VDC signals.

When the signals are part of a balanced interface, the "P" after the signal name refers to the positive connection and the "N" to the negative connection. When the signals are part of an unbalanced interface, the "P" refers to the signal line and the "N" to the signal return.

4.5.1.3.2.1.4 DSCS Equipment Group

The DSCS equipment group shall include an internal modem (or modems) which supports the waveforms specified in 3.1.2.1.2 and shall provide a baseband interface compatible with shipboard baseband systems, as follows:

a. One full duplex black I/O port shall be provided that is capable of operating at data rates up to 1544 kbps.
b. The DSCS unclassified I/O port shall be interoperable with KG-194A cryptographic equipment via ADNS equipment.
c. The DSCS black I/O port interfaces shall be as specified in Table 3.17.

Table 4.17 - DSCS Baseband I/O Port Interface Requirements

Physical characteristics:	EIA/TIA 530A
Electrical characteristics:	RS-422A for balanced circuits RS-423A for unbalanced circuits
Control signals: Clock, Data RTS, CTS, DCD, DTR	 Balanced/Unbalanced Inverted/Non-inverted
Receive clock:	Data-Derived
Transmit clock:	Internal/External
Clock tolerance:	± 0.1% of Nominal Data Rate
EIA/TIA 530A Circuit Mnemonic	Circuit Identification
AB	System signal ground
BA	Transmit data
RR	Receive data
CA	Request to send
CB	Clear to send
CF	Data carrier detect
CD	Data terminal equipment (DTE) ready
DA	External transmit clock
DB	Transmit clock
DD	Receive clock

4.5.1.3.2.2 External IF Interface (DSCS only)

The communications support group shall provide an external 70 megahertz (MHz) IF interface capable of transmit and receive operation. External IF interfaces shall be as specified below.

4.5.1.3.2.2.1 External Transmit IF Interface

The system transmit RF chain shall provide a 70 MHz IF interface for an external modem. This interface shall have the following characteristics.

4.5.1.3.2.2.1.1 Nominal Center Frequency

The system transmit RF chain shall accept IF signals with nominal center frequencies of 70 MHz.

4.5.1.3.2.2.1.1.1 Instantaneous IF Bandwidth

The transmit chain shall provide an instantaneous 1 dB IF bandwidth of 40 MHz at the 70 MHz input.

4.5.1.3.2.2.1.1.2 Impedance

The transmit chain shall have a nominal input impedance of 50 ohms.

4.5.1.3.2.2.1.1.3 Power Level

The transmit chain shall accept IF signals with power levels in the range of -20 decibels referenced to one milliwatt (dBm) to 0 dBm. The transmitter external input shall withstand an input level (from either a single or a combined input signal) +20 dBm without damage.

4.5.1.3.2.2.1.1.4 Voltage Standing Wave Ratio (VSWR)

The transmit chain IF input VSWR shall be 1.25:1 maximum over the IF bandwidth.

4.5.1.3.2.2.1.1.5 Transmit Phase Linearity

The IF-to-RF phase response of the DSCS transmission function shall not deviate from linear by more than the following amounts when operating at rated EIRP less 6 dB.

a. ± 0.1 radian over the center 60 percent of any 40 MHz portion of the RF transmit band.

b. ± 0.25 radian over the center 80 percent of any 40 MHz portion of the RF transmit band.

4.5.1.3.2.2.1.1.6 Transmit amplitude response

The IF-to-RF amplitude variation of the DSCS transmission function shall not exceed the following amounts when operating at rated EIRP less 6 dB.

a. ± 1.0 dB over the center 60 percent of any 40 MHz portion of the RF transmit band.

b. ± 2.0 dB over the center 80 percent of any 40 MHz portion of the RF transmit band.

4.5.1.3.2.2.2 External Receive IF Interface

The system receive chain shall provide a 70 MHz IF interface for an external modem. This interface shall have the following characteristics.

4.5.1.3.2.2.2.1 Nominal Center Frequency

The terminal receive chain shall provide IF signals with nominal center frequencies of 70 MHz.

4.5.1.3.2.2.2.2 Instantaneous IF Bandwidth

The receive chain shall provide an instantaneous 1 dB IF bandwidth of 40 MHz at the 70 MHz output.

4.5.1.3.2.2.2.3 Impedance

The terminal receive chain IF output shall have a nominal output impedance of 50 ohms.

4.5.1.3.2.2.2.4 Power Level

The terminal shall be capable of providing 70 MHz IF output signals at a power level of -50 dBm ±3 dB for a -130 dBm RF signal level at the antenna input.

4.5.1.3.2.2.2.5 VSWR

The terminal receive chain IF output VSWR shall be 1.25:1 maximum over the IF bandwidth.

4.5.1.3.2.2.2.6 Dynamic Range

The dynamic range shall be 40 dB minimum.

4.5.1.3.2.3 Navigation

The SEST system shall provide interfaces to the ships navigation systems SNS as specified herein. Interfaces for SNS outputs of own ship's roll, pitch, heading, speed, latitude, longitude, and velocity (N/S - E/W) shall be provided for antenna pointing and tracking. The SEST system shall be capable of being physically configured to interface to two type of navigation systems (analog and digital). If more than one type of navigation is available, the SEST system shall have the capability to connect to either type based on an operator selection. The capability to designate a primary and back-up SNS input data source shall be provided. Both manual and automatic input of latitude and longitude shall be provided.

4.5.1.3.2.3.1 Analog/Synchro

Interface to the ships navigation for analog signals shall be via the interior communications (IC) and navigation switchboard. Synchro outputs for own ship's roll, pitch, heading, speed, latitude, longitude, and velocity (N/S - E/W) at the IC switchboard are 115 VAC, 400 Hz, 3-phase. Analog/synchro navigation data will be provided by the MK-19, WSN-2, WSN-2A, and the EM log.

4.5.1.3.2.3.1.1 Electrically Suspended Gyro Navigator (ESGN)

Interface to the ship navigation for digital signals shall be via the SAE AS15531 bus interface of the data distribution subsystem. Digital navigation data will be provided by the ESGN in accordance with NAVSEA SE17A-AC-MMF-010/020.

4.5.1.3.2.3.1.2 Global Positioning System (GPS)

The SEST system shall accept GPS data (time and platform location) via the navigation sensor system interface (NAVSSI) (future growth). GPS timing accuracy will be less than 10 sec and position error will be less than 100 meters circular error probability.

4.5.1.3.2.3.1.3 Navigation Transverse Polar Coordinates

The SEST system shall have the capability to convert transverse polar coordinates to true geographical position.

4.5.1.3.2.4 Water cooling

Any inboard SEST system equipment that requires water cooling shall interface with the shipboard electronic cooling water system. Characteristics of shipboard electronic water systems are contained in the applicable shipbuilder s specifications.

4.5.1.3.2.5 Prime Power

The SEST system shall operate using prime power specified in Table 3.18. The SEST system equipment shall not be damaged when subjected to all voltage and frequency conditions specified. Equipment shall be fully operational for worst case voltage and frequency conditions. Equipment input power connector pin assignments and conductor color code shall be in accordance with Table 3.20. The color code for conductors shall be maintained from the input connections to all components having the same voltage and frequency as the input power.

4.5.1.3.2.5.1 Power Factor

The SEST system shall operate within the frequency and voltage tolerances specified in TABLE IV with an overall power factor within the range of 0.80 lagging to 0.95 leading for 60 Hz operation under steady state conditions.

4.5.1.3.2.5.2 Equipment Protection

The SEST system shall provide suitable protection to ensure that the equipment is not damaged when exposed to the following conditions:

a. worst case voltage and frequency conditions as specified in Table 4.18

b. momentary interruption and restoration of power

c. prime power bus is superimposed with 500 ± 50 volts direct current (VDC) (full wave rectified voltage)

d. prime power bus produces a voltage spike as specified in Table 4.18

Table 4.18 - Electric Power System Characteristics

Characteristic	Nominal	Tolerance	Worst Case
FREQUENCY			
Frequency	60 Hz	±5.5%	±5.5%
Frequency modulation	0.5%		
Frequency transient		±4%	
Recovery time	2 seconds		
VOLTAGE			
Voltage	440 or 115 V rms[1]	±5%[2] ±7%[3]	
Line voltage unbalanced			
440 V	0.5%		
115 V	1.0%		
Voltage modulation	2%		
Voltage transients		±16%	±20%[4]
Recovery time	2 seconds		
Voltage spike (<1ms)			
440 V		±2,500 V	
115 V		±1,000 V	
WAVEFORM			
Max total harmonic distortion	5%		
Max single harmonic	3%		
Max deviation factor	3%		
EMERGENCY CONDITIONS			
Frequency exclusion[5]		-100% to +12%	
Frequency exclusion duration	up to 2 minutes		
Voltage excursion		-100% to +35%	
Voltage excursion duration	up to 2 minutes (100%), 2 minutes (+35%)		

Notes:

[1] Ungrounded system.

[2] Average of the three line-to-line voltages.

[3] Any one line-to-line voltage including average line-to-line and line voltage unbalanced.

[4] Worst case from nominal user voltage.

[5] Frequency will not decrease to zero without a drop in voltage.

Table 4.19 - Conductor Designations

Equipment Power Supply	Conductor Assignment	Connector Designation	Conductor Color
Single-phase	115/440 VAC	A	White
	115/440 VAC	C	Black
	Safety ground	B	Green
Three-phase	Phase A	A	Black
	Phase B	B	White
	Phase C	C	Red
	Safety ground	D	Green
Note: Shipboard electrical distribution systems are delta-connected with a floating neutral, precluding the use of the safety ground as a power-carrying conductor. Safety ground connections for bonding and grounding are provided for electromagnetic interference (EMI) and personnel safety considerations.			

4.5.1.3.3 Operator Interface

The SEST system shall provide an operator interface locally at the SEST inboard equipment. The SEST system shall also provide an operator interface remotely via the ADNS operator console(s).

4.5.1.3.3.1 ADNS Interface

The ADNS operator console in the radio room will be the tactical advanced computer (TAC) version X using a local area network architecture. The physical layer of the local area network is Ethernet 802.3 compliant using a standard asynchronous universal interface (AUI) connector. The ADNS interface is unclassified only. The protocol for the control is simple network management protocol (SNMP) version 1 requiring a management interface buffer (MIB) that is MIB II compliant. The MIB shall be defined as part of the design and approved by the Government. MIB elements shall be defined with logical rules and ranges of values for proper operation. Traps shall be defined to aid in asynchronous operations. A capability to configure the system, log system activity, monitor system status, initiate built-in test (BIT)/built-in test equipment (BITE), and display fault indications shall be provided to the ADNS operator console. Operator message preparation and circuit configuration will be provided by the ADNS as a minimum, provisions shall be made to allow for remote control of satellite selection, antenna control and status, and BIT feedback.

4.5.1.3.3.2 JMCIS Compliance

The windowing environment for new equipment shall be compliant with the User Interface Specification for the Joint Maritime Command Information System (JMCIS) and JMCIS Supplement to Version 1.0 of the User Interface Specification for the Global Command and Control System (GCCS).

4.5.1.3.4 Transmission Security (TRANSEC) Interface

An interface shall be provided for TRANSEC devices required by the individual equipment groups. The EHF equipment group shall interface with a KGV-11A TRANSEC device.

4.5.1.3.5 Inboard Equipment Group to Antenna Group

Interfaces between the inboard equipment group and the SEST antenna group shall be provided to support SEST system design. If a bus is required, a standard bus protocol (for example, SAE AS15531) shall be used. As a minimum, interfaces shall make provisions for the following:

a. Antenna pointing feedback data to the operator.

b. Monitoring and initiation of the following control and status functions from an ADNS operator console:

1. Power on/off control
2. System initialization
3. System configuration
4. BIT (on-line/off-line)
5. System performance status

4.5.1.3.6 Diagnostic Equipment Interface

The SEST system shall provide an interface for monitoring and recording real-time system performance, control and status data for the purpose of system troubleshooting, engineering analysis, testing and system enhancement development. The interface shall be compatible with standard personal computer I/O port interfaces (for example an RS-232 serial interface). Data output shall allow system diagnostics, system testing and data collection as a function of time in all operating modes. Data output shall be a form that is conducive for real-time use or for collection and analysis at a later time. The following types of information, as a minimum, shall be captured and recorded: antenna position/performance data (This includes antenna position as a function of ephemeris, navigation input (pitch, roll, and heading), downlink SNR all as a function of time for all operating bands and modes), terminal/satellite protocols (This includes all C2/C3 protocol exchanges between the terminal and the satellite as a function of time for EHF operations in all modes), system control bus communications (This includes all data communications between all terminal processors and subsystems and drawers as a function of time for all operating bands and modes), power amplifier status and output power (This includes the level at which the power amplifier is commanded as a function of time for all operating bands and modes), and operator interface communications (This includes all operator commands, operator messages, and operator display information for all operating bands and modes).

4.5.1.4 Characteristics

4.5.1.4.1 EHF Performance

The SEST system shall support both EHF LDR and MDR operation. Unless otherwise specified herein, EHF performance shall be as specified in the Milstar specification SI-1135, SR-2000, SR-2035, and SR-2300

4.5.1.4.1.1 LDR/MDR Signal Modulation Modes

EHF LDR/MDR uplink and downlink signal modulation modes shall be in accordance with SR-2000.

4.5.1.4.1.2 Simultaneous Operation

The SEST system shall provide simultaneous EHF LDR and EHF MDR operation on different downlinks and timeshared EHF LDR and EHF MDR operation on a single uplink.

4.5.1.4.1.3 Transmitter Characteristics

4.5.1.4.1.3.1 Transmitter Frequency

The transmitter (uplink) frequency band shall be from 43.5 to 45.5 GHz.

4.5.1.4.1.3.2 EIRP

The EIRP shall be 65.7 dBW including all pointing losses.

4.5.1.4.1.3.3 Doppler Shift

The SEST system shall provide Doppler shift correction commensurate with a molniya orbit ±3.5 hours from apogee assuming the following worst case ephemeris: 0.1 angle error; 140 km range error; and 16 m/sec range rate error. The maximum frequency step size for Doppler shift correction shall be 50 Hz.

4.5.1.4.1.3.4 Spurious Outputs

Spurious output requirements shall be as specified in SI-2035. The total spurious power in any fixed 1 kHz frequency band in the 2 GHz bandwidth shall not exceed -60 dBc. The total power contributed by fixed spurs shall not exceed -40 dBc.

4.5.1.4.1.3.5 Phase Noise

Phase noise requirements shall be as specified in SI-2035.

4.5.1.4.1.4 Receiver Characteristics

4.5.1.4.1.4.1 Receiver Frequency

The receiver (downlink) frequency band shall be from 20.2 to 21.2 GHz.

4.5.1.4.1.4.2 G/T

The G/T shall be 10.8 dB/K including all pointing losses.

4.5.1.4.1.4.3 Doppler Shift

The SEST system shall provide Doppler shift correction commensurate with a molniya orbit ±3.5 hours from apogee assuming the following worst case ephemeris (30 days old): 0.1° angle error, 140 km range error, and 16 m/sec range rate error. The maximum frequency step size for Doppler shift correction shall be 50 Hz.

4.5.1.4.1.4.4 Dynamic Range

The receive system shall meet the required for all downlink modulation modes over a range from threshold (minimum required radiated power to noise ratio (Pr/No) of the default modulation mode in the weakest beam, 20° look angle, 3 dB down beam contour, 5 dB of weather loss) to 30 dB above threshold or the strongest signal-to-noise ratio (SNR) level in the best beam, whichever is greater. The strongest downlink SNR is based on the strongest beam center of coverage, 90° look angle, satellite and terminal specified performance, and no weather losses.

4.5.1.4.1.4.5 Spurious Response

Spurious response requirements shall be as specified below

4.5.1.4.1.4.5.1 LDR

The SEST system shall support a 10^{-5} BER for all downlink modulation modes when in the presence of a -90 dBW interfering signal within the receive input RF bandwidth. Pr/No shall be assumed to be 2 dB above threshold for each downlink mode.

4.5.1.4.1.4.5.2 MDR

The SEST system shall support a 10^{-5} BER for all downlink modulation modes when in the presence of a -90 dBW interfering signal within the receive input RF bandwidth. Pr/No shall be assumed to be 2 dB above threshold for each downlink mode.

4.5.1.4.1.4.6 Phase Linearity

The deviation from phase linearity shall not exceed ±0.1 radian in any 2 MHz bandwidth randomly selected over the full 20.2 to 21.2 GHz band and measured at the demodulator input.

4.5.1.4.1.5 Antenna Performance

The antenna performance requirements are as follows.

4.5.1.4.1.5.1 Transmit Polarization

The transmit polarization shall be as specified herein:

a. The antenna transmit polarization shall be right hand circular polarization (RHCP).

b. The axial ratio shall be 4 dB maximum including the radome.

4.5.1.4.1.5.2 Transmit Sidelobe Levels

The transmit sidelobe levels shall be no greater than the levels indicated in Figure 4.14 for both principal and cross polarization.

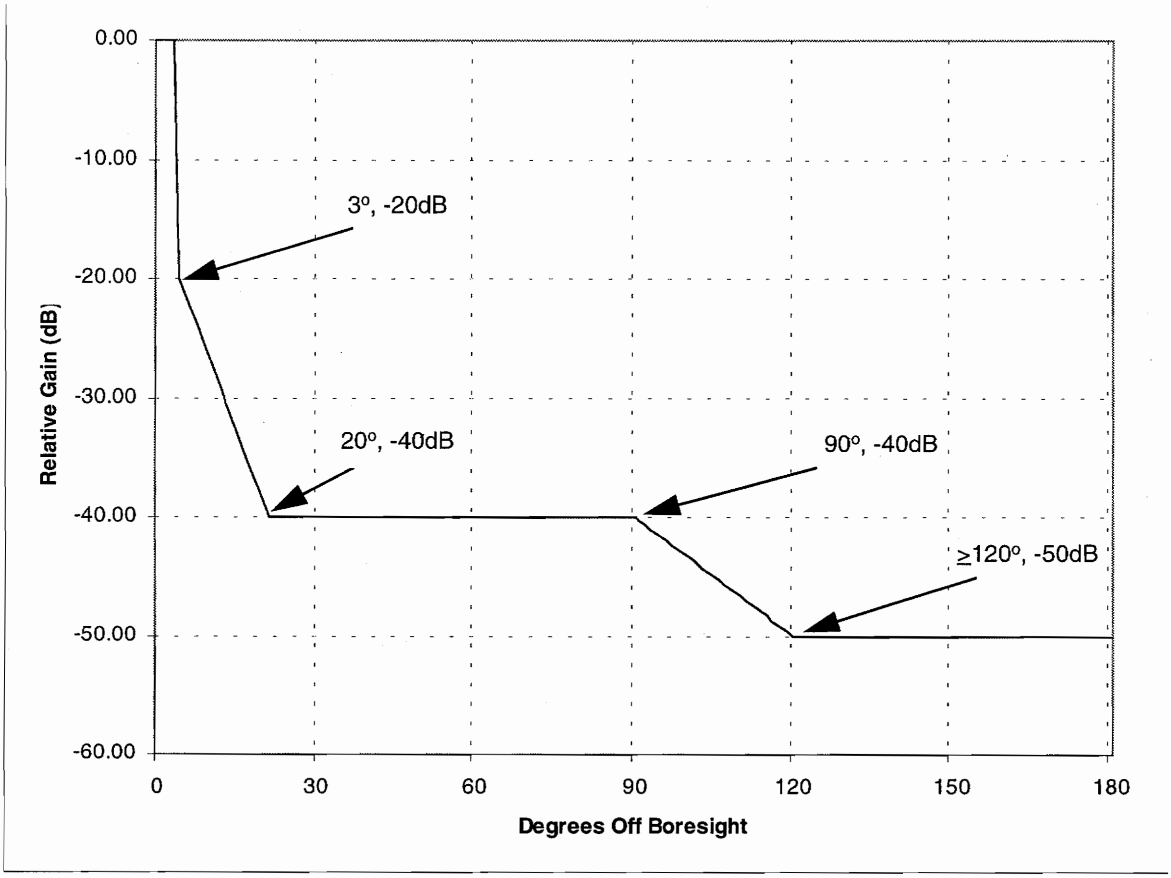


Figure 4.14 - EHF Transmit Sidelobe Level

4.5.1.4.1.5.3 Transmit/Receive Isolation

The transmit/receive isolation shall be sufficient to meet the required BER when transmitting at maximum power output in full duplex operation.

4.5.1.4.1.5.4 Receive Polarization

The antenna receive polarization shall be as specified herein:

a. The antenna receive polarization shall be RHCP.

b. The axial ratio shall be 4 dB maximum including radome.

4.5.1.4.1.5.5 Receive Sidelobe Levels

The antenna receive sidelobe levels shall be no greater than the levels indicated in Figure 4.15 for both principal and cross polarization.

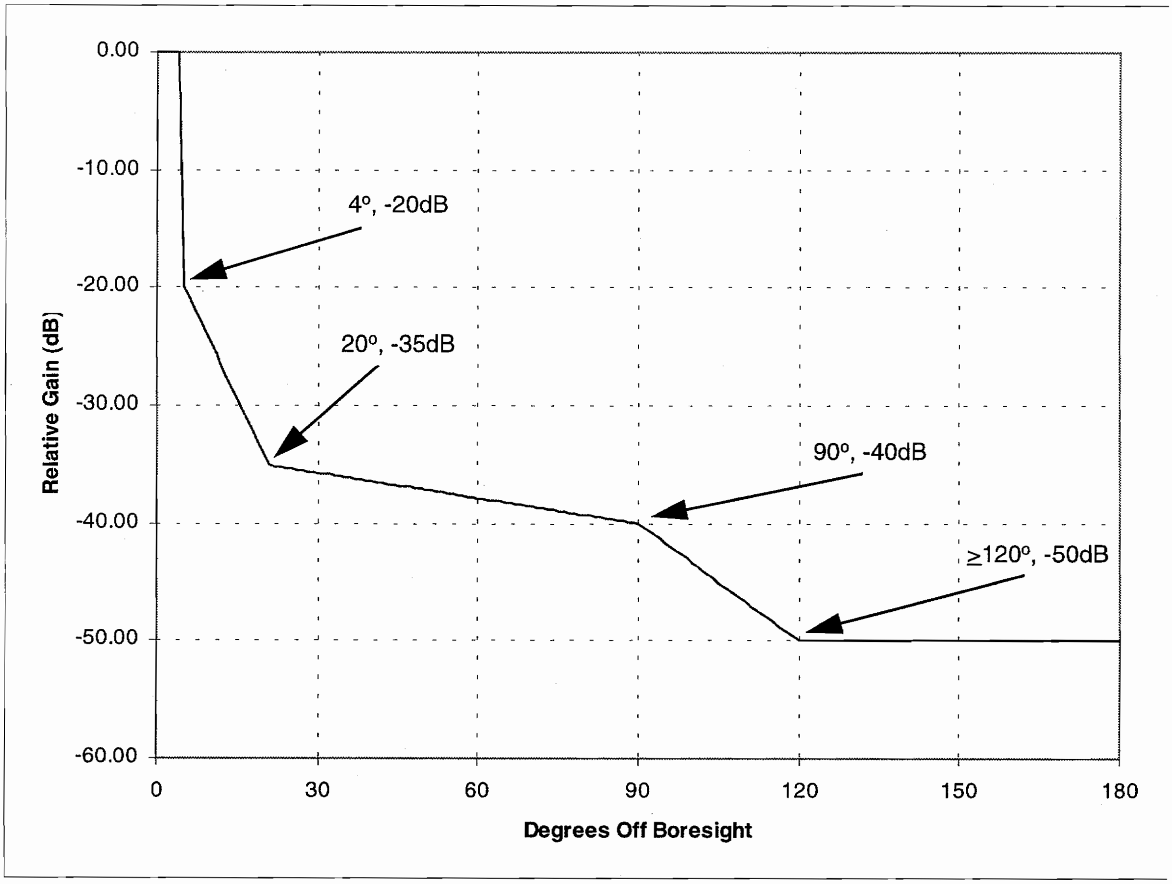


Figure 4.15- EHF Receive Sidelobe Level

4.5.1.4.1.5.6 Pointing

The SEST system shall be capable of antenna pointing at an elevation angle ≥ 20 above the horizon with full platform dynamics. The antenna shall not be inhibited from pointing at satellites down to 0° with full platform dynamics. Uplink pointing error shall be less than or equal to 1 dB with full platform dynamics.

4.5.1.4.2 DSCS Performance

The DSCS portion of the SEST shall provide for one transmit carrier and one receive carrier (if necessary, an additional receive carrier for the satellite beacon signal may be employed).

4.5.1.4.2.1 Operating RF Band

The DSCS equipment group shall transmit and receive multiple RF carriers within the instantaneous bands specified in a and b with up to the maximum number of carriers specified.

a. Instantaneous RF transmit band: 7.90 GHz to 8.40 GHz in 10 kHz tuning increments.

b. Instantaneous RF receive band: 7.25 GHz to 7.75 GHz in 10 kHz tuning increments

4.5.1.4.2.2 RF Carriers

The DSCS equipment group shall provide the capability to operate with one transmit communications carrier and one receive communications carriers. Each communications RF carrier shall be capable of accommodating continuous wave (CW), phase shift keying (PSK), and frequency shift keying (FSK). Frequency, time, and code division multiple access schemes shall be supported. If a beacon carrier signal is required for satellite or modem tracking, the equipment group shall be capable of tracking satellite beacon signals with a minimum EIRP of 12 dBW with no modulation or biphase modulation to 800 Hz.

4.5.1.4.2.3 EIRP

The SEST system SHF EIRP shall be no less than 50.6 dBW.

4.5.1.4.2.4 G/T

The SEST system SHF G/T shall be 10.5 dBi.

4.5.1.4.2.5 Transmit Performance

The transmitter shall provide a transmit signal with the following characteristics

4.5.1.4.2.5.1 Harmonic Outputs

The EIRP of any single harmonic of the fundamental shall be at least 60 dB below the EIRP of the fundamental.

4.5.1.4.2.5.2 Residual Amplitude Modulation (AM)

The residual AM, with one carrier anywhere in the transmit band operating at rated output level, shall be at least 46 dB below carrier level.

4.5.1.4.2.6 Carrier Frequency Selection

The system shall provide tuning of each transmit RF carrier signal over the total transmit band of 3.2.2.1 in tuning steps not greater than 10 kHz. Each RF carrier frequency shall be accurate to within 10^{-7} with no Doppler correction applied.

4.5.1.4.2.6.1 Bandwidth

The transmit chain shall be capable of amplifying a signal anywhere in the 500 MHz band (7.9 GHz to 8.4 GHz). The instantaneous -1 dB bandwidth shall be not less than 40 MHz.

4.5.1.4.2.6.2 EIRP Range

The terminal transmit gain shall be adjustable over a total range of at least 10 dB in 2 dB maximum steps with ± 1 dB accuracy.

4.5.1.4.2.6.3 Doppler Compensation

The internal modem shall compensate for Doppler frequency shift due to relative motion between the ship and the satellite. Frequency variations due to simultaneous satellite and ship motions shall be accommodated. Full terminal operation, including the modem, shall be obtained in the presence of Doppler stress effects due to full platform dynamics.

