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**Final Report**

# AVAILABILITY ANALYSIS OF ALTERNATIVE NAVY COMMUNICATION SYSTEMS



September 1969

Prepared for

U. S. NAVAL ELECTRONICS LABORATORY CENTER
San Diego, California

Under Contract N00244-69-C-0129



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# AVAILABILITY ANALYSIS OF ALTERNATIVE NAVY COMMUNICATION SYSTEMS.



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Prepared by

(10) J. G. Fountain

Approved by

H. A. Lindgren

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ARINC RESEARCH CORPORATION
Western Division
P. O. Box 1375
Santa Ana, California 92702



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# 1. INTRODUCTION AND SUMMARY

This final report discusses an evaluation by ARINC Research Corporation under Contract N00244-69-C-0129 of the availability and cost of eight alternative Navy communication systems representing mixes of satellite, conventional, and advanced high-frequency equipments. The study has established that communication-service availability over the next 20 years on large and medium classes of Navy ships will be more effective, and at a lower life-cycle cost, if the evolutionary process includes advanced modular, automatic HF equipments that can be standardized to reduce logistics problems and controlled in a manner compatible with future satellite systems.

Conventional equipment is considered here as that now in the Navy inventory and used on current ship construction. The "baseline" concept for advanced equipments is the TRED (Transmitting and Receiving Equipment Development), a set of equipment modules together with a control concept, representing an advance in HF equipment design. Satellite equipment includes that for both the DSCS (Defense Satellite Communications System) and the TACSAT (Tactical Satellite), as anticipated for use on large ships.

Two system sizes--large and medium, corresponding to the two contract tasks--are considered in this report. The large ship is typified by the CVA(N)-68, nuclear aircraft carrier; and the medium-sized ship by the DD-963, a destroyer having a communications mission similar to the DX types under development. One large-ship satellite system, designated TRED/SATCOM, has the realistic capabilities of equipments in design or currently available. The second, designated SATCOM/TRED, extrapolates into the 1980 period when satellite capability may be expected to increase and HF will assume a backup role.

## 1.1 OBJECTIVES OF REPORT

It is the underlying assumption of this report that the introduction of satellites into Navy communication systems must be an orderly process involving a change in character of HF capabilities, rather than their elimination. Using HF as an alternate propagation means to satellites will provide a higher communications availability--the probability of having communication circuits when they are needed. The criterion of success, therefore, is the maintenance of adequate communications availability throughout the time period 1970-1990.

The primary objective of this report is to compare eight feasible systems, described herein by system functional block diagrams, for the transition period. Comparisons are made on the basis of the capability of each system to make available adequate communications on demand. This report complements NELC Technical Notes on the TRED program and supports the TRED concept formulation effort.

## 1.2 SUMMARY

Emphasis in this study was on formulating a set of system configurations that could feasibly meet the communication requirements of both large and medium sized ships during a 20- to 30-year life. The analysis is concerned with the shipboard electronic communications equipments. Propagation, antenna pointing, satellite access, and termination at NAVCOMSTA or at another ship are assumed at least equivalent in comparable systems. A more elaborate study would include evaluating one or more ship, air, and land terminals; data on the ionosphere, radio interference, and satellite relay; and an assortment of propagation modes, traffic loading, and sounding. This more elaborate undertaking is recommended for consideration. The eight systems, further described in section 2, are as follows:

1. Conventional large ship
2. TRED-A large ship
3. TRED-B large ship
4. TRED/SATCOM large ship
5. SATCOM/TRED large ship
6. Conventional medium ship
7. TRED-A medium ship
8. TRED-B medium ship

The "A" and "B" versions of the TRED system involve different quantities of essentially the same modules.

For a large ship outfitted with currently planned equipment and a typical mission of 50 transmit or receive half-duplex circuits, communications availability as defined in Section 1.1 will be about 26%. In the early 1970's, this factor could be increased to 96% by the installation of TRED, automatically controlled, modular equipment. Propagation availability (the probability of having an adequate propagation path when needed) could be increased by spectrum occupancy and interference evaluation and sounding. The HF method of communication would then be able to serve as a dependable backup for satellite systems as they are introduced.

The conclusion of this series of analyses is that without the evolution of automatic, modular equipment for HF, there will be no alternative to a degradation of communication at some vital time when the satellite link fails. An HF concept with low availability will not be an adequate backup at that time.

It is shown that the TRED/SATCOM system has an availability of 99.08%, or 22 hours down in 3 months. Similarly the SATCOM/TRED system, where HF is a real backup, has an availability of 99.998%, or only 2.2 minutes down in 3 months.

Table 1-1 summarizes the overall availabilities and life-cycle costs for the various alternative system configurations. The single quantities are aggregated values and represent many assumptions, including some arbitrary groupings of data. In the table, mission and general system capability for information transfer are comparable within each size class vertically. Type of equipment and control concept are comparable horizontally. Cost information is from NELC computations of 20-year-cost-of-ownership or life-cycle cost.

The combined large-ship mission of receiving and transmitting ranges from 40 to 60 circuits. For each possible mission over this range, the availability of these circuits will be different. Conventional and TRED systems under three possible missions with different numbers of circuits required have availabilities as shown in Figure 1-1.

The sensitivity of availability to various factors was investigated as a part of the system comparison. The number of repair facilities has relatively little effect on availability except when levels are less than 70%. In the practical case of a

TABLE 1-1. TOTAL AVAILABILITY/COST SUMMARY

| Configuration | Large Ship | | | Medium Ship | | |
|---|---|---|---|---|---|---|
| | Transmit | Receive | Overall | Transmit | Receive | Overall |
| A. Availabilities | | | | | | |
| Conventional | 0.337 | 0.939 | 0.316* | 0.512 | 0.846 | 0.433 |
| TRED-A | 0.987 | 0.987 | 0.974* | 0.992 | 0.99948 | 0.991 |
| TRED-B | 0.985 | 0.997 | 0.982 | 0.994 | 0.9995 | 0.993 |
| TRED/SATCOM | 0.9985 | 0.9985 | 0.997 | Not Applicable | | |
| SATCOM/TRED | 0.9985 | 0.9985 | 0.997 | Not Applicable | | |
| B. Cost (20 yr.) | | | | Millions of Dollars: | | |
| Conventional | To be Completed | | | 1.79 | 1.13 | 2.92 |
| TRED-A | | | | 1.47 | 0.80 | 2.27 |
| TRED-B | | | | 1.25 | 0.70 | 1.95 |
| TRED/SATCOM | | | | Not Applicable | | |
| SATCOM/TRED | | | | Not Applicable | | |

*With the transceiving requirement, the conventional is 0.26 and TRED-A is 0.96.

manual system, such as that of the CVA(N)-68, availabilities are less than 70% because of repairman limitations. In fact, repairmen may be shared among equipment groups, further lowering their availability. This manual system is then more sensitive to repair facility variation than is an automatic system.

The most sensitive variable in any system is the number of installed spares. In some situations--the large ship TRED transmitting subsystem, for example--the presence of one spare gives an availability increase of two orders of magnitude.*

*The term "order of magnitude" denotes the change, for example from 0.1 to 0.01 in unavailability, which corresponds to a change from 0.9 to 0.99 in availability.

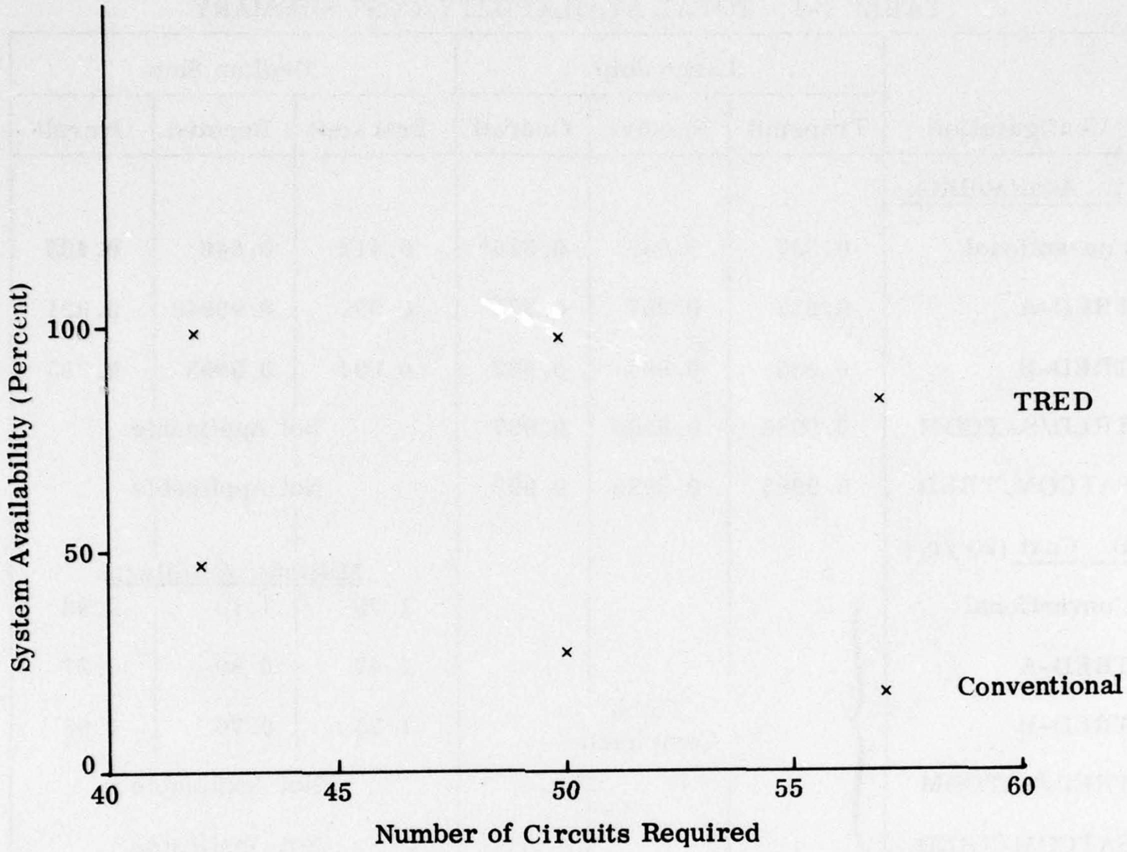


**Figure 1-1. System Availability and Circuit Requirements for Large Ship Models**

# 2. SYSTEM DESCRIPTIONS

## 2.1 GENERAL

The basic components of the alternative systems are equipments representing four concepts:

Current usage

Future HF usage (TRED)

TACSAT (UHF/SHF) SATCOM

DSCS (SHF) SATCOM

Each of these system concepts is individually capable of satisfying at least a portion of the projected requirements. These requirements* encompass those strategic, tactical and other circuits expected to be needed during the period of interest. Two sizes of communications systems are addressed: the large ship typified by the CVA(N)-68, and the medium ship typified by the DD-963/DX.

The current usage equipments do not contain standard modules. Many are individual items designed for relatively limited applications. They are interconnected in a conventional manner by manual patch panels to terminals or antennas as appropriate.

TRED will be a system-oriented set of equipment. In modular form, the HF equipment of the future will allow growth and development to the state of the art within modules while maintaining standard terminal interfaces. Automatic control of configuration by switching, and of capability by remote control, will provide single-operator system control. A prime virtue is that of accommodating satellite modules within a single control concept, making possible the selection of optimum paths and full use of redundant capability.

Two subdivisions, TRED-A and TRED-B, are considered in some of the analyses. While the modules will be the same in both subdivisions, fewer are used in TRED-B because an automatic system with short reconfiguration and retuning times will allow fewer equipments to service the required number of circuits.

TACSAT is intended to be used primarily for tactical circuits, and is characterized by mixing, combining, or multiplexing at high frequencies (70 MHz). Without a time-division-multiplexing (TDM) arrangement, the TACSAT is limited to five voice channels. This limitation is recognized in the TRED/SATCOM system, and a TDM arrangement is postulated for the SATCOM/TRED system. Use of TACSAT for ship-to-air communication is assumed unimpaired.

DSCS is similarly intended for strategic circuits, and is characterized by multiplexing at audio frequencies. It must be assumed from the ship point of view that adequate satellite coverage is available, and that termination of the link at an acceptable NAVCOMSTA is always possible. The current limitation of the AN/SSC-3 shipboard terminal to one voice channel is extended to two for the near-term model, and to the full required six in the far-future.

---

*<u>TRED Program: Interim Summary Report</u>, NELC TN-1438, 10 October 1968.

The foregoing four system concepts are combined into eight alternative systems for this report:

| | |
|---|---|
| Conventional Large Ship | SATCOM/TRED Large Ship |
| TRED-A Large Ship | Conventional Medium Ship |
| TRED-B Large Ship | TRED-A Medium Ship |
| TRED/SATCOM Large Ship | TRED-B Medium Ship |

In the TRED/SATCOM system, 60 percent of the receiving requirements and 75 percent of the transmitting requirements are continued with the TRED HF system. The foreseeable satellite capability extends to 40 percent of the receive capability and only 25 percent of the transmit. The SATCOM/TRED alternative is similar to the foregoing, except that the satellite communication equipment is capable of fulfilling all communicating needs of the large ship.

## 2.2 CONVENTIONAL LARGE SHIP MODEL

The USS NIMITZ, CVA(N)-68, currently under construction, has been taken as representative of large Navy ships. While it is not the largest in communication requirements, it will need a modern flexible communications control facility over the next 20 years, and may well be an "average" large ship. Statements throughout the report will be based on an extremely detailed evaluation of the CVA(N)-68 and generalized to the large-ship class.

Figure 2-1 is a simplified block diagram of the communications complex of a conventional large ship. More detailed description of the receiver portion is given in Figure 3-4, where an equipment level evaluation is described. Five types of receivers are used in the large-ship system:

| | |
|---|---|
| R-1051/URR | HF synthesized receiver |
| R-390A/URR | HF tuned oscillator receiver |
| AN/SRR-19 | LF receiver |
| AN/WRR-3 | MF/LF receiver |
| AN/BRR-3 | VLF receiver |

Antenna couplers used are the AN/SRA-17, -38, -39, and -40 series.

In the transmitting/transceiving subsystem, four types of principal equipment are used:

| | |
|---|---|
| AN/URT-23 | HF manually tuned transmitter |
| AN/SRC-23 | HF automatically tuned transmitter |
| AN/WRT-1A | LF transmitter |
| AN/WRC-1 | HF transceiver. |

Antenna couplers include the automatic AN/SRA-34 and the manual AN/SRA-57 and -58.

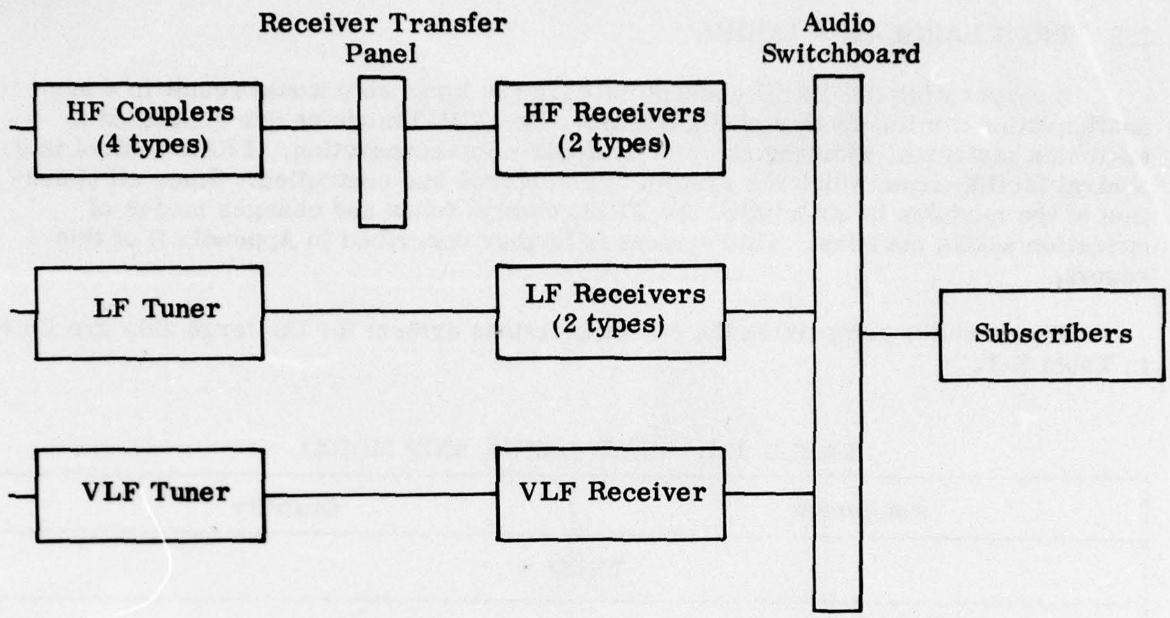


Figure 2-1A. Conventional Large Ship Receiving Subsystem

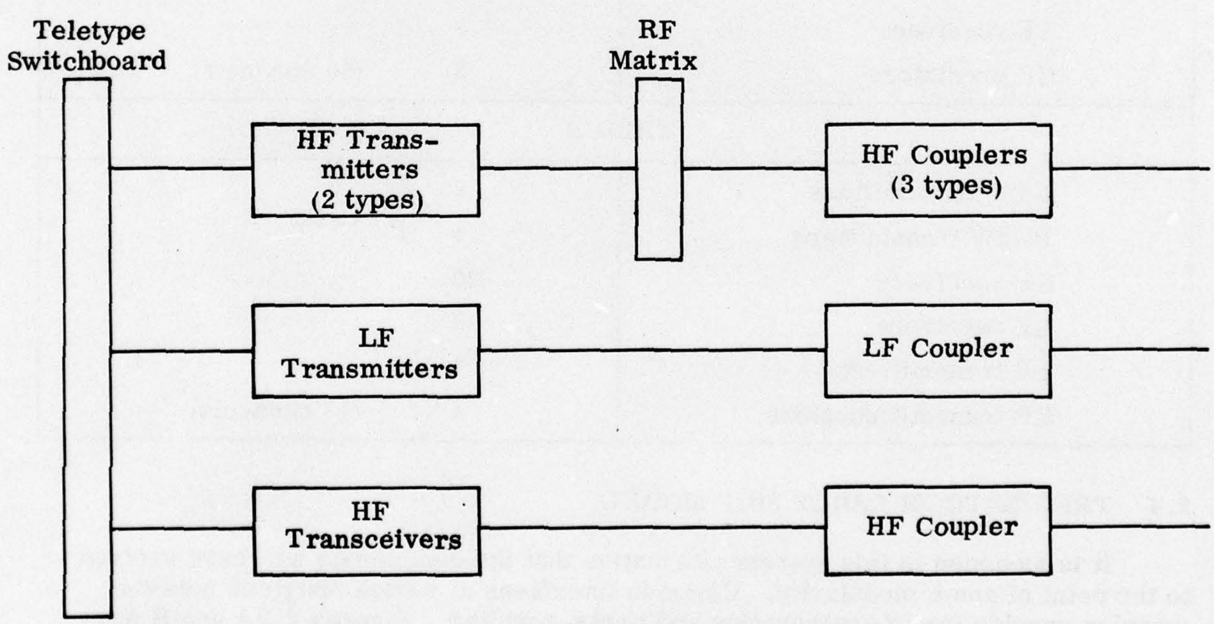


Figure 2-1B. Conventional Large Ship Transmitting/Transceiving Subsystem

## 2.3 TRED LARGE SHIP MODEL

Incorporating the TRED concept onboard the large ship would result in a system configuration similar to that of Figure 2-2. The TRED modules are connected to switching matrices, allowing completely flexible interconnection. TRED control is a central facility from which the system is configured and controlled. Since all operation of the modules is automatic, the TRED control tunes and changes modes of operation within modules. This system is further described in Appendix B of this report.

The modules comprising the communications system for the large ship are listed in Table 2-1.

TABLE 2-1. TRED LARGE SHIP MODEL

| Equipment | Quantity | |
|---|---|---|
| **TRED A** | | |
| 1-kW transmitters | 11 | 16 HF (1-kW and 10-kW transmitters) |
| 10-kW transmitters | 5 | |
| Transmit couplers | 5 | (20 channels) |
| MF transmitters | 2 | |
| HF receivers | 25 | |
| LF receivers | 9 | |
| HF predictors | 3 | (60 channels) |
| **TRED B** | | |
| 1-kW transmitters | 8 | 12 HF (1-kW and 10-kW transmitters) |
| 10-kW transmitters | 4 | |
| HF receivers | 20 | |
| LF receivers | 6 | |
| LF transmitters | 1 | |
| HF transmit couplers | 4 | (16 channels) |

## 2.4 TRED/SATCOM LARGE SHIP MODEL

It is assumed in this system alternative that the equipments will have evolved to the point of some modularity. Common interfaces at switch matrices between modules provide for interconnection and cross-coupling. Figures 2-3A and B show the transmit and receive subsystems, respectively, of the TRED/SATCOM large-ship communication system. In these diagrams, the illustration of a switch matrix does not necessarily imply that it is fully implemented.