4.5.1.4.2.7 Antenna Performance

Antenna performance shall be as contained herein.

4.5.1.4.2.7.1 Pointing

The SEST system shall be capable of antenna pointing at an elevation angle $\geq 20^\circ$ above the horizon with full platform dynamics. The antenna shall not be inhibited from pointing at satellites down to 0° elevation with 50 percent platform dynamics.

4.5.1.4.2.7.2 Mainlobe Radiation Pattern

The antenna mainlobe shall be a single beam with its transmit and receive RF beams boresighted within ± 0.5° of one another over the specified transmit and receive frequency bands.

4.5.1.4.2.7.3 Sidelobe Radiation Pattern

The gain of the antenna shall lie below the specified envelopes:

$$G = 32 - 25 \, \mathrm{Log}_{10}(\varphi) \text{ dBi for } (100\lambda/D)^{\circ} \leq \varphi \leq 48^{\circ}$$
$$G = -10 \text{ dBi for } 48^{\circ} \leq \varphi \leq 180^{\circ}$$

where:
G = the gain relative to an isotropic antenna
φ = the angle in degrees from the axis of the mainlobe in the direction of the geostationary orbit
D = diameter of the antenna
λ = wavelength
dBi = decibels above isotropic

A graphical representation of this antenna gain is shown in Figure 4.16 below assuming a 36" parabolic dish antenna.

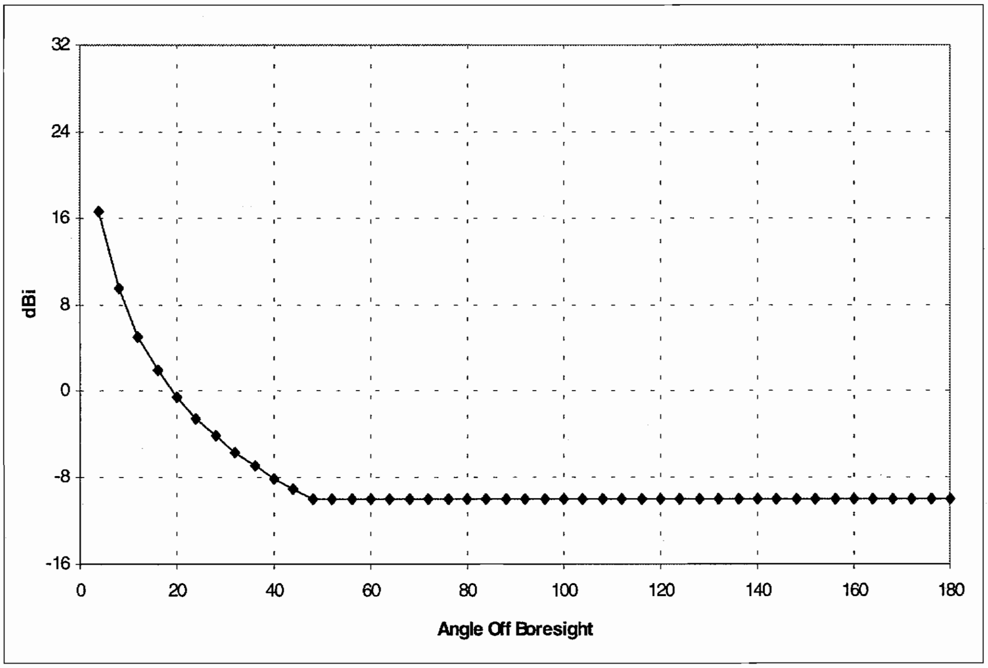


Figure 4.16 - SHF Sidelobe Radiation Pattern

Not more than 10 percent of the sidelobe peaks shall exceed this envelope.

4.5.1.4.2.7.4 Polarization

The antenna shall be right-hand (clockwise) circularly polarized for transmission and left-hand (counterclockwise) circularly polarized for reception.

4.5.1.4.2.8 Communications Support Group External IF Port Performance (DSCS Only)

4.5.1.4.2.8.1 External IF Transmit Characteristics

The external IF transmit port shall provide a translated transmit signal from 70 MHz with the characteristics specified herein.

4.5.1.4.2.8.1.1 Phase Linearity

The IF-to-RF phase response of the DSCS transmission function shall not deviate from linear by more than the following amounts when operating at rated EIRP less 6 dB.

a. ±0.1 radian over the center 60 percent of any 40 MHz portion of the RF transmit band.

b. ±0.25 radian over the center 80 percent of any 40 MHz portion of the RF transmit band.

4.5.1.4.2.8.1.2 Amplitude Response

The IF-to-RF amplitude variation of the DSCS transmission function shall not exceed the following amounts when operating at rated EIRP less 6 dB.

a. ±1.0 dB over the center 60 percent of any 40 MHz portion of the RF transmit band.

b. ±2.0 dB over the center 80 percent of any 40 MHz portion of the RF transmit band.

4.5.1.4.2.8.1.3 Spectral Purity

The single-sideband power spectral density of the continuous component of the phase noise component shall not exceed the envelope defined by the following:

Frequency offset from carrier	Power spectral density
10 Hz	-35 dBc-Hz
100 Hz	-65 dBc-Hz
1 kHz	-75 dBc-Hz
10 kHz	-85 dBc-Hz
100 kHz	-95 dBc-Hz
1 MHz	-95 dBc-Hz

A spurious component at the fundamental alternating current (AC) line frequency shall not exceed -30 dBc. The single sideband sum (added on a power basis) of all other individual spurious components shall not exceed -36 dBc.

4.5.1.4.2.8.1.4 Transmit Extraneous Outputs

The EIRP of white noise, extraneous, and spurious emissions, excluding harmonics and intermodulation products, shall be no greater than 4 dBW when measured in a 4-kHz bandwidth when operating at rated EIRP.

4.5.1.4.2.8.1.5 Harmonic Outputs

The EIRP of any single harmonic of the fundamental shall be at least 60 dB below the EIRP of the fundamental.

4.5.1.4.2.8.1.6 AM to Phase Modulation (PM) Conversion

The AM to PM conversion shall be no more than 8 degrees per dB for transmission function operation at output back-off from rated EIRP of less than 6 dB and shall be no more than 4 degrees per dB for transmission function operation at greater than 6 dB back-off from rated EIRP.

4.5.1.4.2.8.1.7 Spectrum Inversion

There shall be no inversion of the spectrum between any IF input and the transmit port of the antenna feed assembly. Frequency translation shall be accomplished without inverting the logic or signal sense of the data stream.

4.5.1.4.2.8.1.8 Transmit Phase Variation

The rate of change imposed on the RF output phase shall not exceed 20 per 0.2 second time interval with a stable phase IF input signal.

4.5.1.4.2.8.2 Carrier Frequency Selection

The system shall provide tuning of a transmit RF carrier signal over the total transmit band in tuning steps not greater than 10 kHz. The frequency of the RF carrier shall be accurate to within 10^{-7} with no Doppler correction applied.

4.5.1.4.2.8.3 Bandwidth

The transmit chain shall be capable of amplifying the signal from an external modem. The instantaneous -1 dB bandwidth shall be not less than 40 MHz for a 70 MHz signal.

4.5.1.4.2.8.4 Gain

The maximum gain of the terminal shall be such that the single carrier specified EIRP can be attained with a single IF input from an external modem at a level not greater than -10 dBm.

4.5.1.4.2.8.5 Gain Adjustment Range

The terminal transmit gain shall be adjustable over a total range of at least 10 dB in remotely programmable 2-dB steps with ±1 dB accuracy.

4.5.1.4.2.8.6 Gain Stability

With the transmit chain operating in its linear region and a single, constant level IF carrier input, the EIRP of the terminal shall vary not more than ±1.5 dB in any 24-hour period or more than ±1 dB in any 15-minute period and over the operating temperature range specified herein.

4.5.1.4.2.8.7 Doppler Compensation

When the external modem interface is used, the system shall not provide transmit Doppler compensation.

4.5.1.4.2.8.8 Transmit Noise

The terminal broadband noise spectral density, EIRP (No), shall not exceed -70 dBc when measured in a 1-kHz resolution bandwidth at an offset of ± 1 MHz from the carrier when the transmitter is operating at -6 dB back-off.

4.5.1.4.2.8.9 External IF Receive Characteristics

The external IF receive port shall provide a translated receive signal at 70 MHz with the characteristics specified in a through I.

4.5.1.4.2.8.9.1 Phase Linearity

The RF-to-IF phase response of the DSCS reception function shall not deviate from linear by more than the following amounts:

a. ±0.1 radian over the center 60 percent of any 40 MHz portion of the RF receive band.
b. ±0.25 radian over the center 80 percent of any 40 MHz portion of the RF receive band.

4.5.1.4.2.8.9.2 Amplitude Response

The RF-to-IF amplitude variation of the DSCS reception function shall not exceed the following amounts:

a. ±1.0 dB over the center 60 percent of any 40 MHz portion of the RF receive band.
b. ±2.0 dB over the center 80 percent of any 40 MHz portion of the RF receive band.

4.5.1.4.2.8.9.3 Spectral Purity

The spectral purity of any translated carrier using an external reference shall be as defined herein.

4.5.1.4.2.8.9.4 Receive Spurious Output

The sum total of spurious signal power measured at the 70 MHz IF output shall be at least 20 dB below the system noise power measured in a 40 MHz bandwidth with maximum signal into the LNA. No spurious signal shall be greater than an equivalent signal 10 dB below the noise level in a 50 kHz bandwidth at the LNA input. Conformance to the requirements of this paragraph shall be achieved when transmitting a carrier at maximum EIRP and simultaneously receiving two equal-level carriers whose total power equals that of the maximum expected signal level at the input to the LNA.

4.5.1.4.2.8.9.5 Phase Errors

Phase errors (perturbations) introduced by the downconversion process shall not change the phase of the IF carrier by a rate of more than 20 degrees per 0.2-second interval with a phase stable RF signal present at the antenna.

4.5.1.4.2.8.9.6 Receive Spectrum Inversion

There shall be no inversion of the spectrum between the receive port of the antenna feed assembly and the external IF output.

4.5.1.4.2.8.9.7 Transmit to Receive Isolation

Isolation of the receive chain from energy generated by the transmit chain shall be as required to conform to the spectral purity requirements.

4.5.1.4.2.8.9.8 Rejection of Out-of-Band Frequencies

The receive chain shall provide rejection of out-of-band signals as specified in a through c for DSCS satellites.

a. Greater than 65 dB below 5.9 GHz.
b. Greater than 50 dB from 5.9 GHz to 6.6 GHz.
c. Greater than 50 dB from 8.5 GHz to 9.6 GHz.

4.5.1.4.2.8.9.9 Susceptibility to High In-Band Signals

The receive chain shall withstand a continuous input carrier level of +20 dBm anywhere in the operating frequency range without damage or alteration of the electrical characteristics after removal of the high level in-band signals.

4.5.1.4.2.8.10 Receive Carrier Frequency Selection

The system shall provide tuning of each receive RF carrier signal over the total receive band of 3.2.2.1 in tuning steps not greater than 10 kHz. The frequency of the IF signal shall be accurate to within 10^{-7} with no Doppler correction applied.

4.5.1.4.2.8.11 Gain and Stability

The net, overall receive gain of the system (antenna input to modem IF interface) shall be 80 dB nominal. For each modem IF interface, the gain shall be capable of independent attenuation over a minimum range of 30 dB in 1-dB steps. The gain shall vary not more than +1 dB to -1.5 dB in any 24-hour period or more than +1 dB in any 15-minute period for all operating environmental conditions.

4.5.1.4.2.8.12 Receiver Dynamic Range

The receiver shall conform to all specified performance requirements for signal power levels at the input to the antenna ranging from -160 dBm to -120 dBm.

4.5.1.4.2.8.13 Doppler Compensation

The internal modem of the system shall to compensate for Doppler frequency shift due to relative motion between the ship and the satellite. Frequency variations due to simultaneous satellite and ship motions shall be accommodated. Full terminal operation, including the modem, shall be obtained in the presence of Doppler stress effects due to full platform dynamics.

4.5.1.4.3 Antenna Stabilization and Tracking

The SEST system shall point the antenna and track the EHF LDR and MDR and DSCS SHF satellite under full platform dynamic conditions.

4.5.1.4.3.1 Antenna Pointing Accuracy

The antenna controller shall provide antenna pointing accuracy to support link performance for any frequency range while exposed to at-sea conditions up to and including sea state 5 or dockside conditions (zero ship velocity). The SEST system shall not depend on antenna installation location accuracy to meet the specified performance.

4.5.1.4.3.2 Communications Duration

The system shall maintain the specified antenna pointing accuracy continuously with no loss of communications.

4.5.1.4.3.3 Acquisition Time

4.5.1.4.3.3.1 EHF Acquisition Time

The SEST downlink acquisition time shall be less than 2 minutes. Uplink acquisition time shall be less than 2 minutes assuming no contention. Acquisition time shall include errors attributed to old ephemeris as specified in SI-1135, navigation errors of ± 1 nautical mile and time standard drift of 150 μsec.

4.5.1.4.3.3.2 DSCS Acquisition Time

The SEST system shall be able to acquire a satellite in 5 minutes or less under full platform dynamics. The terminal shall be capable of conforming to the acquisition time using only the nominal beacon frequency and the satellite's nominal suborbital points of latitude and longitude. Other satellite parameters, such as satellite oscillator frequency offset and other ephemeris data, shall not be required.

4.5.1.4.3.4 Antenna Pointing Tests

The antenna stabilization and tracking shall have provisions for conducting antenna pointing non-operational tests which exercise the antenna pedestal's full range of motion and verify that the antenna has been pointed correctly and maintains specified pointing accuracy under full platform dynamics. Each axis of the antenna shall be tested separately.

4.5.1.4.3.5 Range of Motion

The antenna stabilization and tracking shall have the capability to command the antenna pedestal from +20° to +90° in elevation earth reference and 360° in azimuth under full platform dynamics. The antenna stabilization and tracking performance shall not exhibit a "keyhole" effect. The antenna shall not be inhibited from pointing at satellites down to 0° elevation with full platform dynamics.

4.5.1.4.3.6 Ship Dynamic Attitude

The SEST system shall provide the specified performance with the following platform dynamic characteristics.

a. Maximum speed of 20 knots.
b. Roll: 12 second period, ± 30 amplitude.
c. Pitch: 6 second period, ± 10 amplitude.
d. Heading: 3°/second.
e. Heave: 1 knot maximum.
f. Sea state: up to and including sea state 5.

4.5.1.4.3.7 Antenna Non-Operating State

When in the non-operating state (power off) the SEST Antenna Group shall meet the requirements specified herein:

4.5.1.4.3.7.1 Environmental

When subjected to the required environmental conditions, damage to the antenna and pedestal shall be prevented.

4.5.1.5 Physical Characteristics

4.5.1.5.1 Inboard Equipment Dimensions

Inboard SEST system equipment shall not exceed 48.26 centimeters (cm) (19 inches) in width nor 55.8 cm (22 inches) in depth (including mating connectors and clamps) (one standard 19-inch shipboard rack). Front panel controls, indicators, and handles shall not protrude more than 11.43 cm (4.5 inches) from the mounting surface of the rack. EIA 310-C provides guidance for critical dimensions to ensure compatibility between racks, panels, and equipment mounting rails. SEST system maximum rack height shall be 66 inches. Cable bend radius shall not exceed 30.48 cm (12 inches).

4.5.1.5.2 Antenna Group Weight and Dimensions

The weight of the SEST antenna group shall not exceed 1200 pounds.

4.5.1.5.3 SEST System Weight

The cumulative weight of the SEST system shall not exceed 2200 pounds excluding the antenna group.

4.5.1.5.4 Radome Water Shedding Capability

The radome water shedding capability shall be as specified herein:

a. The outer surface of the radome shall have an inherent capability to shed salt water such that transmitted power through the wetted surface is at least 90% as compared to a dry radome surface within 7.5 seconds after being removed from salt water.

b. The salt water droplets on the radome surface shall have a contact angle of at least 85° and the salt water adhesion to the surface shall be such that a 0.5 cubic centimeter droplet shall begin to run off at an angle of 30° or less.

c. If temporary coatings such as wax are used to achieve the performance requirements in a and b then this coating shall retain its performance properties for a minimum of 100 days when subjected to a shipboard at-sea environment.

4.5.1.5.5 Handling

SEST inboard equipment weighing more than 46 kilograms (100 pounds) shall be provided with lifting features which will accommodate a 26 mm (1-inch) line. The center of gravity and the weight of equipment shall be distinctly marked in accordance with ASTM F 1166. "LIFT HERE" shall be marked adjacent to the lifting area. Handles or bails shall be provided for removing units or chassis from enclosures. Handles or bails on the front panels of equipment shall be positioned to protect the front panel instruments and controls when the unit or chassis are withdrawn and when the front panel is placed in a down position. Equipment weighing 23 kilograms (50 pounds) to 46 kilograms (100 pounds) shall require two-man lifting and shall provide handles and grasp areas as defined in ASTM F 1166. The weight shall be clearly marked on the external surface of the equipment and readily visible during installation and removal. The marking shall be as permanent as the normal life expectancy of the unit to which it is applied. All removable line replaceable units (LRUs) or carried units weighing 4.5 kilograms (10 pounds) or more shall be provided with handles or other suitable means for grasping, handling, and carrying as specified in ASTM F 1166.

4.5.1.5.6 Portability and Load Carrying

SEST equipment shall meet the requirements of ASTM F 1166 and provide suitable protection against damage to components.

4.5.1.6 System Quality Factors

4.5.1.6.1 Reliability

The reliability design for inboard mission critical equipment and all outboard equipment shall be as follows. SEST equipment reliability shall be calculated using a reliability model for continuous usage systems.

4.5.1.6.1.1 System Reliability Requirements

The SEST system shall have a mean time between failure (MTBF) of 1250 operating hours. The MTBF shall include all hardware faults and critical software errors.

4.5.1.6.2 Maintainability

The system maintainability design shall be compatible with the following concepts.

4.5.1.6.2.1 System Mean Time to Repair (MTTR)

4.5.1.6.2.1.1 Organizational level (O-level)

O-level corrective maintenance shall be performed on inboard components only. Inboard equipment shall have an MTTR of not more than 1.0 hour, with 95% confidence level. The maximum corrective maintenance time (Mmaxct) 3.0 hours to the 95% percentile when corrective maintenance is accomplished by the replacement of lowest subassemblies (printed wiring boards/modules) and chassis-mounted components. The corrective maintenance time includes localization, isolation, disassembly, interchange, reassembly, alignment, and checkout using standard shipboard general purpose electronic test equipment (GPETE). The use of any special support equipment (for example, tool, extender cable, extender card, test equipment, etc.) to support corrective maintenance shall be provided as part of each SEST system.

4.5.1.6.2.1.2 Intermediate level (I-level)

I-level corrective maintenance shall be performed on outboard components. Lowest subassembly and component replacement of the SEST antenna group shall be performed at the I-level repair facility by a Navy "A" school technician graduate. The SEST antenna group shall interface to a test set that will provide BIT/BITE indications to support troubleshooting to the lowest subassembly level for removal and replacement. The MTTR at the I-level shall not exceed 4 hours with a 95% confidence level. The Mmaxct shall be 12 hours to the 95% percentile. The MTTRs shall not include either removal and replacement of the SEST Antenna Group or hydrostatic pressure tests, when applicable. Overhauls of system equipment will be performed at the depot level (D-level).

4.5.1.6.2.2 Preventive Maintenance

There shall be no preventive maintenance for the system during a 90-day period which will take the equipment off-line. Preventive maintenance between 90-day missions shall not exceed 8 hours in total with no single task exceeding 2 hours.

4.5.1.6.2.3 Test Monitoring and Diagnostic Equipment (TMDE)

The SEST equipment shall contain the test provisions specified herein.

4.5.1.6.2.3.1 Class A Test Provisions

Class A test provisions shall provide a means to verify that the on-line equipment is operating properly. At least 96% of the failures shall be detected and reported on-line. Failures shall be localized to the SEST Inboard Equipment Group, SEST Antenna Group, or loss of any system interface (e.g., water cooling, navigation, timing, etc.). In addition, the SEST system shall provide the capability of an on-line satellite loop-back test. All failures shall be reported via the operator interface as a detected failure, with any further localization or isolation information as may be available from the on-line TDME. Class A test provisions shall be energized automatically without operator's initiation and shall not affect terminal operations. Use of external support equipment is prohibited.

4.5.1.6.2.3.2 Class B Test Provisions

Class B test provisions shall provide a means to fault isolate at least 85% of the system failures to a single replaceable unit (RU), either on-line, off-line or a combination of the two. Ambiguous faults shall be reported to a specific RU unless there is at least a 98% confidence factor that the failure of the tested function is due to the failure of that RU. Failures shall be reported via the operator interface. Means for manual fault isolation to one RU shall be provided for faults which result in ambiguity groups (more than one RU involved). Use of external support equipment for manual isolation is acceptable. Use of Maintenance Assistance Modules (MAMs) is prohibited.

4.5.1.6.2.3.3 Class C Test Provisions

Class C test provisions shall provide a means for the SEST Antenna Group, removed form the ship and connected to the IMA test station, to verify the equipment is operating properly. At least 98% of the failures shall be detected and reported at the IMA test station. At least 90% of the failures detected shall be isolated to a single RU and reported at the IMA test station. Ambiguous faults shall not be reported to a specific RU unless there is at least a 98% confidence factor that the failure of the tested function is due to the failure of that RU. Means for manual fault isolation to one RU shall be provided for faults which result in ambiguity groups (more than one RU involved). Use of external support equipment for manual isolation is acceptable. Confidence factor (CF) for a given function shall be defined as follows:

$$CF = \frac{Fr_{on} \times 100}{Fr_{off} + Fr_{on}}$$

where:

- Fr_{on} is the sum of the piece part failure rates of all components involved in the tested function located on any of LRUs to be identified as failed.
- Fr_{off} is the sum of the piece part failure rates of all components involved in the tested function not located on any of the LRUs to be identified, less failure rates, of those components in the group involved in the tested function which have been declared good due to an earlier test in the testing sequence.

4.5.1.7 Environmental Conditions

System equipment shall withstand the following environmental conditions during transportation, storage, and operation and shall be capable of continuous and reliable operation under the specified environmental conditions.

4.5.1.7.1 Transportation and Storage

4.5.1.7.1.1 Altitude, Non-Operating

SEST system equipment performance shall not be degraded after transportation in an unpressurized cargo bay of an aircraft at an altitude of 15,000 feet.

4.5.1.7.1.2 Temperature

System outboard equipment shall meet specified performance requirements after being subjected to a non-operating temperature range of - 62° C to + 71° C. System inboard equipment shall meet specified performance requirements after being subjected to a non-operating temperature range of - 40° C to +71° C.

4.5.1.7.2 Operation

4.5.1.7.2.1 Temperature

4.5.1.7.2.1.1 Outboard Equipment Low and High Temperature

The SEST antenna group shall meet the performance requirements of this specification when exposed to a low temperature of -54° C and a high temperature of 65° C (including the effects of solar radiation).

4.5.1.7.2.1.2 Inboard Equipment Low and High Temperature

Inboard equipment shall meet the performance requirements of this specification while operating down to a temperature of 0° C and up to a temperature of 50° C.

4.5.1.7.2.2 Power-On Conditions

The SEST system shall be fully operational within 5 minutes of initial power on for operating temperature of 0° C and above. For operating temperatures below 0° C, the SEST system shall be fully operational within 10 minutes of initial power on.

4.5.1.7.2.3 Solar Radiation

Outboard system components shall not sustain any detrimental actinic effects (for example, discoloration, decomposition, or delamination) when exposed to solar radiation.

4.5.1.7.2.4 Wind Effects

System outboard components shall operate within performance requirements when exposed to winds having a relative velocity of 75 knots and shall withstand, without damage, winds having a relative velocity as great as 100 knots.

4.5.1.7.2.5 Humidity

System inboard equipment shall meet performance requirements without degradation when exposed to a relative humidity of 95% non-condensating for up to 8 hours.

4.5.1.7.2.6 Shock

4.5.1.7.2.6.1 Inboard Equipment

Inboard mission critical equipment shall meet performance requirements without any degradation when subjected to shock as specified in MIL-S-901, Grade A, Class I, Type A.

4.5.1.7.2.6.2 Outboard Equipment

System outboard equipment shall meet performance requirements without any degradation when subjected to shock as specified in MIL-S-901.

4.5.1.7.2.7 Vibration

System equipment shall meet performance requirements without any degradation when subjected to vibration as specified herein.

4.5.1.7.2.7.1 Inboard Equipment

Inboard mission critical equipment shall withstand without damage or performance degradation vibrations of amplitudes and frequencies as specified in Table 4.20. Inboard equipment shall be subjected to 2 minutes of excitation at each frequency and amplitude, in 1 hertz increments, over the frequency range specified in Table 4.20. Inboard equipment shall be subjected to 2 hours of excitation at the most damaging resonant frequencies and amplitudes or at 33 Hz with an amplitude of 0.010 ± 0.002 inches, whichever is the most severe condition. The inboard equipment shall be subjected to excitation in 3 axes.

Table 4.20 - Vibratory Displacement Of Environmental Vibration

Frequency Range (Hz)	Table Amplitude (inches)
4 to 15	0.030 ± 0.006
16 to 25	0.020 ± 0.004
26 to 33	0.010 ± 0.002

4.5.1.7.2.7.2 Outboard Equipment

Outboard equipment shall withstand without damage or performance degradation vibrations of amplitudes and frequencies as specified in Table 4.21. Outboard equipment shall be subjected to 2 minutes of excitation at each frequency and amplitude, in 1 hertz increments, over the frequency range specified in Table 4.21. Outboard equipment shall be subjected to 2 hours of excitation at the most damaging resonant frequencies and amplitudes or at 33 Hz with an amplitude of 0.010 ± 0.002 inches, whichever is the most severe condition. The outboard equipment shall be subjected to excitation in 3 axes.

Table 4.21 - Vibratory Displacement Of Environmental Vibration For Outboard Equipment

Frequency Range (Hz)	Table Amplitude (inches)
4 to 10	0.100 ± 0.010
11 to 15	0.030 ± 0.006
16 to 25	0.020 ± 0.004
26 to 33	0.010 ± 0.002

4.5.1.7.2.8 Thermal Shock

System outboard equipment shall meet all performance requirements and shall not be physically damaged after being subjected to low temperature and high temperature thermal shock cycles.

4.5.1.7.2.9 Outboard Equipment Corrosion Resistance

The SEST system outboard equipment mechanical integrity and electrical performance shall not be degraded by active or passive corrosion due to leakage currents or galvanic action over a 20 year service life.

4.5.1.8 Design and Construction

4.5.1.8.1 Parts

arts shall be selected as specified herein. Parts selected in accordance with this specification shall not relieve the contractor of responsibility for compliance with other provisions of this specification.

4.5.1.8.1.1 Obsolescence or Non-Availability

The design and method of parts selection shall minimize the impact of parts obsolescence or non-availability. Government off-the-shelf (GOTS) or commercial off-the-shelf (COTS) hardware or software may be used.

4.5.1.8.1.2 Electrostatic Discharge (ESD) Sensitivity Design

EIA 625 shall be used for ESD sensitivity classification. Enclosures, assemblies, and subassemblies containing ESD sensitive components, parts, or assemblies shall be marked with the sensitive electronic device symbol of EIA 471. An ESD warning plate conforming to the sensitive electronic device symbol shall be readily visible to personnel prior to gaining access to the ESD sensitive parts or assemblies.

4.5.1.8.1.3 Unused Cable Conductors

Interface cable assemblies between the SEST Inboard Equipment Group, platform equipment and the SEST Antenna Group shall have unused cable conductors available for future use. The unused cable conductors shall be grounded. The minimum quantity shall be as shown in Table 4.22.

Table 4.22 - Required Number of Unused Conductors

Number of Used Conductors in Cable	Minimum Number of Unused Conductors
1 - 25	2
26 - 100	4
over 101	6

4.5.1.8.2 Materials

Materials shall be as specified herein.

4.5.1.8.2.1 Prohibited Materials

Materials listed herein shall not be used. These chemical substances are prohibited for internal shipboard use in pure form or technical grade.

a. Flammable materials
b. Asbestos; asbestos compounds; and asbestos-filled molding compounds
c. Lithium, lithium compounds, or lithium batteries
d. Magnesium or magnesium alloys
e. Zinc or zinc alloys
f. Beryllium and beryllium compounds (unless approved by the procuring activity)
g. Carcinogens
h. Radioactive materials
i. Polychlorinated biphenyl (PCB)
j. Polyvinyl chloride (PVC), except where used for component leads
k. Mercury or its compounds and amalgams

l. Cadmium, where it may be exposed to temperatures above 205° C or where it may come into contact with petroleum based products
m. Chlorofluorocarbons (CFC) (Freon)
n. Ethylene glycol
o. Lead and lead compounds
p. Phenols and phenolic compounds

4.5.1.8.2.2 Corrosion Protection

Metals and alloys shall be corrosion-resistant or shall be given a corrosion-resistant treatment or coating. The selection of metals shall be made according to best engineering practices. When dissimilar metals are assembled in intimate contact with each other, an interposing material comparable to both shall be used. Insulating material is not required between corrosion-resistant steel inserts and aluminum castings when the inserts are integrally cast in the aluminum. When design requirements preclude the insulation of dissimilar metals from each other, the combination shall be isolated from exterior environments.

4.5.1.8.2.3 Hazardous Material (HAZMAT) and Hazardous Waste Minimization

The SEST system shall minimize the use of hazardous materials. Any use of potentially HAZMAT with the supplied products shall be approved by the procuring activity.

4.5.1.8.2.4 Flammability

SEST system equipment and parts shall be noncombustible or fire retardant in the most hazardous conditions of atmosphere, pressure, or temperature expected in the shipboard environment. Fire retardant activities may be used, provided it do not adversely affect the specified performance of the basic material and do not contaminate the shipboard atmosphere. Fire retardance shall not be achieved by use of nonpermanent additives to the basic materials.

4.5.1.8.3 Painting

Painting shall be as specified herein.

4.5.1.8.3.1 Outboard Equipment

The exterior surfaces shall be gray. To eliminate painting of the radome a gray colored material or resin is required. If the radome must be painted the effects of the paint shall be accounted for in the SEST system performance. Radome material, resin or paint with hydrophobic properties is preferred.

4.5.1.8.3.2 Inboard Equipment

The exterior surfaces shall be gray in accordance with Color Chip Number 26307. COTS equipment does not require repainting.

4.5.1.8.4 Nuclear Effects

The EHF LDR portion of the SEST system shall be hardened or shall be demonstrated to be intrinsically hardened against the nuclear threat. Nuclear event detection and automatic system protection shall be provided. Electromagnetic pulse (EMP) protection shall be provided.

4.5.1.8.5 Electromagnetic Compatibility (EMC)

The SEST system shall be self-compatible, shall operate compatibly in the shipboard electromagnetic environment, and shall meet the requirements of MIL-STD-461 Table II for equipment and subsystems installed on ships, when tested in accordance with MIL-STD-462.

4.5.1.8.6 Nameplates and Product Marking

The SEST system equipment shall be marked with the appropriate nomenclatures, part numbers, ESD markings, weight markings, and safety warnings in accordance with best commercial practices.

4.5.1.8.6.1 Markings

All equipment shall be marked with the appropriate part number and unit, assembly and subassembly level markings. Inboard equipment group, outboard equipment group and units associated within each group shall be marked with nameplates when appropriate. Nameplates shall be of a size compatible with the size of the equipment to which the plate will be attached. The following information shall be on each item requiring a nameplate: assigned nomenclature (item name and type designation), serial number with assigned suffix letter, contract number (procurement instrument identification number), and Government ownership designation (US) on last line.

4.5.1.8.6.2 Mounting and Location

Identification plates, information plates, and product markings shall be mounted or marked in a conspicuous place, generally on the front panel of the item to the level which it applies. Nameplates and product markings shall be legible and permanent.

4.5.1.8.6.3 Marking ESD Components

Enclosures, assemblies, and subassemblies containing ESD components with class I or class II parts or assemblies shall be marked in accordance with the EIA 471 sensitive electronic device symbol. An ESD cautionary statement shall be readily visible to personnel prior to gaining access to class I or II parts or assemblies. ESD warning labels shall be affixed to the protective packaging and to the equipment.

4.5.1.8.7 Workmanship

General workmanship shall conform to best commercial practices for the following requirements: wiring, shielding, fastening, and cleaning.

4.5.1.8.7.1 Workmanship Screen

Each piece of equipment in the SEST system shall withstand a defect detection screening process as specified below. Random vibration shall be conducted prior to temperature cycling.

4.5.1.8.7.1.1 Random vibration

Prior to temperature cycling, all equipment shall be subjected to random vibration. Unless otherwise approved by the Government the equipment shall be mounted in its normal operational position and the vibration stress applied vertically. The equipment shall withstand random vibration for an accumulated time of 10 minutes. Input vibration levels shall be measured at the mounting points of the unit being subjected to random vibration. The unit under test shall be energized and monitored to ensure proper functionality is maintained when subjected to the random vibration. All failures occurring during random vibration shall be corrected before the equipment under test is further subjected to random vibration.

4.5.1.8.7.1.2 Temperature Cycling

All equipment shall be subjected to temperature cycling, with a temperature rate of change of not less than 5° C per minute. All equipment shall be subjected to 10 cycles. Equipment power shall be turned on and off at the indicated times. Exposure shall be such that the equipment sustains maximum temperature change. When performance measurements are called for, operating tests shall be performed to ensure that proper functionality is maintained. The dwell time temperature shall be maintained until the largest electrical or electronic component reaches 80 percent of the chamber temperature. All failures occurring during temperature cycling shall be corrected before the equipment under test is further subjected to temperature cycling.

4.5.1.8.8 Interchangeability

All functionally identical assemblies, subassemblies, and replacement parts (including enclosures and slide mounted chassis) shall be physically, electrically, and functionally interchangeable.

4.5.1.8.9 Safety

Safety requirements shall be as specified herein.

4.5.1.8.9.1 Personnel Safety

The SEST system shall be designed to prevent injury to operating and maintenance personnel as specified herein.

4.5.1.8.9.1.1 Fail Safe

Fail safe features shall be provided for safety of personnel during installation, operation, maintenance, repair and interchange of any component within the SEST system.

4.5.1.8.9.1.2 Electrical

The design shall incorporate methods to protect personnel from inadvertent contact with voltages capable of producing shock hazards.

4.5.1.8.9.1.3 Power

Means shall be provided so that power may be cut off while installing, replacing, or interchanging any component within the SEST system. If a main power switch is provided, it shall be clearly labeled as such and shall cut off all power to the complete SEST system.

4.5.1.8.9.1.4 Ground

Design and construction shall insure that all external parts, surfaces, and shields, exclusive of antenna and transmission line terminals, are at ground potential at all times during normal operation. Antenna and transmission line terminals shall be at ground potential except for RF energy on the external surfaces. Hinges and slides shall not be used for grounding paths. Panels and doors containing meters, switches, test points, etc. shall be attached or hinged in such a manner as to insure that it is at the same ground potential as the equipment in which it is mounted, whether in a closed or open position. A ground shall be considered satisfactory if the electrical connection between the door or panel and the system tie point exhibits a resistance of 0.1 ohm or less.

4.5.1.8.9.1.5 Grounding Methods

Ground connections to shields, hinges, and other mechanical parts shall not be used to complete electrical circuits. Any external or interconnecting cable, where a ground is part of the circuit, shall carry a ground wire in the cable terminated at both ends in the same manner as the other conductors. In no case, except with coaxial cables, shall the shield be depended upon for a current-carrying ground connection. Static and safety grounds shall not be used to complete electrical circuits. A point on the electrically conductive chassis or equipment frame shall serve as the common tie point for static and safety grounding. The path from the tie point to the ground shall:

a. Be continuous and permanent,
b. Have ample carrying capacity to conduct safely any fault currents that may be imposed on it,
c. Have impedance sufficiently low to limit the potential above ground and to facilitate the operation of the over current devices in the circuits, and
d. Have Sufficient Mechanical Strength Of The Material To Minimize Possibility Of Ground Disconnection Shielding

Except where a conflict with single-point shield grounding requirements would be created, shielding on wire or cable shall be grounded to the chassis or frame.

4.5.1.8.9.1.6 Guards and Barriers

The design shall incorporate methods to protect personnel from accidental contact with voltages in excess of 30 volts during normal operation. All contacts, terminals and like devices having voltages between 70 and 500 volts with respect to ground shall be guarded from accidental contact by personnel. Guards or barriers may be provided with test probe holes where maintenance testing is required. Assemblies operating at potentials in excess of 500 volts shall be completely enclosed from the remainder of the assembly and equipped with non-bypassable interlocks.

4.5.1.8.9.1.7 Voltage Measurements

When the operation or maintenance of equipment employing potentials in excess of 300 volts peak could require that these voltages be measured, the equipment shall be provided with test points so that these voltages can be measured at a relatively low potential level. In no case shall the potential exceed 300 volts peak relative to ground. Test points with voltages above 30 volts shall have the conducting material recessed a distance no less than the diameter of the probe hole and a minimum of 1.5 millimeter. If a voltage divider is used, the voltage divider resistance between the test point and ground shall consist of at least two resistors of equal value in parallel.

4.5.1.8.9.1.8 Guarding of RF Voltages

Transmitter output terminals, antenna, and other devices that carry sufficient RF voltage to burn or injure personnel shall be protected from accidental contact in the same manner as for AC voltages in the 70 to 500 volt range. A grounding stud shall be provided where transmitting equipment operates with voltages in excess of 70 volts RMS or DC. The connection of a shorting rod to the stud shall be such that accidental loosening or high resistance to ground is prevented.

4.5.1.8.9.1.9 Main Power Switch

The power input side of the main power switch and the incoming power line connections shall be given physical protection against accidental contact.

4.5.1.8.9.1.10 Interlocks

Access doors, covers, or plates, shall be interlocked as follows:

a. No interlocks are required when all potential in excess of 70 volts are completely protected with guards or barriers.

b. Bypassable interlocks are required when voltages between 70 and 500 volts are exposed as the result of an access door, cover, or plate being opened. The bypass device shall be of such design that closing the associated door, cover, or plate will automatically open the bypass device and leave the interlock in position to function normally. Visual means shall be provided to indicate when the interlock is bypassed.

4.5.1.8.9.1.11 Automatic Discharge Devices

High voltage circuits and capacitors shall be provided with discharging devices unless it discharges to 30 volts or less within two seconds after power removal. The particular discharging device that is chosen shall insure that the capacitor or high voltage circuit is discharged to 30 volts or less within two seconds.

4.5.1.8.9.1.12 Connectors

Connectors used in multiple electric circuits shall be selected to preclude mismating. Where design considerations require plug and receptacles of similar configuration in close proximity, the mating plugs and receptacles shall be suitable coded or marked to clearly indicate the mating connectors. The design of connectors shall be such that the operator is not exposed to electrical shock or burns when normal disconnect methods are used. Exposed pin contacts shall not be energized (hot) after being disconnected from the socket contacts.

4.5.1.8.9.1.13 Mechanical Design

The design of the equipment shall provide personnel maximum access and safety while installing, operating, and maintaining the system. Provisions shall be made to prevent accidental pulling out of drawers or rack-mounted equipment components. Suitable protection shall be provided to prevent contact with moving mechanical parts such as fans when the equipment is complete and operating. Sharp projections on cabinets, doors, and similar parts shall be avoided. Doors or hinged covers shall be rounded at the corners and provided with stops to hold them down. Design of rack-mounted equipment shall maintain a low center of gravity to minimize possibility of tip-over.

4.5.1.8.9.1.14 Mechanical Interconnection

Positive means shall be provided to prevent the inadvertent reversing or mismating of fittings, couplings, and mechanical linkages.

4.5.1.8.9.1.15 Power Switch Location

Equipment power switches shall be so selected and located that accidental contact by personnel will not place equipment in operation.

4.5.1.8.9.1.16 Equipment Safety Markings

Danger, caution, etc. signs, labels and markings shall be used to warn of specific hazards such as voltage, current, thermal, or physical.

4.5.1.8.9.1.17 Leakage Current

The leakage current (vector sum of all phases) of the SEST system, when EMI filtering is not required, shall not exceed 5 milliamperes (mA). When EMI filtering is required, line-to-line filters are preferred over line-to-ground filters. The maximum line-to-ground capacitance shall be as specified in MIL-STD-461.

4.5.1.8.9.2 Thermal Design

Equipment handles, knobs, and operator controls shall not exceed 49° C. Other operator accessible surfaces shall not exceed 60° C. Surfaces on which temperatures may jeopardize operator safety shall be labeled with a temperature hazard warning. When tested under conditions of maximum intended load, equipment shall not attain a temperature at any location which constitutes a risk of injury to personnel or risk of fire or damage to any materials used within the equipment.

4.5.1.8.9.3 Critical Controls

Critical controls, the accidental activation of which may cause damage to equipment, injury to personnel, or degradation of functions, shall be designed and located so that it is not susceptible to being moved accidentally.

4.5.1.8.10 Human Factors Engineering

The SEST system shall provide a work environment which fosters effective procedures, work patterns, and personnel safety and health, and which minimizes factors which degrade human performance or increase error. Design shall be such that operator workload, accuracy, time constraints, mental processing, and communication requirements do not exceed operator capabilities. The Human Factors Engineering design shall comply with ASTM F 1166.

4.5.1.9 Maintenance

The design of the SEST system and associated support equipment shall be in concert with the maintenance concept for the SEST system as specified herein. Maintenance shall consist of three levels of repair: Organizational (O-level), Intermediate (I-level), and Depot (D-level).

4.5.1.9.1 O-level

Corrective maintenance at the O-level shall be limited to SEST system inboard components. O-level corrective maintenance is characterized by on-line and off-line BIT circuitry to provide rapid detection, localization, and isolation of failures to the defective LRU. The SEST system outboard components shall not require O-level corrective maintenance, but BIT circuitry shall be provided to permit detection and localization of failed outboard functions.

4.5.1.9.2 I-level

I-level corrective maintenance of the SEST system shall include the antenna group and shall consist of removal and replacement. LRUs within the SEST antenna group will be fault isolated at the IMA and defective LRUs will be removed and replaced.

4.5.1.9.3 D-level

Depot level maintenance shall consist of contractor field engineering services for maintenance beyond the capability of the IMA, for depot repair of defective LRUs, and for equipment overhaul as needed.

4.5.1.10 Manpower, Personnel, and Training

The SEST system shall be operable by personnel having the equivalent skill levels of a radioman "A" school graduate. The SEST system shall be maintained at both the organizational and intermediate level by personnel having the equivalent skill levels of an electronic technician "A" school graduate.

4.5.1.11 Software Development

All newly developed software shall be developed in the Ada programming language using ANSI 1815A-1983 or equivalent.

4.5.1.12 Verification

The aforementioned requirements shall be verified by multiple levels of verification.

4.5.1.12.1 First Article Inspection (FAI)

The first SEST unit(s) will undergo first article inspection in accordance with Table 4.23.

4.5.1.12.2 Quality Conformance Inspection (QCI)

Each SEST unit will undergo conformance inspection in accordance with Table 4.23.

4.5.1.12.3 System-Level Performance Tests

Each unit will undergo system-level performance tests in accordance with Table 4.23.

Table 4.23 - Requirement Verification Matrix

Requirement	FAI	QCI	System
System Description	D		
Major Components	D		
Inboard Equipment Group	D		
Communications Support Group	D		
EHF Equipment Group	D		
DSCS Equipment Group	D		
Antenna Controller	D		
Amplifier Group	D		
Antenna Group	D		
Multi-Band Antennas	D		
RF Transmission And Reception	D		
Interface Definition	D		
External Communications Interface	D		
EHF	D		
DSCS	D		
Platform Systems Interface	D	T	

Requirement	FAI	QCI	System
Baseband Interfaces	D	T	
EHF Equipment Group	D	T	
MDR Baseband Interface Signals	T	T	
Transmit Data	T	T	
Transmit Clock	T	T	
External Transmit Clock	T	T	
Receive Data	T	T	
Receive Clock	T	T	
Request To Send	T	T	
Clear To Send	T	T	
Receiver Ready	T	T	
Signal Ground/Common Return	T	T	
Chassis Ground	T	T	
LDR Baseband Interface Signals	T	T	
DSCS Equipment Group	D	T	
External IF Interface	T	T	
External Transmit IF Interface	T	T	
Nominal Center Frequency	T	T	
Instantaneous Bandwidth	T	T	
Impedance	T	T	
Power Level	T	T	
VSWR	T	T	
Transmit Phase Linearity	T	T	
Transmit Amplitude Response	T	T	
External Receive IF Interface	T	T	
Nominal Center Frequency	T	T	
Instantaneous IF Bandwidth	T	T	
Impedance	T	T	
Power Level	T	T	
VSWR	T	T	
Dynamic Range	T	T	
Navigation	D		
Analog/Synchro	T		
ESGN	T		
GPS	T		
Navigation Transverse Polar Coordinates	T		
Water Cooling	D		
Prime Power	T		
Power Factor	T		
Equipment Protection	T		
Operator Interface	D		
ADNS Interface	D		
JMCIS Compliance	D		

Requirement	FAI	QCI	System
TRANSEC Interface	D		
Inboard Equipment Group To Antenna Group	D		
Diagnostic Equipment Interface	T	T	
Characteristics			
EHF Performance	D	T	T
LDR/MDR Signal Modulation Modes	T	T	T
Simultaneous Operations	T	T	T
Transmitter Characteristics	T	T	
Transmitter Frequency	T	T	
EIRP	T/A	T/A	
Doppler Shift	D		
Spurious Outputs	A		
Phase Noise	A		
Receiver Characteristics	T		
Receiver Frequency	T		
G/T	T/A	T/A	
Doppler Shift	T	T	
Dynamic Range	T		
Spurious Response	T		
LDR	T		
MDR	T		
Phase Linearity	T		
Antenna Performance	T		
Transmit Polarization	T		
Transmit Sidelobe Levels	T	T	
Transmit/Receive Isolation	T	T	
Receive Polarization	T	T	
Receive Sidelobe Levels	T	T	
Pointing	T	T	
DSCS Performance	D	T	T
Operating RF Band	T	T	T
RF Carriers	T	T	T
EIRP	T/A	T	
G/T	T/A	T	
Transmit Performance	T	T	
Harmonic Outputs	T		
Residual AM	T		
Carrier Frequency Selection	T		
Bandwidth	T	T	
EIRP Range	T	T	
Doppler Compensation	T		
Antenna Performance	T		
Pointing	T	T	

Requirement	FAI	QCI	System
Mainlobe Radiation Pattern	T	T	
Sidelobe Radiation Pattern	T	T	
Polarization	T	T	
Communications Support Group External IF Port Performance	T		
External IF Transmit Characteristics	T		
Phase Linearity	T		
Amplitude Response	T		
Spectral Purity	T		
Transmit Extraneous Outputs	T		
Harmonic Outputs	T		
AM To PM Conversion	T		
Spectrum Inversion	A		
Transmit Phase Variation	T		
Carrier Phase Variation	T		
Carrier Frequency Selection	D		
Bandwidth	T	T	
Gain	T	T	
Gain Adjustment Range	D	T	
Gain Stability	T	T	
Doppler Compensation	T		
Transmit Noise	T		
External IF Receive Characteristics	D		
Phase Linearity	T		
Amplitude Response	T		
Spectral Purity	T/A		
Receive Spurious Output	T		
Phase Errors	T		
Receive Spectrum Inversion	T		
Transmit To Receive Isolation	T		
Rejection Of Out-Of-Band Frequencies	T		
Susceptibility To High In-Band Signals	T		
Receive Carrier Frequency Selections	T		
Gain And Stability	T		
Receiver Dynamic Range	T		
Doppler Compensation	T		
Antenna Stabilization And Tracking	T		
Antenna Pointing Accuracy	T		
Communications Duration	D		
Acquisition Time	D		
EHF Acquisition Time	T	T	T
DSCS Acquisition Time	T	T	T
Antenna Pointing Tests	T	T	T

Requirement	FAI	QCI	System
Range Of Motion	T	T	
Ship Dynamic Attitude	T		
Antenna Non-Operating State	D		
Environmental	T		
Physical Characteristics	D		
Inboard Equipment Dimensions	I	I	
Antenna Group Weight And Dimensions	T	T	
SEST System Weight	T	T	
Radome Water Shedding Capability	T/A		
Handling	D		
Portability And Load Carrying	D		
System Quality Factors	D		
Reliability	T/A		
System Reliability Requirements	T/A		
Maintainability	T		
MTTR	T		
O-Level	T		
I-Level	A		
Preventative Maintenance	D		
TDME	D		
Class A Test Provisions	A		
Class B Test Provisions	A		
Class C Test Provisions	A		
Environmental Conditions	D		
Transportation And Storage	D		
Altitude, Non-Operating	A		
Temperature	T		
Outboard Equipment Low And High Temperature	T		
Inboard Equipment Low And High Temperature	T		
Power-On Condition	D		
Solar Radiation	T		
Wind Effects	T		
Humidity	T		
Shock	T		
Inboard Equipment	T		
Outboard Equipment	T		
Vibration	T		
Inboard Equipment	T		
Outboard Equipment	T		
Thermal Shock	T		
Outboard Equipment Corrosion Resistance	A		
Design And Construction	D		
Parts	C		

Requirement	FAI	QCI	System
Obselescence Or Non-Availability	C		
ESD Sensitivity Design	I		
Unused Cable Conductors	I		
Materials	C		
Prohibited Materials	C		
Corrosion Protection	C		
HAZMAT And Hazardous Waste Minimization	C		
Flammability	C		
Painting	I	I	
Outboard Equipment	I	I	
Inboard Equipment	I	I	
Nuclear Effects	A		
EMC	T		
Nameplates And Product Marking	I	I	
Markings	I	I	
Mounting And Location	I	I	
Marking ESD Components	I	I	
Workmanship	T		
Workmanship Screen	T		
Random Vibration	T		
Temperature Cycling	T		
Interchangeability	A		
Safety	A		
Personnel Safety	A		
Fail Safe	T		
Electrical	T		
Power	T		
Ground	T		
Grounding Methods	A		
Shielding	A		
Guards And Barriers	A		
Voltage Measurements	T		
Guarding Of RF Voltages	A		
Main Power Switch	I		
Interlocks	D		
Automatic Discharge Devices	I		
Connectors	I		
Mechanical Design	I		
Mechanical Interconnection	I		
Power Switch Location	I		
Equipment Safety Markings	I		
Leakage Current	A		
Thermal Design	A		

Requirement	FAI	QCI	System
Critical Controls	I		
Human Factors Engineering	I		
Maintenance	D		
O-Level	D		
I-Level	A		
D-Level	A		
Manpower, Personnel, And Training	I		
Software Development	C		

T = Test; D = Demonstration; I = Inspection; A = Analysis; C = Certification

4.6 Conceptual Design Results

The following decisions have been reached during the conceptual design phase:

Link Availability

1. The EHF uplink rain margin shall be 10.5 dB which provides for an availability of 98% in the intended areas of operation.
2. The EHF downlink rain margin shall be 6.0 dB which provides for an availability of 99.5% in the intended areas of operation.
3. The SHF uplink rain margin shall be 2.6 dB which provides for an availability of 99.9% in the intended areas of operation.
4. The SHF downlink rain margin shall be 1.9 dB which provides for an availability of 99.9% in the intended areas of operation.

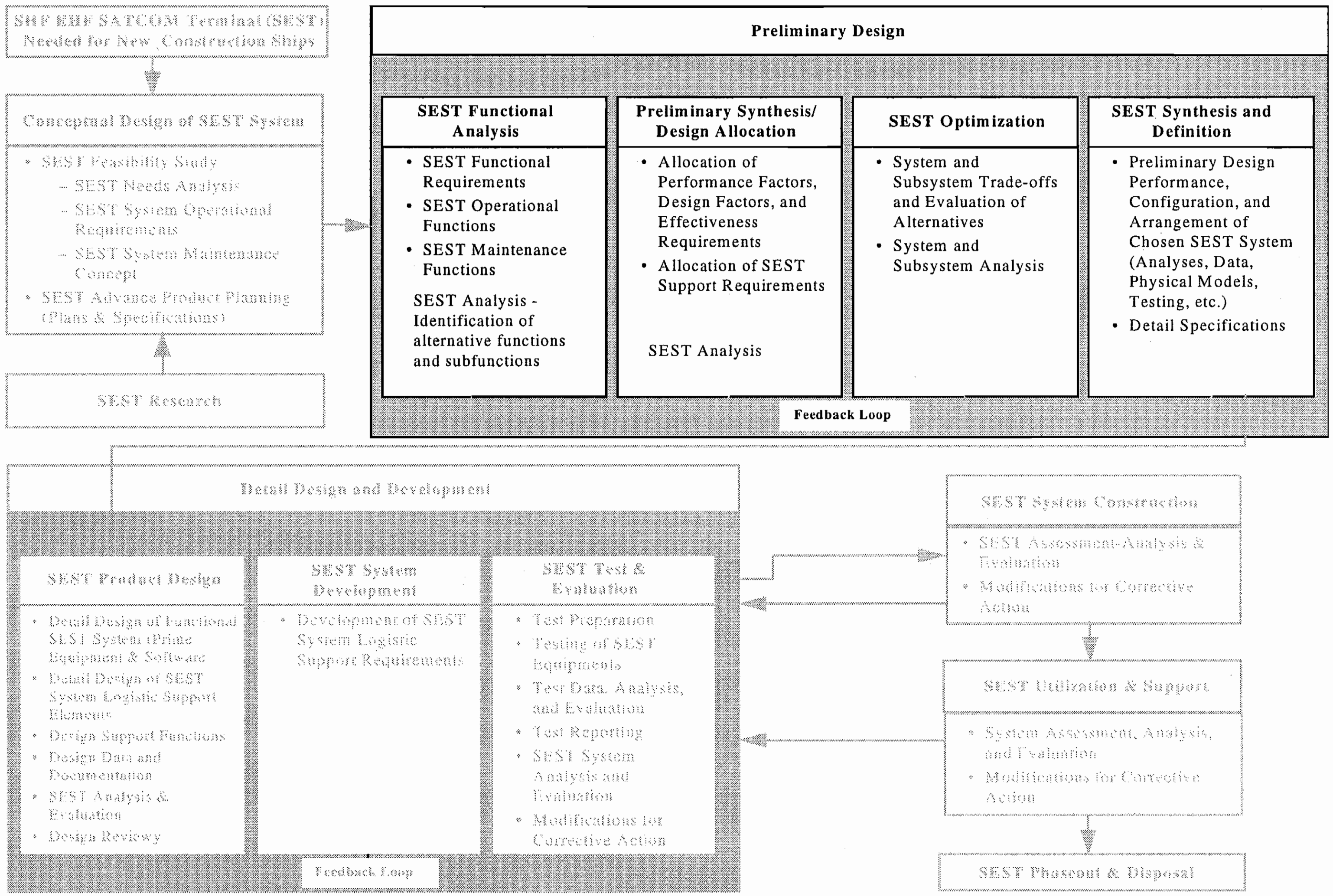
Link Budgets

1. The minimum required EHF EIRP is 65.2 dBW.
2. The minimum required EHF G/T is 13.0 dB/K.
3. The minimum required SHF EIRP is 50.6 dBW.
4. The minimum required SHF G/T is 10.5 dB/K.