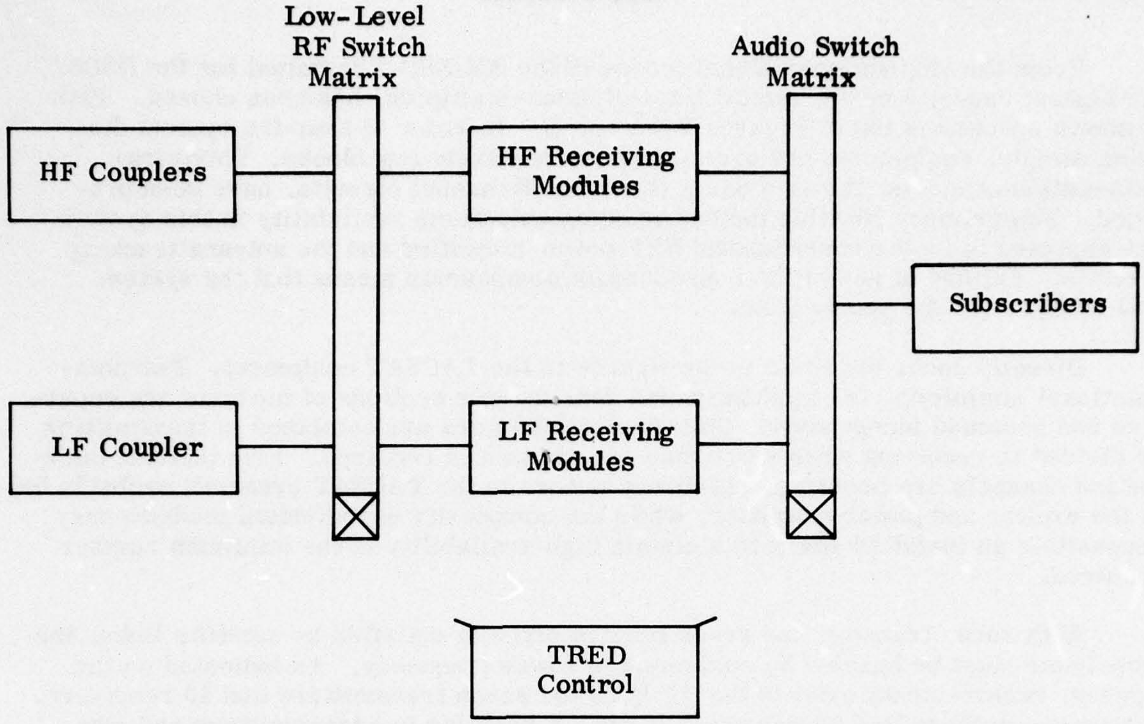


Figure 2-2A. TRED Large Ship Receiving Subsystem

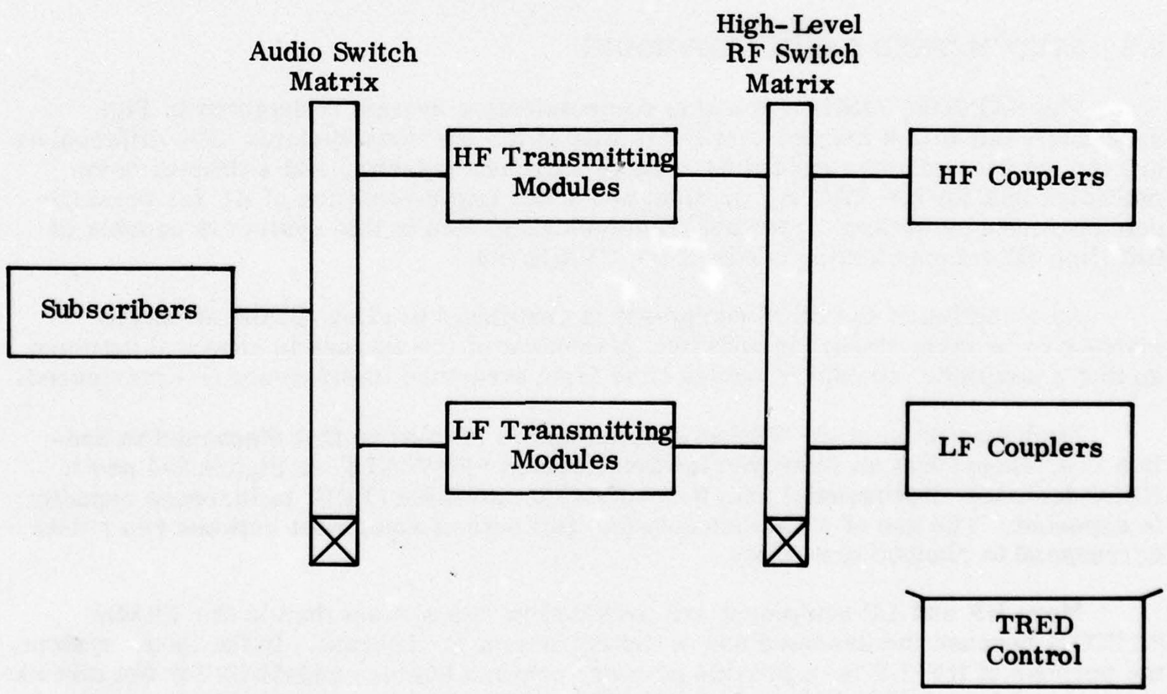


Figure 2-2B. TRED Large Ship Transmitting Subsystem

From the various operational modes of the AN/SSC-3 terminal for the DSCS, the highest capacity mode, digital time-division-multiplex, has been chosen. This is shown across the top of Figures 2-3A and B. In order to keep the system diagram simple, equipments are grouped into a relatively few blocks. Thirty-two information channels, the equivalent of two multichannel circuits, have been provided. The primary limiting factors to communications availability in this system are expected to be the nonredundant SHF power amplifier and the antenna tracking circuits. Failure of any of the nonredundant components means that the system will be down for the repair time.

Directly under the DSCS in the figures is the TACSAT equipment. For computational simplicity, the modulator and demodulator sections of modems are separated and assumed independent. Outputs of modulators are combined in transmitting or divided in receiving when more than one channel is required. Five tactical information channels are provided. Limiting factors in the TACSAT area will probably be in the exciter and power amplifier, while the complexity of individual modems may necessitate an installed spare to maintain high availability of the minimum number required.

With seven transmit and seven receive circuits satisfied by satellite links, the remainder must be handled by equipment of lower frequency. As indicated on the figures, requirements exist in the HF band for seven transmitters and 13 receivers. Concurrently there is a requirement in the LF band for two transmitters and nine receivers. Three HF couplers and one LF tuner are needed in order to cover the frequency range of the receivers and transmitters.

## 2.5 SATCOM/TRED LARGE SHIP MODEL

The SATCOM/TRED large-ship communication system is depicted in Figures 2-4A and B in a manner similar to that of the previous system. The differences are the addition of some redundant units to increase capacity, and a time-division multiplex unit for the TACSAT portion; and a full implementation of HF for the dedicated circuits as backup. Satellite communication then in this system is capable of fulfilling all communicating needs of the CVA(N)-68.

An evolution of the DSCS equipment is postulated to allow all the strategic circuits to be maintained. In addition, placement of the antenna is assumed optimum so that a negligible amount of outage time from structure interference is experienced.

Implementation of the TACSAT equipment is similar to that discussed in Section 2.4, except that an improved modem (termed "POSTATS" in Figure 2-4 and in NELC technical discussions) with time-division multiplex (TDM) to increase capacity is expected. The use of TDM demands that full sets of equipment between two points correspond to planned time slots.

More HF and LF equipment are provided in this system than in the TRED/SATCOM because the assumed use of the equipment is different. In the latter system, the purpose of HF-LF is to provide primary communications capability for the circuits not covered by satellite links. In SATCOM/TRED, HF-LF is to provide protection for the satellite circuits which may be designated, under current usage, as dedicated. In the LF band, six receivers and one transmitter are required; while in the HF band, 21 receivers and 14 transmitters are needed.