Antenna Type

1. A concentric SHF and EHF feed non-simultaneous multi-band parabolic dish antenna approach will be further investigated.
2. A simultaneous multi-band Luneberg lens antenna will be further investigated. Due to risks with this approach, single band Luneberg lens antennas will not be further considered.
3. Phased array antennas with phase shift beamsteering in elevation and mechanical steering in azimuth will be further considered.

5. Phase 2 -- Preliminary System Design



5.1 System Functional Analysis

The SEST system will require inboard and outboard equipment to fulfill its operational requirements. This section begins to break down the major subsystems of the inboard and outboard equipment. The major subsystem breakdown will be accomplished in terms of the transmit and receive chains.

5.1.1 EHF/SHF Transmit Chain

Figure 5.1 below shows the EHF and SHF transmit chains and the associated major subsystems.

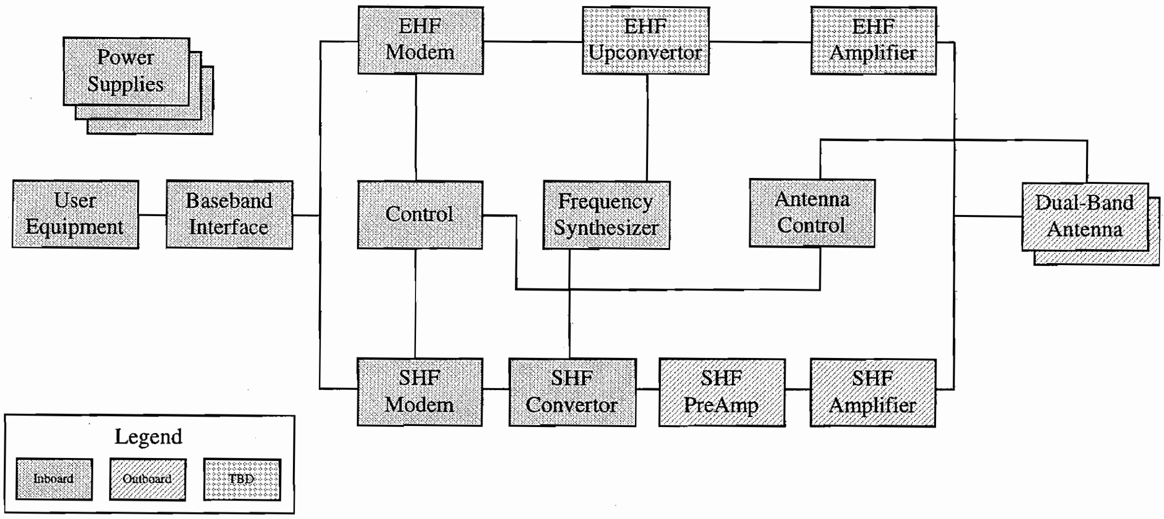


Figure 5.1 - EHF/SHF Transmit Chain

The subsystems which are labeled as inboard are required to be inboard for the user or its operation in such that it is not required to be outboard. The subsystems which are labeled as outboard are required to be outboard since its operation requires them to be outboard or, for example, placing them outboard close to the antenna reduces RF losses. The subsystems which are labeled as TBD should, in general, be located outboard are close to the antenna as possible to reduce RF losses, but the exact subsystem design or selection will impact the decision. For example, the EHF amplifier should be placed as close to the antenna as possible to reduce RF transmission losses. Since there are two antennas per ship for a full hemispherical coverage for when the superstructure impinges the view to the satellite, this could imply two EHF amplifiers --

one collocated with each SEST antenna. However, as solid state amplifiers are not as mature at EHF frequencies as other lower frequencies, a more traditional amplifier such as a traveling wave tube (TWT) may be required. Depending on the type TWT used, placing a TWT at each SEST antenna may be cost prohibitive. In this case, a single, higher power TWT based amplifier may be placed inboard between the two antennas and then the RF is switched to the antenna with the view to the satellite.

A list of the separate major inboard and outboard transmit chain subsystems required from Figure 4.1 is as follows:

Inboard

1. Power Supplies
2. Baseband Interface
3. Terminal Control
4. SHF Modem
5. EHF Modem
6. Frequency Synthesizer
7. SHF Convertor
8. Antenna Controller

Outboard

1. EHF Upconvertor[12]
2. SHF Preamp
3. SHF Amplifier
4. EHF Amplifier[13]
5. Dual-Band Antenna

5.1.2 EHF/SHF Receive Chain

The Figure 5.2 shows the EHF and SHF receive chains and the associated major subsystems.

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[12] Location Design Dependent

[13] Location Design Dependent

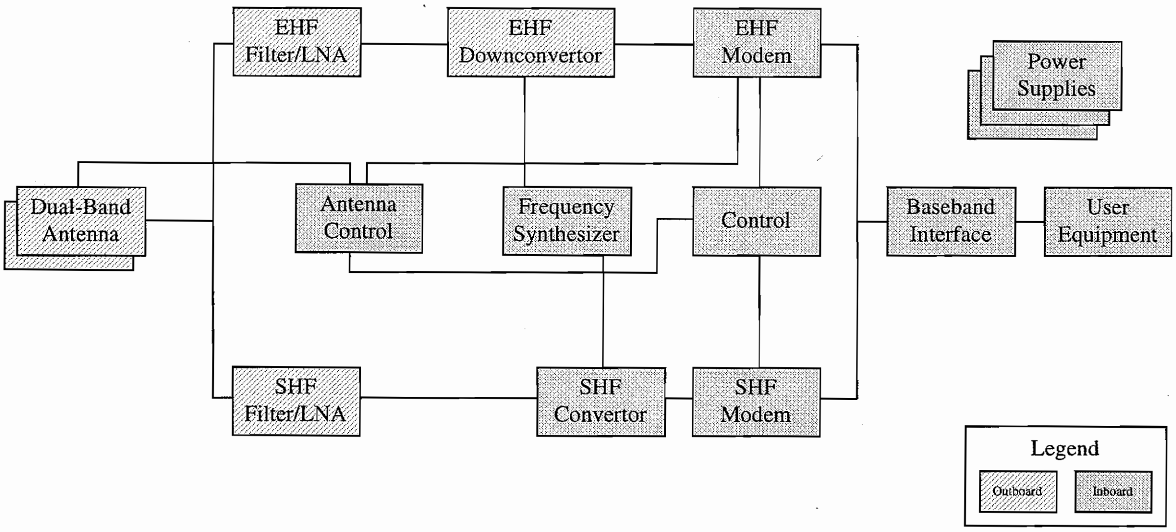

Figure 5.2 - EHF/SHF Receive Chain

A list of the separate major inboard and outboard transmit chain subsystems required from Figure 5.2 which have not been previously accounted for in the transmit chain is as follows:

Inboard

- None

Outboard

1. SHF Filter/Low Noise Amplifier (LNA)
2. EHF Filter/LNA
3. SHF Downconvertor
4. EHF Downconvertor

5.1.3 Functional Equipment Break Down.

Figure 5.3 provides an top level break down of the SEST system .

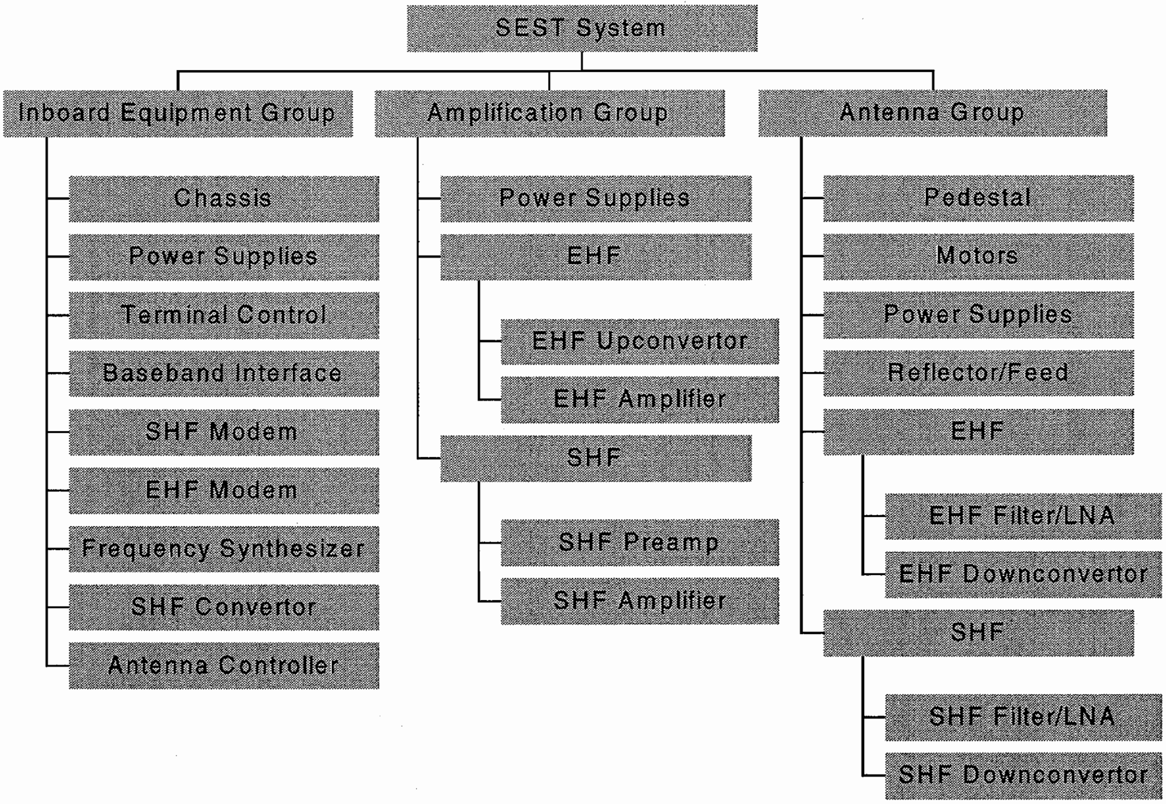

Figure 5.3 - SEST Functional Equipment Break Down

5.2 Preliminary Design Synthesis

5.2.1 Allocation of Requirements

After the functional layout of the system is determined, allocation of the performance requirements to the subsystems can begin. This allocation is design dependent and may help to eliminate and/or refine system design alternatives. Figure 5.4 below gives an example of a simple requirement, weight, that is allocated throughout the components of the system. This process is followed for all applicable requirements. In some cases, the requirement in question may not be 'additive' as the weight requirement was. Rather, it may simply highlight in shat subsystem a given function or requirement is to be performed.

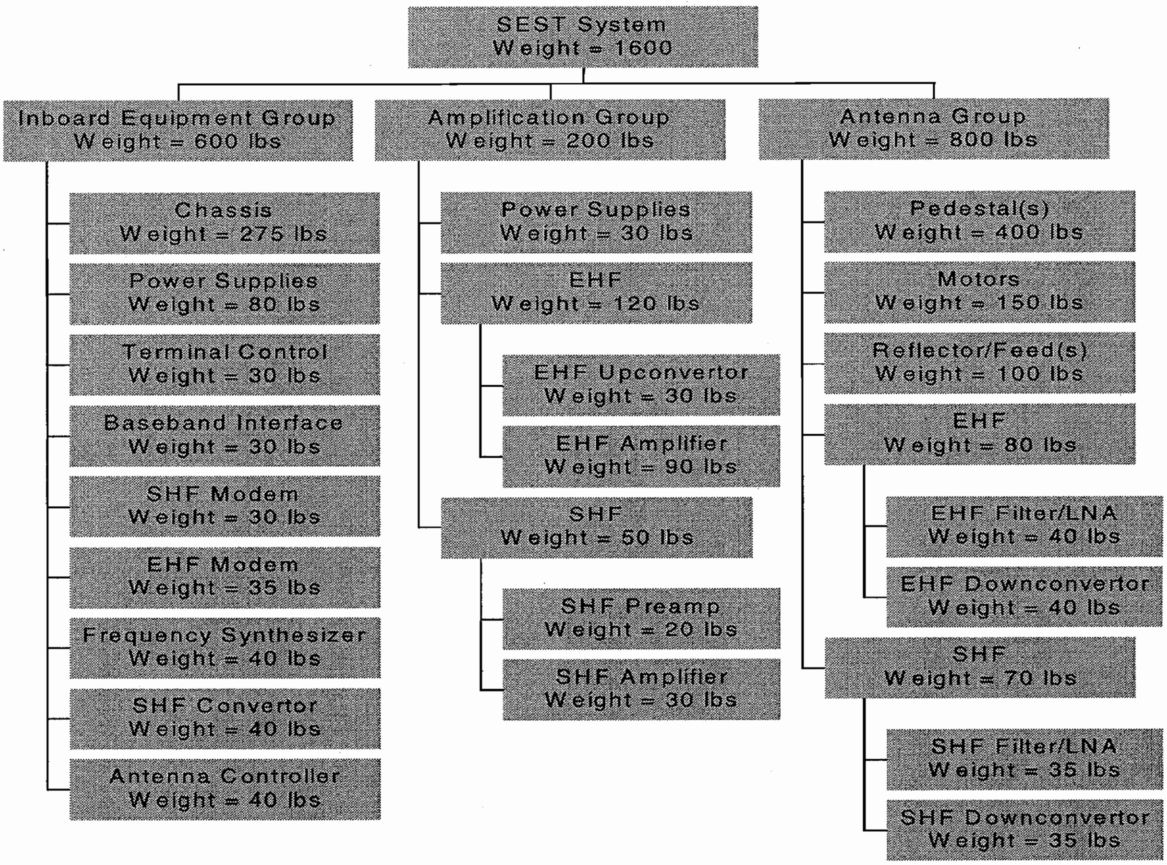

Figure 5.4 - Allocation of Weight Requirement

5.2.2 Allocation of System Effectiveness Factors

The top level reliability requirement of the SEST system is an MTBF of 1250 hours. The reliability can be expressed equivalently as the failure rate, λ, based on the following equation:

$$MTBF_{system} = 1/\lambda_{system}{}^{14} \qquad \text{(Equation 5.1)}$$

If the system failure rate, the required failure rates of the subsystems can be determined using the following equation:

$$1/\lambda_{system} = 1/(\lambda_{subsystem\ 1} + \lambda_{subsystem\ 2} + \ldots \lambda_{subsystem\ n})^{15} \qquad \text{(Equation 5.2)}$$

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[14] Blanchard, B.S., and Fabrycky, W.J., *Systems Engineering and Analysis*, Englewood Cliffs, NJ, Prentice Hall, 1990.

In order to help allocate the failure rate requirements across the individual subsystems, a complexity factor may be used. This subjectively rates the complexity of a subsystem based on how elaborate the design or unreliable the technology may be. Figure 5.5 provides a preliminary allocation of system reliability. During detailed design, the allocations may be revisited based on prototype test results, test data, etc.

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[15] Blanchard, B.S., and Fabrycky, W.J., *Systems Engineering and Analysis*, Englewood Cliffs, NJ, Prentice Hall, 1990.

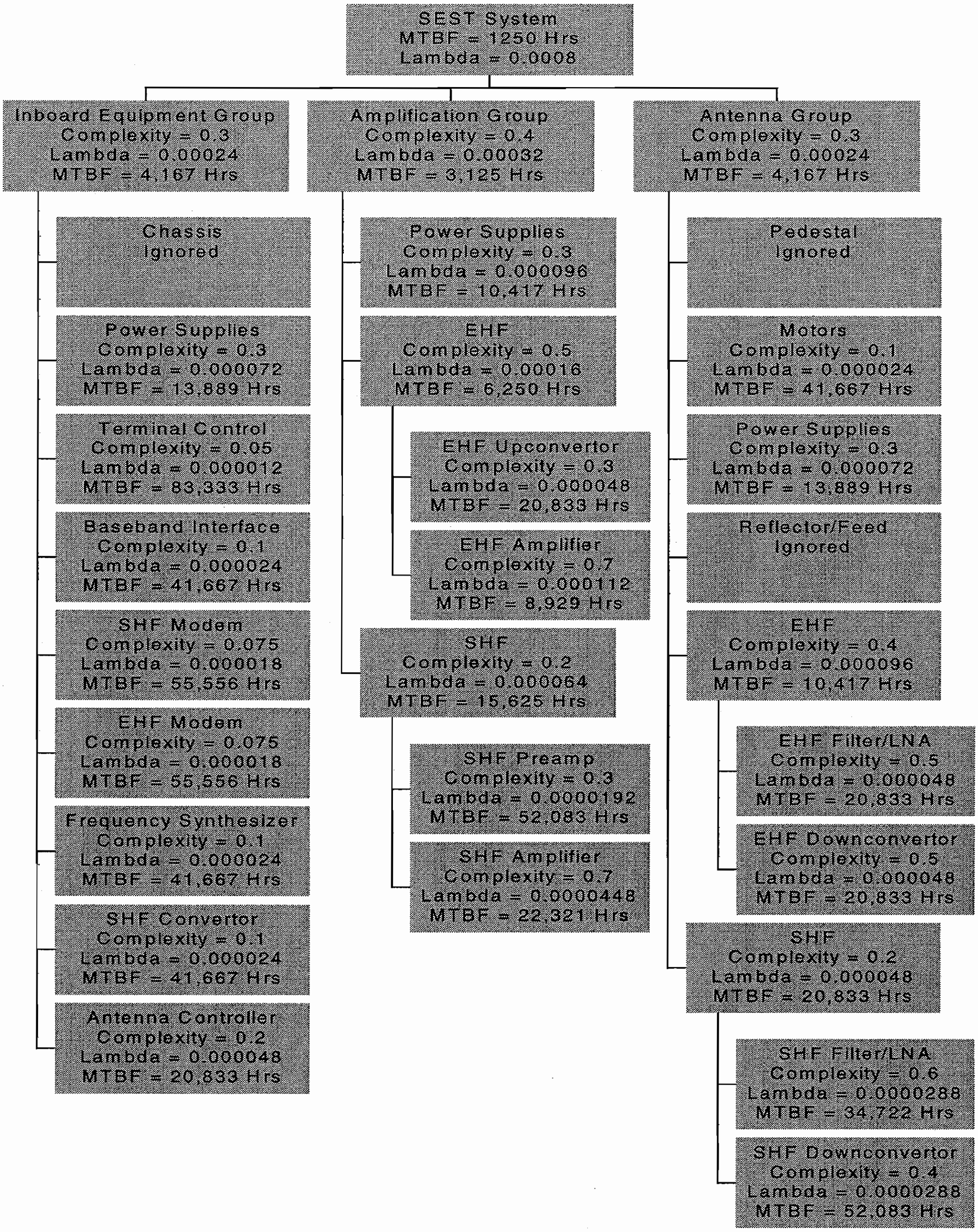

Figure 5.5 - Allocation of SEST System Effectiveness Parameters

5.3 Trade-Off and Optimization

5.3.1 Link Budgets

Due the radar cross section requirements, the antenna size will be limited to 36 inches plus any required radome for conventional parabolic dish antennas. This is due to the fact that the radar cross section performance of this size antenna is known since the current EHF terminals have 3 foot antenna. The Luneberg lens antenna is limited to a size of 42 inches as this is the lens size that will fit within the same size radome as the 36 inch parabolic dish. Phased arrays that are integrated with the ship's superstructure, do not have any size limitation except those imposed by the limited planar surfaces on the ship.

5.3.1.1 EHF EIRP

5.3.1.1.1 Parabolic Dish Antenna

For the antenna gain, the following assumptions will be made:

- a 36" dish reflector
- an efficiency of 55%
- the wavelength of the bottom of the band -- 42.5 GHz -- or 6.59×10^{-3}m.

Antenna gain is calculated as follows:

$$G = \frac{\eta(4\pi A)}{\lambda^2} \qquad \text{(Equation 5.3)}$$

$$G = \frac{\eta 4(\pi r)^2}{\lambda^2}$$

$$G = \frac{(0.55)(4)(\pi)^2(0.4572)^2}{(6.59 \times 10^{-3})^2}$$

$$G = 50.19 \text{ dBi}$$

Next, the EIRP for the following alternative amplifier and parabolic dish antenna combinations will be calculated:

1. Parabolic Dish Antenna with a 40W EHF Solid State Power Amplifier (SSPA) on the back of each antenna pedestal.
2. Parabolic Dish Antenna with a 100W Helix TWT on the back of the each pedestal.

3. Parabolic Dish Antenna with a centrally located 400W Coupled Cavity TWT

5.3.1.1.1.1 EIRP Of A Parabolic Dish Antenna With A 40W EHF SSPA On The Back Of Each Antenna Pedestal

An EIRP link budget for this configuration antenna is shown in Table 5.1 below.

Table 5.1 - EHF EIRP Budget of Parabolic Dish Antenna with SSPA on Pedestal

EHF EIRP Element	Units	Value
EHF Amplifier Output	dBW	+ 16.02
Amplifier to Waveguide Flange Loss	dB	- 1.00
Pedestal Loss	dB	- 0.50
Axial Ratio Mismatch Loss	dB	- 0.20
Antenna Gain	dBi	+ 50.19
Pointing Error Loss	dB	- 0.80
Tracking Loss	dB	- 0.70
Dry Radome Loss	dB	- 0.90
EIRP at Surface of Radome	**dBW**	**62.11**
Required Terminal EIRP	**dBW**	**65.20**
Margin	**dBW**	**- 3.09**

From this budget, it can be seen that this SSPA configuration does not meet the EIRP requirements. Further, it is not believed that an SSPA can satisfy the SEST requirements given the fact that a 40W EHF SSPA is state-of-the-art in solid state technology.

5.3.1.1.1.2 EIRP Of A Parabolic Dish Antenna With A 100W Helix TWT On The Back Of The Each Pedestal

An EIRP link budget for this configuration antenna is shown in Table 5.2 below.

Table 5.2 - EHF EIRP Budget of Parabolic Dish Antenna with Helix TWT on Pedestal

EHF EIRP Element	Units	Value
EHF Amplifier Output	dBW	+ 20.00
Amplifier to Waveguide Flange Loss	dB	- 1.00
Pedestal Loss	dB	- 0.50
Axial Ratio Mismatch Loss	dB	- 0.20
Antenna Gain	dBi	+ 50.19
Pointing Error Loss	dB	- 0.80
Tracking Loss	dB	- 0.70
Dry Radome Loss	dB	- 0.90
EIRP at Surface of Radome	**dBW**	**66.09**
Required Terminal EIRP	**dBW**	**65.20**
Margin	**dBW**	**+ 0.89**

From this budget, it can be seen that this Helix TWT configuration meets the SEST EHF EIRP requirements and has approximately 0.9 dB of margin. Therefore, this configuration will be further considered and evaluated from a cost and performance perspective.

5.3.1.1.1.3 EIRP Of A Parabolic Dish Antenna With A Centrally Located 400W Coupled Cavity TWT

An EIRP link budget for this configuration antenna is shown in Table 5.3 below.

Table 5.3- EHF EIRP Budget of Parabolic Dish Antenna with 400W Centrally Located Coupled Cavity TWT

EHF EIRP Element	Units	Value
EHF Amplifier Output	dBW	+ 26.00
Amplifier to Waveguide Flange Loss	dB	- 1.00
Waveguide Loss	dB	- 4.00
Pedestal Loss	dB	- 2.00
Axial Ratio Mismatch Loss	dB	- 0.20
Antenna Gain	dBi	+ 50.19
Pointing Error Loss	dB	- 0.80
Tracking Loss	dB	- 0.70
Dry Radome Loss	dB	- 0.90
EIRP at Surface of Radome	**dBW**	**66.59**
Required Terminal EIRP	**dBW**	**65.20**
Margin	**dBW**	**+ 1.39**

From this budget, it can be seen that this 400W centrally located coupled cavity configuration meets the SEST EHF EIRP requirements and has approximately 1.4 dB of margin. Therefore, this configuration will be further considered and evaluated from a cost and performance perspective.

5.3.1.1.2 Luneberg Lens Antenna

For the antenna gain, the following assumptions will be made:

- a 42" lens with an effective elliptical aperture of 42 x 36 inches (the sides of the lens are truncated where it attaches to the pedestal).
- an efficiency of 45%
- the wavelength of the bottom of the band -- 42.5 GHz -- or 6.59×10^{-3}m.

Antenna gain is calculated as follows:

$$G = \frac{\eta(4\pi A)}{\lambda^2}$$

The area of the lens antenna will be calculated as the area of an ellipse or $A = \pi ab$ where a and b are the semimajor axis and the semiminor axis, respectively. Substituting provides

$$G = \frac{(0.45)(4)(\pi)(\pi)(0.5334 \times 0.4572)}{(6.59 \times 10^{-3})^2}$$

$$G = 49.59 \text{ dBi}$$

Next, the EIRP for the following alternative amplifier and Luneberg Lens antenna combinations will be calculated:

1. Luneberg Lens Antenna with an 40 Watt EHF Solid State Amplifier on each antenna pedestal.
2. Luneberg Lens Antenna with a 100W Helix TWT on each pedestal.
3. Luneberg Lens Antenna with a centrally located 400W Coupled Cavity TWT

5.3.1.1.2.1 EIRP Of A Luneberg Lens Antenna With A 40W EHF Solid State Amplifier On The Back Of Each Antenna Pedestal

An EIRP link budget for this configuration antenna is shown in Table 5.4 below.

Table 5.4 - EHF EIRP Budget of Luneberg Lens with SSPA on Pedestal

EHF EIRP Element	Units	Value
EHF Amplifier Output	dBW	+ 16.02
Amplifier to Waveguide Flange Loss	dB	- 1.00
Pedestal Loss	dB	- 0.50
Axial Ratio Mismatch Loss	dB	- 0.20
Antenna Gain	dBi	+ 49.59
Pointing Error Loss	dB	- 1.00
Tracking Loss	dB	- 0.70
Dry Radome Loss	dB	- 0.90
EIRP at Surface of Radome	**dBW**	**61.31**
Required Terminal EIRP	**dBW**	**65.20**
Margin	**dBW**	**- 3.89**

From this budget, it can be seen that this Luneberg lens antenna/SSPA configuration does not meet the EIRP requirements. Once again, it is not believed that an Luneberg lens antenna/SSPA can satisfy the SEST requirements.