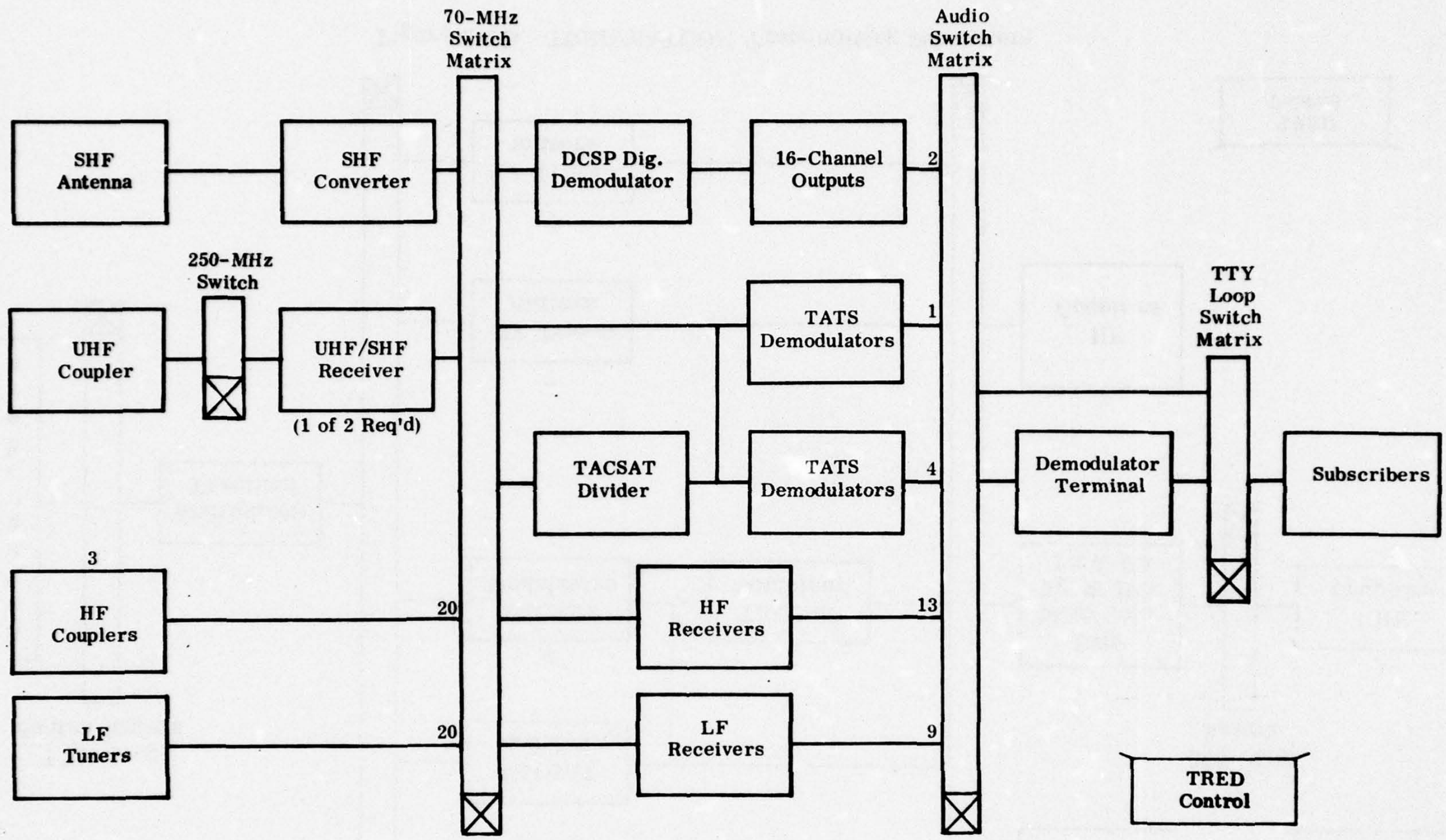


Figure 2-3A. TRED/SATCOM Receiving Subsystem

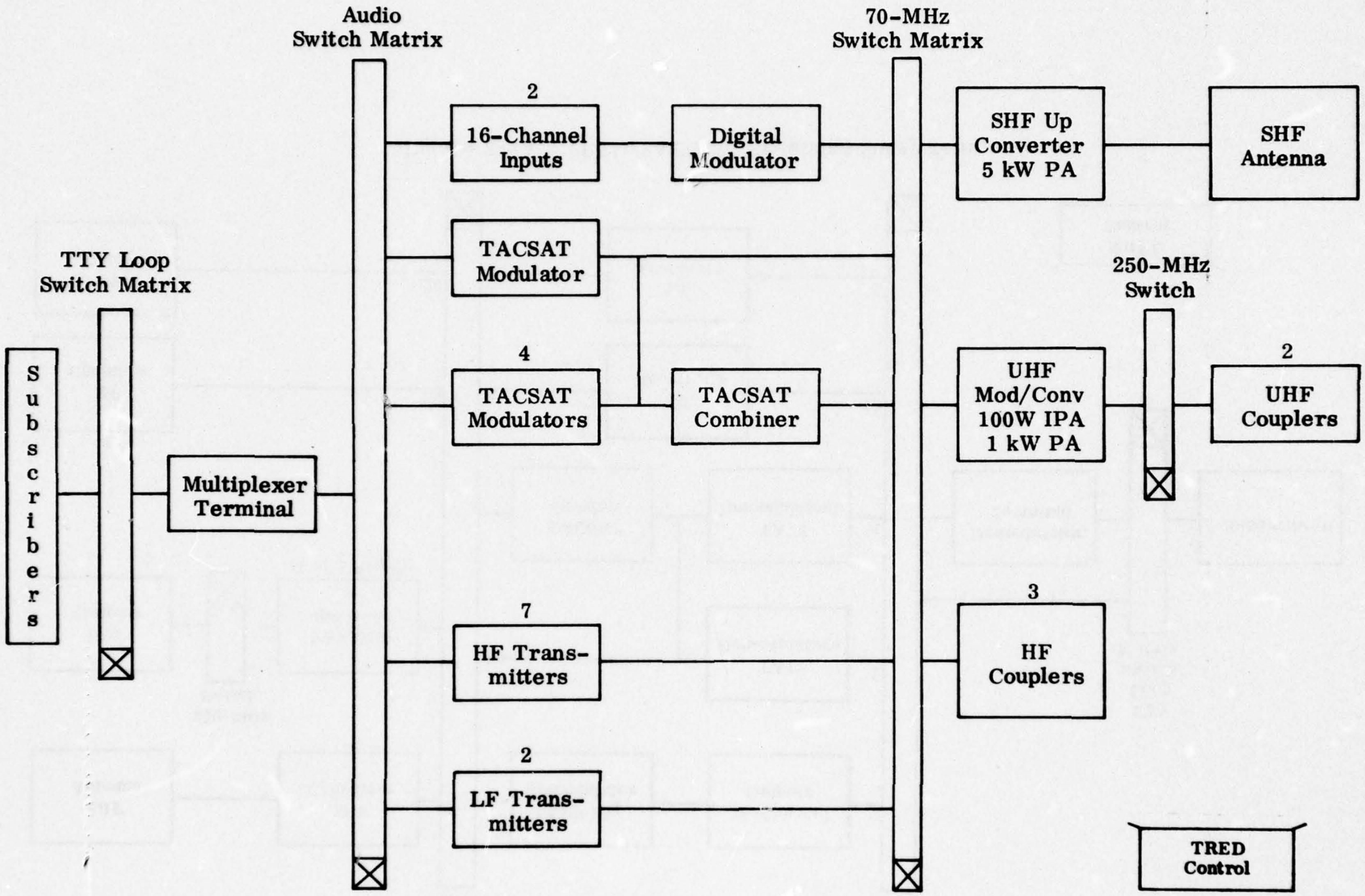


Figure 2-3B. TRED/SATCOM Transmitting Subsystem

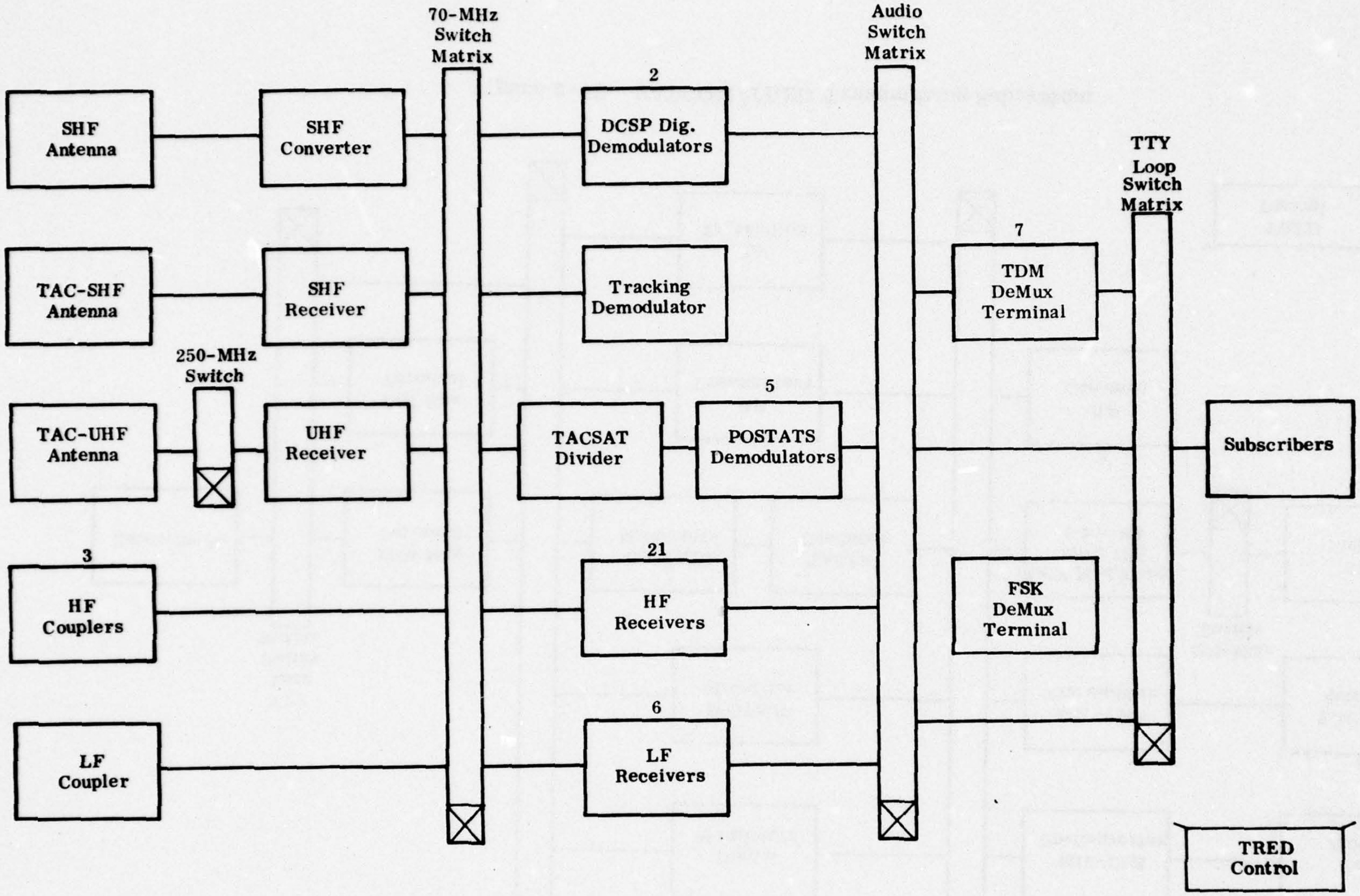


Figure 2-4A. SATCOM/TRED Receiving Subsystem

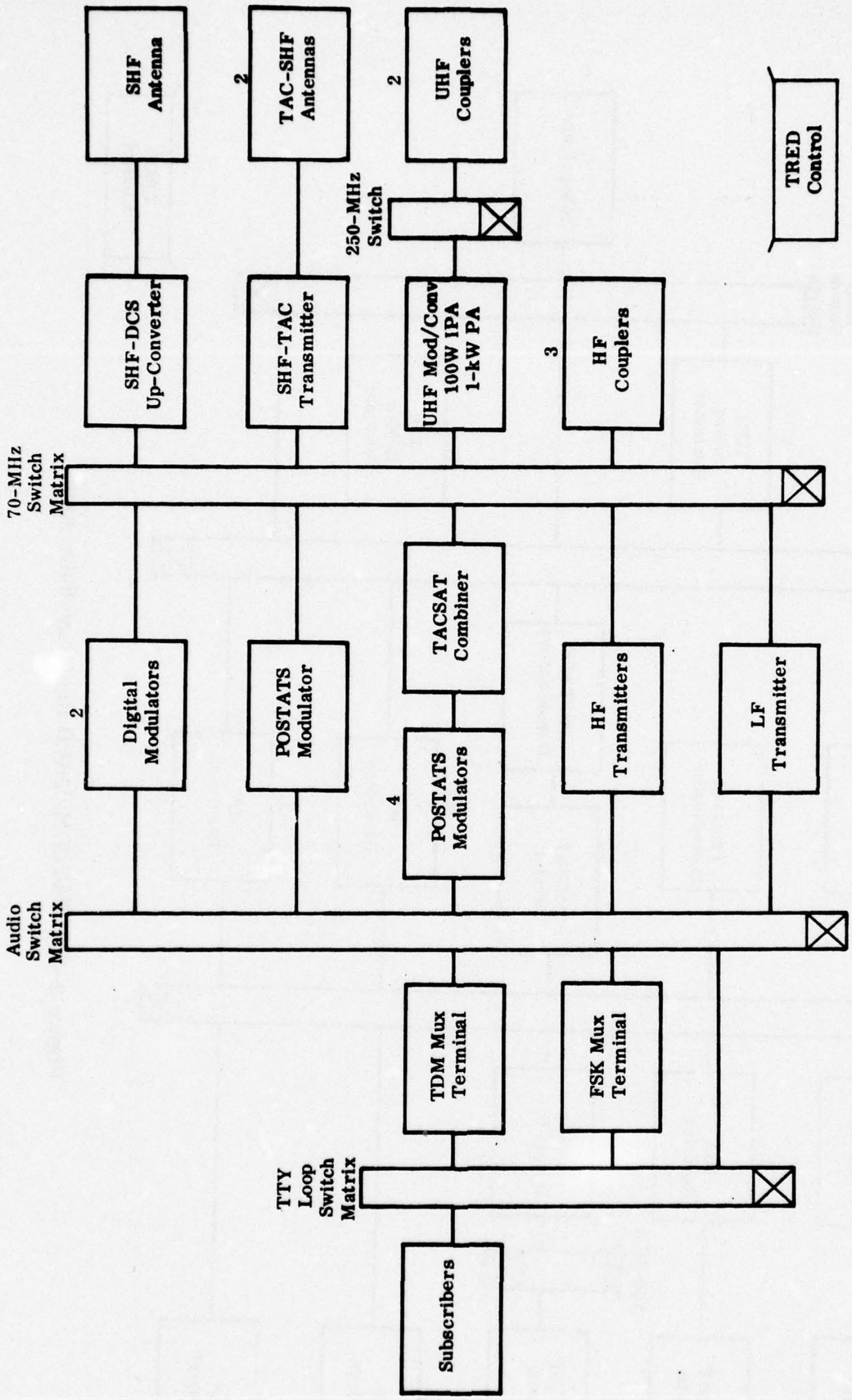


Figure 2-4B. SATCOM/TRED Transmitting Subsystem

It is not intended that the two satellite systems presented here be considered as contemporary. Rather they illustrate two points in time as a large-ship communicating system evolves. Taken together, they should be compared against the alternative of continued use of present-day LF-HF manually patched equipments with similar satellite development. The communications industry has recognized the value of electronically controlled, automatic switching systems for increased effectiveness. Measures of effectiveness are circuit availability and mean-waiting-time to complete circuit connection. The focus of attention should be upon the orderly transition in including the state-of-the-art satellite development into established HF communication. It is firmly believed that this transition is best accomplished by accelerated automation of both HF and satellite equipments so that they may complement each other and satisfy communication requirements.

## 2.6 CONVENTIONAL MEDIUM SHIP MODEL

Some of the same equipments of the conventional large-ship model are also used on the conventional medium-ship model shown in Figure 2-5. Instead of the AN/SRA-38, -39, and -40, the HF receiving multicoupler used on this ship is a single AN/SRA-49 having similar subassemblies. Most of the load is carried by the R-1051/URR for receiving and the AN/URT-23 for transmitting.

## 2.7 TRED MEDIUM SHIP

Both TRED-A and TRED-B system models are shown in Figure 2-6. The arrangement of the modules is the same in both cases but the quantities of modules would be different, as indicated in Table 2-2. In order to parallel the coupler bandwidth of the conventional system, and recognize the technical state of the art and operational practice, the TRED couplers in this case have been separated into the three indicated bands: 2-6, 4-12, and 10-30 MHz.

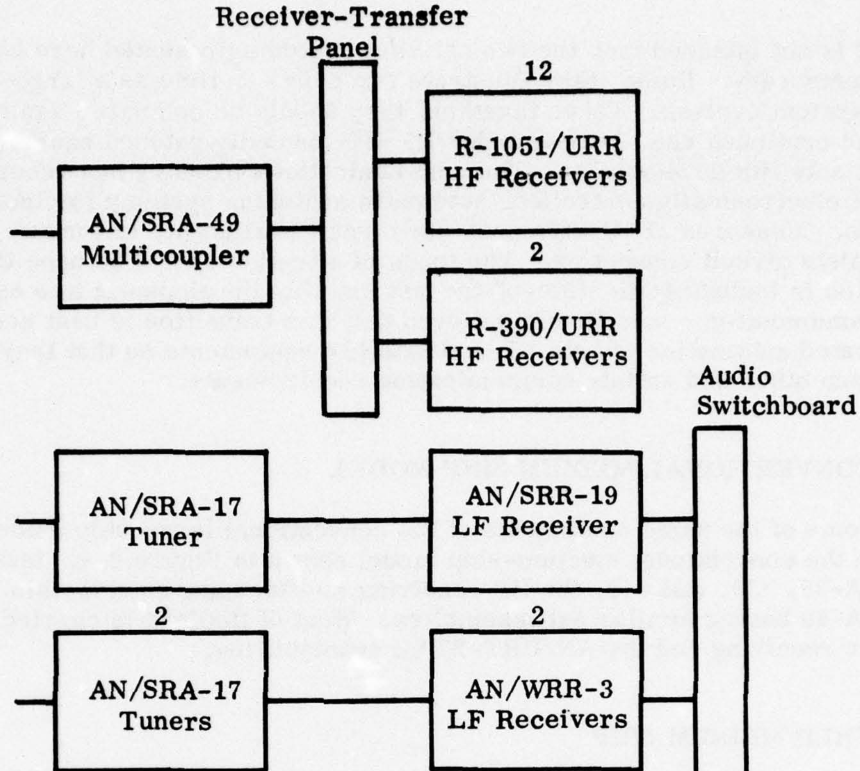


**Figure 2-5A. Conventional Medium Ship Receiving Model**

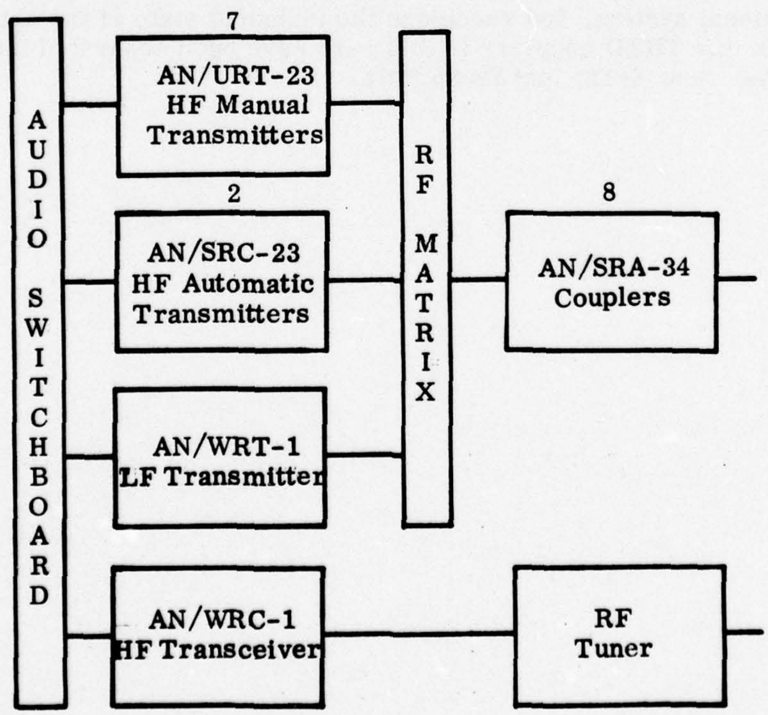


**Figure 2-5B. Conventional Medium Ship Transmitting Model**

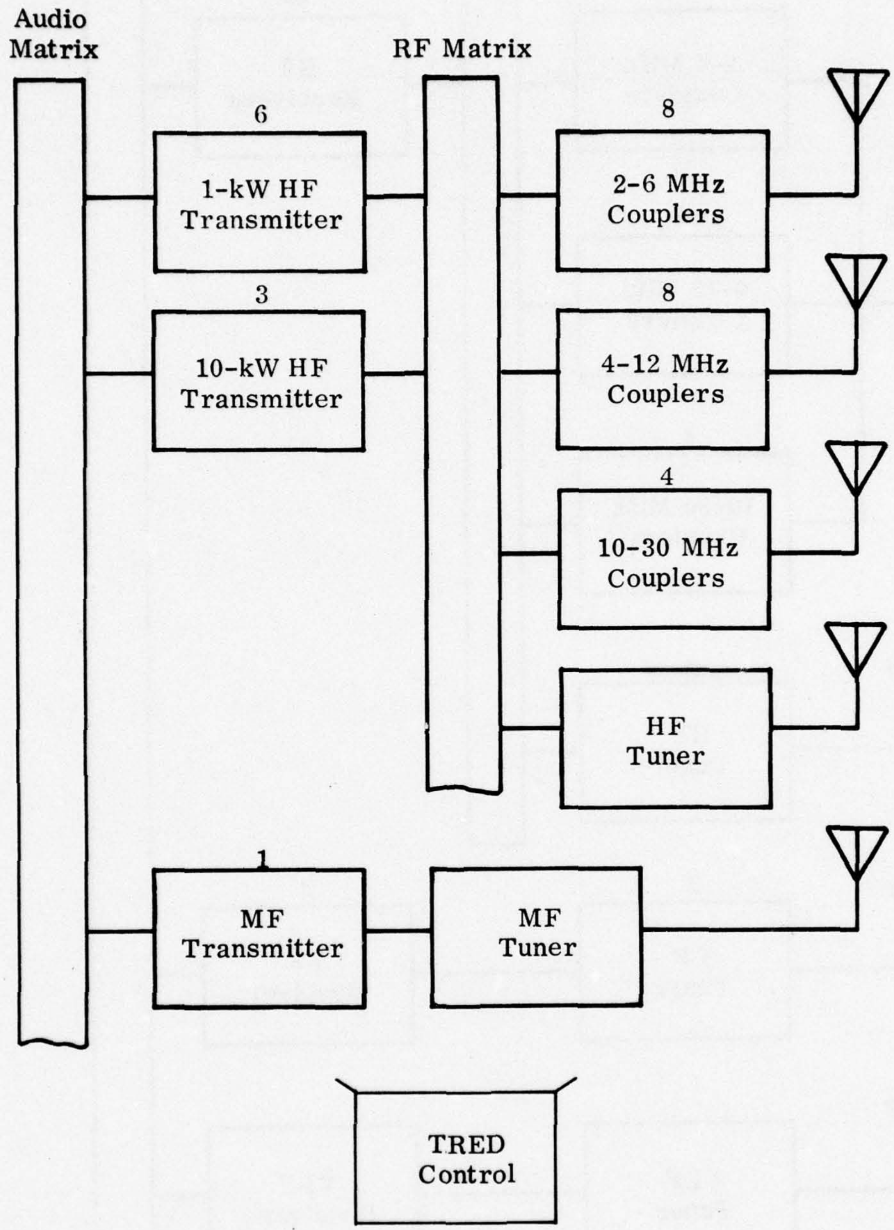


Figure 2-6A. TRED Medium Ship Transmitting Model

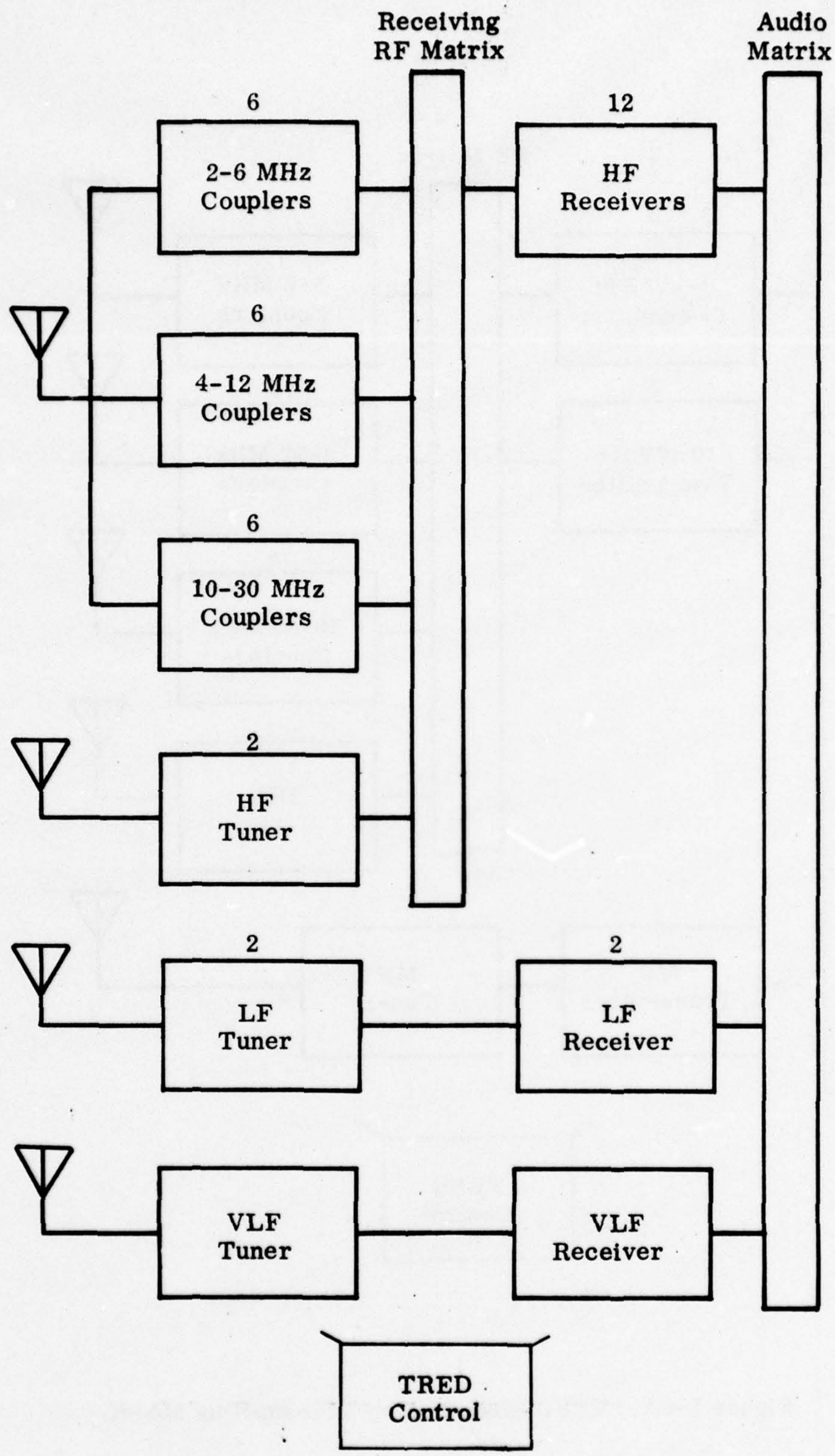


Figure 2-6B. TRED Medium Ship Receiving Model

TABLE 2-2. TRED MEDIUM SHIP MODEL

| Item | Quantity Model A | Quantity Model B |
|---|---|---|
| **A. TRANSMITTING** | | |
| 1-kW Transmitter | 6 | 4 |
| 10-kW Transmitter | 3 | 2 |
| 2-6 MHz Coupler | 8 | 6 |
| 4-12 MHz Coupler | 8 | 3 |
| 10-30 MHz Coupler | 4 | 3 |
| HF Tuner | 1 | 1 |
| MF Transmitter | 1 | 1 |
| MF Tuner | 1 | 1 |
| **B. RECEIVING** | | |
| HF Receivers | 12 | 10 |
| 2-6 MHz Couplers | 6 | 6 |
| 4-12 MHz Couplers | 6 | 4 |
| 10-30 MHz Couplers | 6 | 4 |
| HF Tuners | 2 | 2 |
| LF Tuners | 2 | 2 |
| LF Receivers | 2 | 2 |
| VLF Tuners | 1 | 1 |
| VLF Receivers | 1 | 1 |
| **C. SWITCHES (Same for Both Models)** | | |
| Transmitting — One RF and one audio | | |
| Receiving — One RF and one audio | | |
| **D. CONTROL** | | |
| One control console for both transmitting and receiving. | | |

# 3. TRADEOFF DATA BASE DEVELOPMENT

A precondition of tradeoff analysis is that an underlying relationship exist between or among the factors to be traded off. Ideally, the investigation of the relationship by evaluating the effect of varying, singly and in combination, the input factors will lead to a maximization of some measure of system value. Care must be taken in the selection of the one or more measures of system value so that the so-called "principle of suboptimization" will not be dominant. This principle states that independent optimization of subsystems will not necessarily lead to an optimized system.[1] The use of communication service availability as a measure of system value often avoids this problem, since system availabilities are a direct combination of subsystem availabilities.

Considerable effort has been applied to the development of a methodology for the evaluation of the availability of paths through a network, and the consequent cost of providing a network to meet a given availability requirement. By adapting the mathematics of system reliability[2,3] to the multi-stage communication problem, it was possible to use the same technique in evaluating all system alternatives.

## 3.1 TRADEOFF METHODOLOGY

### 3.1.1 General

For communications systems the formulation of system level tradeoffs is especially difficult. Other systems, having discrete mission durations and success criteria, allow convenient tradeoff between performance-specification (availability, reliability, etc.) parameters. The communication system's mission is usually one of supporting the simultaneous accomplishment of several other missions through a service consisting of circuit connections. The service is a continuing one in terms of the overall mission support function. Without a discrete performance time and a unique mission, it is difficult to formulate a tradeoff between such performance parameters as accuracy and dependability. It is thus equally difficult to derive, from this approach, a system-level dependability requirement.

This report is based upon a different approach to stating the system mission. The dependability of the system is defined independently of the performance aspects of any individual circuit. Specifically the dependability requirement is in terms of maintaining a given number of circuits in operating condition (i.e., within performance specs) for a given time in a given environment. The technical characteristics of the circuits may then be controlled by specification independently from the system mission dependability. The given time may be one message length, but should be a much longer period. With the above mission statement format, a mission profile may be developed with respect to the number of circuits involved. The dependability of the communication system may then be defined as the degree to which it is able to respond to the mission profile.

[1] Machol, R. E., System Engineering Handbook, McGraw-Hill Book Company, 1965.

[2] Sandler, G. H., System Reliability Engineering, Prentice-Hall, Inc., 1963.

[3] ARINC Research Corp., Reliability Engineering, Prentice-Hall, Inc., 1961.

Ideally, a mission profile would define the exact portion of time a given number of circuits would be required. This may be generalized to a probability density of circuit requirements, a plot of the proportion of time different numbers of circuits would be required in a given mission. The mission profile shown in Figure 3-1, for instance, depicts a mission in which one circuit is used 20% of the time, two circuits 60% of the time, and three circuits for the remaining 20% of the time. The most probable number of circuits to be used on the mission is two.

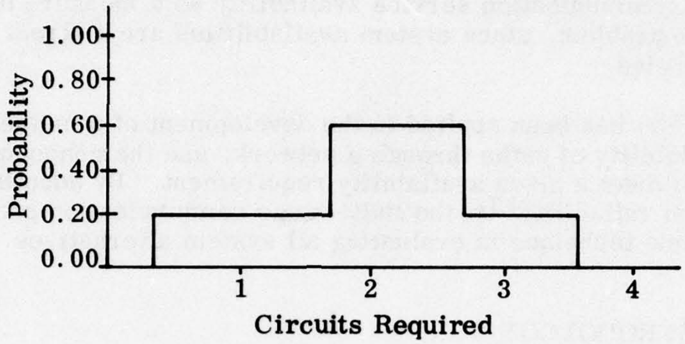


Figure 3-1. Mission Profile

Using the above mission profile and a system with installed capability of three circuits, there is a good chance that one circuit would be available. There is a lesser probability of two, and a still lesser probability of three circuits being available. The sum of the three probabilities would be the system availability for the given mission.

The dependability of the system is measured by the chance it would be ready if needed (availability); and the chance that, being ready, it would continue to operate satisfactorily for the mission time (reliability). The length of time absolutely required for a circuit to be failure-free is the order of one message length, a time so short that availability is the controlling variable.

It is possible therefore to develop a tradeoff methodology on the basis of system availability and reliability requirements. Caution is necessary because extremes of reliability and maintainability allow obviously unacceptable solutions to meet these requirements. The addition of cost as a control parameter precludes the possibility of extreme values. Morever, it adds the opportunity to minimize cost while satisfying essential constraints such as performance adequacy and availability requirements. Integrating cost in the availability model is accomplished by locating the functional (tradeoff) relationships, or estimating the relationships among the various factors and cost.

### 3.1.2 Procedure

In the context of cost-effectiveness for the total system, the approach taken is to evaluate the availability of the given system under conditions of varying mission requirements. Since the system is given, the installed quantities are known and the cost-of-ownership can be derived.

The procedure for evaluating the availability of a repairable, complex system involves the ordered gathering of relative information and reducing it to the final result. The steps, not in a required order of performance, are:

a. Determine system configuration in detail.

b. Determine mission profile.

c. Define maintenance concept.

d. Estimate reliability.

e. Estimate maintainability.

f. Compute availability.

g. Define cost elements from configuration.

h. Compute cost of ownership.

The terms in which each of the steps are expressed must be consistent and complementary. This is especially important in the case of configuration and mission profile. If the system configuration is defined in terms of a set of performance parameters, then the mission requirements must also be. For this analysis, the common denominator is the number of operationally similar equipments. These are equipments which could replace one another if required. The assumption is made that a circuit requirement could be satisfied on a number of frequencies so that multi-couplers are interchangeable.

3.1.2.1 System Configuration Determination

The system configuration is the quantity of equipments installed and the location of switching interfaces. In each of the alternative systems, the configuration is disclosed by a table of equipment descriptions and an interconnection block diagram. Equipment nomenclature is an adequate description for military standard equipment, while more complete information must be supplied for the new equipment. A simple interconnection block diagram leads to a quicker understanding of system capabilities. The quantities of equipments in each block should be shown in both the table and the block diagram.

3.1.2.2 Mission Profile

Specification of the mission of a communication system has been treated in various ways in the past. The concept of a "mission profile" has not been used to any great degree. Therefore it is necessary to describe in some detail the approach used here.

Individual requirements have been set down in the mission and performance envelope for the TRED system. Each of these is a mission requirement that must be met by some capability of the equipment or system. Quantifying a mission or group of missions in these terms is difficult and probably unrewarding. If, however, the mission is thought of as a sequence of demands which the system should be able to meet, then some order is established. A single demand includes a specific power, bandwidth, accuracy, stability, sensitivity, etc., which is responded to by the system capability of available power, bandwidth, accuracy, stability, sensitivity, etc. The mission is now reduced to the different numbers of equipments that may be required at all times or at some given time.

During an in-port or at-sea period, certain tactical missions are defined. Communication-mission requirements may well change within the tactical missions. The most detailed communications mission statements are at each watch change. The conclusion is that at some period of time greater than the watch length and less than or equal to the tactical mission length, there is a communication mission time. Within this time the requirements may change, so the mission statement must be able to accommodate these changes.

The mission profile is the distribution of the various communications requirements which could occur within the mission time. The requirements are the numbers of demands made upon the system which it should be able to meet. Availability will be computed as the degree to which the mission requirements are met.

An example of a mission profile is the following. During the mission:

a. There is no possibility that less than 27 circuits will be required;

b. 27 circuits will be required about 50% of the time;

c. 28 circuits will be required about 35% of the time;

d. 29 circuits will be required 10% of the time;

e. 30 circuits will be required 5% of the time;

f. No more than 30 circuits will be required at any time.

The foregoing is represented in Figure 3-2.

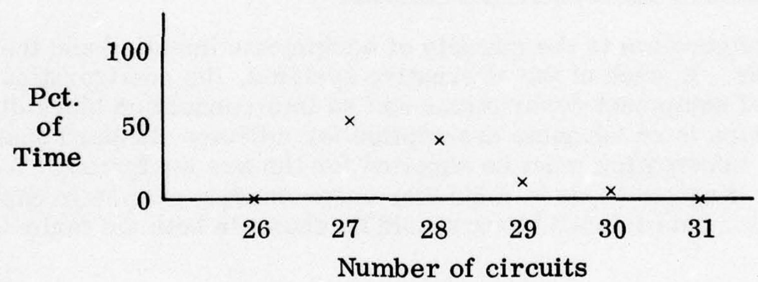


Figure 3-2. Mission Profile Example

When preparing a mission profile, it is necessary that all of the time be accounted for. That is, the numbers of circuits included in the statement should be mutually exclusive and the time allocation collectively exhaustive.

Another example is that shown in Figure 3-3. The increase in circuit utilization in this case is obvious.

### 3.1.2.3 Maintenance Concept

Ideally, the maintenance concept should include all factors influencing the maintenance of the equipment--at least, the number, capability and location of maintenance stations. A comprehensive concept is a multiple-stage, multi-server

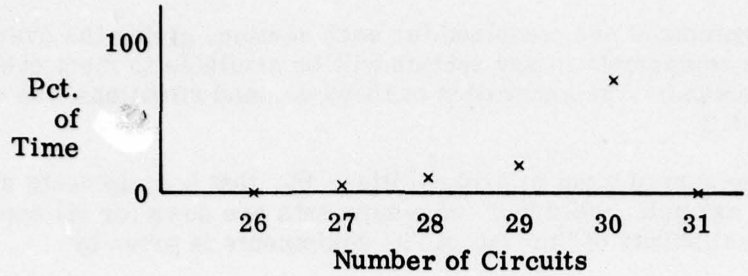


Figure 3-3. Mission Profile Example

supply model covering switching, patching, remove-and-replace, repair, parts supply, logistics, and procurement. Times to accomplish each activity, efficiency of the activity, and the numbers of facilities available to simultaneously take care of several failures would all be included.

For this analysis the efficiency of repair will be assumed to be 100%; the switching and patching activities instantaneous; and the supply-logistics-procurement group representable as part of repair. An average down-time will be computed from a composite of active repair, administrative, logistics, etc., times and used to compute availability. It will also be assumed that adequate test equipment is at hand if more than one repairman is required.

Maintenance capability includes both personnel and test equipment. In the TRED case, fault identification and location are assumed independent and parallel for each module. Spare procurement time is zero when a spare switchable module is available. Replacement of modules in that situation is a serial process, since it is conducted by one repair "facility" (the switch control).

### 3.1.2.4 Reliability

Reliability estimation takes many forms. A necessary output is the mean time between failures (MTBF) for blocks of components. The use of a systematic approach such as illustrated in Appendix B minimizes the number of hours spent in computational tasks. For this analysis, complexities were estimated for the subassemblies in the module block diagrams. Rough failure rates were assigned on the basis of active element groups (defined later); and MTBF was then computed.

### 3.1.2.5 Maintainability

Maintainability is measured by the mean time to repair/restore. This is the most difficult characteristic of a system to forecast. There is provision in the availability equations for the case when the number of repairs required exceeds the number of repairmen on site to do the job. There is no provision, however for the case when the time to repair will change because of changes in personnel, environment, etc.

### 3.1.2.6 Availability

The availability of a repairable system having a number of switchable sections and subjected to varying demands is best calculated by a computer. A set of probabilities must be computed and combined for each section, giving the overall probability that enough equipments in any section will be available to meet every possible situation of demand. The generation of these demand situations was discussed in Section 3.1.2.2.

Availability is the sum of a set of probabilities, $P_k$, that k equipments are down or not available. For example, when k=0, no equipments are down (or all equipments are available). The availability of "m" out of "n" equipments is given by

$$A = \sum_{k=0}^{k=n-m} P_k$$

For example, when n equipments are installed and n are required, then A is the probability that they will all be available.

The $P_k$ values are dependent on the reliability and maintainability of the equipment and on the number of repair facilities available for simultaneous use (see Appendix A). The computer program developed by ARINC Research Corporation and modified by NELC programmers to operate on its CDC 1604 is designed to evaluate this set of probabilities.

3.1.2.7 Cost

Cost computations are related to the ARINC Research Cost-of-Ownership model, which accounts for the cost of:

- Development
- Procurement
- Installation
- Maintenance
- Operation
- Service
- Modification
- Disposal

The elements are in turn broken down into subcategories. From the configuration information defining the type of equipment, each of the cost elements may be estimated. In some cases actual data is available at this time; in others, data is being collected. Some cost-estimating relationships have been developed which may be used to predict cost elements from equipment characteristics.

Finally, the cost of ownership may be computed from the cost elements. This, together with previously evaluated availability and reliability, constitutes the product of the cost-effectiveness evaluation methodology developed herein. Cost computations have been made by NELC.

## 3.2 LARGE-SHIP RECEIVERS

To demonstrate the methodology discussed in Section 3.1, the high-frequency portion of the CVA(N)-68 receiver subsystem will be discussed in detail.

The HF band is covered by two receivers, R-390/URR and R-1051/URR. Only the R-1051/URR will be considered, since the other receiver is involved primarily in less important voice applications. Twenty-nine R-1051/URR receivers with their attendant couplers, the AN/SRA-38, -39, and -40, account for the majority of the HF receiving requirements of the CVA(N)-68, as shown in Table 3-1.

TABLE 3-1. EQUIPMENTS OF HF RECEIVING SUBSYSTEM OF CVA(N)-68

| Equipment Designation | Quantity |
|---|---|
| LP-101C (Filter) | 14 |
| AN/SRA-38 (Coupler, 2-6 mc) | 1 |
| AN/SRA-39 (Coupler, 4-12 mc) | 1 |
| AN/SRA-40 (Coupler, 10-30 mc) | 1 |
| RF Line Sensors | 29 |
| Receiver Transfer Panel | 1 |
| RF Line Sensors | 29 |
| R-1051B/URR (Receiver, HF) | 29 |
| Audio Line Sensors | 29 |
| Audio Patch Panel | 1 |
| Audio Line Sensors | 29 |

A block diagram of the system model is shown in Figure 3-4A and B. For simplicity of the initial evaluation, it has been assumed that, if required, circuits may be shifted in frequency by retuning the receiver and changing the antenna multicoupler to another frequency band segment. This assumption is quite often correct and enables the individual three-mesh coupler units to be considered as interchangeable.

### 3.2.1 Evaluation

The model system configuration shown in Figure 3-4 was used as the basis for the evaluation. Mission profiles are those described in Section 3.1.2.2. Reliability, maintainability, availability, and cost estimates for the system were derived from the best available Navy and ARINC Research data sources.

Reliability, expressed as mean time between failures (MTBF) for the total system, is estimated as 42.3 hours. For each equipment set equivalent to one channel, the MTBF is estimated to be 1290 hours. Table 3-2 summarizes the contribution of each equipment in MTBF, the failure rate, and the basis for estimation.

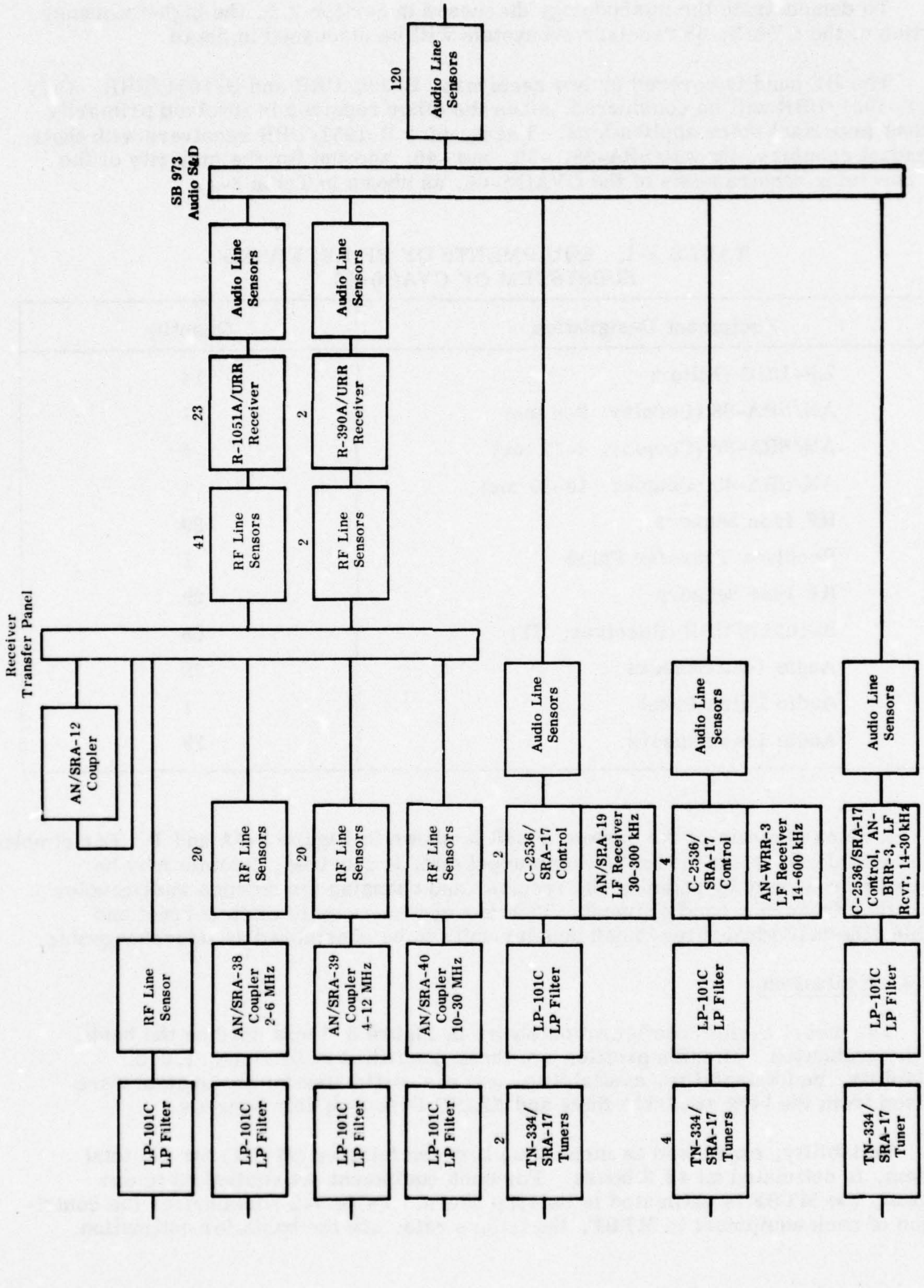


**Figure 3-4A. CV(N)-68 Receiving Communications Center**

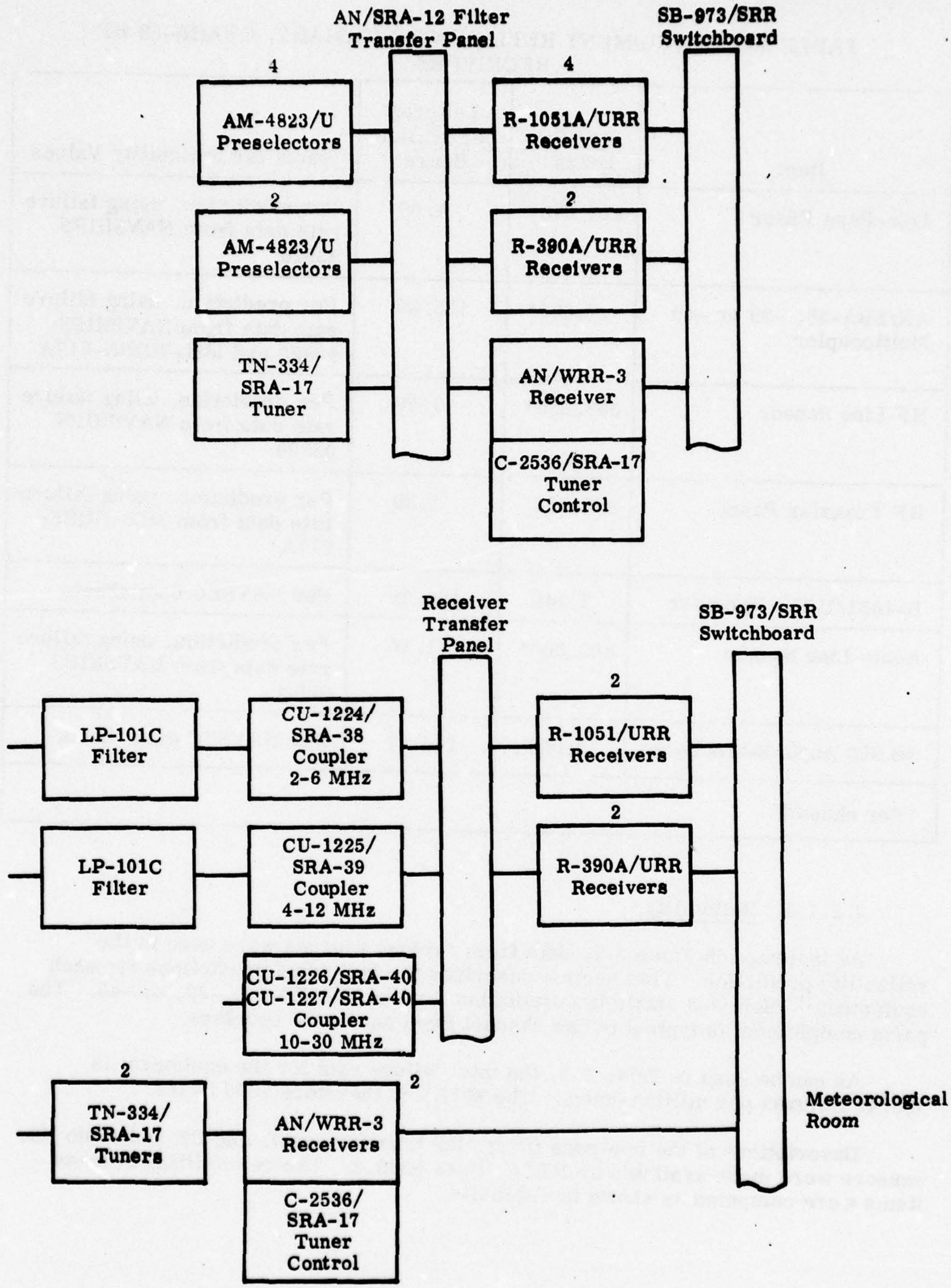


Figure 3-4B. CV(N)-68 Supplementary Radio Receiving Subsystem

TABLE 3-2. EQUIPMENT RELIABILITY SUMMARY, CVA(N)-68 HF RECEIVERS

| Item | MTBF, hours | Failures per Million Hours | Basis for Reliability Values |
|---|---|---|---|
| Low-Pass Filter | 213,675* | 4.68 | Per prediction, using failure rate data from NAVSHIPS 93820 |
| AN/SRA-38, -39 or -40 Multicoupler | 7,500* | 133.55 | Per prediction, using failure rate data from NAVSHIPS 93820 and MIL-HDBK-217A |
| RF Line Sensor | 588,235* | 1.70 | Per prediction, using failure rate data from NAVSHIPS 93820 |
| RF Transfer Panel | 833,333 | 1.20 | Per prediction, using failure rate data from MIL-HDBK-217A |
| R-1051/URR, Receiver | 2,146 | 465.98 | Per NAVSEC data sheets |
| Audio Line Sensor | 862,000* | 1.16 | Per prediction, using failure rate data from NAVSHIPS 93820 |
| SB 973 Audio Switchboard | 6,000 | 166.67 | Per NAVSEC data sheets |
| *Per channel | | | |

### 3.2.1.1 Reliability

As indicated in Table 3-2, data from various sources were used in the reliability prediction. This section describes the individual predictions for each equipment. Table 3-3 shows the prediction for the AN/SRA-38, -39, or -40. The parts complement is typical of one channel from any of the couplers.

As can be seen in Table 3-3, the total failure rate for the equipment is 133.45 failures per million hours. The MTBF is therefore 7500 hours.

Descriptions of the low-pass filter, RF transfer panel, and RF and audio line sensors were made available by NELC, Code S340.3. The reliabilities of these items were computed as shown in Table 3-4.

TABLE 3-3. RELIABILITY ESTIMATE, AN/SRA-38, -39, -40

| Part Type | Failures Per Million Hours | Data Source | Qty. per Link | Total Failures Per Million Hours for Part Type |
|---|---|---|---|---|
| RF Transformer | 1.16 | NAVSHIPS 93820, Table 3 | 1 | 1.16 |
| RF Choke | 0.28 | NAVSHIPS 93820, Table 3 | 3 | 0.84 |
| Capacitor (Air and Variable) | 0.13 | NAVSHIPS 93820, Table 3 | 7 | 0.91 |
| Resistor (Wirewound Power) | 1.40 | NAVSHIPS 93820, Table 3 | 1 | 1.40 |
| Voltage Regulator Tube | 42.88 | NAVSHIPS 93820, Table 3 | 3 | 128.64 |
| Neon Indicator, NE-51 | 0.2 | MIL-HDBK-217A, Table VII-XXVI | 1 | 0.20 |
| Gear Box* | 0.4 | NAVSHIPS 93820, Table 3 (Mech. Hdwe.) | 1 | 0.40 |
| TOTAL | | | | 133.55 |

*Four gears per box was assumed.