5.3.1.1.2.2 EIRP Of A Luneberg Lens Antenna With A 100W Helix TWT On Each Pedestal

An EIRP link budget for this configuration antenna is shown in Table 5.5 below.

Table 5.5 - EHF EIRP Budget of Luneberg Lens with Helix TWT on Pedestal

EHF EIRP Element	Units	Value
EHF Amplifier Output	dBW	+ 20.00
Amplifier to Waveguide Flange Loss	dB	- 1.00
Pedestal Loss	dB	- 0.50
Axial Ratio Mismatch Loss	dB	- 0.20
Antenna Gain	dBi	+ 49.59
Pointing Error Loss	dB	- 1.00
Tracking Loss	dB	- 0.70
Dry Radome Loss	dB	- 0.90
EIRP at Surface of Radome	**dBW**	**65.29**
Required Terminal EIRP	**dBW**	**65.20**
Margin	**dBW**	**+ 0.09**

From this budget, it can be seen that this Luneberg lens antenna/Helix TWT configuration meets the SEST EHF EIRP requirements and has approximately no margin. Therefore, this configuration will be further considered and evaluated from a cost and performance perspective.

5.3.1.1.2.3 EIRP Of A Luneberg Lens Antenna With A Centrally Located 400W Coupled Cavity TWT

An EIRP link budget for this configuration antenna is shown in Table 5.6 below.

Table 5.6- EHF EIRP Budget of Luneberg lens Antenna with a 400W Centrally Located Coupled Cavity TWT

EHF EIRP Element	Units	Value
EHF Amplifier Output	dBW	+ 26.00
Amplifier to Waveguide Flange Loss	dB	- 1.00
Waveguide Loss	dB	- 4.00
Pedestal Loss	dB	- 0.50
Axial Ratio Mismatch Loss	dB	- 0.20
Antenna Gain	dBi	+ 49.59
Pointing Error Loss	dB	- 1.00
Tracking Loss	dB	- 0.70
Dry Radome Loss	dB	- 0.90
EIRP at Surface of Radome	**dBW**	**67.29**
Required Terminal EIRP	**dBW**	**65.20**
Margin	**dBW**	**+ 2.09**

From this budget, it can be seen that this 400W centrally located Coupled Cavity configuration meets the SEST EHF EIRP requirements and has approximately 2.0 dB of margin. Therefore, this configuration will be further considered and evaluated from a cost and performance perspective.

5.3.1.1.3 Phased Array Antenna

The gain of a phase array is calculated using the following equation:

$$G = \frac{\eta(4\pi A)\cos(\theta)(1-|\Gamma(\theta)|^2)}{\lambda^2}$$[16] (Equation 5.4)

where:

A = area of element multiplied by the total number of elements in the array antenna

η = aperture efficiency corresponding to the amplitude distribution across the array aperture, with $\eta = 1$ for uniform amplitude distribution

θ = beam scan angle

$|\Gamma(\theta)|$ = magnitude of reflection coefficient at scan angle θ

In order to solve this equation for gain, several assumptions must be made including assumptions regarding the spacing of the elements including:

- The phased array will be canted 50° up with a scan angle of 45° providing coverage from 5° to 95° in elevation as shown in Figure 5.6 below.

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[16] Y.T. Lo, S.W. Lee, *Antenna Handbook, Volume III*, Van Nostrand Reinhold, New York, 1993.

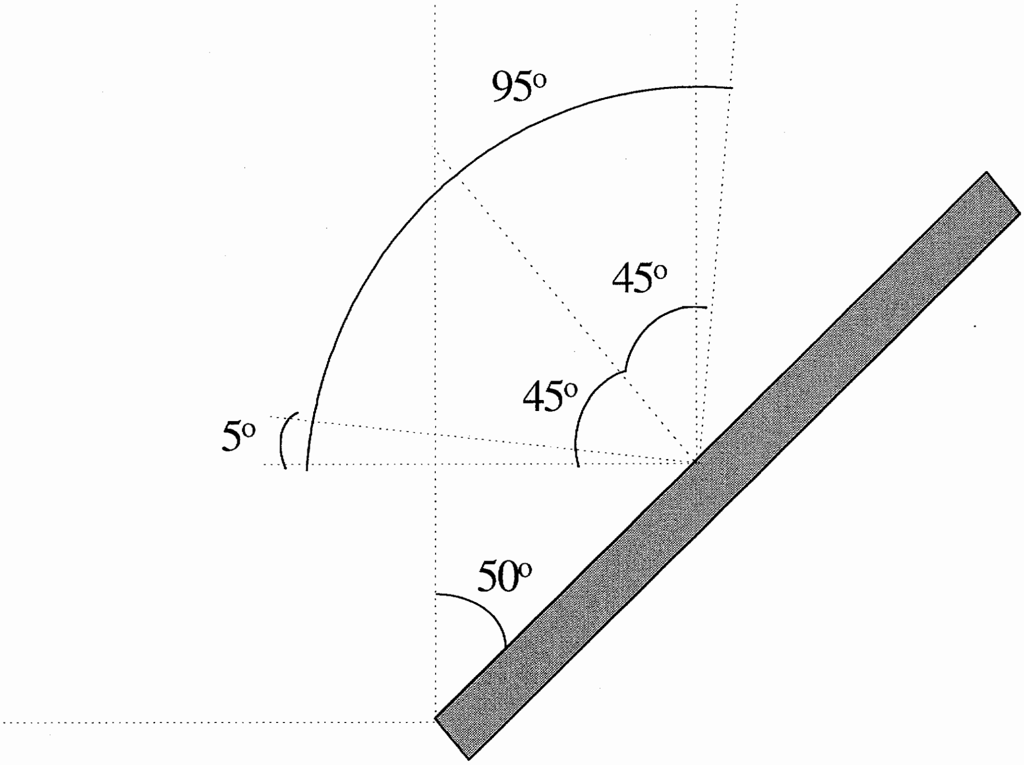

Figure 5.6 - Phased Array Antenna Approach

{It should be noted that this configuration has antenna pointing limitations in elevation under full platform dynamics. With this design, the minimum elevation angle is 5°, however, when looking at a satellite at 20° with full 35° roll, the antenna must look down to -15°. To accommodate this, the phased array would have to be canted 40° with a 55° scan angle. However, this would decrease the efficiency of the array by approximately 20% (i.e., cos(55)/cos(45) = 0.81) and would further increase the cost the array by requiring additional elements.}

- The amplitude of the elements will be the same; therefore, $\eta = 1$
- $|\Gamma(\theta)| = 0.2$
- The transmit elements are 350 mW elements with a power combining efficiency of 20%
- The element size will be 1/2 λ or 0.345 cm
- The array will be rectangular with two times the number of elements per row as there are rows

In addition, in order to prevent grating lobe formation, the element spacing along a given scan plan must satisfy the following formula:

$$\frac{d}{\lambda} = \frac{1}{1 + \sin \theta_{max}}$$ [17] (Equation 5.5)

Solving equation 4.5 for *d* with $\theta_{max} = 45^{\circ}$, provides a maximum element spacing of 0.404 cm leading to the last EHF assumption:

- The EHF element spacing $d = 0.345$ cm for consistency between the spacing and the element size

Substituting the knowns and assumptions into equation 4.4 provides:

$$G = \frac{(4\pi)(A)\cos(45)(1-|.2|^2)}{0.00005}$$

$$G = 179{,}350(A) = 179{,}350(\#\ \text{elements})(0.345)(0.345)$$

The power of the array can be expressed as a function of the number of elements as follows:

$$P = (\text{Power/element})(\#\ \text{elements})(\text{Power adding efficiency})$$

Since both the gain (aperture) and the power of the array are a function of the number of elements, Table 5.7 of candidate arrays and the associated gain, power, and EIRP is calculated.

Table 5.7 - EHF Transmit EIRP of Various Size Phased Arrays

Rows	Elements per Row	# Elements	Area (m^2)	Array Width (in)	Array Height (in)	Array Power (W)	Pwr (dBW)	Gain (dB)	EIRP (dBW)
10	20	200	0.002	5.43	2.72	14	11.46	26.30	37.76
20	40	800	0.010	10.87	5.43	56	17.48	32.32	49.81
30	60	1800	0.021	16.30	8.15	126	21.00	35.85	56.85
40	80	3200	0.038	21.73	10.87	224	23.50	38.34	61.85
50	**100**	**5000**	**0.060**	**27.17**	**13.58**	**350**	**25.44**	**40.28**	**65.72**
60	120	7200	0.086	32.60	16.30	504	27.02	41.87	68.89
70	140	9800	0.117	38.03	19.02	686	28.36	43.21	71.57
80	160	12800	0.152	43.46	21.73	896	29.52	44.37	73.89
90	180	16200	0.193	48.90	24.45	1134	30.55	45.39	75.93
100	200	20000	0.238	54.33	27.17	1400	31.46	46.30	77.76

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[17] Y.T. Lo, S.W. Lee, *Antenna Handbook, Volume III*, Van Nostrand Reinhold, New York, 1993.

From this table it can be seen that an array approximately 27" wide and 13.5" high of approximately 5000 elements, 50 rows of 100 elements per row, can satisfy the EHF EIRP requirement with approximately 0.5 dB of margin.

5.3.1.2 SHF EIRP

5.3.1.2.1 Parabolic Dish Antenna

For the antenna gain, the following assumptions will be made:

- a 36" dish reflector
- an efficiency of 55%
- the wavelength of the bottom of the band -- 7.9 GHz -- or 3.797 x 10^{-2}m.

Antenna gain is calculated as follows:

$$G = \frac{\eta(4\pi A)}{\lambda^2} \qquad \text{(Equation 5.6)}$$

$$G = \frac{\eta 4(\pi r)^2}{\lambda^2}$$

$$G = \frac{(0.55)(4)(\pi)^2(0.4572)^2}{(3.797 \times 10^{-2})^2}$$

$$G = 34.98 \text{ dBi}$$

Next, the EIRP for a 100W SHF SSPA on the back of each pedestal will be calculated in Table 5.8 below.

Table 5.8 - SHF EIRP Budget of Parabolic Dish Antenna with SSPA on Pedestal

EHF EIRP Element	Units	Value
SHF Amplifier Output	dBW	+ 20.00
Amplifier to Waveguide Flange Loss	dB	- 0.50
Pedestal Loss	dB	- 0.50
Axial Ratio Mismatch Loss	dB	- 0.20
Antenna Gain	dBi	+ 34.98
Pointing Error Loss	dB	- 0.40
Tracking Loss	dB	- 0.30
Dry Radome Loss	dB	- 0.50
EIRP at Surface of Radome	**dBW**	**52.58**
Required Terminal EIRP	**dBW**	**50.60**
Margin	**dBW**	**+ 1.98**

From this budget, it can be seen that this SSPA configuration meets the EIRP requirements with nearly 2 dB of margin.

5.3.1.2.2 Luneberg Lens Antenna

For the antenna gain, the following assumptions will be made:

- a 42" lens with an effective elliptical aperture of 42 x 36 inches (the sides of the lens are truncated where it attaches to the pedestal).
- an efficiency of 50%
- the wavelength of the bottom of the band -- 7.9 GHz -- or 3.797×10^{-2}m.

Antenna gain is calculated as follows:

$$G = \frac{\eta(4\pi A)}{\lambda^2} \qquad \text{(Equation 5.7)}$$

The area of the lens antenna will be calculated as the area of an ellipse or $A = \pi ab$ where a and b are the semimajor axis and the semiminor axis, respectively. Substituting provides

$$G = \frac{(0.50)(4)(\pi)(\pi)(0.5334 \times 0.4572)}{(3.797 \times 10^{-2})^2}$$

$$G = 35.24 \text{ dBi}$$

Next, the EIRP for the Luneberg Lens with a 100 Watt SHF SSPA on each antenna pedestal is calculated in Table 5.9 below.

Table 5.9- SHF EIRP Budget of Luneberg Lens with SSPA on Pedestal

EHF EIRP Element	Units	Value
EHF Amplifier Output	dBW	+ 20.00
Amplifier to Waveguide Flange Loss	dB	- 0.50
Pedestal Loss	dB	- 0.50
Axial Ratio Mismatch Loss	dB	- 0.20
Antenna Gain	dBi	+ 35.24
Pointing Error Loss	dB	- 0.40
Tracking Loss	dB	- 0.30
Dry Radome Loss	dB	- 0.50
EIRP at Surface of Radome	**dBW**	**52.58**
Required Terminal EIRP	**dBW**	**50.60**
Margin	**dBW**	**+ 2.24**

From this budget, it can be seen that this Luneberg lens antenna SHF SSPA configuration meets the EIRP requirements with approximately 2.25 dB of margin.

5.3.1.2.3 Phased Array

Many of the previous phased array assumptions are the same; however, for completeness the all assumptions will be listed.

- The phased array will be canted 50° up with a scan angle of 45° providing coverage from 5° to 95° in elevation as shown in Figure 4.5.
- The amplitude of the elements will be that same; therefore, $\eta = 1$
- $|\Gamma(\theta)| = 0.2$
- The transmit elements are 5 W elements with a power combining efficiency of 40%
- The element size will be 1/2 λ or 2.15 cm
- The array will be rectangular with two times the number of elements per row as there are rows

In addition, in order to prevent grating lobe formation, the element spacing along a given scan plan must satisfy equation 4.5. Solving equation 4.5 for d with $\theta_{max} = 45°$, provides a maximum SHF element spacing of 1.16 cm leading to the last SHF assumption:

- The SHF element spacing $d = 1$ cm for convenience

Table 5.10 provides candidate SHF arrays and the associated gain, power, and EIRP calculated as above.

Table 5.10 - SHF Transmit EIRP of Various Size Phased Arrays

Rows	Elements per Row	# Elements	Area (m^2)	Array Width (in)	Array Height (in)	Array Power (W)	Pwr (dBW)	Gain (dB)	EIRP (dBW)
5	10	50	0.023	12.40	6.20	100	20.00	21.36	41.36
6	12	72	0.033	14.88	7.44	144	21.58	22.94	44.53
7	14	98	0.045	17.36	8.68	196	22.92	24.28	47.20
8	16	128	0.059	19.84	9.92	256	24.08	25.44	49.52
9	**18**	**162**	**0.075**	**22.32**	**11.16**	**324**	**25.11**	**26.46**	**51.57**
10	20	200	0.092	24.80	12.40	400	26.02	27.38	53.40
11	22	242	0.112	27.28	13.64	484	26.85	28.21	55.06
12	24	288	0.133	29.76	14.88	576	27.60	28.96	56.57
13	26	338	0.156	32.24	16.12	676	28.30	29.66	57.96
14	28	392	0.181	34.72	17.36	784	28.94	30.30	59.24
15	30	450	0.208	37.20	18.60	900	29.54	30.90	60.44

From this table it can be seen that an array approximately 22.5" wide and 11" high of approximately 152 elements, 9 rows of 18 elements per row, can satisfy the SHF EIRP requirement with approximately 1.0 dB of margin.

5.3.1.3 EHF G/T

5.3.1.3.1 Parabolic Dish Antenna

Antenna G/T is a function of antenna gain and noise temperatures of the various antenna components and is expressed as

$$G/T = G_{antenna}\text{ (in dB)} - 10\log_{10}[T_{system}\text{ (in Kelvin)}]\ dBK^{-1}$$ [18]

For the antenna gain, the following assumptions will be made:

- a 36" dish reflector
- an efficiency of 55%
- the wavelength of the bottom of the band -- 20.2 GHz -- or 14.85×10^{-3}m.

Antenna gain is calculated as follows:

$$G = \frac{\eta(4\pi A)}{\lambda^2}$$

$$G = \frac{\eta 4(\pi r)^2}{\lambda^2}$$

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[18] T. Pratt, C. W. Bostian, *Satellite Communications*, John Wiley & Sons, New York, 1986.

$$G = \frac{(0.55)(4)(\pi)^2(0.4572)^2}{(14.85 \text{ x } 10^{-3})^2}$$

$$G = 43.11 \text{ dBi}$$

Next, the system noise temperature will be calculated. System noise temperature is approximated as:

$$T_{system} \cong T_{antenna} + T_{LNA}$$[19]

For the antenna system noise temperature, the following assumptions will be made:

- an overall antenna efficiency of 55%
- sky temperature at 21.2 GHz is 200K
- other contributors to antenna noise temperature are 150% of the sky temperature contribution
- the EHF LNA noise temperature is 50K

From these assumptions, the system noise temperature is calculated as follows:

$$T_{antenna} = 0.55(200K) + 1.5(0.55)(200K) = 275K$$

$$T_{system} \cong T_{antenna} + T_{LNA} = 275K + 50K = 325K = 25.12 \text{ dBK}$$

Finally, the G/T for a generic parabolic dish antenna will be calculated in Table 5.11.

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[19] T. Pratt, C. W. Bostian, *Satellite Communications*, John Wiley & Sons, New York, 1986.

Table 5.11 - EHF Parabolic Dish G/T Budget

EHF G/T Element	Units	Value
Dry Radome Loss	dB	- 0.60
Pointing Error Loss	dB	- 0.60
Tracking Loss	dB	- 0.50
Axial Ratio Mismatch Loss	dB	- 0.20
Antenna Gain	dBi	+ 43.11
System Noise Temperature	dBK	- 25.12
G/T	**dB/K**	**16.09 dB/K**
Required G/T	**dB/K**	**13.00 dB/K**
Margin		**3.09 dB**

From this table it can be seen that a 36" parabolic dish antenna can meet the required EHF G/T with approximately 3 dB or margin.

5.3.1.3.2 Luneberg Lens Antenna

For the antenna gain, the following assumptions will be made:

- a 42" lens with an effective elliptical aperture of 42 x 36 inches (the sides of the lens are truncated where it attaches to the pedestal).
- an efficiency of 45%
- the wavelength of the bottom of the band -- 20.2 GHz -- or 14.85 x 10^{-3}m.

Antenna gain is calculated as follows:

$$G = \frac{\eta(4\pi A)}{\lambda^2}$$

$$G = \frac{(0.45)(4)(\pi)(\pi)(0.5334 \text{ x } 0.4572)}{(14.85 \text{ x } 10^{-3})^2}$$

$$G = 42.93 \text{ dBi}$$

Next, the system noise temperature will be calculated. For the antenna system noise temperature, the following assumptions will be made:

- an overall antenna efficiency of 45%
- sky temperature at 21.2 GHz is 200K
- other contributors to antenna noise temperature are 150% of the sky temperature contribution
- the EHF LNA noise temperature is 50K

From these assumptions, the system noise temperature is calculated as follows:

$$T_{antenna} = 0.45(200K) + (1.5)(0.45)(200K) = 225K$$

$$T_{system} \cong T_{antenna} + T_{LNA} = 225K + 50K = 275K = 24.39 \text{ dBK}$$

Finally, the G/T for a Luneberg lens antenna will be calculated in Table 5.12.

Table 5.12 - EHF Luneberg Lens G/T Budget

EHF G/T Element	Units	Value
Dry Radome Loss	dB	- 0.60
Pointing Error Loss	dB	- 0.60
Tracking Loss	dB	- 0.50
Axial Ratio Mismatch Loss	dB	- 0.20
Antenna Gain	dBi	42.93
System Noise Temperature	dBK	- 24.39
G/T	**dB/K**	**16.64 dB/K**
Required G/T	**dB/K**	**13.0 dB/K**
Margin		**3.64 dB**

From this table it can be seen that a Luneberg lens antenna can meet the required EHF G/T with approximately 3.6 dB of margin.

5.3.1.3.3 Phased Array Antenna

Instead of calculating the EHF G/T for the phased array antenna, it will be assumed that the G/T is satisfied if the area of the receive array is twice the area of the transmit array based on model arrays. The number of receive elements is determined based on the number of elements that can fit within that area.

The array area is assumed to be 27" by 27" or 0.47 m^2. The element size will be assumed to 1/2 λ or 0.7425 cm. Using equation 4.5, the maximum element spacing is 0.8699 cm. Therefore, an element spacing of 0.7425 cm will be assumed for convenience. Computing the number of elements in the 0.47m^2 area can be accomplished as follows:

27" x 27" = 68.58 cm x 68.58 cm

68.58 cm/2 = 34.29 cm

Dividing the element size, 0.7425 cm, into 34.29 available cm provides:

$$34.29/0.7425 = 46.18 \cong 46 \text{ elements}$$

Thus, the number of elements is $(46)^2$ or 2116 elements.

5.3.1.4 SHF G/T

5.3.1.4.1 Parabolic Dish Antenna

Antenna G/T is a function of antenna gain and noise temperatures of the various antenna components and is expressed as

$$G/T = G_{\text{antenna}} \text{ (in dB)} - 10 \log_{10}[T_{\text{system}} \text{ (in Kelvin)}] \text{ dBK}^{-1}$$ [20]

For the antenna gain, the following assumptions will be made:

- a 36" dish reflector
- an efficiency of 55%
- the wavelength of the bottom of the band -- 7.25 GHz -- or 4.138×10^{-2}m.

Antenna gain is calculated as follows:

$$G = \frac{\eta 4(\pi r)^2}{\lambda^2}$$

$$G = \frac{(0.55)(4)(\pi)^2(0.4572)^2}{(4.138 \times 10^{-2})^2}$$

$$G = 34.23 \text{ dBi}$$

Next, the system noise temperature will be calculated. System noise temperature is approximated as:

$$T_{\text{system}} \cong T_{\text{antenna}} + T_{\text{LNA}}$$ [21]

For the antenna system noise temperature, the following assumptions will be made:

- an overall antenna efficiency of 55%
- sky temperature at 7.25 GHz is 40K

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[20] T. Pratt, C. W. Bostian, *Satellite Communications*, John Wiley & Sons, New York, 1986.

[21] T. Pratt, C. W. Bostian, *Satellite Communications*, John Wiley & Sons, New York, 1986.

- other contributors to antenna noise temperature are 150% of the sky temperature contribution
- the SHF LNA noise temperature is 50K

From these assumptions, the system noise temperature is calculated as follows:

$$T_{antenna} = 0.55(40K) + 1.5(0.55)(40K) = 55K$$

$$T_{system} \cong T_{antenna} + T_{LNA} = 55K + 50K = 105K = 20.21 \text{ dBK}$$

Finally, the SHF G/T for a generic parabolic dish antenna will be calculated in Table 5.13.

Table 5.13 - EHF Parabolic Dish G/T Budget

EHF G/T Element	Units	Value
Dry Radome Loss	dB	- 0.40
Pointing Error Loss	dB	- 0.30
Tracking Loss	dB	- 0.30
Axial Ratio Mismatch Loss	dB	- 0.20
Antenna Gain	dBi	+ 34.23
System Noise Temperature	dBK	- 20.21
G/T	**dB/K**	**12.82 dB/K**
Required G/T	**dB/K**	**10.50 dB/K**
Margin		**2.32 dB**

From this table it can be seen that a 36” parabolic dish antenna can meet the required SHF G/T with approximately 2.3 dB of margin.

5.3.1.4.2 Luneberg Lens Antenna

For the antenna gain, the following assumptions will be made:

- a 42” lens with an effective elliptical aperture of 42 x 36 inches (the sides of the lens are truncated where it attaches to the pedestal).
- an efficiency of 50%
- the wavelength of the bottom of the band -- 7.25 GHz -- or 4.138×10^{-2}m.

Antenna gain is calculated as follows:

$$G = \frac{\eta(4\pi A)}{\lambda^2}$$

$$G = \frac{(0.50)(4)(\pi)(\pi)(0.5334 \times 0.4572)}{(4.138 \times 10^{-2})^2}$$

$$G = 34.49 \text{ dBi}$$

Next, the system noise temperature will be calculated. For the antenna system noise temperature, the following assumptions will be made:

- an overall antenna efficiency of 50%
- sky temperature at 7.25 GHz is 40K
- other contributors to antenna noise temperature are 150% of the sky temperature contribution
- the SHF LNA noise temperature is 50K

From these assumptions, the system noise temperature is calculated as follows:

$$T_{antenna} = 0.50(40K) + (1.5)(0.50)(40K) = 50K$$

$$T_{system} \cong T_{antenna} + T_{LNA} = 50K + 50K = 100K = 20.00 \text{ dBK}$$

Finally, the SHF G/T for a Luneberg lens antenna will be calculated in Table 5.14.

Table 5.14 - SHF Luneberg Lens G/T Budget

EHF G/T Element	Units	Value
Dry Radome Loss	dB	- 0.40
Pointing Error Loss	dB	- 0.30
Tracking Loss	dB	- 0.30
Axial Ratio Mismatch Loss	dB	- 0.20
Antenna Gain	dBi	34.49
System Noise Temperature	dBK	- 20.00
G/T	**dB/K**	**13.29 dB/K**
Required G/T	**dB/K**	**10.50 dB/K**
Margin		**2.79 dB**

From this table it can be seen that a Luneberg lens antenna can meet the required SHF G/T with approximately 2.8 dB of margin.

5.3.1.4.3 Phased Array Antenna

Instead of calculating the SHF G/T for the phased array antenna, it will be assumed that the G/T is satisfied if the area of the receive array the same size as the transmit array based on model arrays. The number of receive elements is determined based on the number of elements that can fit within that area.

The array area is assumed to be 22" by 11" or 0.156 m^2. The element size will be assumed to 1/2 λ or 2.069 cm. Using equation 4.5, the maximum element spacing is 2.424 cm. Therefore, an element spacing of 2.069 cm will be assumed for convenience. Computing the number of elements in the 0.156 m^2 area can be accomplished as follows:

22" x 11" = 55.88 cm x 27.94 cm

55.88 cm/2 = 27.94 cm

Dividing the element size, 2.069 cm, into 27.94 available cm provides:

$$27.94/2.069 = 13.5 \cong 14 \text{ elements}$$

27.94 cm/2 = 13.97 cm

Dividing the element size, 2.069 cm, into 13.97 available cm provides:

$$13.97/2.069 = 6.75 \cong 7 \text{ elements}$$

Thus, the number of elements is 14 x 7 or 98 elements.

5.4 Life Cycle Cost Estimates

5.4.1 Life Cycle Cost Estimates of Alternatives

5.4.1.1 SEST Terminal with Parabolic Dish with Helix TWT EHF Amplifiers and SHF SSPA

A life cycle cost estimate for this configuration will be performed for comparison to other alternative configurations for completeness.

5.4.1.1.1 Assumptions

The general life cycle cost assumptions for this configuration include:

1. The average developer manyear cost is $150K ($12.5K/month)
2. A total of 20 terminals are required -- 4 will be build the first year of production, 8 the second year, and 8 the third year
3. A 90% unit learning is assumed for production
4. Terminals are installed and fully operational the second year after production begins
5. Hardware costs for the first unit are calculated in Table 5.15 which includes labor based on a component build-up using analogies to similar equipment.