3.2.1.2 Maintainability

The prediction of maintainability is in no way as straightforward as that for reliability. Since the first iteration of data gathering produced no experience data on either mean time to repair (MTTR) or mean down time (MDT), a prediction was necessary. Table 3-5 lists the values used. An estimate of the ratio MDT/MTTR was obtained from an analysis of Summary Report 2A of Navy failure reporting form 10550-1.* The data had a wide range, with a best estimate of 14 for this ratio.

3.2.1.3 Availability

System availability may now be computed from the reliability, maintainability, and mission profiles. The probability of occurrence of each mission condition is multiplied by the availability of the system to that requirement, and the weighted availabilities are added. The result is the expected value of system availability as shown in Table 3-6. The first two missions are those of Section 3.1.2.2. The third is a situation in which the use of any number of channels from 27 to 30 is equally likely. Figure 3-5 is a plot of system availability versus channels required, with the three mission points indicated.

*N.J. Scarlett, Reliability, Maintainability and Availability Improvement Potential in Advanced Shipboard Communications, ARINC Research Publication 404-01-5-615, dated August 1966, page 2.

TABLE 3-4. RELIABILITY ESTIMATES, HF EQUIPMENT

| Part Type | Failures Per Million Hours | Data Source | Qty. per Link | Total Failures Per Million Hours for Part Type |
|---|---|---|---|---|
| A. Low-Pass Filter | | | | |
| RF Choke | 0.28 | NAVSHIPS 93820, Table 3 | 2 | 0.56 |
| Capacitor | 2.06 | NAVSHIPS 93820, Table 3 | 2 | 4.12 |
| | | | TOTAL | 4.68 |
| B. RF Line Sensor | | | | |
| RF Choke | 0.28 | NAVSHIPS 93820, Table 3 | 2 | 0.56 |
| Capacitor | 0.57 | NAVSHIPS 93820, Table 3 | 2 | 1.14 |
| | | | TOTAL | 1.70 |
| C. RF Transfer Panel | | | | |
| Coaxial Connectors | 0.04 | MIL-HDBK-217A, Figure 7.9.8 | 30 | 1.20 |
| Coaxial Cable | (No data) | --- | 30 | -- |
| | | | TOTAL | 1.20 |
| D. Audio Line Sensor | | | | |
| Audio Transformer | 1.16 | NAVSHIPS 93820, Table 3 | 1 | 1.16 |
| | | | TOTAL | 1.16 |

TABLE 3-5. MAINTAINABILITY PREDICTION

| Item | MTTR, hours | MDT, hours | Basis for MTTR Values |
|---|---|---|---|
| Low-Pass Filter | 1.5 | 21 | Per NAVSHIPS 94324, Section 3, Para. 13.1 |
| AN/SRA-38, -39, or -40 | 1.5 | 21 | Per NAVSHIPS 94324, Section 3, Para. 13.1 |
| RF Line Sensor | 1.5 | 21 | Per NAVSHIPS 94324, Section 3 |
| RF Transfer Panel | 1.5 | 1.5* | Per NAVSHIPS 94324, Section 3 |
| R-1051/URR | 4 | 56 | Per NAVSEC Data Sheets |
| Audio Line Sensor | 1.5 | 21 | Per NAVSHIPS 94324, Section 3, Para. 13.1 |
| SB-973 Audio Switchboard | 1.5 | 1.5* | Per NAVSHIPS 94324, Section 3, Para. 13.1 |

*Assume no administrative or logistics delay in restoration of equipment because of installed spares.

TABLE 3-6. REPAIRABLE-SYSTEM AVAILABILITY COMPUTATION

| Cir-cuits Req'd | Availabilities | | | | | | Mission I* | | Mission II* | | Mission III* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cou-pler | RF Panel | R-1051 | AF Panel | Line Sen-sor | Sys-tem | P | A | P | A | P | A |
| 27 | 1.000 | 1.000 | 0.764 | 1.000 | 1.000 | 0.764 | 0.50 | 0.382 | 0.05 | 0.038 | 0.25 | 0.191 |
| 28 | 0.999 | 1.000 | 0.645 | 1.000 | 1.000 | 0.644 | 0.35 | 0.225 | 0.10 | 0.064 | 0.25 | 0.161 |
| 29 | 0.996 | 1.000 | 0.483 | 0.999 | 1.000 | 0.480 | 0.10 | 0.048 | 0.15 | 0.072 | 0.25 | 0.120 |
| 30 | 0.912 | 1.000 | 0.270 | 0.993 | 0.999 | 0.245 | 0.05 | 0.012 | 0.70 | 0.172 | 0.25 | 0.062 |
| Overall System Avail. | | | | | | | | 0.667 | | 0.346 | | 0.534 |

*P is the percent of the time (probability) that each number of circuits will be required; A is the availability.

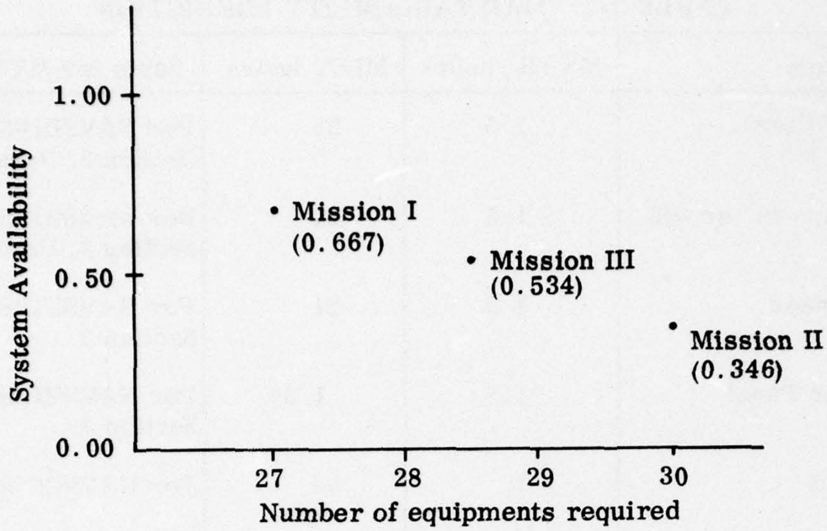


Figure 3-5. System Availability Summary

## 3.3 LARGE-SHIP COMMUNICATIONS COMPLEX

The large-ship communications complex can be described in terms of the number of equipments installed and the location of the switching interfaces. The equipment descriptions consisted of active-element-group (AEG) counts by subassembly, and consequent MTBF and MTTR estimates based on instruction books, schematics, parts lists, and other data sources.

Because of the lack of documented reliability and maintainability information on the equipment to be placed aboard the CVA(N)-68, most of the estimates were based on investigations of schematics, assembly drawings, and parts lists. Those entries in the tables of this section which have no AEG count indicated were derived from the data sources made available by NELC: Equipment Description Sheets (ACMO), 10550-1 Electronic Equipment Failure/Replacement Report, DD-787 (Proposed), and NAVSHIPS 3878 performance and operations reports (NAVSEC).

### 3.3.1 Reliability

The prediction of equipment reliability from information on equipment characteristics and functions performed is well based in recent literature.* Unfortunately, the lack of time has forced reliance on only the AEG as an indicator of complexity and therefore reliability. The Department of Defense, through MIL-STD-756, has advocated this approach to initial reliability-feasibility predictions based on the definition of active element as an electron tube, transistor, or ten computer-type diodes.

This approach represents an improvement in the timeliness of reliability predictions, but it has been criticized as being too inaccurate for wide application. For example, no consideration is given to the type of active element, although it is generally agreed that a transistorized AEG will have a lower failure rate than a functionally equivalent tubed-AEG. An adjusted AEG count is used for reliability evaluation in this report:

$$\text{AEG's/Eqpt.} = 3(\text{Number of Tubes}) + (\text{Number of Transistors}) + 0.1(\text{Number of Diodes})$$

An equivalent failure rate for one AEG and associated components is assumed to be 0.5 failures per million hours. This figure is based on a combination of

a. 0.3 failures per million hours for either
   1) an integrated circuit,
   2) an NPN silicon transistor with normalized junction temperature of 0.3, or
   3) a PNP silicon transistor with normalized junction temperature of 0.1; and

b. 0.2 failures per million hours for other associated components (ref. MIL-HDBK-217).

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*RADC Technical Reports: TDR-63-146, May 1963; TDR-63-600, March 1965; TDR-65-27, 1965. ARINC Publication 317-01-3-745, October 1966, "Avionics Reliability and Maintainability Prediction by Function."

In addition to AEG's, special consideration was given to motors and power or other "exotic" vacuum tubes. Parts lists and assembly drawings were reviewed to locate areas of unusual mechanical complexity, as well.

3.3.2 Maintainability

The prediction of maintainability is, as noted earlier, much more complex than that for reliability. The MTTR's in this report have been either found on data sheets from ACMO or NAVSEC, or have been estimated using NAVSHIPS 94324, Section 3.

3.3.3 Receiving Subsystem

In Table 3-7 the total receiving equipment complement of the CVA(N)-68 is shown. The primary-equipment description parameters include complexity (AEG units), reliability (MTBF), and maintainability (MDT). The costs given in the table are the estimated procurement costs for one unit in large quantities.

TABLE 3-7. CVA(N)-68 RECEIVING SUBSYSTEM

| Equipment | Quantity | AEG | MTBF, hr | MDT, hr | Cost, $ |
|---|---|---|---|---|---|
| AN/SRA-17 | 12 | 3 | 100,000 | 20 | 671 |
| AN/BRR-3 | 1 | | 6,415 | 14 | |
| AN/SRR-19A | 2 | 54 + 4 digital modules | 1,000 | 14 | 4,454 |
| AN/WRR-3B | 7 | 16 + mechanical linkages | 1,800 | 58 | 1,350 |
| AN/SRA-38 | 1 20-channel | | 7,500 | 21 | 8,300 |
| AN/SRA-39 | 1 20-channel | | 7,500 | 21 | 8,200 |
| AN/SRA-40 | 1 20-channel | | 7,500 | 21 | 8,247 |
| AN/SRA-49 | 1 20-channel | | 7,500 | 21 | 8,950 |
| AM-4823 | 6 | | 45,000 | 21 | |
| R-390/URR | 6 | | 2,556 | 56 | 1,250 |
| R-1051B/URR | 29 | 130 | 2,146 | 56 | 4,000 |
| AN/SRA-12 | 1 | | 213,675 | 1.5 | |
| LP-101C | 14 | | 833,000 | 1.5 | 260 |

The receiving subsystem interconnection block diagram is shown in Figure 3-4. Three locations are shown: the communications center (Figure 3-4A), the supplementary radio room (Figure 3-4B), and the meteorological room (Figure 3-4B). A simplified reliability block diagram appears as Figure 3-6.

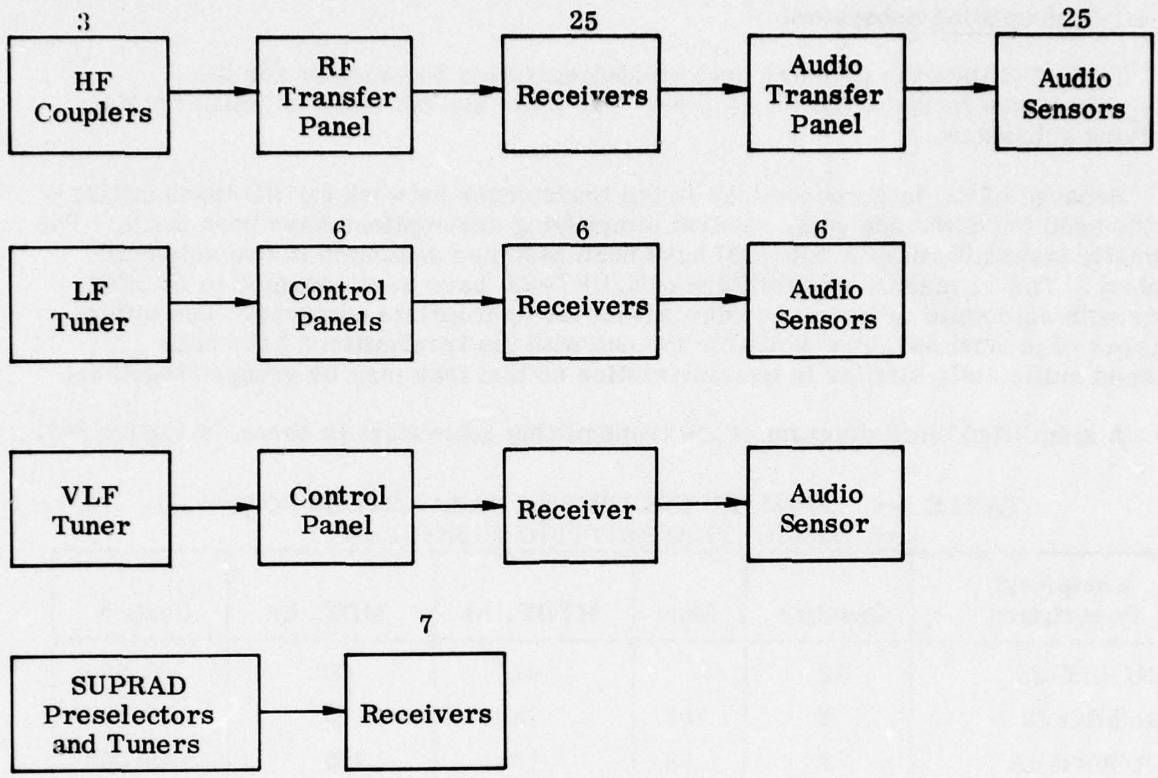


Figure 3-6. Receiver Block Diagram

### 3.3.4 Transmitting Subsystem

Table 3-8 lists the primary equipment-description parameters for the transmitting subsystem of the CVA(N)-68. The units are the same as those for the receiving subsystem.

Because of the interconnections in the transmitter network for HF transmitting and the need for quick analysis, several simplifying assumptions have been made. The automatic transmitters (AN/SRC-23) have been assumed dedicated to two automatic couplers. The 12 manual transmitters (AN/URT-23) have been assumed to be used either with automatic or manual couplers with the appropriate adapters. The different types of manual adapters available for use with the transmitters have been assumed sufficiently similar in characteristics so that they may be grouped together.

A simplified block diagram of the transmitting subsystem is shown in Figure 3-7.

TABLE 3-8. PRIMARY EQUIPMENT PARAMETERS FOR LARGE-SHIP TRANSMITTING SUBSYSTEM

| Equipment Description | Quantity | AEG | MTBF, hr | MDT, hr | Cost, $ |
|---|---|---|---|---|---|
| AN/URT-23 | 12 | | 415 | 60 | 8,900 |
| AN/SRC-23 | 2 | 707 | 740 | 60 | 16,000 |
| AN/WRT-1A | 2 | 78 | 795 | 120 | 13,500 |
| CU-760/WRT-1A | 2 | | 8,000 | 1.5 | 1,076 |
| TN-345/WRT-1 | 2 | | 6,700 | 1.5 | |
| MX-4847/SRA-34 | 12 | 33 | 60,000 | 21 | 1,118 |
| MX-4845/SRA-34 | 17 | 32 | 60,000 | 21 | 1,120 |
| OA-4794/SRA-34 | 2 | 250 | 1,540 | 60 | 45,000 |
| AN/SRA-57 | 2 | 9 | 10,000 | 20 | 7,451 |
| AN/SRA-58 | 1 | 9 | 10,000 | 20 | 12,000 |
| CU-938/URA-38 | 5 | | 8,285 | 20 | 2,800 |
| C-3698/URA-38 | 5 | | 6,805 | 20 | |
| SA-1070/SRA-34 | 4 | 10 | 10,000 | 1.5 | |
| CU-4787/SRA-34 | 4 | 33 | 60,000 | 1.5 | |
| AN/WRC-1 | 2 | | 1,618 | 90 | 6,000 |

### 3.3.5 System Availability

Figure 3-8 shows the output of a computer run of the availability of equipments of the large-ship communications system. The first column contains the MTBF's of equipments expressed as powers of ten. That is,

$$2.13300E\ 03 = 2.133 \times 10^3 = 2,133 \text{ hours.}$$

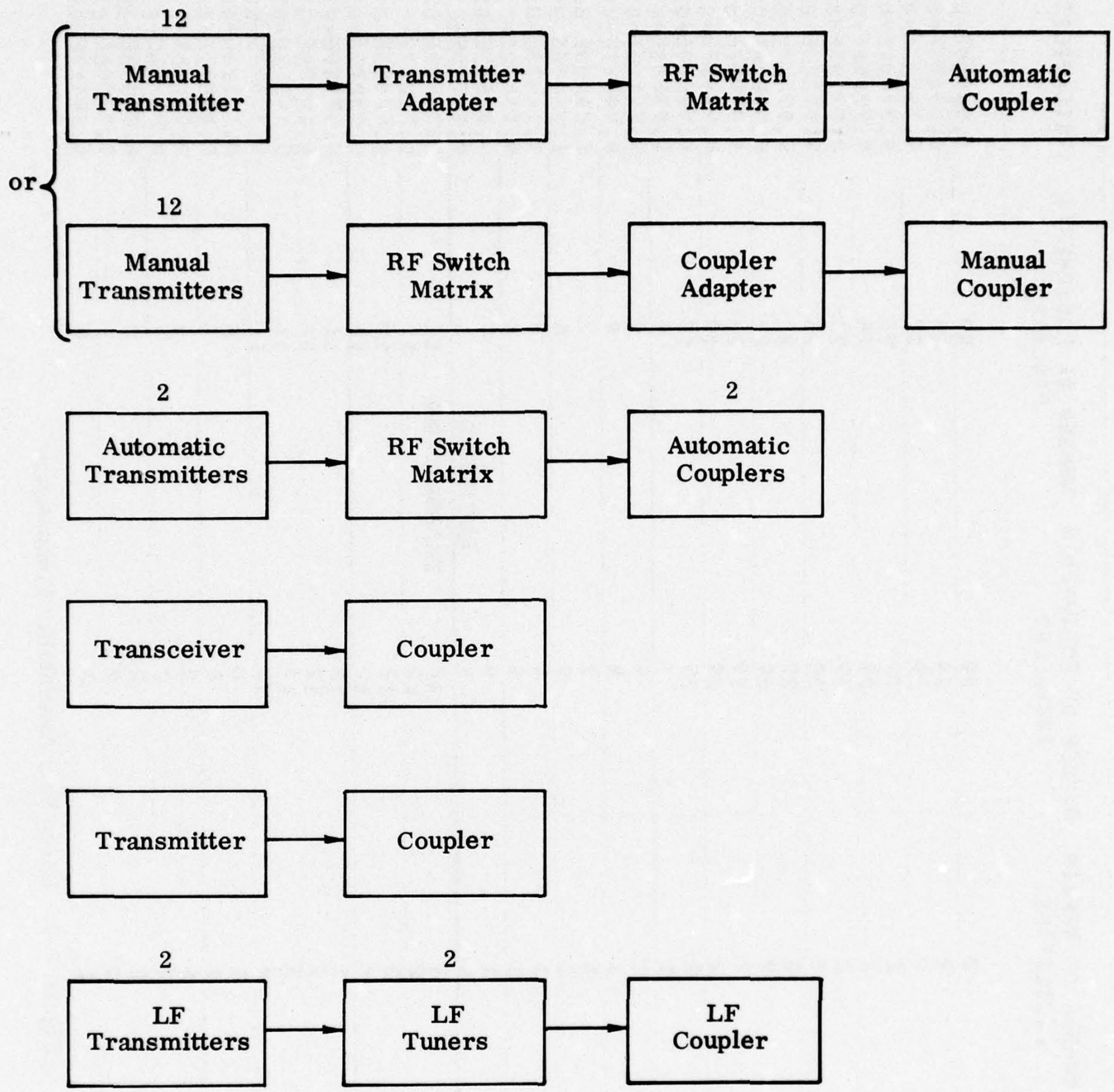


Figure 3-7. Transmitter Block Diagram

AVAILABILITY FOR CVAN-68 2ND SYSTEM

| MTBF/HOURS | MTTR/HOURS | NUMBER OF REPAIR FACILITIES | NUMBER OF EQUIPMENTS INSTALLED | NUMBER OF EQUIPMENTS REQUIRED | AVAILABILITY |
|---|---|---|---|---|---|
| 2,13300E 03 | 5,60000E 01 | 2 | 29 | 29 | 4,56550E-01 |
| 2,13300E 03 | 5,60000E 01 | 2 | 29 | 28 | 8,04153E-01 |
| 2,13300E 03 | 5,60000E 01 | 2 | 29 | 27 | 9,31917E-01 |
| 2,13300E 03 | 5,60000E 01 | 2 | 29 | 26 | 9,77201E-01 |
| 2,13300E 03 | 5,60000E 01 | 2 | 29 | 25 | 9,92656E-01 |
| 2,13300E 03 | 5,60000E 01 | 2 | 29 | 24 | 9,97728E-01 |
| 2,13300E 03 | 5,60000E 01 | 2 | 29 | 23 | 9,99326E-01 |
| 2,13300E 03 | 5,60000E 01 | 2 | 29 | 22 | 9,99809E-01 |
| 2,13300E 03 | 5,60000E 01 | 2 | 29 | 21 | 9,99948E-01 |
| 2,13300E 03 | 5,60000E 01 | 2 | 29 | 20 | 9,99987E-01 |
| 2,13300E 03 | 5,60000E 01 | 2 | 29 | 19 | 9,99997E-01 |
| 2,13300E 03 | 5,60000E 01 | 2 | 29 | 18 | 9,99999E-01 |
| 6,35000E 03 | 1,40000E 01 | 1 | 1 | 1 | 9,97800E-01 |
| 1,00000E 05 | 2,10000E 01 | 1 | 9 | 9 | 9,98110E-01 |
| 1,00000E 05 | 2,10000E 01 | 1 | 9 | 8 | 9,99997E-01 |
| 1,00000E 05 | 2,10000E 01 | 1 | 9 | 7 | 1,00000E 00 |
| 1,00000E 05 | 2,10000E 01 | 1 | 9 | 6 | 1,00000E 00 |
| 1,50000E 03 | 1,40000E 01 | 1 | 9 | 9 | 9,16837E-01 |
| 1,50000E 03 | 1,40000E 01 | 1 | 9 | 8 | 9,93852E-01 |
| 1,50000E 03 | 1,40000E 01 | 1 | 9 | 7 | 9,99602E-01 |
| 1,50000E 03 | 1,40000E 01 | 1 | 9 | 6 | 9,99978E-01 |
| | | | **RECEIVING** | | |
| | | | **TRANSMITTING** | | |
| 4,10000E 02 | 6,00000E 01 | 1 | 12 | 12 | 2,38572E-02 |
| 4,10000E 02 | 6,00000E 01 | 2 | 12 | 12 | 1,51007E-01 |
| 4,10000E 02 | 6,00000E 01 | 3 | 12 | 12 | 1,87423E-01 |
| 4,10000E 02 | 6,00000E 01 | 4 | 12 | 12 | 1,93272E-01 |
| 4,10000E 02 | 6,00000E 01 | 1 | 12 | 11 | 6,57529E-02 |
| 4,10000E 02 | 6,00000E 01 | 2 | 12 | 11 | 4,16190E-01 |
| 4,10000E 02 | 6,00000E 01 | 3 | 12 | 11 | 5,16556E-01 |
| 4,10000E 02 | 6,00000E 01 | 4 | 12 | 11 | 5,32677E-01 |
| 1,54000E 03 | 2,10000E 01 | 1 | 8 | 8 | 8,92524E-01 |
| 1,54000E 03 | 2,10000E 01 | 1 | 8 | 7 | 9,89891E-01 |
| 1,54000E 03 | 2,10000E 01 | 1 | 8 | 6 | 9,99105E-01 |
| 7,40000E 02 | 8,00000E 00 | 2 | 2 | 1 | 9,99886E-01 |
| 1,61800E 03 | 9,10000E 01 | 2 | 2 | 2 | 8,96340E-01 |
| 6,60000E 03 | 2,10000E 01 | 1 | 2 | 1 | 9,99980E-01 |
| 1,00000E 03 | 1,00000E 01 | 1 | 3 | 2 | 9,99412E-01 |

Figure 3-8. Large Ship Availability Computation

The equipments are grouped such that all those switched together are combined into one MTBF. The second column, "MTTR," and last column, "Availability," use the same notation. The first availability is therefore 0.456550 or 46 percent. In the first line, the R-1051 MTBF of 2146 hours is combined with the MTBF's of sensors and transfer-panel crosspoints to arrive at a composite of 2133 hours. The computation of availability for this unit is shown in Figure 3-9.

Above the heavy line of Figure 3-8 are elements of the receiving subsystem. The effect of spare units (installed units minus required units) on availability is dramatically evident. With 29 units installed, one spare HF receiver raises the availability from 46 to 80 percent when all units are required. The expected number of dedicated circuits, 18, will be maintained with a probability of 0.999999. As demands upon the system increase, however, the availability decreases about one order of magnitude for each additional receiver required.

Below the heavy line of Figure 3-8 are elements of the transmitting subsystem. The first unit, AN/URT-23, and its associated equipments is critical. The low time between failures and high expected repair time result in extremely low availability even when extra repair facilities are provided. This is shown in the first eight lines where "Number of Repair Facilities" is varied.

From the availability standpoint, the HF receiver group best illustrates (see Figure 3-10) the tradeoff of the number of sharable equipments. Given the installation of 29 units, the probability of having the 18 required and dedicated circuits available is 0.999999 – extremely high. That implies, however, that all 11 extra units are not used for other shared circuits but are on hot standby for the dedicated units. The same situation would exist when shared circuits are used but given low priority so that traffic would be dropped to maintain a dedicated circuit.

If, for instance, eight circuits in addition to the 18 dedicated are required, then the availability drops to 0.977, or 100 hours down in three months. Alternatively stated, this subsystem could meet a 98-percent availability requirement with 18 dedicated circuits and eight sharable circuits. As the requirement is increased, the number of backup on redundant units must be increased. This decreases the number of usable circuits for shared operation.

$$A = \left[ \sum \frac{29!}{(29-K)!K!} \left(\frac{56}{2133}\right)^K + \sum \frac{29!}{(29-K)!2!} \left(\frac{56}{2133}\right)^2 \left(\frac{56}{2133 \times 2}\right)^{K-1} \right]^{-1}$$

$$= \left[ 1 + 29\left(\frac{56}{2133}\right) + \frac{29.28}{2}\left(\frac{56}{2133}\right)^2 + \frac{29!}{2} \frac{56^2}{2133^2} \sum \frac{56^{K-2}}{(29-K)!\ 4266^{K-2}} \right]^{-1}$$

$$= \left[ 1 + .76142 + .28090 + .14800 \right]^{-1}$$

$$= (2.1900)^{-1} = 0.45655$$

Figure 3-9. Sample Availability Calculation

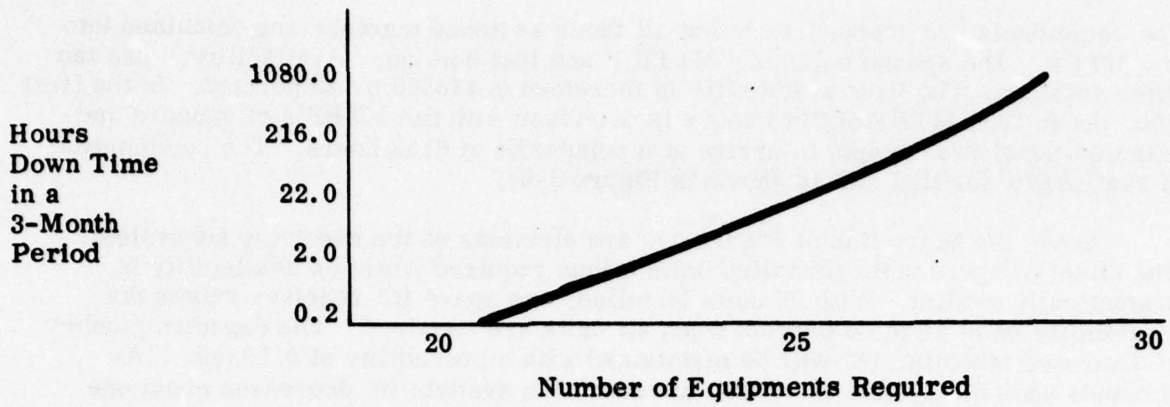


Figure 3-10. Availability of HF Receiver Group

## 3.4 TRED SYSTEM

Definition of the TRED system is based upon a detailed document and drawing analysis prepared by ARINC Research. A set of block diagrams, a system outline, and complexity estimates for modules and their replaceable subassemblies are included in Appendix B. Assumptions basic to the evaluation of TRED availability are the following:

a. Positive environmental control (i.e., shock, vibration and temperature control) to increase MTBF;

b. Semiautomatic fault location and isolation to lower MTTR;

c. Quick access packaging to allow low remove-and-replace times;

d. Standardization of interchangeable subassemblies to lower logistics times and increase the probability of having a replacement part.

TRED-module MTBF's are summarized in Table 3-9.

TABLE 3-9. TRED MODULE RELIABILITIES

| Module | Subsystem | MTBF, hr |
|---|---|---|
| RF/IF | R | 15,500 |
| RF/IF | T | 16,300 |
| AF/IF | R or T | 12,700 |
| Power Supply | R or T | 150,000 |
| Power amplifier (1 kW) | T | 1,030 |
| Power amplifier (10 kW) | T | 930 |
| Multicoupler | R & T | 7,700 |
| Switch Matrix | R & T | 87,000 |
| Control | R & T | 57,000 |
| Thermal control | R & T | 1,000 |

The availability of the TRED system when fully loaded is 0.996 for receiving and 0.988 for transmitting, or 0.984 overall.

3.4.1 Reliability Estimate

The following steps were taken in detailing the TRED system block diagrams:

a. The TRED technical exhibit requirements were considered (see Appendix B);

b. Required functions were outlined;

c. The internal configuration of each module was developed from experience and available literature;

d. Functions were added as necessary to complete an operational module block diagram.

Where TRED functional descriptions were either unavailable or unclear, engineering judgments were made, based on research into possible equipment functions.

The purpose of the module block diagrams is to arrive at an estimate of system complexity. They are not intended to imply a firm design concept.

The complexity of each of the blocks in each block diagram was estimated on the basis of active element groups. This estimate was made again from engineering judgment and the best available information. A typical AEG for transistorized systems consists of one silicon transistor, one silicon diode, three composition resistors, and two paper capacitors.

System reliability as measured by mean time between maintenance (MTBM) may be interpreted in two ways. First, when the system if fully loaded with information being processed by each module, the MTBM is the MTBF for the system. The assumption is that the failure of any information-carrying module would interrupt a communication circuit. Second, when the system is partially loaded – that is, with fewer circuits used than are actually installed – events requiring maintenance action are not necessarily system failures. The distinction is made in the state of the system when maintenance is performed.

3.4.2 Maintainability Estimate

In estimating the mean-time-to-repair/restore, two possible procedures may be used. The prediction-by-function technique relates observed experience to equipment parameters. A set of 14 prediction equations enable MTTR to be derived from maintenance concept characteristics such as type of maintenance, depth of maintenance penetration, weight, volume, etc. The MIL-M-23313* procedure provides for predicting MTTR by considering only typical diagnostic procedures and replacement items. The latter technique is used in this report, and is applicable during the equipment planning stage when at least the following have been established:

a. The planned packaging arrangement, to the extent that the method of repair can be determined (that is, whether units, assemblies, subassemblies, or parts will be replaced);

*Superseded by MIL-STD-470.

b. The planned method of equipment fault diagnosis to the extent that the general functional level of localization and isolation features can be determined.

The four-step procedure may be outlined as follows:

a. Determine the degree of modularization to be employed in the equipment.

b. Determine the general level at which automatic localization, semiautomatic isolation, and manual isolation will be used.

c. Select the MTTR value from the appropriate specification table.

d. Average MTTR values for combinations of maintenance plans.

For the TRED system, three maintenance plans are contemplated for use at different conditions of system operation. In the situation where the system is fully loaded, localization and isolation will be automatic to the module level. Physical replacement of the item is then required. When the system is partially loaded, the same localization and isolation procedures will lead to a replacement by switching-in a spare module. The failed unit is then replaced physically when convenient. The third plan is for failed modules, and consists of semiautomatic localization and isolation to the replacement part level. Parts are assumed to be always available.

Table 3-10 shows the MTTR's expected for the various subsystems and maintenance plans applicable. The fully automatic plan is shown as being not applicable to the switching and control subsystems because switched elements are not available. In the example used for comparing systems (Section 4.4), the system is considered to be less than fully loaded. Therefore switching is available to decrease the MTTR. On the basis of assumptions b, c, and d of Section 3.4, page 3-22, the mean down time is assumed to be 0.7 hour.

The current experience in maintenance down time has been reported previously.* The point was made that active repair time, while ranging from 3 to 13 hours, contributed less than 10 percent to the mean down time of communications receivers. Similar information for transmitters compared active repair time of from 2 to 12 hours to total down times ranging from 23.7 to 118.8 hours. Less than 14 percent of the total in this case was caused by active repair time. For the TRED system, a decrease in logistics time is expected. This decrease cannot now be forecast with any degree of accuracy, but will be caused by the procurement concept, the rigid terminal specifications, the standard module size, and the evolution of Navy logistics. Because of the specific effort in this system given to decreasing both administrative and logistic time, the ratio of MDT to MTTR is assumed equal to one. It is recommended that additional effort be put into the more accurate evaluation of this ratio or some other significant statistic.

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*N. J. Scarlett, Reliability, Maintainability and Availability Improvement Potential in Advanced Shipboard Communications, ARINC Research Publication 404-01-5-615, dated August 1966.

TABLE 3-10. MTTR'S FOR VARIOUS MAINTENANCE PLANS

| Maintenance Plan | MTTR, hr, for Indicated Subsystem | | | |
|---|---|---|---|---|
| | Transmitting | Receiving | Control | Switching |
| Fully automatic (with switching) | 0.2 | 0.2 | N.A. | N.A. |
| Semiautomatic (without switching) | 0.7* 1.0 | 0.7 1.0 | 0.7 1.0 | 0.7 1.0 |
| Module level | 1.8 | 1.8 | 0.6 | 1.8 |
| *Upper number for large ship; lower for small ship. | | | | |

3.4.3 TRED Configuration Summary

By combining the TRED modules into functional elements, the various systems may be configured. Four configurations are given in Table 3-11 and 3-12. Two sizes of ship class and two types of system operation are considered. As in other sections of this report, the sizes of ships being used are 1) the large, as represented by the CVA(N)-68, and 2) the medium, as represented by the DD-963. The two TRED models are the model A, having the same number of equipments as the conventional systems; and the model B, with reduced numbers of equipments to reflect the circuit-sharing capability of the quick-shift automatic system. The basis for equipment reduction in the model B system is an estimate by NELC Code S340 that a transmitter which can be tuned in one minute or less can be used to replace two or more non-automatic transmitters on low-usage circuits.

Because the items listed in Tables 3-11 and 3-12 are groups of modules, some explanation of their contents is required. A TRED transmitter is composed of an RF/IF module, AF/IF module, power supply module, and power-amplifier module. Multicouplers and tuners for both transmitting and receiving are units for matching antennas to multiple channels or a single channel of hardware. The TRED receiver contains a receiving RF/IF module and an AF/IF module.

3.5 MEDIUM-SHIP COMMUNICATIONS COMPLEX

Listed in Tables 3-13 and 3-14 is the total receiving and transmitting equipment complement of the DD-963. The primary equipment parameters include complexity (AEG units), reliability (MTBF), and maintainability (MTTR). Data for the various equipments were obtained from the large ship analysis, since the same equipments are used on the smaller ships as on the larger, except in smaller quantities. The interconnection diagram for the medium-sized ship is shown in Figure 2-5.

TABLE 3-11. DESCRIPTION OF EQUIPMENTS IN TRED LARGE-SHIP TRANSMITTING AND RECEIVING SUBSYSTEMS

| Equipment | Quantities | | AEG | MTBF (Hours) | MDT (Hours) | Cost (Dollars) |
|---|---|---|---|---|---|---|
| | A | B | | | | |
| 1-kW Transmitter | 11 | 8 | 436 + Power Tubes | 900 | 1 | 16,000 |
| 10-kW Transmitter | 5 | 4 | 436 + Power Tubes | 824 | 1 | 16,000 |
| Transmit Multicoupler | 5 | 4 | 30 + Electromechanical | 7,700 | 1 | 45,000 |
| MF Transmitter and Tuner | 2 | 1 | 439 + Mechanical | 890 | 1 | 2,800 |
| Receiver | 34 | 26 | 288 | 6,980 | 0.2 | 4,000 |
| Receiver Multicoupler | 3 | 3 | 30 + Electromechanical | 7,700 | 0.2 | 9,000 |
| Receiver Switch Matrix | 1 | 1 | 23 + Cross Points | 87,000 | 0.2 | 15,000 |
| Transmit Switch Matrix (Hi Power) | 1 | 1 | 23 + Cross Points | 87,000 | 1 | 35,000 |
| Transmit Switch Matrix (Low Power) | 1 | 1 | 23 + Cross Points | 87,000 | 0.2 | 15,000 |
| Control Console | 1 | 1 | 35 | 17,300 | 0.2 | 100,000 |

TABLE 3-12. DESCRIPTION OF EQUIPMENTS IN TRED MEDIUM-SHIP TRANSMITTING AND RECEIVING SUBSYSTEMS

| Equipment | Quantities | | AEG | MTBF (Hours) | MDT (Hours) | Cost (Dollars) |
|---|---|---|---|---|---|---|
| | A | B | | | | |
| 1-kW Transmitter | 7 | 5 | 436 + Power Tubes | 900 | 1 | 16,000 |
| 10-kW Transmitter | 3 | 2 | 436 + Power Tubes | 824 | 1 | 16,000 |
| Transmit Multicoupler | 5 | 3 | 30 + Electromechanical | 7,700 | 1 | 45,000 |
| Transmit Tuner | 2 | 1 | 30 | 7,700 | 1 | 2,800 |
| Receiver | 15 | 13 | 288 | 6,980 | 0.2 | 4,000 |
| Receiver Tuner | 5 | 4 | 30 | 7,700 | 0.2 | 1,000 |
| Receiver Multicoupler | 1 | 1 | 30 + Electromechanical | 7,700 | 0.2 | 9,000 |
| Receiver Switch Matrix | 1 | 1 | 23 + Cross Points | 87,000 | 0.2 | 15,000 |
| Transmit Switch Matrix (Hi Power) | 1 | 1 | 23 + Cross Points | 87,000 | 1 | 35,000 |
| Transmit Switch Matrix (Low Power) | 1 | 1 | 23 + Cross Points | 87,000 | 0.2 | 15,000 |
| Control Console | 1 | 1 | 35 | 17,300 | 0.2 | 100,000 |

TABLE 3-13. DESCRIPTION OF DD-963 RECEIVING SUBSYSTEM

| Equipment | Quantity | AEG's | MTBF (Hours) | MDT (Hours) | Cost (Dollars) |
|---|---|---|---|---|---|
| R-1051/URR | 12 | 130 | 2,146 | 56 | 4,000 |
| R-390/URR | 2 | | 2,556 | 56 | 1,300 |
| AN/WRR-3 | 2 | 16 + Mechanical | 1,800 | 58 | 1,400 |
| AN/SRR-19 | 1 | 54 + 4 Digital Modules | 1,000 | 14 | 4,500 |
| AN/SRA-17 | 3 | 3 | 100,000 | 20 | 721 |
| AN/SRA-49 | 1 20-channel | 3 | 7,500 | 21 | 9,000 |
| Patch Panel | 1 | | – | – | 1,500 |

TABLE 3-14. DD-963 TRANSMITTING SUBSYSTEM

| Equipment | Quantity | AEG's | MTBF (Hours) | MDT (Hours) | Cost (Dollars) |
|---|---|---|---|---|---|
| AN/URT-23 | 7 | | 415 | 60 | 8,900 |
| AN/SRC-23 | 2 | 707 | 740 | 60 | 16,000 |
| AN/WRT-1<br>CU760/WRT-1 | 1<br>1 | 78 | 795<br>8,000 | 120<br>1.5 | 14,600 |
| AN/SRA-57, 58 | 12 | 9 | 10,000 | 20 | 12,000 |
| OA-4794/SRA-34 | 8 | 250 | 1,540 | 60 | 45,000 |
| MX-4845/SRA-34 | 12 | 32 | 60,000 | 21 | 1,100 |
| MX-4847/SRA-34 | 7 | 33 | 60,000 | 21 | 1,100 |
| CU-938/URA-38<br>C-3698/URA-38 | 1<br>1 | | 8,285<br>6,805 | 20<br>20 | 2,800 |
| SA-1070/SRA-34 | 3 | 10 | 10,000 | 1.5 | 13,000 |
| SB-863 | 12 | | – | – | 400 |
| AN/WRC-1 | 1 | | 1,618 | 90 | 6,000 |

# 4. SYSTEM COMPARISONS

Because of the large number of possible system tradeoffs that could be made, the approach of paired system comparisons has been selected. Reasonable sets of alternatives are postulated, and a detailed tradeoff analysis made within that framework. Factors involved in each system comparison include:

a. System size
b. System technology
c. Receive or transmit circuitry
d. Propagation mode (HF or satellite)
e. Frequency band
f. Equipment quantity installed
g. Equipment quantity required, mission profile
h. Redundancy of low-availability equipments
i. Item reliability
j. Item maintainability
k. Maintenance concept

In this section, an example comparison will be made on the basis of the system configuration used in the TRED Technical Exhibit (see Section 4.1); several comparisons will be made within the large ship size (Section 4.2); the two satellite system alternatives will be considered together (Section 4.3); and a theoretical comparison will be presented and quantified by computer solution (Section 4.4).