Table 5.15 - First Unit Cost for SEST Terminal with Parabolic Dish Antenna with Helix TWT EHF Amplifiers and SHF SSPA

Group	Unit	Unit Cost	Quantity	Total Cost
Inboard Equipment	VME Chassis	$100K	1	$100K
	Power Supplies	$15K	4	$60K
	Terminal Controller	$35K	1	$35K
	Baseband Interface	$15K	3	$45K
	SHF Modem	$60K	1	$60K
	EHF Modem	$75K	1	$75K
	Frequency Synthesizer	$40K	1	$40K
	SHF Convertor	$25K	1	$25K
	Antenna Controller	$25K	2	$50K
Amplification Group	Power Supplies	$15K	2	$30K
	EHF Upconvertor	$35K	2	$70K
	EHF Amplifier	$60K	2	$120K
	SHF Preamp	$10K	2	$20K
	SHF Amplifier	$50K	2	$100K
Antenna Group	Pedestal	$5K	2	$10K
	Motors	$5K	6	$30K
	Power Supplies	$15K	2	$30K
	Reflector/Subreflector/Feed	$50K	2	$100K
	EHF Filter/LNA	$20K	2	$40K
	EHF Downconvertor	$15K	2	$30K
	SHF Filter/LNA	$15K	2	$30K
	SHF Downconvertor	$10K	2	$20K
Total			45	$1,120K

5.4.1.1.1.1 Research and Development Assumptions

The research and development assumptions for this configuration include:

1997

1. Management is 20% of the sum of the other R&D efforts
2. Planning, including specification development, is a 6 person effort for 2 months
3. Research, included the feasibility studies and market research, and is a 3-person effort for 2 months
4. Engineering design is an 12 person effort for 9 months
5. Hardware costs include building one prototype terminal which is tested to ensure the design meets specifications
6. Design documentation is 15% of the engineering design cost
7. Software is estimated to be 80,000 lines of code of which 40,000 is GUI code at a cost of \$25/line and 40,000 is executable code for terminal control at a cost of \$100/line and includes documentation
8. Test and evaluation is a 2 person effort averaged over the 12 months

1998

1. Management is 20% of the sum of the other R&D efforts
2. Engineering design changes as a result of testing the prototype and preparing for production is a 2 person effort for 6 months
3. Hardware costs due to design changes is 10% of the original hardware cost
4. Design documentation is 15% of the engineering design cost
5. Software redesign is estimated to be 8,000 lines of code which 4,000 is GUI code at a cost of \$25/line and 4,000 is executable code for terminal control at a cost of \$100/line and includes documentation
6. Test and evaluation of the prototype is a 4 person effort averaged over the entire 12 month period
7. Research and development is completed in this year

5.4.1.1.1.2 Production Assumptions

The production assumptions for this configuration include:

1997

1. Management is 20% of the sum of the other production efforts
2. Manufacturing consists of the equipment necessary to set up a production line and is approximated at $750K
3. Industrial engineering includes production planning and is a 4 person effort for 3 months

1998

1. Management is 20% of the sum of the other production efforts
2. Manufacturing consists of the equipment necessary to complete the production line set up and is approximated at $250K
3. The per unit hardware costs include documentation.
4. Hardware costs include building 4 terminals with a 90% learning curve (i.e., the per unit cost of 4 units is $(0.9)^2$x\$1,120K or \$907K)
5. Industrial engineering includes production planning completion and ongoing production process engineering and is a 2 person effort for 12 months
6. Test and evaluation at the assembly level is included in the hardware costs; test and evaluation at the system level is an a 6 person effort for 6 months
7. Quality control is a 2 person effort for 12 months
8. Initial spares are 20% of the hardware costs

1999 - 2000

1. Management is 20% of the sum of the other production efforts
2. Hardware costs include building 8 terminals in with a 90% learning curve (i.e., the per unit cost of 4 units is $(0.9)^3$x\$1,120K or \$816K).
3. Industrial engineering includes ongoing production process engineering and is a 1 person effort for 12 months
4. Test and evaluation at the assembly level is included in the hardware costs; test and evaluation at the system level is an a 8 person effort for 6 months

5. Quality control is a 2 person effort for 12 months
6. Initial spares are 20% of the hardware costs
7. Residual production costs in 2001 are covered by previous year production costs

5.4.1.1.1.3 Operations Assumptions

The operations assumptions for this configuration include:

1999 - 2017

1. Management is a 3 person effort
2. For operations there is 1 crew per ship; 3 operators per crew; 1 hour of active operations per 8 hour shift. The average operator manyear cost is $75K
3. Maintenance cost is the cost of the active repair time the maintainer spends repairing the equipment. It is assumed that the equipment just meets its maintainability requirement of 2 hours/failure. The system is operating continuously and just meets the required MTBF (i.e., MTBF = 1250 hours). This equates to 8766 hours/year/1250 hours/failure or 7.013 failures per year. The average maintainer manyear cost is $75K.
4. Spares and inventory costs are based on the average costs of failures per year per system. The average cost of a failure is based on half the non-mechanical cost in Table X divided by the non-mechanical assembly count in Table X, $910/40/2, or $11.375K per failure
5. Operator/Maintainer Training is a 2 person effort for 2 weeks per crew. After training for the initial 20 platforms is complete, 6 crews per year must be trained.
6. System improvements are assumed to be both software and hardware. The software improvements are estimated as 5,000 lines of code at $100/line. Hardware improvements are assumed to be minor in nature and equivalent to the software improvements. System improvements are not performed in 2016 and 2017 as the system will soon be disposed of.

5.4.1.1.1.4 Retirement and Disposal Assumptions

The retirement and disposal for this configuration include:

2000 - 2017

1. Consumables disposal is assumed to be $1K per terminal year.

2. System disposal is assumed to cost $100K to deinstall the equipment form the ship. 5 terminals are disposed of at the end of 2016. The remaining 15 terminals are disposed of at the end of 2017.
3. Documentation costs are assumed to be 20% of the consumables and system disposal total.

5.4.1.1.2 Life Cycle Cost Estimate

The life cycle cost estimate for this SEST configuration is shown in tabular form in Table 5.16 and graphically in Figure 5.7.

Table 5.16 - Life Cycle Cost Estimate for SEST Terminal with Parabolic Dish Antenna with Helix TWT EHF Amplifiers and SHF SSPA

	Cost				Cost/Year ($K)						
SEST Activity	Designator	97	98	99	00	01	02	03-15	16	17	Total
A. Research and Development	C_R	9837	1661	0	0	0	0	0	0	0	11498
1. Management	C_{RM}	1640	277								1916
2. Planning	C_{RP}	150									150
3. Research	C_{RR}	75									75
4. Engineering Design	C_{RE}	1350	150								1500
5. Hardware	C_{RH}	1120	112								1232
6. Design Documentation	C_{RD}	203	23								225
7. Software	C_{RS}	5000	500								5500
8. Test and Evaluation	C_{RT}	300	600								900
B. Manufacturing and Assembly	C_P	1080	6060	9359	9359	0	0	0	0	0	25859
1. Production Management	C_{PA}	180	405	471	471						1528
2. Hardware	C_{PH}		3629	6532	6532						16692
3. Manufacturing	C_{PM}	750	250								1000
4. Industrial Engineering	C_{PI}	150	300	150	150						750
5. Test and Evaluation	C_{PT}		450	600	600						1650
6. Quality Control	C_{PQ}		300	300	300						900
7. Initial Spares	C_{PS}		726	1306	1306						3338
C. Operations and Management	C_O	0	0	550	1061	2883	3656	47522	2656	2142	60470
1. Operations Management	C_{OA}			450	450	450	450	5850	450	450	8550
2. Operations	C_{OO}				90	270	450	5850	450	338	7448
3. Maintanance	C_{OM}				2	6	10	131	10	8	167
4. Spares and Inventory	C_{OS}				319	957	1595	20741	1595	1197	26405
5. Operator/Maintainer Training	C_{OT}			100	200	200	150	1950	150	150	2900
6. System Improvements	C_{OI}					1000	1000	13000			15000
D. Retirement and Disposal	C_D	0	0	0	5	14	24	312	624	1818	2797
1. Consumables Disposal	C_{DC}				4	12	20	260	20	15	331
2. System Disposal	C_{DS}								500	1500	2000
3. Documentation	C_{DD}				1	2	4	52	104	303	466
Total SEST Cost	C	10917	7721	9909	10425	2898	3680	47834	3280	3960	100624

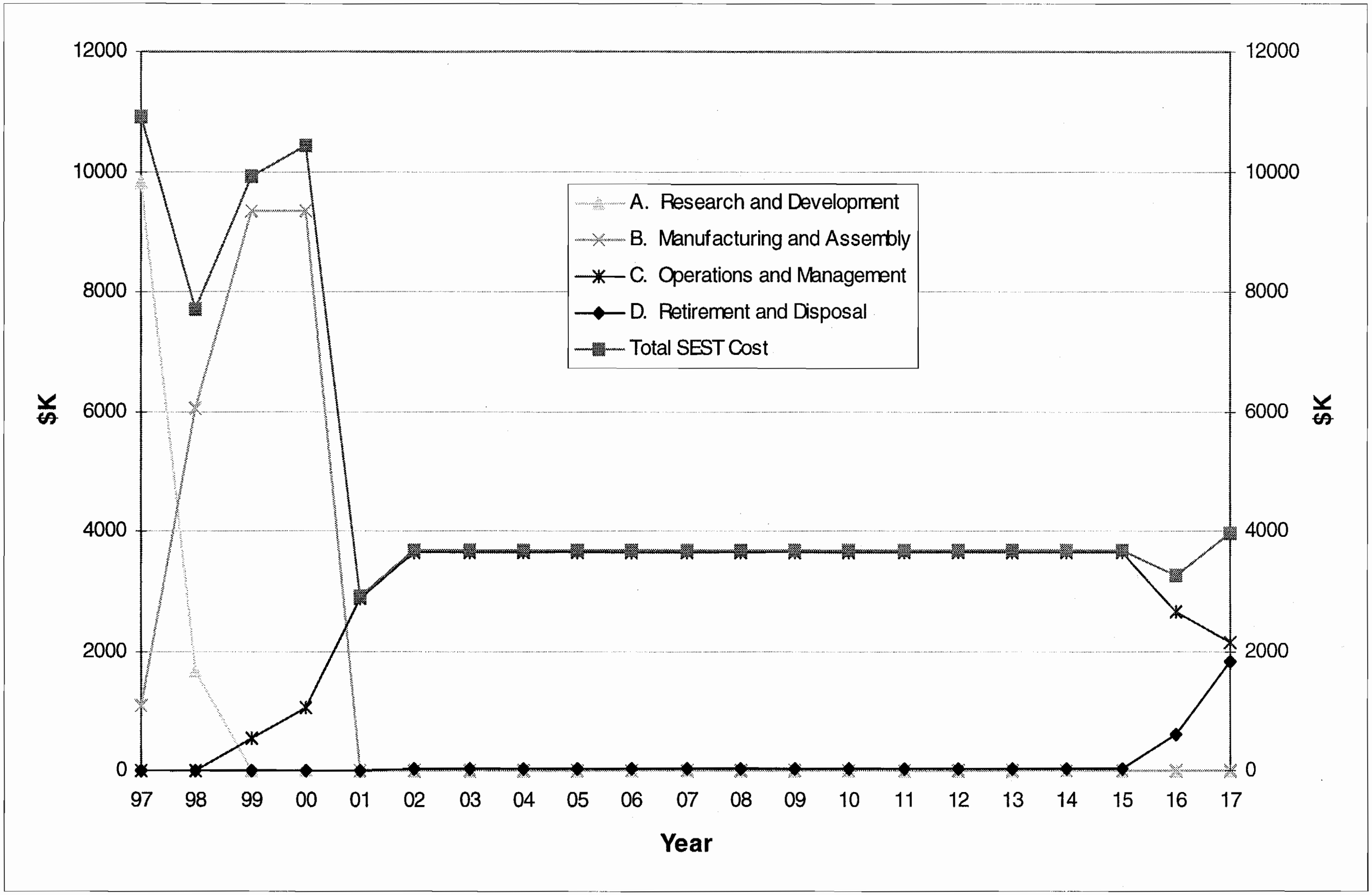


Figure 5.7 - Life Cycle Cost Estimate for SEST Terminal with Parabolic Dish Antenna with Helix TWT EHF Amplifiers and SHF SSPA

5.4.1.2 SEST Terminal with Parabolic Dish Antenna with Single Coupled Cavity EHF TWT and SHF Amplifiers

A life cycle cost estimate for this configuration will be performed for comparison to other alternative configurations.

5.4.1.2.1 Assumptions

The general life cycle cost assumptions which differ from the general life cycle cost assumptions for the first configuration include:

1. Hardware costs for the first unit are calculated in Table 5.17 which includes labor based on a component build-up using analogies to similar equipment.

Table 5.17 - First Unit Cost for SEST Terminal with Parabolic Dish Antenna with Single Coupled Cavity EHF TWT and SHF SSPA

Group	Unit	Unit Cost	Quantity	Total Cost
Inboard Equipment	VME Chassis	$100K	1	$100K
	Power Supplies	$15K	4	$60K
	Terminal Controller	$35K	1	$35K
	Baseband Interface	$15K	3	$45K
	SHF Modem	$60K	1	$60K
	EHF Modem	$75K	1	$75K
	Frequency Synthesizer	$40K	1	$40K
	SHF Convertor	$25K	1	$25K
	Antenna Controller	$25K	2	$50K
Amplification Group	Power Supplies	$15K	2	$30K
	EHF Upconvertor	$35K	1	$35K
	EHF Amplifier/Switches	$140K	1	$140K
	SHF Preamp	$10K	2	$20K
	SHF Amplifier	$50K	2	$100K
Antenna Group	Pedestal	$5K	2	$10K
	Motors	$5K	6	$30K
	Power Supplies	$15K	2	$30K
	Reflector/Subreflector/Feed	$50K	2	$100K
	EHF Filter/LNA	$20K	2	$40K
	EHF Downconvertor	$15K	2	$30K
	SHF Filter/LNA	$15K	2	$30K
	SHF Downconvertor	$10K	2	$20K
Total			43	$1,105K

5.4.1.2.1.1 Research and Development Assumptions

The research and development assumptions for this configuration are the same as the research and development assumptions for the first configuration.

5.4.1.2.1.2 Production Assumptions

The production assumptions for this configuration which are different from the research and development assumptions for the first configuration include:

1998

1. Hardware costs include building 4 terminals with a 90% learning curve (i.e., the per unit cost of 4 units is $(0.9)^2$x\$1,105K or \$895K)

1999 - 2000

1. Hardware costs include building 8 terminals in with a 90% learning curve (i.e., the per unit cost of 4 units is $(0.9)^3$x\$1,120K or \$806K).

5.4.1.2.1.3 Operations Assumptions

The operations assumptions for this configuration which are different from the operations assumptions for the first configuration include:

1999 - 2017

1. The system is operating continuously and is 10% short of meeting the required MTBF (i.e., MTBF = 1125 hours) based on historical performance of this configuration. This equates to 8766 hours/year/1125 hours/failure or 7.792 failures per year.
2. The average cost of a failure is based on half the non-mechanical cost in Table 5.17 divided by the non-mechanical assembly count in Table 5.17, \$895/38/2, or \$11.776K per failure

5.4.1.2.1.4 Retirement and Disposal Assumptions

The retirement and disposal assumptions for this configuration are the same as the retirement and disposal assumptions for the first configuration.

5.4.1.2.2 Life Cycle Cost Estimate

The life cycle cost estimate for this SEST configuration is shown in tabular form in Table 5.18 and graphically in Figure 5.8.

Table 5.18 - Life Cycle Cost Estimate for SEST with Parabolic Antenna Single Coupled Cavity EHF TWT and SHF SSPA

	Cost				Cost/Year ($K)						
SEST Activity	Designator	97	98	99	00	01	02	03-15	16	17	Total
A. Research and Development	C_R	9819	1660	0	0	0	0	0	0	0	11479
1. Management	C_{RM}	1637	277								1913
2. Planning	C_{RP}	150									150
3. Research	C_{RR}	75									75
4. Engineering Design	C_{RE}	1350	150								1500
5. Hardware	C_{RH}	1105	111								1216
6. Design Documentation	C_{RD}	203	23								225
7. Software	C_{RS}	5000	500								5500
8. Test and Evaluation	C_{RT}	300	600								900
B. Manufacturing and Assembly	C_P	1080	5999	9251	9251	0	0	0	0	0	25581
1. Production Management	C_{PA}	180	403	468	468						1519
2. Hardware	C_{PH}		3580	6444	6444						16469
3. Manufacturing	C_{PM}	750	250								1000
4. Industrial Engineering	C_{PI}	150	300	150	150						750
5. Test and Evaluation	C_{PT}		450	600	600						1650
6. Quality Control	C_{PQ}		300	300	300						900
7. Initial Spares	C_{PS}		716	1289	1289						3294
C. Operations and Management	C_O	0	0	550	1109	3028	3896	50653	2896	2322	64456
1. Operations Management	C_{OA}			450	450	450	450	5850	450	450	8550
2. Operations	C_{OO}				90	270	450	5850	450	338	7448
3. Maintanance	C_{OM}				2	7	11	146	11	8	186
4. Spares and Inventory	C_{OS}				367	1101	1835	23857	1835	1376	30372
5. Operator/Maintainer Training	C_{OT}			100	200	200	150	1950	150	150	2900
6. System Improvements	C_{OI}					1000	1000	13000			15000
D. Retirement and Disposal	C_D	0	0	0	5	14	24	312	624	1818	2797
1. Consumables Disposal	C_{DC}				4	12	20	260	20	15	331
2. System Disposal	C_{DS}								500	1500	2000
3. Documentation	C_{DD}				1	2	4	52	104	303	466
Total SEST Cost	C	10899	7659	9801	10365	3042	3920	50965	3520	4140	104313

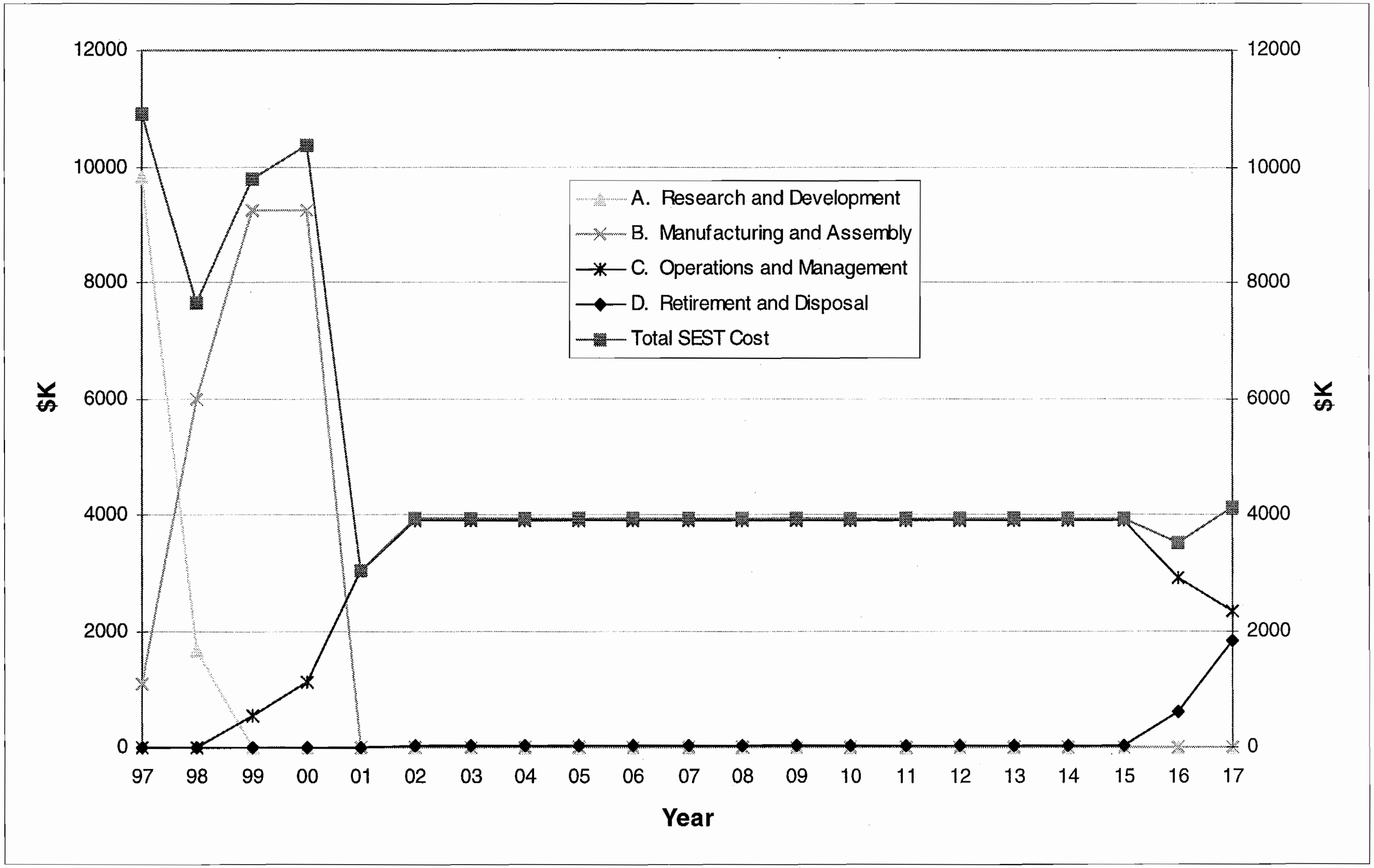


Figure 5.8 - Life Cycle Cost Estimate for SEST with Parabolic Dish Antenna with Single Coupled Cavity EHF TWT and SHF Amplifiers

5.4.1.3 SEST Terminal with Luneberg Lens Antenna with Helix TWT EHF Amplifiers and SHF SSPA

A life cycle cost estimate for this configuration will be performed for comparison to other alternative configurations.

5.4.1.3.1 Assumptions

The general life cycle cost assumptions which differ from the general life cycle cost assumptions for the first configuration include:

1. Hardware costs for the first unit are calculated in Table 5.19 which includes labor based on a component build-up using analogies to similar equipment.

Table 5.19- First Unit Cost for SEST Terminal with Luneberg Lens Antenna with Helix TWT EHF Amplifiers and SHF SSPA

Group	Unit	Unit Cost	Quantity	Total Cost
Inboard Equipment	VME Chassis	$100K	1	$100K
	Power Supplies	$15K	4	$60K
	Terminal Controller	$35K	1	$35K
	Baseband Interface	$15K	3	$45K
	SHF Modem	$60K	1	$60K
	EHF Modem	$75K	1	$75K
	Frequency Synthesizer	$40K	1	$40K
	SHF Convertor	$25K	1	$25K
	Antenna Controller	$25K	2	$50K
Amplification Group	Power Supplies	$15K	2	$30K
	EHF Upconvertor	$35K	2	$70K
	EHF Amplifier	$60K	2	$120K
	SHF Preamp	$10K	2	$20K
	SHF Amplifier	$50K	2	$100K
Antenna Group	Pedestal	$5K	2	$10K
	Motors	$5K	4	$20K
	Power Supplies	$15K	2	$30K
	Lens/Feed	$150K	2	$300K
	EHF Filter/LNA	$20K	2	$40K
	EHF Downconvertor	$15K	2	$30K
	SHF Filter/LNA	$15K	2	$30K
	SHF Downconvertor	$10K	2	$20K
Total			43	$1,310K

5.4.1.3.1.1 Research and Development Assumptions

The research and development assumptions for this configuration that differ from the first configuration research and development assumptions include:

1997

1. Research, included the feasibility studies and market research, and is a 4 person effort for 2 months
2. Engineering design is an 16 person effort for 9 months

5.4.1.3.1.2 Production Assumptions

The production assumptions for this configuration include which differ from the production assumptions of the first configuration include:

1998

1. Hardware costs include building 4 terminals with a 90% learning curve (i.e., the per unit cost of 4 units is $(0.9)^2$x$1,310K or $1062K

1999 - 2000

1. Hardware costs include building 8 terminals in with a 90% learning curve (i.e., the per unit cost of 4 units is $(0.9)^3$x$1,310K or $955K).

5.4.1.3.1.3 Operations Assumptions

The operations assumptions for this configuration include which differ from the operations assumptions of the first configuration include:

1999 - 2017

1. The average cost of a failure is based on half the non-mechanical cost in Table 5.19 divided by the non-mechanical assembly count in Table 4.19, $900/39/2, or $11.538K per failure

5.4.1.3.1.4 Retirement and Disposal Assumptions

The retirement and disposal assumptions for this configuration are the same as the retirement and disposal assumptions of the first configuration.

5.4.1.3.2 Life Cycle Cost Estimate

The life cycle cost estimate for this SEST configuration is shown in tabular form in Table 5.20 and graphically in Figure 5.9.