## 4.1 TRED/NON-TRED SYSTEM COMPARISON

Comparison of two system concepts on the basis of availability is a matter of arriving at compromises. The essential elements of the TRED concept are detailed in Section 3. Each element therein is incorporated to some degree in one or more systems now in use. To permit a fair comparison of the two concepts, no specific ship class is assumed here. A conventional system will be envisioned which incorporates each TRED concept element to an "average" degree. Some switching, some modularity, some remote control, etc., may be assumed if parameters of an average group of communications equipments are considered. This hypothetical system is, in fact, considerably more reliable than those of actual ship classes considered elsewhere in the report.

The characteristics of the TRED system will be taken as those established in Section 3.4 of this report. The configuration of the TRED system will be taken as defined in the TRED Technical Exhibit* and expanded in the block diagrams of Appendix B herein.

*Technical Exhibit (Performance and Design Requirements) for Phase I of TRED; NELC unnumbered document, 10/16/67, Figure 4.3.

As a result of a previous study by ARINC Research, present levels of reliability and maintainability of Navy communications equipment have been documented.[1] The comparison system characteristics will be the same as for the "average shipboard" communications system as defined in Tables 1 and 2 of that report. That is, the transmitter will have an MTBF of 1643 hours and an MTTR of 7.8 hours, while a receiver will have an MTBF of 4054 hours and an MTTR of 5.3 hours. This system is designated as non-TRED for obvious reasons.

To make a meaningful comparison, a mission of seven transmitting and 17 receiving frequencies (guarded) will be assumed. Under these conditions, a comparison may be made upon the basis of availability. The results of the comparison are given in Table 4-1. The fact that there is almost an order-of-magnitude difference in subsystem availability level between the two should be noted, even though transmitter MTBF is considerably lower in the TRED because of motor-driven tuning elements. Contributions of the transmitting multicouplers and receiving control-line signal monitors are significant. These are units about which little may be forecast at this time; therefore the confidence in the computed availabilities is somewhat less than that where more is known.

In order to relate the concept of system availability to a typical communications system, the assumption is that downtime would occur neither in a single outage nor in a long series of very short outages. Total outage time is then related to mission length in the manner shown in Table 4-2. The specific downtimes for the TRED and non-TRED availability comparison were given in Table 4-1.

## 4.2 LARGE-SHIP SYSTEM COMPARISON

A more complex mission statement that better approximates the large-ship communications mission is applied in this section. The CVA(N)-68 is the specific reference for the large ship.

In making an availability comparison, mission requirement and system capability must be specified in the same terms. This is illustrated in Tables 4-3 and 4-4. Mission requirements[2] for the large ship are 39 dedicated receiving, transmitting, or transceiving circuits, and from 7 to 18 shared circuits. As shown in Table 4-4, the Conventional provides 39 dedicated and 14 sharable circuits. TRED is able to provide similar capability with 36 dedicated circuits and 10 sharable circuits. Three dedicated and one sharable transceiver-circuits are not provided by TRED.

The availability problem is concerned with both dedicated and sharable circuits. To maintain a given number of dedicated circuits with minimum availability, extra dedicated spares must be provided which can be switched in to cover any failed item.

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[1] N. J. Scarlett, Reliability, Maintainability and Availability Improvement Potential in Advanced Shipboard Communications, ARINC Research Publication 404-01-5-615, August 1966.

[2] W. H. Hockstra, TRED: CVA(N) Circuits (U), Confidential, NELC Memorandum from SOGO, dated 25 April 1968.

TABLE 4-1. SYSTEM COMPARISON

A. RECEIVER SUBSYSTEM

| | MC | RF/IF | AF/IF | PS | LSM | Total TRED Receivers | Non-TRED Receivers |
|---|---|---|---|---|---|---|---|
| Number | 3 of 3 | 17 of 18 | 17 of 18 | 9 of 9 | 18 of 18 | 18 of 18 | 17 of 18 |
| MTBF | 7700 | 16,000 | 13,000 | 60,000 | 74,000 | 1800 | 4054 |
| MTTR | 0.2 | 0.2 | 0.2 | 0.7 | 0.7 | 0.7 | 5.3 |
| Avail. | 0.999999 | 0.999944 | 0.999944 | 0.99989 | 0.99983 | 0.99961 | 0.9958 |
| Downtime Base (in 3 Mo.) | 6 sec. | 7 min. | 7 min. | 14 min. | 22 min. | 50 min. | 9 hr 5 min. |

B. TRANSMITTER SUBSYSTEM

| | Transmitters | MC | PS | LSM | Total TRED Transmitters | Non-TRED Transmitters |
|---|---|---|---|---|---|---|
| Number | 7 of 8 | 3 of 3 | 4 of 4 | 8 of 8 | 7 of 8 | 7 of 8 |
| MTBF | 910 | 7700 | 60,000 | 74,000 | 850 | 164.3 |
| MTTR | 0.2 | 0.2 | 0.7 | 0.7 | 0.7 | 7.8 |
| Avail. | 0.999999 | 0.99933 | 0.999953 | 0.999924 | 0.99917 | 0.9985 |
| Downtime (in 3 Mo.) | 6 seconds | 1 hr 30 min. | 6 min. | 10 min. | 1 hr 46 min. | 3 hr 15 min. |

<u>LEGEND:</u>
MC – Multicoupler
PS – Power supply
RF – Radio frequency
IF – Interim frequency
AF – Audio frequency
LSM – Line selector module

TABLE 4-2. RELATION OF OUTAGE TIME TO MISSION LENGTH AT VARIOUS LEVELS OF SYSTEM AVAILABILITY

| System Availability | Risk of Outage | Average Down-time in Three Months | Average Down-time in Five Days | Average Down-time in One Day |
|---|---|---|---|---|
| 0.5 | 0.5 | 1080 hrs | 60 hrs | 12 hrs |
| 0.9 | 0.1 | 216 hrs | 12 hrs | 2 hrs |
| 0.95 | 0.05 | 113 hrs | 6 hrs | 1 hr |
| 0.99 | $10^{-2}$ | 22 hrs | 1 hr | 15 min |
| 0.999 | $10^{-3}$ | 2 hrs | 5 min | 1 min |
| 0.9999 | $10^{-4}$ | 12 min | 40 sec | 8 sec |
| 0.99999 | $10^{-5}$ | 1 min | 4 sec | 0.8 sec |
| 0.999999 | $10^{-6}$ | 6 sec | 0.4 sec | 80 msec |

TABLE 4-3. LARGE-SHIP MISSION REQUIREMENTS

| Function | Usage | Band | | Total |
|---|---|---|---|---|
| | | HF | LF/MF | |
| Receiving | Dedicated<br>Shared | 18<br>2-11 | 6<br>2-4 | 24<br>4-15 |
| Transmitting | Dedicated<br>Shared | 11<br>1 | 1<br>1 | 12<br>2 |
| Transceiving | Dedicated<br>Shared | 3<br>1 | 0<br>0 | 6<br>2 |
| Total | | | | 50-61 |

Table 4-5 provides the basic availability information for each system alternative. It is broken down into cells by system, function, band, and dedicated/shared for about 50 circuits. Totals are summarized below.

| Alternative | Availability HF | Availability LF | Availability Total |
|---|---|---|---|
| Conventional T/R* | 0.344 | 0.752 | 0.262 |
| Without T/R | 0.414 | 0.762 | 0.316 |
| TRED-A T/R | 0.984 | 0.990 | 0.974 |
| Without T/R | 0.967 | 0.990 | 0.957 |
| TRED-B T/R | | | 0.981 |
| Without T/R | | | |

*T/R indicates transceiving capability.

TABLE 4-4. LARGE SHIP SYSTEM ALTERNATIVE CONFIGURATIONS

| Function | Alternative | | Input Lines | Process HF | Process LF | Output Lines |
|---|---|---|---|---|---|---|
| Receive | Conventional | Dedicated | 24 | 18 | 6 | 24 |
| | | Shared | 58 | 11 | 4 | 104 |
| | TRED | Dedicated | 24 | 18 | 6 | 24 |
| | | Shared | 45 | 4 | 3 | 1 |
| Transmit | Conventional | Dedicated | 12 | 11 | 1 | 12 |
| | | Shared | 79 | 2 | 1 | 13 |
| | TRED | Dedicated | 12 | 11 | 1 | 12 |
| | | Shared | 3 | 3 | 0 | 3 |
| Transceive | Conventional | Dedicated | 3 | 3 | 0 | 3 |
| | | Shared | 1 | 1 | 0 | 1 |
| | TRED | | Uses Transmitters and Receivers | | | |

TABLE 4-5. LARGE-SHIP SYSTEM AVAILABILITIES

| | | | HF | LF |
|---|---|---|---|---|
| Conventional | Receiving | Dedicated | 18/22<br>0.998 | 6/6<br>0.944 |
| | | Shared | 4/7<br>0.9999 | 3/4<br>0.997 |
| | Transmitting | Dedicated | 11/12<br>0.416 | 1/1<br>0.900 |
| | | Shared | 1/2<br>0.9998 | 1/1<br>0.900 |
| | Transceiving | Dedicated | 3/4<br>0.896 | 0/0 |
| | | Shared | 1/1<br>0.925 | 0/0 |
| TRED | Receiving | Dedicated | 18/18<br>0.999 | 6/6<br>0.995 |
| | | Shared | 4/4<br>0.996 | 3/3<br>0.997 |
| | Transmitting | Dedicated | 11/11<br>0.992 | 1/1<br>0.999 |
| | | Shared | 3/3<br>0.997 | 1/1<br>0.999 |

It is noted that the TRED system does not satisfy the transceiving requirements as does the CVA(N)-68. Addition of four transmitters and four receivers will be necessary if that requirement is to be met. This addition would degrade 0.984 to approximately 0.967, and 0.974 to 0.957, which is still significantly higher than for the CVA(N)-68.

An interpretation of the total system availabilities in terms of system downtime for various operation periods appears below.

| Operating Period (Month) | Total System Downtimes (Hours) | | |
|---|---|---|---|
| | Conventional | TRED-A | TRED-B |
| 3 | 1590 | 56 | 39 |
| 6 | 2950 | 112 | 82 |
| 9 | 4425 | 168 | 123 |

## 4.3 SATELLITE SYSTEM COMPARISON

The evaluation of availability of the two satellite mix systems proceeds along lines similar to those of the earlier analyses (Sections 4.1 and 4.2). Research into the functional capability of the components provides the basis for a system block diagram. The diagram is kept simple but retains the essential characteristics of the system. Quantities of components are then added so that system requirements may be satisfied. From the block diagram, availabilities of blocks of equipment which perform the same function are determined from a computer program. Availabilities of circuit sets are computed by combining equipment availabilities through subsystem and system levels. In this way the most important redundancies of function within the system may be accounted for in an expeditious manner.

Data sources for MTBF's and MTTR's, as well as functional capability, were applicable drawings, instruction books, reports, and interview with NELC technical personnel. Primary data sources are the following:

DSCS — Maintenance Engineering Monthly Status Report No. 8 on the AN/SSC-3 Shipboard Satellite Communications Set, March 1968 and Feb. 1969; Hughes Aircraft Co., Contract N00024-67-C-1561.

TACSAT — TSCP Reliability Prediction Summary Report Revision Pages, April 22, 1968, Collins Letter TSCP-E-323-4-5-68

TRED — TRED Availability Control Plan, ARINC Research Corp. Rough-draft report dated February 1968

An attempt was made to validate the DSCS information by comparison with other test data from Hughes in-plant tests, reported in its July 1967 Reliability/Maintainability Monthly Letter. Because of a disparity of notation and numbering of individual components and groups, no significant conclusion could be reached.

One item of TACSAT data which is questioned is the MTBF of 98,000 hours for the 1-kilowatt power amplifier. It would seem that, under the best of conditions, something less than 10,000 hours would be appropriate.

### 4.3.1 TRED/SATCOM

Table 4-6 is the computer printout of the availability of various equipments of the TRED/SATCOM system. Added to the printout are typed notations identifying each line of information. Each line is for one set of similar equipment and is made up of the following:

MTBF – Mean time between failures for the set, in hours (1.68E 03 = 1,680 hours)

MTTR – Mean time to repair for the set, in hours

Number of Repair Facilities – Self-explanatory

Number of Equipments Installed – The total number of the set of equipments which may be used if all were working.

Number of Equipments Required – The minimum number of equipments needed to fulfill a mission.

Availability – The percentage of time or probability that the number required will actually be available (9.988E-01 = 0.9988 = 99.88%). This column is computed from all the others as input data.

Some extra lines have been introduced by changing the installed or required quantity in order to estimate the sensitivity of availability to these quantities. In this way, three lines at the top relate to the SHF antenna and tracking circuitry. The antenna availability resulting from installing two instead of one increases from 0.9988 to 0.999999. This is equivalent to an increase of three orders of magnitude, or a reduction in antenna downtime of from two hours in three months to a matter of seconds.

The availability of various configurations may be computed on the basis of this printout. One line for each equipment is selected and the availabilities are multiplied. This is reasonable, since availabilities are interpreted as probabilities and each set of equipment may be assumed independent. In Table 4-7 two possible configurations are shown. The "best" configuration includes possible redundancy of low-availability equipments. The "worst" configuration includes only the quantities shown in Figure 2-3. Subsystem and system availabilities are summarized below.

| | Best Configuration | Worst Configuration |
|---|---|---|
| Receiving | 0.99941 | 0.99490 |
| Transmitting | 0.99935 | 0.9959 |
| Total System | 0.99876 | 0.9908 |
| Total System Downtime in 3 Months | 2.7 hr | 22 hr |

## TABLE 4-6. AVAILABILITY FOR TRED SATCOM-RECV SYSTEM

| | MTBF/HOURS | MTTR/HOURS | NUMBER OF REPAIR FACILITIES | NUMBER OF EQUIPMENTS INSTALLED | NUMBER OF EQUIPMENTS REQUIRED | AVAILABILITY | |
|---|---|---|---|---|---|---|---|
| | 1.68000E 03 | 2.00000E 00 | 2 | 1 | 1 | 9.98811E-01 | SHF Antenna & Tracking |
| RECEIVE | 1.68000E 03 | 2.00000E 00 | 2 | 2 | 1 | 9.99999E-01 | |
| | 1.68000E 03 | 2.00000E 00 | 2 | 3 | 1 | 1.00000E 00 | |
| | 3.82000E 03 | 5.00000E-01 | 2 | 1 | 1 | 9.99869E-01 | |
| | 3.82000E 03 | 5.00000E-01 | 2 | 2 | 1 | 1.00000E 00 | SHF Converter |
| DSCS | 2.20000E 04 | 5.00000E-01 | 2 | 1 | 1 | 9.99977E-01 | |
| | 2.20000E 04 | 5.00000E-01 | 2 | 2 | 1 | 1.00000E 00 | DSCS Demodulator |
| | 3.60000E 04 | 5.00000E-01 | 2 | 2 | 2 | 9.99972E-01 | UHF Coupler |
| | 3.52000E 03 | 1.00000E 00 | 2 | 1 | 1 | 9.99716E-01 | |
| | 3.52000E 03 | 1.00000E 00 | 2 | 2 | 1 | 1.00000E 00 | |
| | 3.52000E 03 | 1.00000E 00 | 2 | 3 | 1 | 1.00000E 00 | S/UHF Receiver |
| TACSAT | 1.00000E 04 | 7.00000E-01 | 2 | 1 | 1 | 9.99930E-01 | TACSAT Divider |
| | 3.40000E 03 | 7.00000E-01 | 2 | 5 | 3 | 1.00000E 00 | |
| | 3.40000E 03 | 7.00000E-01 | 2 | 5 | 4 | 1.00000E 00 | TATS Demodulator |
| | 3.40000E 03 | 7.00000E-01 | 2 | 5 | 5 | 9.98971E-01 | |
| | 7.70000E 03 | 7.00000E-01 | 2 | 1 | 1 | 9.99909E-01 | HF Coupler |
| | 6.95000E 03 | 7.00000E-01 | 2 | 13 | 13 | 9.98692E-01 | |
| | 6.95000E 03 | 7.00000E-01 | 2 | 14 | 13 | 9.99999E-01 | HF Receiver |
| | 6.95000E 03 | 7.00000E-01 | 2 | 14 | 14 | 9.98591E-01 | |
| HF | 7.70000E 03 | 7.00000E-01 | 2 | 1 | 1 | 9.99909E-01 | LF Coupler |
| | 6.95000E 03 | 7.00000E-01 | 2 | 9 | 8 | 1.00000E 00 | |
| | 6.95000E 03 | 7.00000E-01 | 2 | 9 | 9 | 9.99994E-01 | LF Receiver |
| | 1.00000E 04 | 7.00000E-01 | 2 | 1 | 1 | 9.99930E-01 | DeMux Terminal |
| | 3.40000E 04 | 1.80000E 00 | 2 | 3 | 3 | 9.99841E-01 | Switch Matrices |
| | 1.68000E 03 | 2.00000E 00 | 2 | 1 | 1 | 9.98811E-01 | |
| TRANSMIT | 1.68000E 03 | 2.00000E 00 | 2 | 2 | 1 | 9.99999E-01 | SHF Antenna & Tracking |
| | 1.62500E 03 | 2.00000E 00 | 2 | 3 | 1 | 1.00000E 00 | |
| | 2.72000E 03 | 5.00000E-01 | 2 | 1 | 1 | 9.99816E-01 | |
| | 2.72000E 03 | 5.00000E-01 | 2 | 2 | 1 | 1.00000E 00 | SHF Up-converter |
| DSCS | 1.20000E 04 | 5.00000E-01 | 2 | 1 | 1 | 9.99958E-01 | |
| | 1.20000E 04 | 5.00000E-01 | 2 | 2 | 1 | 1.00000E 00 | DCSP Modulator |
| | 5.00000E 05 | 5.00000E-01 | 2 | 2 | 2 | 9.99998E-01 | UHF Coupler (Diplexer) |
| | 2.19000E 03 | 1.00000E 00 | 2 | 1 | 1 | 9.99544E-01 | SHF/UHF Transmitter |
| | 2.19000E 03 | 1.00000E 00 | 2 | 2 | 1 | 1.00000E 00 | |
| | 2.19000E 03 | 1.00000E 00 | 2 | 3 | 1 | 1.00000E 00 | |
| TACSAT | 1.00000E 04 | 1.00000E 00 | 2 | 1 | 1 | 9.99900E-01 | TACSAT Combiner |
| | 3.60000E 03 | 1.00000E 00 | 2 | 5 | 3 | 1.00000E 00 | TATS Modulator |
| | 3.60000E 03 | 1.00000E 00 | 2 | 5 | 4 | 9.99999E-01 | |
| | 3.60000E 03 | 1.00000E 00 | 2 | 5 | 5 | 9.98612E-01 | |
| | 7.70000E 03 | 1.80000E 00 | 2 | 1 | 1 | 9.99766E-01 | HF Coupler |
| | 8.22000E 02 | 7.00000E-01 | 2 | 7 | 7 | 9.94059E-01 | HF Transmitter |
| | 8.22000E 02 | 7.00000E-01 | 2 | 8 | 7 | 9.99980E-01 | |
| | 8.22000E 02 | 7.00000E-01 | 2 | 9 | 7 | 1.00000E 00 | |
| HF | 7.70000E 03 | 1.80000E 00 | 2 | 1 | 1 | 9.99766E-01 | |
| | 7.70000E 03 | 1.80000E 00 | 2 | 2 | 1 | 1.00000E 00 | LF Coupler |
| | 8.94000E 02 | 7.00000E-01 | 2 | 2 | 2 | 9.98436E-01 | |
| | 8.94000E 02 | 7.00000E-01 | 2 | 3 | 2 | 9.99998E-01 | |
| | 8.94000E 02 | 7.00000E-01 | 2 | 4 | 2 | 1.00000E 00 | LF Transmitter |
| | 1.00000E 04 | 7.00000E-01 | 2 | 1 | 1 | 9.99930E-01 | Mux Terminal |
| | 3.00000E 04 | 1.80000E 00 | 2 | 3 | 3 | 9.99820E-01 | Switch Matrices |

TABLE 4-7. TRED/SATCOM AVAILABILITY

| Unit | Best | | Worst | |
|---|---|---|---|---|
| | Required/Installed | Availability | Required/Installed | Availability |
| **A. RECEIVER SUBSYSTEM** | | | | |
| SHF Antenna and Tracking | 1/2 | 1.0 | 1/1 | 0.9988 |
| SHF Converter | 1/2 | 1.0 | 1/1 | 0.99987 |
| SHF Demodulator | 1/2 | 1.0 | 1/1 | 0.99998 |
| UHF Coupler | 2/2 | 0.99997 | 2/2 | 0.99997 |
| UHF Receiver | 1/2 | 1.0 | 1/1 | 0.9997 |
| TACSAT Divider | 1/1 | 0.99993 | 1/1 | 0.99993 |
| TATS Demodulator | 4/5 | 1.0 | 5/5 | 0.9990 |
| HF Coupler | 1/1 | 0.9999 | 1/1 | 0.9999 |
| HF Receiver | 13/14 | 1.0 | 14/14 | 0.9986 |
| LF Coupler | 1/1 | 0.9999 | 1/1 | 0.9999 |
| LF Receiver | 8/9 | 1.0 | 9/9 | 0.999 |
| De-Mux Terminal | 1/1 | 0.99993 | 1/1 | 0.99993 |
| Switch Matrices | 3/3 | 0.99984 | 3/3 | 0.99984 |
| Total Receiving Subsystem | | 0.99941 | | 0.99490 |
| **B. TRANSMITTER SUBSYSTEM** | | | | |
| SHF Antenna | 1/2 | 1.0 | 1/1 | 0.9988 |
| SHF Up-Converter | 1/2 | 1.0 | 1/1 | 0.9998 |
| DCSP Modulator | 1/2 | 1.0 | 1/1 | 0.999958 |
| UHF Coupler | 2/2 | 1.0 | 2/2 | 1.0 |
| SHF/UHF Transmitter | 1/2 | 1.0 | 1/1 | 0.99954 |
| TACSAT Combiner | 1/1 | 0.9999 | 1/1 | 0.9999 |
| TATS Modulator | 4/5 | 1.0 | 5/5 | 0.9986 |
| HF Coupler | 1/1 | 0.99977 | 1/1 | 0.99977 |
| HF Transmitter | 7/9 | 1.0 | 7/8 | 0.99998 |
| LF Coupler | 1/2 | 1.0 | 1.1 | 0.9998 |
| LF Transmitter | 1/2 | 1.0 | 2/2 | 0.9984 |
| Mux Terminal | 1/1 | 0.99993 | 1/1 | 0.99993 |
| Switch Matrices | 3/3 | 0.99982 | 3/3 | 0.99982 |
| Total Transmitting Subsystem | | 0.99935 | | 0.9959 |

## 4.3.2 SATCOM/TRED

Table 4-8 is the availability printout for the SATCOM/TRED system. It is to be interpreted in exactly the same manner as Table 4-6. Subsystem and system availabilities are listed in Table 4-9 and summarized below.

| | Best Configuration | Worst Configuration |
|---|---|---|
| Receiving | 0.99999994 | 0.999989 |
| Transmitting | 0.9999997 | 0.999994 |
| Total System | 0.9999996 | 0.999983 |
| Total System Downtime in 3 Months | 3 sec. | 2.2 min. |

It will be noted that the "worst" transmitting availability is higher than the corresponding receiving availability. This was caused by the allowance of one spare HF transmitter, which is feasible; and gives the HF availability an increase of several orders of magnitude.