Table 5.20 - Life Cycle Cost Estimate for SEST with Luneberg Lens Antenna with Helix TWT EHF Amplifiers and SHF SSPA

	Cost				Cost/Year ($K)						
SEST Activity	Designator	97	98	99	00	01	02	03-15	16	17	Total
A. Research and Development	C_R	10716	1684	0	0	0	0	0	0	0	12400
1. Management	C_{RM}	1786	281								2067
2. Planning	C_{RP}	150									150
3. Research	C_{RR}	100									100
4. Engineering Design	C_{RE}	1800	150								1950
5. Hardware	C_{RH}	1310	131								1441
6. Design Documentation	C_{RD}	270	23								293
7. Software	C_{RS}	5000	500								5500
8. Test and Evaluation	C_{RT}	300	600								900
B. Manufacturing and Assembly	C_P	1080	6823	10734	10734	0	0	0	0	0	29370
1. Production Management	C_{PA}	180	430	516	516						1641
2. Hardware	C_{PH}		4244	7640	7640						19524
3. Manufacturing	C_{PM}	750	250								1000
4. Industrial Engineering	C_{PI}	150	300	150	150						750
5. Test and Evaluation	C_{PT}		450	600	600						1650
6. Quality Control	C_{PQ}		300	300	300						900
7. Initial Spares	C_{PS}		849	1528	1528						3905
C. Operations and Management	C_O	0	0	550	1066	2897	3678	47820	2678	2159	60848
1. Operations Management	C_{OA}			450	450	450	450	5850	450	450	8550
2. Operations	C_{OO}				90	270	450	5850	450	338	7448
3. Maintanance	C_{OM}				2	6	10	131	10	8	167
4. Spares and Inventory	C_{OS}				324	971	1618	21038	1618	1214	26783
5. Operator/Maintainer Training	C_{OT}			100	200	200	150	1950	150	150	2900
6. System Improvements	C_{OI}					1000	1000	13000			15000
D. Retirement and Disposal	C_D	0	0	0	5	14	24	312	624	1818	2797
1. Consumables Disposal	C_{DC}				4	12	20	260	20	15	331
2. System Disposal	C_{DS}								500	1500	2000
3. Documentation	C_{DD}				1	2	4	52	104	303	466
Total SEST Cost	C	11796	8507	11284	11804	2911	3702	48132	3302	3977	105416

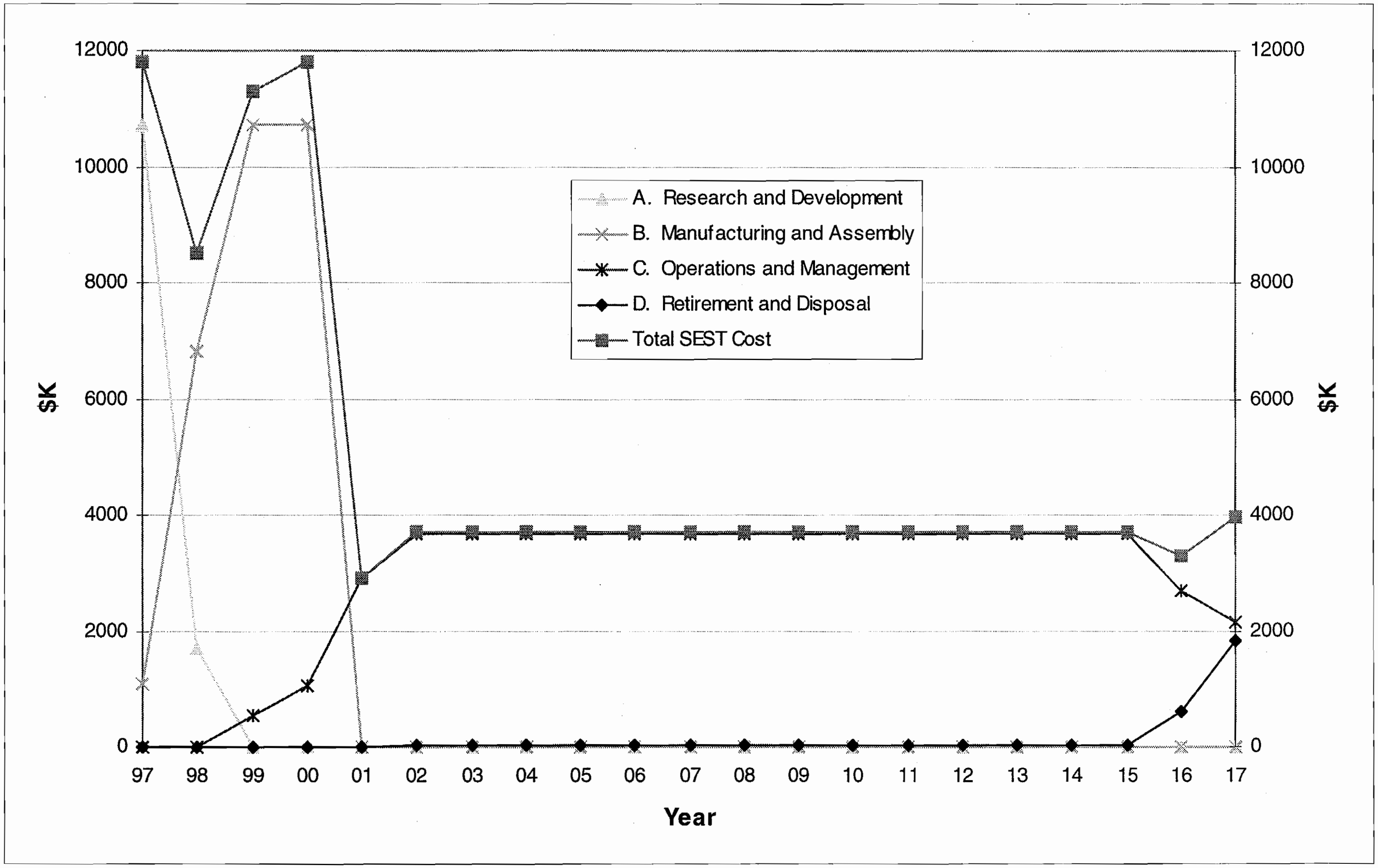


Figure 5.9 - Life Cycle Cost Estimate for SEST Terminal with Luneberg Lens Antenna with Helix TWT EHF Amplifiers and SHF SSPA

5.4.1.4 SEST Terminal with Luneberg Lens Antenna with Single Coupled Cavity EHF TWT and SHF SSPA

A life cycle cost estimate for this configuration will be performed for comparison to other alternative configurations.

5.4.1.4.1 Assumptions

The general life cycle cost assumptions which differ from the general life cycle cost assumptions for the first Luneberg Lens configuration include:

1. Hardware costs for the first unit are calculated in Table 5.21 which includes labor based on a component build-up using analogies to similar equipment.

Table 5.21 - First Unit Cost for SEST Terminal with Luneberg Lens Antenna with Single Coupled Cavity EHF TWT and SHF SSPA

Group	Unit	Unit Cost	Quantity	Total Cost
Inboard Equipment	VME Chassis	$100K	1	$100K
	Power Supplies	$15K	4	$60K
	Terminal Controller	$35K	1	$35K
	Baseband Interface	$15K	3	$45K
	SHF Modem	$60K	1	$60K
	EHF Modem	$75K	1	$75K
	Frequency Synthesizer	$40K	1	$40K
	SHF Convertor	$25K	1	$25K
	Antenna Controller	$25K	2	$50K
Amplification Group	Power Supplies	$15K	2	$30K
	EHF Upconvertor	$35K	1	$35K
	EHF Amplifier/Switches	$140K	1	$140K
	SHF Preamp	$10K	2	$20K
	SHF Amplifier	$50K	2	$100K
Antenna Group	Pedestal	$5K	2	$10K
	Motors	$5K	4	$20K
	Power Supplies	$15K	2	$30K
	Lens/Feed	$150K	2	$300K
	EHF Filter/LNA	$20K	2	$40K
	EHF Downconvertor	$15K	2	$30K
	SHF Filter/LNA	$15K	2	$30K
	SHF Downconvertor	$10K	2	$20K
Total			41	$1,295K

5.4.1.4.1.1 Research and Development Assumptions

The research and development assumptions for this configuration are the same as the research and development assumptions for the first Luneberg Lens configuration.

5.4.1.4.1.2 Production Assumptions

The production assumptions for this configuration include which differ from the production assumptions of the first Luneberg Lens configuration include:

1998

1. Hardware costs include building 4 terminals with a 90% learning curve (i.e., the per unit cost of 4 units is $(0.9)^2$x\$1,295K or \$1049K

1999 - 2000

1. Hardware costs include building 8 terminals in with a 90% learning curve (i.e., the per unit cost of 4 units is $(0.9)^3$x\$1,295K or \$944K).

5.4.1.4.1.3 Operations Assumptions

The operations assumptions for this configuration include which differ from the operations assumptions of the first configuration include:

1999 - 2017

1. The system is operating continuously and is 10% short of meeting the required MTBF (i.e., MTBF = 1125 hours) based on historical performance of this configuration. This equates to 8766 hours/year/1125 hours/failure or 7.792 failures per year.
2. The average cost of a failure is based on half the non-mechanical cost in Table 5.21 divided by the non-mechanical assembly count in Table 5.21, \$885/36/2, or \$12.29K per failure

5.4.1.4.1.4 Retirement and Disposal Assumptions

The retirement and disposal assumptions for this configuration are the same as the retirement and disposal assumptions of the first Luneberg Lens configuration.

5.4.1.4.2 Life Cycle Cost Estimate

The life cycle cost estimate for this SEST configuration is shown in tabular form in Table 5.22 and graphically in Figure 5.10.

Table 5.22 - Life Cycle Cost Estimate for SEST with Luneberg Lens Antenna with Helix TWT EHF Amplifiers and SHF SSPA

	Cost				Cost/Year ($K)						
SEST Activity	Designator	97	98	99	00	01	02	03-15	16	17	Total
A. Research and Development	C_R	10698	1682	0	0	0	0	0	0	0	12380
1. Management	C_{RM}	1783	280								2063
2. Planning	C_{RP}	150									150
3. Research	C_{RR}	100									100
4. Engineering Design	C_{RE}	1800	150								1950
5. Hardware	C_{RH}	1295	130								1425
6. Design Documentation	C_{RD}	270	23								293
7. Software	C_{RS}	5000	500								5500
8. Test and Evaluation	C_{RT}	300	600								900
B. Manufacturing and Assembly	C_P	1080	6763	10625	10625	0	0	0	0	0	29093
1. Production Management	C_{PA}	180	428	512	512						1632
2. Hardware	C_{PH}		4196	7552	7552						19301
3. Manufacturing	C_{PM}	750	250								1000
4. Industrial Engineering	C_{PI}	150	300	150	150						750
5. Test and Evaluation	C_{PT}		450	600	600						1650
6. Quality Control	C_{PQ}		300	300	300						900
7. Initial Spares	C_{PS}		839	1510	1510						3860
C. Operations and Management	C_O	0	0	550	1125	3076	3977	51695	2977	2382	65781
1. Operations Management	C_{OA}			450	450	450	450	5850	450	450	8550
2. Operations	C_{OO}				90	270	450	5850	450	338	7448
3. Maintanance	C_{OM}				2	7	11	146	11	8	186
4. Spares and Inventory	C_{OS}				383	1149	1915	24899	1915	1436	31698
5. Operator/Maintainer Training	C_{OT}			100	200	200	150	1950	150	150	2900
6. System Improvements	C_{OI}					1000	1000	13000			15000
D. Retirement and Disposal	C_D	0	0	0	5	14	24	312	624	1818	2797
1. Consumables Disposal	C_{DC}				4	12	20	260	20	15	331
2. System Disposal	C_{DS}								500	1500	2000
3. Documentation	C_{DD}				1	2	4	52	104	303	466
Total SEST Cost	C	11778	8445	11175	11755	3090	4001	52007	3601	4200	110052

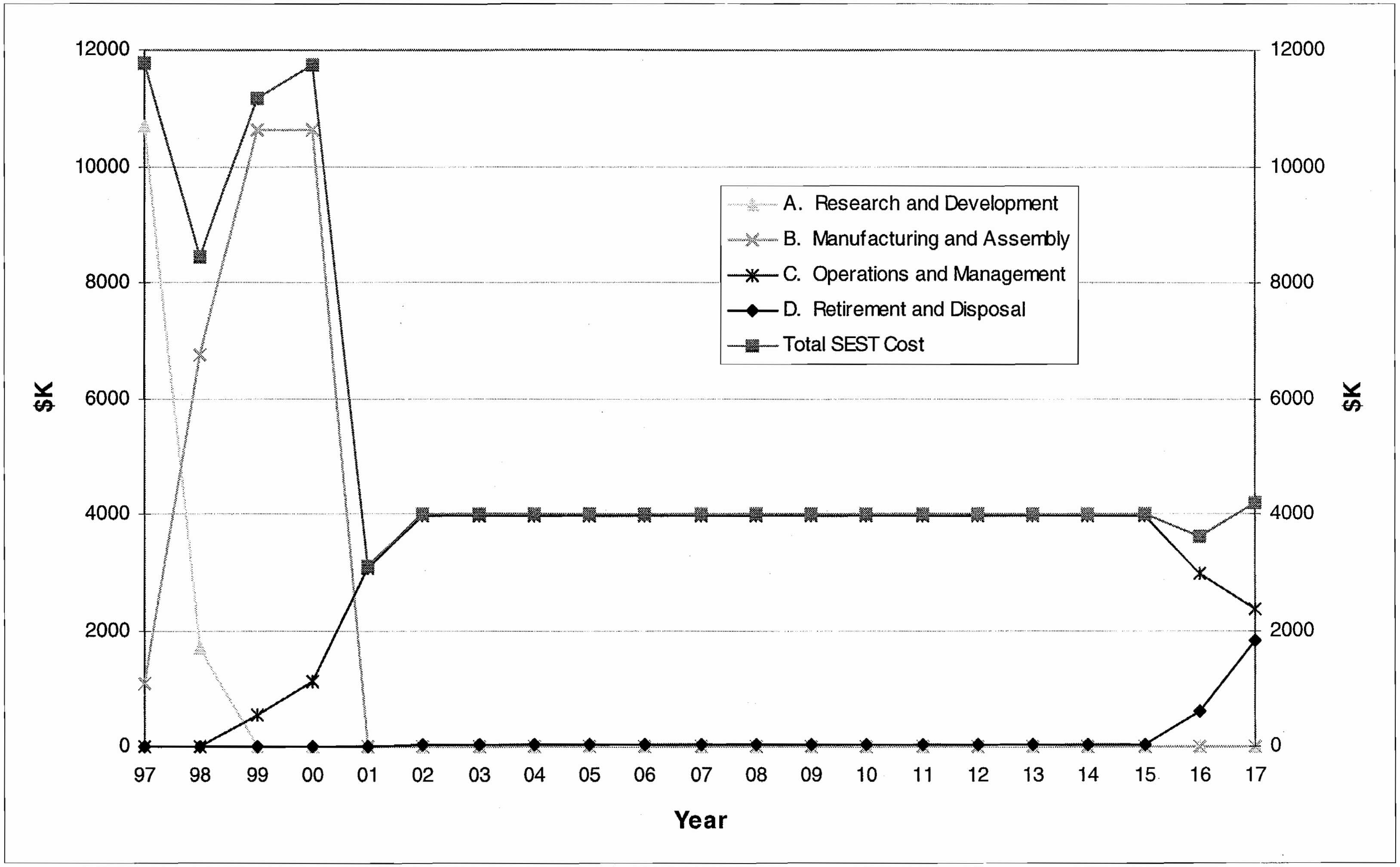


Figure 5.10- Life Cycle Cost Estimate for SEST with Luneberg Lens Antenna with and SHF SSPA

5.4.1.5 SEST Terminal Phased Array EHF and SHF Antenna with Phase Shift Beamsteering in Elevation and Mechanical Steering in Azimuth

A life cycle cost estimate for this configuration will be performed for comparison to other alternative configurations for completeness.

5.4.1.5.1 Assumptions

The general life cycle cost assumptions which differ from the general life cycle cost assumptions for other configurations include:

1. Hardware costs for the first unit are calculated in Table 5.23 which includes labor based on a component build-up using analogies to similar equipment.

Table 5.23 - First Unit Cost for SEST Terminal with Phased Array EHF and SHF Antenna with Phase Shift Beamsteering in Elevation and Mechanical Steering in Azimuth

Group	Unit	Unit Cost	Quantity	Total Cost
Inboard Equipment	VME Chassis	$100K	1	$100K
	Power Supplies	$15K	4	$60K
	Terminal Controller	$35K	1	$35K
	Baseband Interface	$15K	3	$45K
	SHF Modem	$60K	1	$60K
	EHF Modem	$75K	1	$75K
	Frequency Synthesizer	$40K	1	$40K
	Antenna Controller	$25K	2	$50K
Amplification Group	N/A; Part of Antenna Group			$0K
Antenna Group	Pedestal	$5K	2	$10K
	Motors	$5K	2	$10K
	Power Supplies	$15K	2	$30K
	EHF Transmit Arrays	$750K	4	$3000K
	EHF Receive Arrays	$500K	4	$2000K
	SHF Transmit Arrays	$125K	4	$500K
	SHF Receive Arrays	$75K	4	$300K
Total			36	$6315K

5.4.1.5.1.1 Research and Development Assumptions

The research and development assumptions for this configuration which are different from the research and development assumptions for other configurations include:

1997

1. Research, included the feasibility studies and market research, and is a 6-person effort for 2 months
2. Engineering design is an 20 person effort for 9 months
3. Software is estimated to be 100,000 lines of code of which 40,000 is GUI code at a cost of $25/line and 60,000 is executable code for terminal control at a cost of $100/line and includes documentation
4. Test and evaluation is a 3 person effort averaged over the 12 months

1998

1. Software redesign is estimated to be 10,000 lines of code which 4,000 is GUI code at a cost of $25/line and 6,000 is executable code for terminal control at a cost of $100/line and includes documentation
2. Test and evaluation of the prototype is a 6 person effort averaged over the entire 12 month period

5.4.1.5.1.2 Production Assumptions

The production assumptions for this configuration which are different from the production assumptions for other configurations include:

1998

1. Hardware costs include building 4 terminals with a 90% learning curve (i.e., the per unit cost of 4 units is $(0.9)^2$x$6,315K or $5,115K)
2. Initial spares are 5% of the hardware costs

1999 - 2000

1. Hardware costs include building 8 terminals in with a 90% learning curve (i.e., the per unit cost of 4 units is $(0.9)^3$x\$6,315K or \$4604K).
2. Initial spares are 5% of the hardware costs

5.4.1.5.1.3 Operations Assumptions

The operations assumptions for this configuration which are different from the operations assumptions for other configurations include:

1999 - 2017

1. It is assumed that the equipment exceeds just meets its maintainability requirement of 2 hours/failure. The system is operating continuously and exceeds the required MTBF by 20% (i.e., MTBF = 1500 hours). This equates to 8766 hours/year/1500 hours/failure or 5.844 failures per year.
2. The average cost of a failure is based on half the non-mechanical cost in Table 5.23 divided by the non-mechanical assembly count in Table 5.23, \$405/17/2, or \$11.912K per failure. It is assumed that the phased array antennas experience no 'failures' over the life of the system. Instead, failures of individual elements impose a graceful degradation to system performance, but not below specification.

5.4.1.5.1.4 Retirement and Disposal Assumptions

The retirement and disposal for this configuration are the same as earlier configurations.

5.4.1.5.2 Life Cycle Cost Estimate

The life cycle cost estimate for this SEST configuration is shown in tabular form in Table 5.24 and graphically in Figure 5.11.

Table 5.24- Life Cycle Cost Estimate for SEST with Luneberg Lens Antenna with Helix TWT EHF Amplifiers and SHF SSPA

	Cost	Cost/Year ($K)									
SEST Activity	Designator	97	98	99	00	01	02	03-15	16	17	Total
A. Research and Development	C_R	20163	2885	0	0	0	0	0	0	0	23048
1. Management	C_{RM}	3361	481								3841
2. Planning	C_{RP}	150									150
3. Research	C_{RR}	150									150
4. Engineering Design	C_{RE}	2250	150								2400
5. Hardware	C_{RH}	6315	632								6947
6. Design Documentation	C_{RD}	338	23								360
7. Software	C_{RS}	7000	700								7700
8. Test and Evaluation	C_{RT}	600	900								1500
B. Manufacturing and Assembly	C_P	1080	23248	40299	40299	0	0	0	0	0	104926
1. Production Management	C_{PA}	180	465	578	578						1801
2. Hardware	C_{PH}		20461	36829	36829						94119
3. Manufacturing	C_{PM}	750	250								1000
4. Industrial Engineering	C_{PI}	150	300	150	150						750
5. Test and Evaluation	C_{PT}		450	600	600						1650
6. Quality Control	C_{PQ}		300	300	300						900
7. Initial Spares	C_{PS}		1023	1841	1841						4706
C. Operations and Management	C_O	0	0	550	1020	2760	3451	44859	2451	1988	57079
1. Operations Management	C_{OA}			450	450	450	450	5850	450	450	8550
2. Operations	C_{OO}				90	270	450	5850	450	338	7448
3. Maintanance	C_{OM}				2	5	8	110	8	6	139
4. Spares and Inventory	C_{OS}				278	835	1392	18100	1392	1044	23042
5. Operator/Maintainer Training	C_{OT}			100	200	200	150	1950	150	150	2900
6. System Improvements	C_{OI}					1000	1000	13000			15000
D. Retirement and Disposal	C_D	0	0	0	5	14	24	312	624	1818	2797
1. Consumables Disposal	C_{DC}				4	12	20	260	20	15	331
2. System Disposal	C_{DS}								500	1500	2000
3. Documentation	C_{DD}				1	2	4	52	104	303	466
Total SEST Cost	C	21243	26133	40849	41324	2775	3475	45171	3075	3806	187850

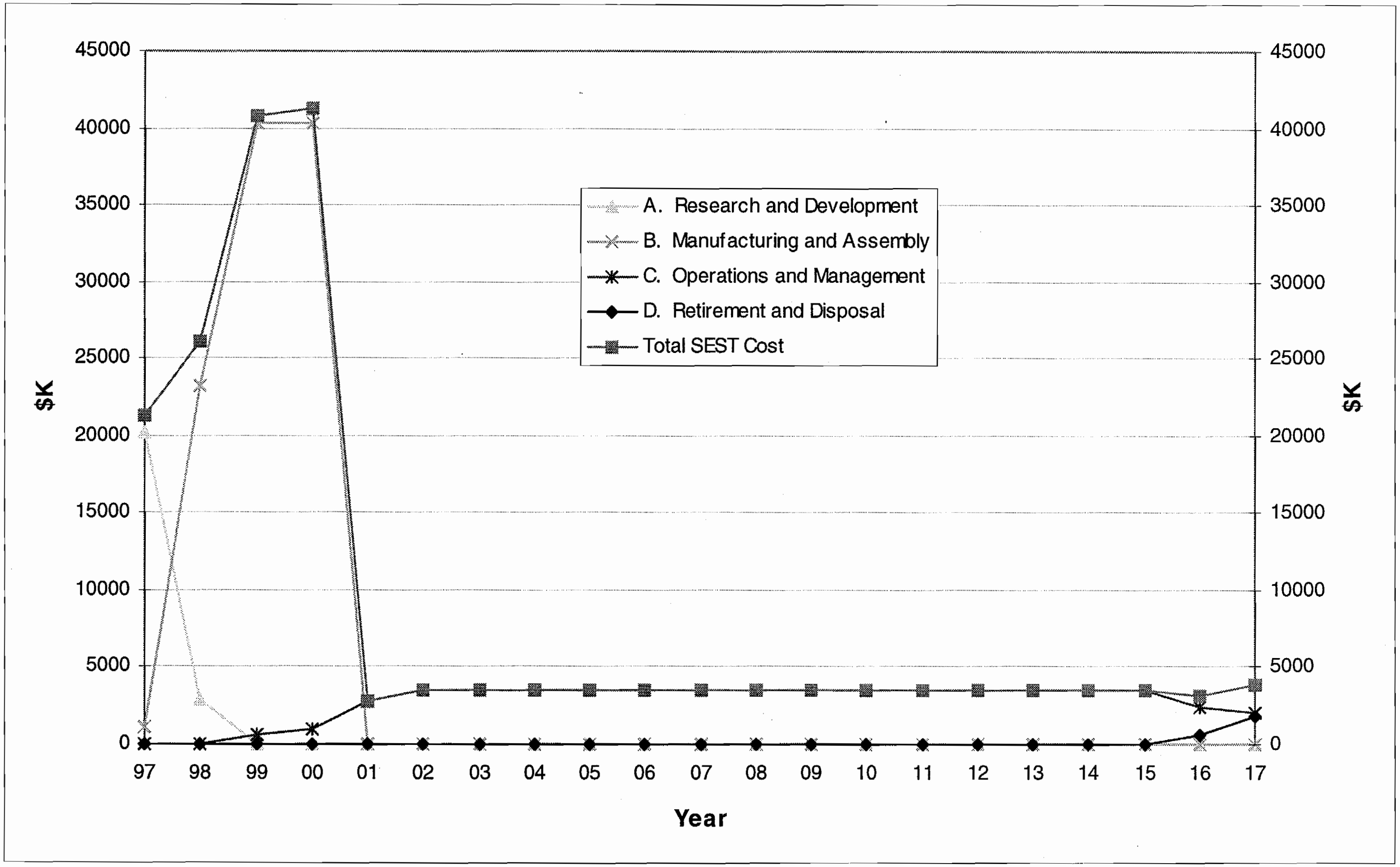


Figure 5.11- Life Cycle Cost Estimate for SEST with Luneberg Lens Antenna with Helix TWT EHF Amplifiers and SHF SSPA

5.4.2 Life Cycle Cost Estimate Comparisons

Figure 5.12 compares the research and development costs of the five alternatives under consideration. It shows alternative 2, the parabolic dish with an EHF coupled cavity TWT and SHF SSPA, having the lowest research and development cost.

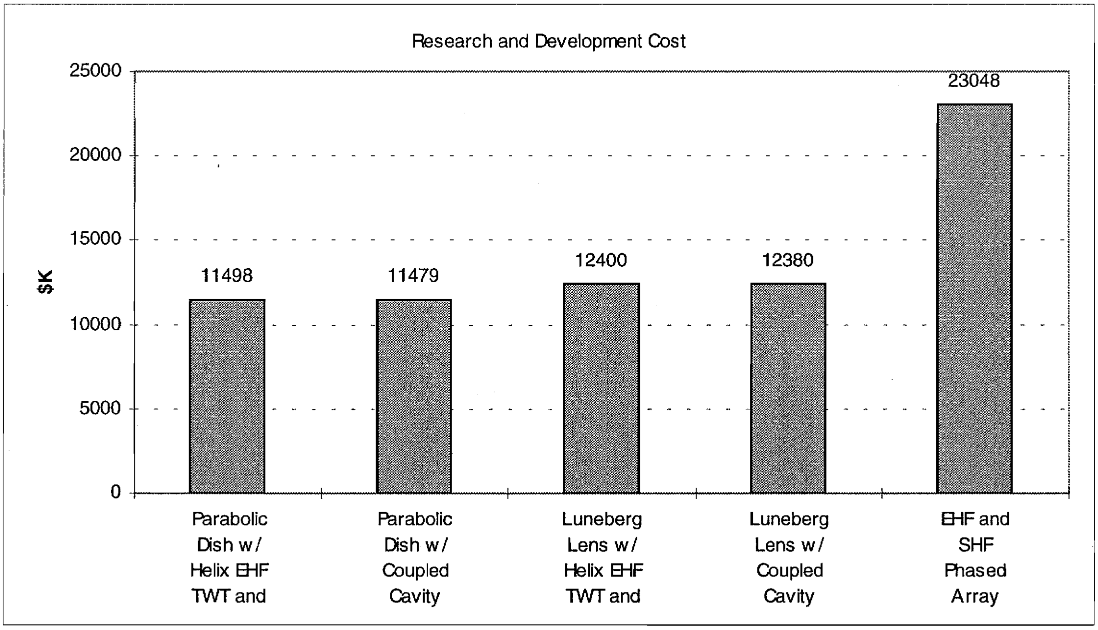


Figure 5.12 - Research and Development Cost Estimate Comparison of SEST Alternatives

Figure 5.13 compares the manufacturing and assembly (or production) costs of the five alternatives under consideration which shows alternative 2, the parabolic dish with an EHF coupled cavity TWT and SHF SSPA, having the lowest manufacturing and assembly cost.

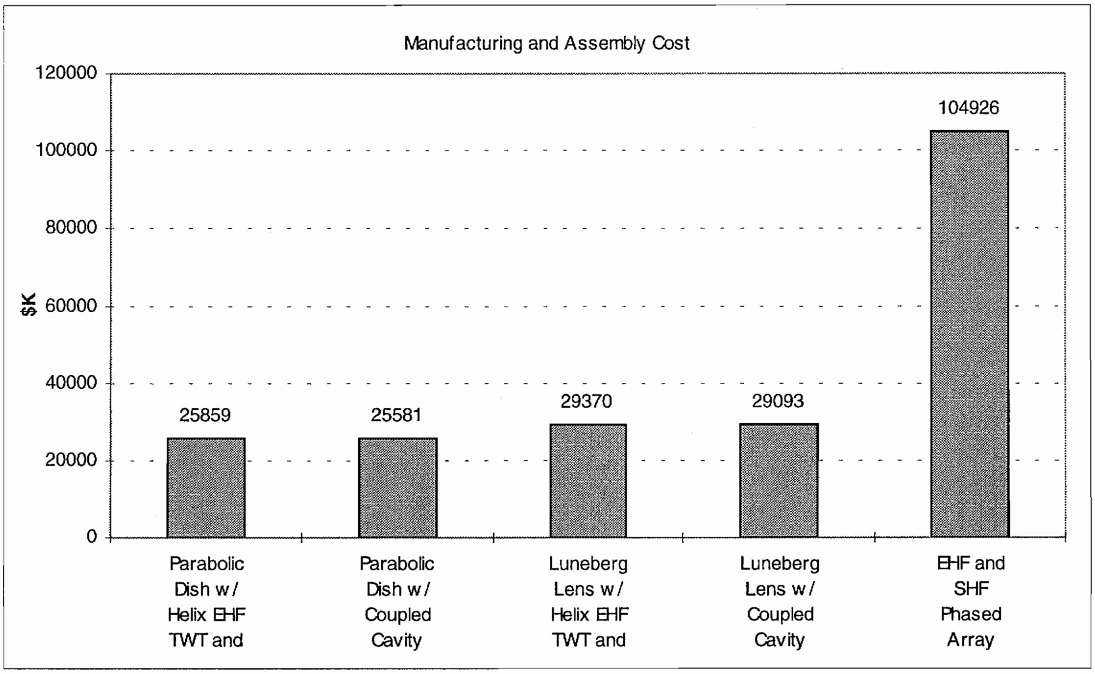


Figure 5.13 - Production Cost Estimate Comparison of SEST Alternatives

Figure 5.14 compares the operations and maintenance costs of the five alternatives under consideration which shows alternative 5, the EHF and SHF phased array antenna approach, having the lowest operations and maintenance cost.

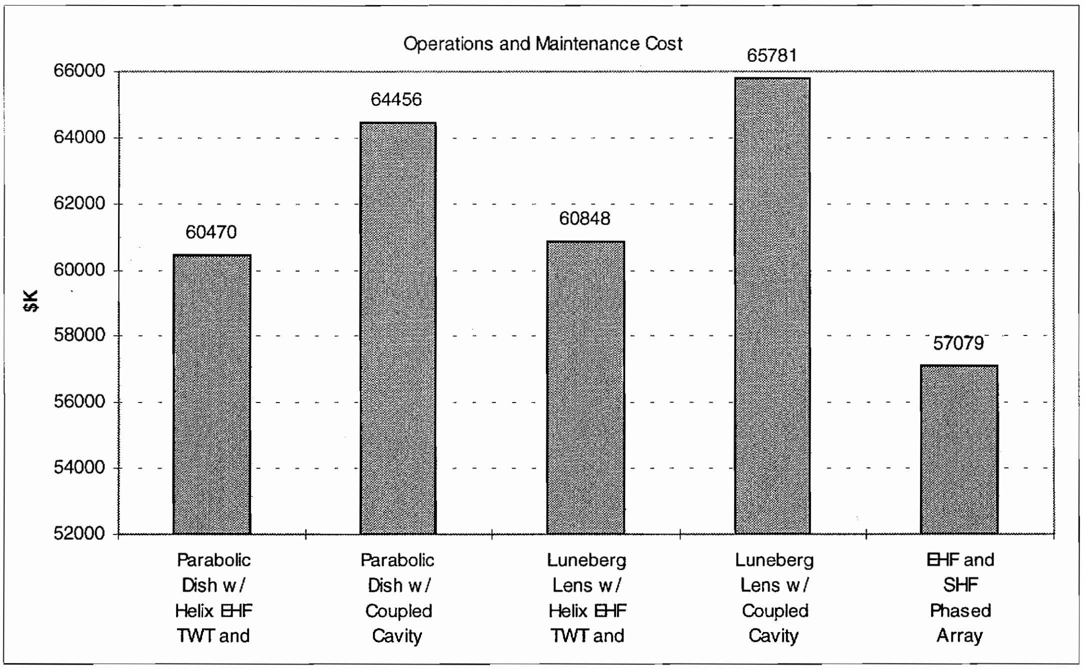


Figure 5.14 - Operations and Maintenance Cost Estimate Comparison of SEST Alternatives

Figure 5.15 compares the retirement and disposal costs of the alternatives and shows all alternatives being equal given the coarse retirement and disposal assumptions that were used.

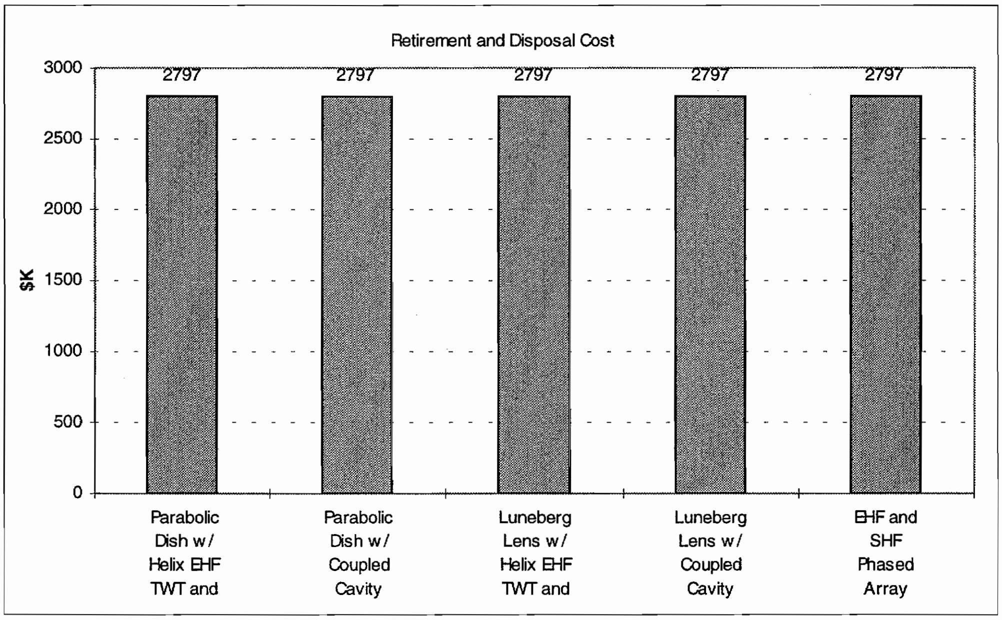


Figure 5.15 - Retirement and Disposal Cost Estimate Comparison of SEST Alternatives

Figure 5.16 compares the total life cycle costs of the alternatives which shows alternative 1, the parabolic dish with EHF Helix TWT and SHF SSPA, having the lowest life cycle cost.

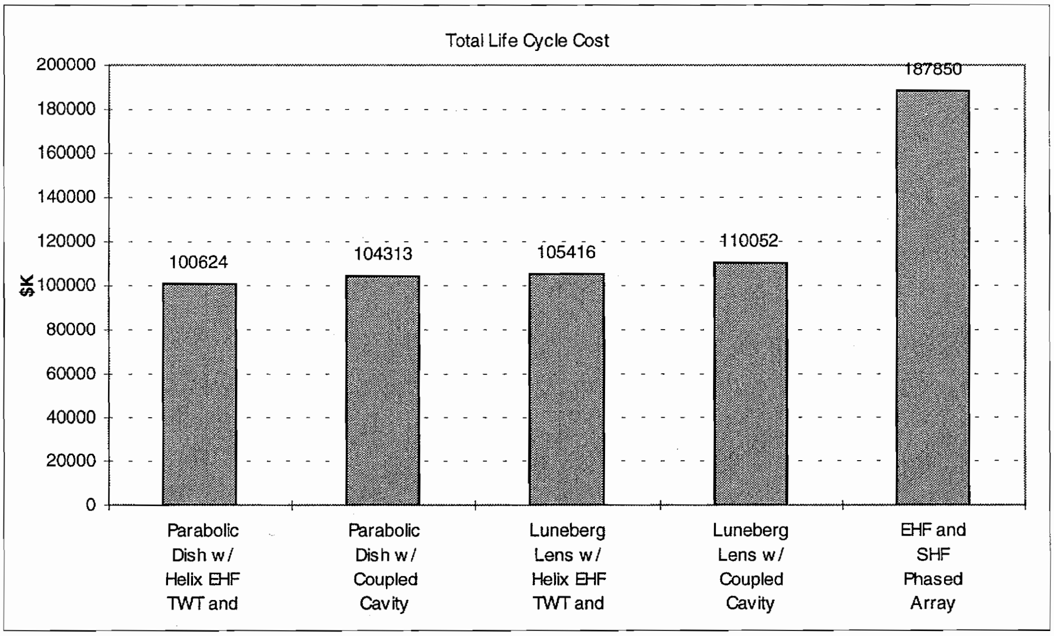


Figure 5.16 - Life Cycle Cost Estimate Comparison of SEST Alternatives

The most interesting point to these cost comparisons is that the overall lowest life cycle cost approach may not be the lowest research and development or production cost approach. For example, despite alternative 1 having higher research and development costs and higher production costs than alternative 2, it has the lowest overall life cycle cost estimate.

Another interesting point is that the most costly alternative with respect to research and development, production, and life cycle cost, the EHF and SHF phased array approach, has the lowest operations and maintenance cost.

From this information, alternative 1, the parabolic dish with Helix EHF TWT and SHF SSPA approach would be selected if life cycle cost were of primary importance. If simultaneous EHF and SHF communications were a priority, alternative 3, the Luneberg lens with Helix TWT and SHF SSPA could be selected, at an increase of approximately $5M in over the life cycle. However, based on some of this risks of a Luneberg lens antenna approach in a shipboard environment, the risk of this approach is greater than alternative 1.

5.5 Software

During this phase, the software performance requirements are documented in a program performance specification or the like usually by the systems engineers. From this, more detailed software specifications are developed by the software developers that translates the program performance specification into explicit, implicit, and derived requirements that are used by the programmer to write the software. Considerations such as processor memory requirements and throughput are assessed to properly address the system requirements.

5.6 Preliminary System Design Results

During the preliminary system design phase, the following was accomplished:

1. System functional analysis and requirements allocation was performed
2. Link budgets were analyzed for the range of alternative considerations
3. Life cycle cost estimates were performed for the remaining alternatives

Table 5.25 below summarizes the alternative, link budget, and life cycle cost conclusions.

Table 5.25 - Preliminary System Design Results

Alternative	EIRP Satisfied	G/T Satisfied	Life Cycle Cost
Parabolic w/ EHF and SHF SSPAs	No	✓	N/A
Parabolic w/ EHF Helix TWT and SHF SSPA	✓	✓	$100,624K
Parabolic w/ Coupled Cavity EHF TWT and SHF SSPAs	✓	✓	$104,313K
Lens w/ EHF and SHF SSPAs	No	✓	N/A
Lens w/ EHF Helix TWT and SHF SSPA	✓	✓	$105,416K
Lens w/ Coupled Cavity EHF TWT and SHF SSPAs	✓	✓	$110,052K
EHF and SHF Phased Arrays	✓	✓	$187,850K

5.7 Product Specifications

During this phase of the SEST program, detailed specifications for each of the system subassemblies would be prepared. From these specifications, a make or buy analysis could be performed to determine if it would be more cost effective to build the subassembly or contract out for it.

5.8 Level of Repair Analysis

Also during this phase, the subassemblies are evaluated for the level at which they should be repaired -- O-level; I-level; or D- level -- based on a cost analysis. For example, a level of repair analysis would look at whether a SEST subassembly should be repaired at the intermediate level, repaired by the manufacturer or supplier, or discarded and replaced. Given overhead rates, facilities, quantities and other considerations, it may be most cost effective to repair certain items while other items may be more cost effective to send back to the supplier to repair or simply discard and replace the item.

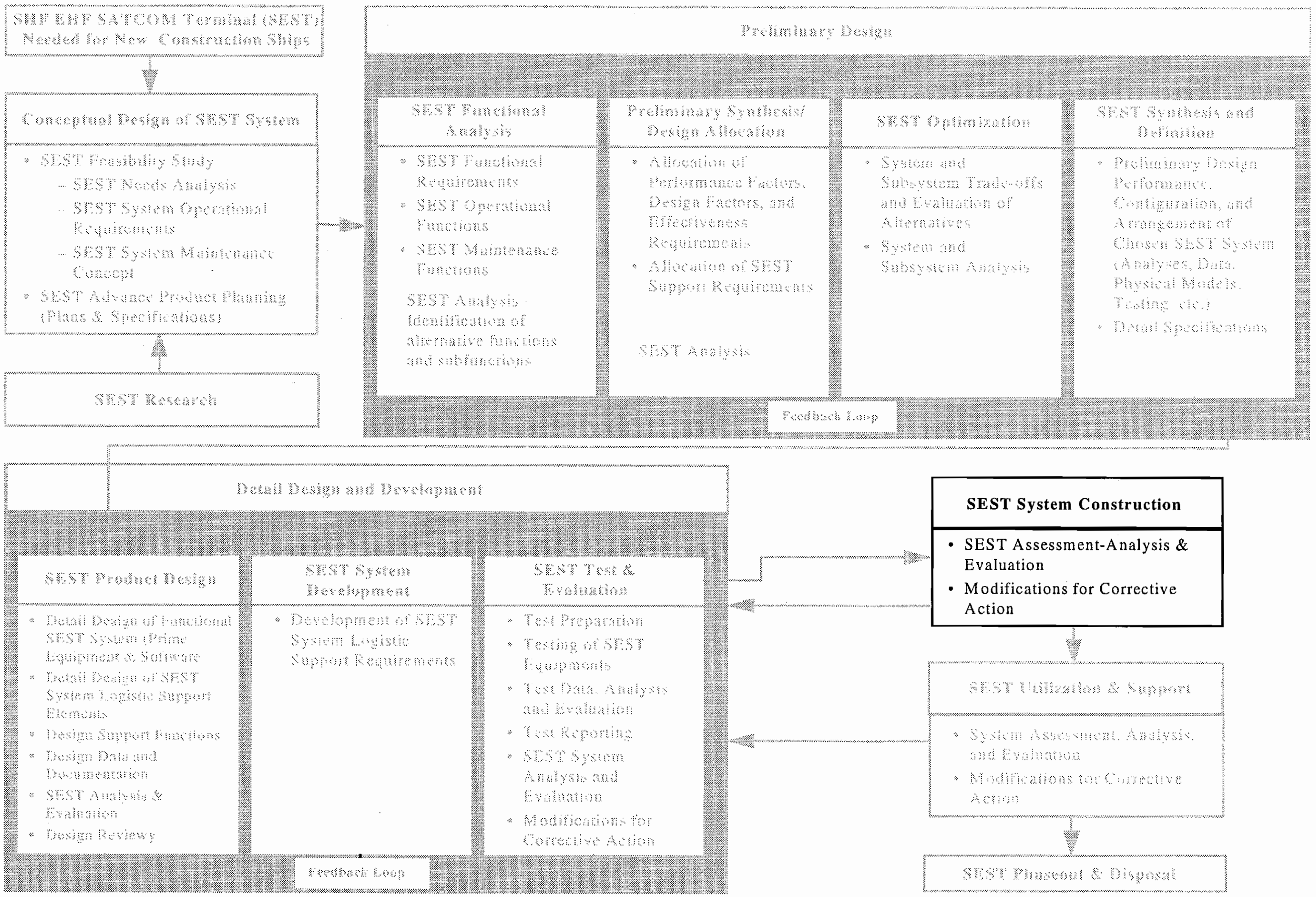
5.9 Maintenance Task Analysis

Similarly, maintenance task analysis is performed during this phase. The intent of maintenance task analysis is to help determine the times, sequences, and frequencies of specific maintenance actions. In addition, spare parts requirements, associated inventories, special purpose and general purpose test equipment, personnel skill levels, facilities, transportation, packaging and handling, and technical data requirements can be determined.

5.10 Software

By this time in the program, actual software is being written and tested. Near the end of this phase, the software will be integrated with the prototype hardware and will undergo a system test to verify that the design meets the specifications. Items such as processor memory requirements and throughput are verified in the prototype during system testing.

6. Phase 3 -- Production and Installation



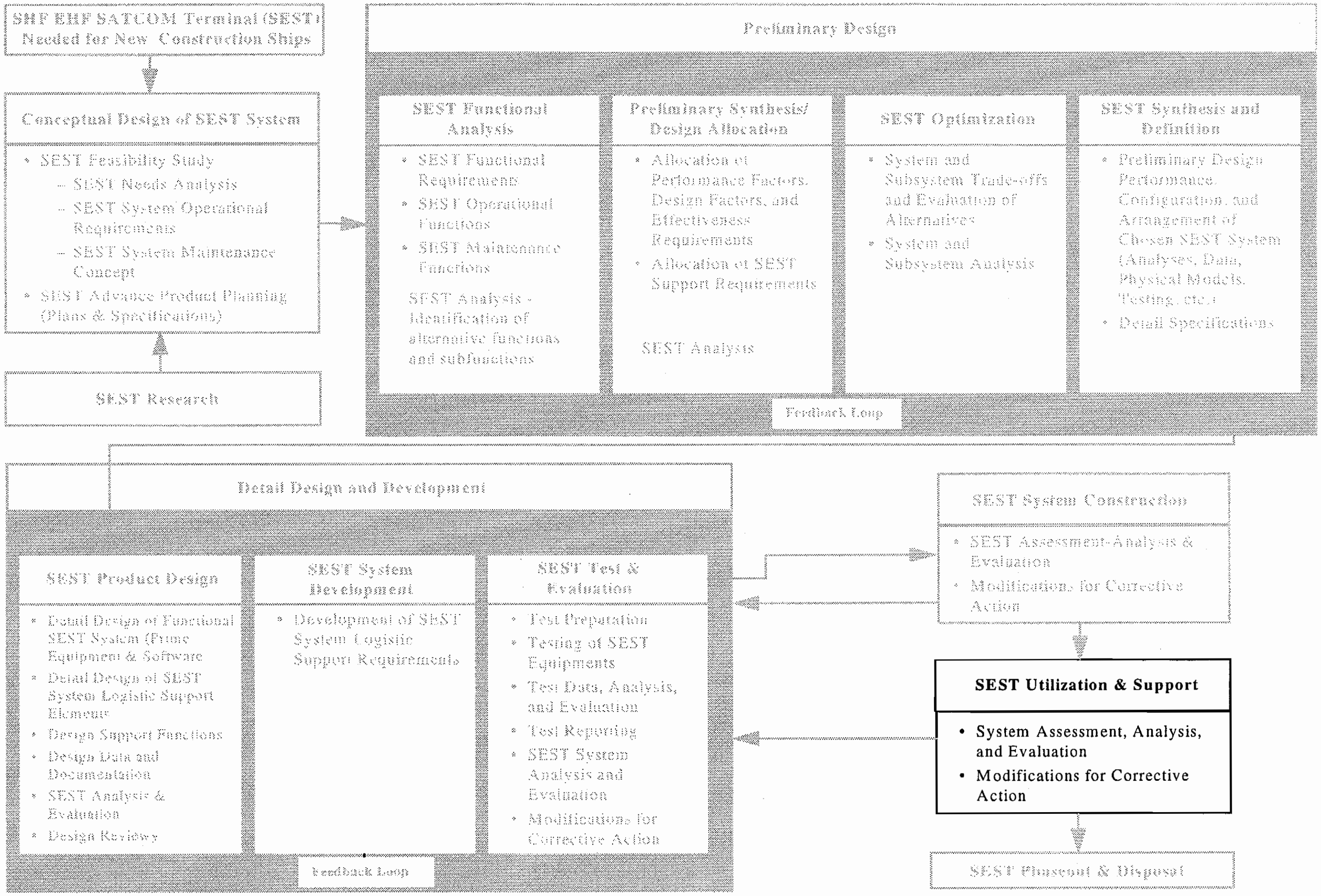
6.1 Statistical Process Control

During production, statistical process control techniques should be implemented in order to highlight problem areas and measure the overall effectiveness of the production process. For example, if the statistical process analysis reveals a large amount of defects with a certain component of the system during workmanship screening, it may highlight a manufacturing problem with that subassembly.

6.2 Test and Evaluation

Test and evaluation will occur at the unit and system level during production including software. Ultimately, a system level test will also be performed after the equipment is installed in its host platform to ensure that the requirements are satisfied. Typically, independent operational testing will be performed to determine the operational effectiveness and operational suitability of the system.

7. Phase 4 - Utilization and Support



7.1 FRACAS

A FRACAS system should be implemented to report failures and identify corrective action to improve the system performance over its life. As part of the system, corrective actions will be identified that must be either made at a convenient point in time (e.g., correct a problem with a circuit card when that circuit card has been send back for repair) or by an upgrade approach. Life cycle cost should be considered when make such trade-offs.

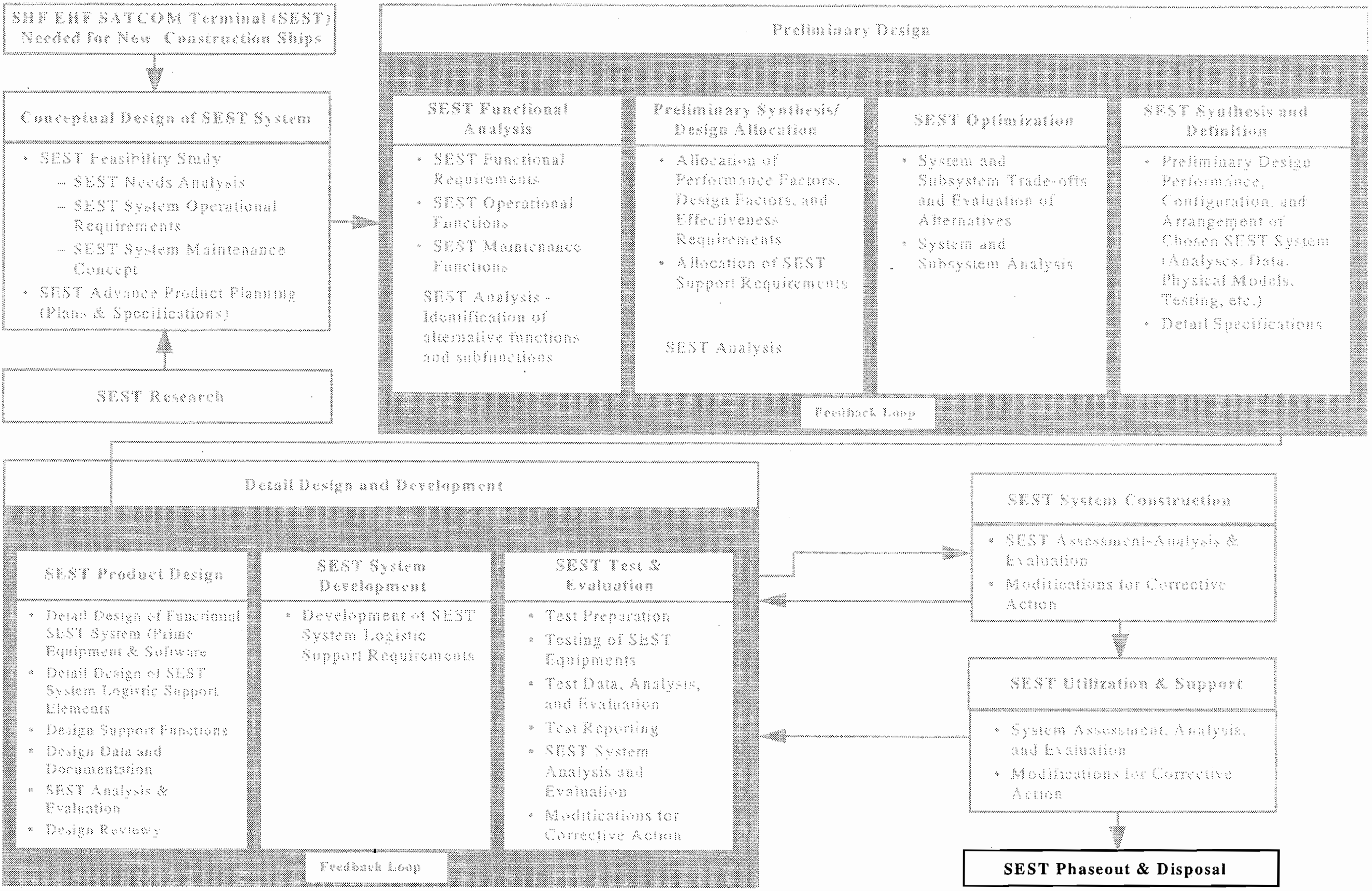
7.2 Operator/Maintainer Training

Operator and maintainer training will most likely be conducted as part of a radioman and electronics technician training school. Initially, training may be provided by the manufacturer. In addition, approaches such as computer based training (CBT) and interactive electronic technical manuals (IETM) may reduce the need for training schools and their associated costs.

7.3 System Improvements

During the utilization and support phase, items requiring improvement as well as candidates for enhancement will be identified. As this system will most likely be software intensive, from a functionality perspective, upgrades will often be performed by software updates. In addition, since the system will use a VME open architecture, capabilities can be added, with the appropriate software, in a relatively simple fashion.

8. Phase 5 -Phaseout and Disposal



8.1 Consumables

The level of consumables related to this system will be determined as part of the level of repair analysis. It may be more cost effective to dispose of a failed subassembly that attempt to repair it or to set-up the facilities to repair it. One item that will almost undoubtedly be a consumable is any TWT associated with the system as they are not repairable. Other consumables may be identified as part of preventative maintenance such as filters, etc.

8.2 Disposal

Disposal of the system is assumed to be relatively simple. As it is required that there be no hazardous materials used in the system, no special disposal procedures are envisioned.

9. Conclusions

The systems engineering process, stepping through the conceptual and preliminary system design into production, can be used to develop a flexible SHF EHF SATCOM Terminal. Using this approach, several concepts were identified, reduced down based on preliminary analysis, further reduced down based on more detailed analysis, and then, ultimately, a decision was made based on life cycle cost. By using life cycle costs instead of development and production costs, optimum decisions and/or selections can be made as evidenced by alternative 3 costing less in development and production, but alternative 2 costing less over the life cycle.

Although a lens antenna and a phased array antenna offer the promise of simultaneous EHF and SHF communications from a single antenna, there are risk and cost problems, respectively, which prevent then from being the first selection for SEST.

Given the range of options considered, the best technical/lowest risk solution with the best life cycle cost is a non-simultaneous parabolic dish antenna with a helix EHF TWT and a solid state SHF amplifier mounted on the antenna pedestal. Simultaneous communications can either be provided with an additional set of antennas or through a technology insertion/upgrade program after the simultaneous approaches reduce the risk and/or cost.

10. Further Work Required

10.1 RCS Refinements

The extent to which RCS requirements are addressed in this report is 1) attempting to reduce the physical quantity of antennas; and 2) considering a separate or integrated structure from the ships superstructure. Much additional work is required to adequately address these requirements. Namely, once an approach is selected, such things as radome shaping techniques and the strategic use of radar absorbing material (RAM) and radar absorbing structures (RAS) can greatly reduce the contribution of the SATCOM system to a platforms RCS signature.

10.2 Cost Estimates

The cost estimates contained in this report are order of magnitude estimates only. More accurate estimates must be prepared by collecting vendor quotes, updating estimates based on development progress, etc. In addition, the detailed type of information contained in a reliability prediction report would be helpful in more accurately determining the operations and support costs.

Steven B. Harrell