TABLE 4-8. AVAILABILITY FOR SATCOM TRED-R+T SYSTEM

| MTBF/HOURS | MTTR/HOURS | NUMBER OF REPAIR FACILITIES | NUMBER OF EQUIPMENTS INSTALLED | NUMBER OF EQUIPMENTS REQUIRED | AVAILABILITY | |
|---|---|---|---|---|---|---|
| 1.68000E 03 | 2.00000E 00 | 2 | 1 | 1 | 9.98811E-01 | |
| 1.68000E 03 | 2.00000E 00 | 2 | 2 | 1 | 9.99999E-01 | SHF Antenna and Tracking |
| 1.68000E 03 | 2.00000E 00 | 2 | 3 | 1 | 1.00000E 00 | |
| 3.82000E 03 | 5.00000E-01 | 2 | 1 | 1 | 9.99869E-01 | SHF Converter |
| 2.20000E 04 | 5.00000E-01 | 2 | 2 | 2 | 9.99955E-01 | DCSP Demodulator |
| 4.35000E 04 | 5.00000E-01 | 2 | 2 | 1 | 1.00000E 00 | Tracking Demodulator |
| 1.68000E 03 | 2.00000E 00 | 2 | 1 | 1 | 9.98[illegible]E-01 | TAC SHF Antenna - Use above |
| 3.60000E 03 | 5.00000E-01 | 2 | 1 | 1 | [illegible]E-01 | TAC SHF Receiver |
| 3.60000E 04 | 5.00000E-01 | 2 | 2 | 2 | 9.99972E-01 | UHF Coupler |
| 3.52000E 03 | 5.00000E-01 | 2 | 1 | [illegible] | 9.99850E-01 | |
| 3.52000E 03 | 5.00000E-01 | 2 | 2 | 1 | 1.00000E 00 | UHF Receiver |
| 3.52000E 03 | 5.00000E-01 | 2 | 3 | 1 | 1.00000E 00 | |
| 1.00000E 04 | 5.00000E-01 | 2 | 1 | 1 | 9.99950E-01 | |
| 1.00000E 04 | 5.00000E-01 | 2 | 2 | 1 | 1.00000E 00 | TACSAT Divider |
| 4.00000E 03 | 5.00000E-01 | 2 | 5 | 5 | 9.99375E-01 | |
| 4.00000E 03 | 5.00000E-01 | 2 | 6 | 5 | 1.00000E 00 | |
| 4.00000E 03 | 5.00000E-01 | 2 | 7 | 5 | 1.00000E 00 | POSTATS Demodulator |
| 7.70000E 03 | 7.00000E-01 | 2 | 1 | 1 | 9.99909E-01 | HF Coupler |
| 6.95000E 03 | 7.00000E-01 | 2 | 21 | 21 | 9.97887E-01 | |
| 6.95000E 03 | 7.00000E-01 | 2 | 22 | 21 | 9.99998E-01 | |
| 6.95000E 03 | 7.00000E-01 | 2 | 23 | 21 | 1.00000E 00 | HF Receiver |
| 7.70000E 03 | 7.00000E-01 | 2 | 1 | 1 | 9.99909E-01 | LF Coupler |
| 6.95000E 03 | 7.00000E-01 | 2 | 6 | 6 | 9.99396E-01 | |
| 6.95000E 03 | 7.00000E-01 | 2 | 7 | 6 | 1.00000E 00 | |
| 6.95000E 03 | 7.00000E-01 | 2 | 8 | 6 | 1.00000E 00 | LF Receiver |
| 3.00000E 04 | 7.00000E-00 | 2 | 7 | 7 | [illegible]E 00 | |
| 3.00000E 04 | 5.00000E-01 | 2 | 8 | 7 | 1.00000E 00 | |
| 3.00000E 04 | 5.00000E-01 | 2 | 9 | 7 | 1.00000E 00 | TDM De Mux |
| 1.00000E 04 | 5.00000E-01 | 2 | 1 | 1 | 9.99950E-01 | |
| 1.00000E 04 | 5.00000E-01 | 2 | 2 | 1 | 1.00000E 00 | FSK De Mux |
| 3.40000E 04 | 1.80000E 00 | 2 | 3 | 3 | 9.99841E-01 | Switch Matrices |
| 1.68000E 03 | 2.00000E 00 | 2 | 1 | 1 | 9.98811E-01 | SMT - SHF Antenna |
| 2.72000E 03 | 5.00000E-01 | 2 | 1 | 1 | 9.99816E-01 | SHF Up-Converter |
| 1.20000E 04 | 5.00000E-01 | 2 | 2 | 2 | 9.99917E-01 | DCSP Modulator |
| 1.68000E 03 | 2.00000E 00 | 2 | 1 | 1 | 9.98811E-01 | TAC SHF Antenna |
| 2.72000E 03 | 5.00000E-01 | 2 | 1 | 1 | 9.99816E-01 | TAC SHF Transmitter |
| 5.00000E 05 | 5.00000E-01 | 2 | 2 | 2 | 9.99998E-01 | UHF Coupler |
| 2.19000E 03 | 7.00000E-01 | 2 | 1 | 1 | 9.99680E-01 | |
| 2.19000E 03 | 7.00000E-01 | 2 | 2 | 1 | 1.00000E 00 | |
| 2.19000E 03 | 7.00000E-01 | 2 | 3 | 1 | 1.00000E 00 | UHF Transmitter |
| 1.00000E 04 | 7.00000E-01 | 2 | 1 | 1 | 9.99930E-01 | TACSAT Combiner |
| 4.00000E 03 | 7.00000E-01 | 2 | 5 | 5 | 9.99125E-01 | |
| 4.00000E 03 | 7.00000E-01 | 2 | 6 | 5 | 1.00000E 00 | |
| 4.00000E 03 | 7.00000E-01 | 2 | 7 | 5 | 1.00000E 00 | POSTATS |
| 7.70000E 03 | 1.80000E 00 | 2 | 1 | 1 | 9.99766E-01 | HF Coupler |
| 8.22000E 02 | 7.00000E-01 | 2 | 14 | 14 | 9.98154E-01 | |
| 8.22000E 02 | 7.00000E-01 | 2 | 15 | 14 | 9.99924E-01 | |
| 8.22000E 02 | 7.00000E-01 | 2 | 16 | 14 | 9.99999E-01 | HF Transmitter |
| 8.94000E 02 | 7.00000E-01 | 2 | 1 | 1 | 9.99218E-01 | |
| 8.94000E 02 | 7.00000E-01 | 2 | 2 | 1 | 9.99999E-01 | |
| 8.94000E 02 | [illegible]0 | 2 | 3 | 1 | 1.00000E 00 | LF Transmitter |
| 3.00000E 04 | 7.00000E-01 | 2 | 7 | 7 | 9.99837E-01 | |
| 3.00000E 04 | 7.00000E-01 | 2 | 8 | 7 | 1.00000E 00 | |
| 3.00000E 04 | 7.00000E-01 | 2 | 9 | 7 | 1.00000E 00 | TDM Mux |
| 1.00000E 04 | 7.00000E-01 | 2 | 1 | 1 | 9.99930E-01 | |
| 1.00000E 04 | 7.00000E-01 | 2 | 2 | 1 | 1.00000E 00 | FSK Mux |



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TABLE 4-9. SATCOM/TRED AVAILABILITY

| Unit | Best | | Worst | |
|---|---|---|---|---|
| | Required/Installed | Availability | Required/Installed | Availability |
| **A. RECEIVER SUBSYSTEM** | | | | |
| SHF Antenna and Tracking | 1/2 | 0.999999 | 1/1 | 0.9988 |
| SHF Converter | 1/1 | 0.99987 | 1/1 | 0.99987 |
| DCSP Demodulator | 2/2 | 0.99996 | 2/2 | 0.99996 |
| Tracking Demodulator | 1/2 | 1.0 | 1/2 | 1.0 |
| TAC SHF Antenna and Tracking | 1/2 | 0.999999 | 1/1 | 0.9988 |
| TAC SHF Receiver | 1/1 | 0.99986 | 1/1 | 0.99986 |
| UHF Coupler | 2/2 | 0.99997 | 2/2 | 0.99997 |
| UHF Receiver | 1/2 | 1.0 | 1/1 | 0.99986 |
| TACSAT Divider | 1/2 | 1.0 | 1/1 | 0.99995 |
| POSTATS Demodulator | 5/6 | 1.0 | 5/5 | 0.99938 |
| HF Coupler | 1/1 | 0.99991 | 1/1 | 0.99991 |
| HF Receiver | 21/23 | 1.0 | 21/21 | 0.9979 |
| LF Coupler | 1/1 | 0.99991 | 1/1 | 0.99991 |
| LF Receiver | 6/7 | 1.0 | 6/6 | 0.9994 |
| TDM De-Mux | 7/8 | 1.0 | 7/7 | 0.99984 |
| FSK De-Mux | 1/2 | 1.0 | 1/1 | 0.99995 |
| Switch Matrices | 3/3 | 0.99984 | 3/3 | 0.99984 |
| Total Receiving Subsystem | | 0.99999994 | | 0.999989 |
| Satellite | | 0.99966 | | 0.9965 |
| HF | | 0.99982 | | 0.9969 |
| **B. TRANSMITTER SUBSYSTEM** | | | | |
| SHF Antenna and Tracking | 1/2 | 0.999999 | 1/1 | 0.9988 |
| SHF Up-Converter | 1/1 | 0.99982 | 1/1 | 0.99982 |
| DCSP Modulator | 2/2 | 0.99917 | 2/2 | 0.99917 |
| TAC SHF Antenna | 1/2 | 0.999999 | 1/1 | 0.9988 |
| TAC SHF Transmitter | 1/1 | 0.99982 | 1/1 | 0.99982 |
| UHF Coupler | 2/2 | 0.999998 | 2/2 | 0.999998 |
| UHF Transmitter | 1/2 | 1.0 | 1/1 | 0.99968 |
| TACSAT Combiner | 1/1 | 0.99993 | 1/1 | 0.99993 |
| POSTATS Modulator | 5/6 | 1.0 | 5/5 | 0.99913 |
| HF Coupler | 1/1 | 0.99977 | 1/1 | 0.99977 |
| HF Transmitter | 14/16 | 0.999999 | 14/15 | 0.99992 |
| LF Transmitter | 1/2 | 0.999999 | 1/1 | 0.9992 |
| TDM Mux | 7/8 | 1.0 | 7/7 | 0.99984 |
| FSK Mux | 1/2 | 1.0 | 1/1 | 0.99930 |
| Switch Matrices | 3/3 | 0.99984 | 3/3 | 0.99984 |
| Total Transmitting Subsystem | | 0.9999997 | | 0.999994 |
| Satellite | | 0.9988 | | 0.9952 |
| HF | | 0.99976 | | 0.9987 |

## 4.4 THEORETICAL COMPARISON

The comparison made in this section is based on general equations governing system availability. The results provide insight into the behavior of communication systems, and the sensitivity of availability and reliability to the important system parameters.

A state model of availability is used in which the system is configured from a series of sets of effectively paralleled equipments. For satisfactory system operation, at least $m_i$ out of $n_i$ equipments in the $i^{th}$ set must be operating. This provides m circuits through the system. The states are referenced to each set and identified by the number of failed equipments not replaced.

There are acceptable states where m or more equipments are operating, and unacceptable states where fewer than m are operating. The reliability is the probability that the system will remain in an acceptable state for a given period of time. The mean time between failures is the time between entries into unacceptable states. Availability is the probability of being in an acceptable state, allowing transitions between all states (including unacceptable ones).

The availability of m out of n equipments with failure rate $\lambda$ and repair rate $\mu$ is given by

$$A = \sum_{i=m}^{n} \binom{n}{i} \left(\frac{\mu}{\lambda+\mu}\right)^{i} \left(\frac{\lambda}{\lambda+\mu}\right)^{n-i}$$

where $\binom{n}{i}$ is the binomial coefficient

$$\frac{n!}{i!\,(n-i)\,!}$$

If we set

$$\rho = \frac{\lambda}{\mu}$$

then

$$A = \sum_{i=m}^{n} \binom{n}{i} \left(\frac{1}{1+\rho}\right)^{i} \left(\frac{\rho}{1+\rho}\right)^{n-i} = \sum_{i=m}^{n} \binom{n}{i} \frac{\rho^{n-i}}{(1+\rho)^{n}}$$

and

$$A = (1+\rho)^{-n} \sum_{i=m}^{n} \binom{n}{i} \rho^{n-i}$$

The first term, $(1+\rho)^{-n}$, is a power series which may be written

$$\left( \sum_{i=0}^{n} \binom{n}{i} \rho^{i} \right)^{-1}$$

allowing the availability to be rewritten,

$$A = \frac{\sum_{i=m}^{n} \binom{n}{i} \rho^{n-i}}{\sum_{i=0}^{n} \binom{n}{i} \rho^{i}}$$

The basis for comparing two availabilities may be either $\frac{\log A_1}{\log A_2}$ or $\frac{1 - A_1}{1 - A_2}$.

These ratios are similar to the ratio of downtimes in the various data tables of this report. An improvement in availability from 0.95 to 0.99 is therefore 0.05/0.01, or a factor of five. Assuming equal values of n,

$$\frac{1 - A_1}{1 - A_2} = \frac{1 - \sum_{i=m_1}^{n} \binom{n}{i} \rho_1^{\,n-i} \Big/ \sum_{i=0}^{n} \binom{n}{i} \rho_1^{\,i}}{1 - \sum_{i=m_2}^{n} \binom{n}{i} \rho_2^{\,n-1} \Big/ \sum_{i=0}^{n} \binom{n}{i} \rho_2^{\,i}}$$

$$= \frac{\sum_{i=0}^{n} \binom{n}{i} \rho_1^{\,i} - \sum_{i=0}^{n-m_1} \binom{n}{i} \rho_1^{\,i}}{\sum_{i=0}^{n} \binom{n}{i} \rho_2^{\,i} - \sum_{i=0}^{n-m_2} \binom{n}{i} \rho_2^{\,i}} \times \frac{\sum_{i=0}^{n} \binom{n}{i} \rho_2^{\,i}}{\sum_{i=0}^{n} \binom{n}{i} \rho_1^{\,i}}$$

$$= \frac{\sum_{i=n-m_1+1}^{n} \binom{n}{i} \rho_1^{\,i}}{\sum_{i=0}^{n} \binom{n}{i} \rho_1^{\,i}} \times \frac{\sum_{i=0}^{n} \binom{n}{i} \rho_2^{\,i}}{\sum_{i=n-m_2+1}^{n} \binom{n}{i} \rho_2^{\,i}}$$

Even in this form, little intuitive insight can be gained from inspection of the tradeoff relationship.

Because of the difficulty of comparing availabilities analytically, the basic availability equations were programmed for solution on a computer.* A general tabular and graphical solution was derived from a series of order-of-magnitude solutions. Some of these solutions are shown in Table 4-10 and Figure 4-2.

TABLE 4-10. NUMBER OF EQUIPMENTS WHICH MUST BE INSTALLED AS A FUNCTION OF EQUIPMENT TYPES AND DOWNTIMES

| Downtime in 3 Months | Equipment Type | Number of Equipments That Must be Provided When Minimum Number Required is: | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 5 | 10 | 20 |
| 22 hr | 2 | 2 | 3 | 4 | 6 | 12 | 22 |
| | 3 | 1 | 2 | 3 | 5 | 10 | 21 |
| 2 hr | 2 | 2 | 3 | 4 | 7 | 12 | 22 |
| | 3 | 2 | 3 | 4 | 6 | 11 | 21 |
| | 4 | 1 | 2 | 4 | 5 | 11 | 20 |
| | 5 | 1 | 2 | 3 | 5 | 10 | 20 |
| 12 min | 2 | 3 | 4 | 5 | 8 | 13 | 22 |
| | 3 | 2 | 3 | 4 | 6 | 11 | 21 |
| | 4 | 1 | 3 | 4 | 6 | 11 | 21 |
| | 5 | 1 | 2 | 3 | 5 | 10 | 20 |
| 1 min | 2 | 3 | 5 | 6 | 8 | 13 | 22 |
| | 3 | 2 | 3 | 5 | 7 | 12 | 22 |
| | 4 | 2 | 3 | 4 | 6 | 11 | 21 |
| | 5 | 1 | 2 | 3 | 6 | 11 | 21 |

Table 4-10 summarizes major quantitative results by indicating the number of items that must be provided in order to achieve particular levels of system availability. In the table, system availability has been shown in column 1 as the amount of system downtime which will occur during a three-month mission. The number of items that must be provided is further shown to be a function of the number of items required (demand) and the level of reliability and maintainability for those items. The reliability and maintainability level is denoted in the table by "Equipment Type,"

*NSACS Availability Tradeoff Studies, ARINC Research Publication 404-01-8-678, November 1966.

(column 2), where type classification is based on the ratio of MTTR to MTBF, as shown below.

| Type | MTTR/MTBF |
|---|---|
| 1 | 0.1 |
| 2 | 0.01 |
| 3 | 0.001 |
| 4 | 0.0001 |
| 5 | 0.00001 |

An increasing type number denotes increasing reliability and/or increasing maintainability.

Table 4-10 can be used to determine the number of items of a given type that must be provided in order to limit downtime to a specified level for a specified demand. For example, the table illustrates that if a) equipment reliability is 1000 hours and maintainability is 10 hours (i.e., MTTR/MTBF = 0.01), b) the equipment is Type 2, and c) a minimum of five equipments are required, then seven equipments must be provided in order to hold system downtime to two hours for a three-month mission. Other uses of the table include determination of additional spares required to improve system availability by a specified amount, the effect of improved reliability on the number of items required, and the effect of increased demand on the number of items that must be provided.

The information is further summarized in Figure 4-1, which illustrates the relationship between the important parameters of interest. This figure generally describes the relationship between demand (number of equipments required) and availability for two different levels of reliability and maintainability. It further illustrates the effect of providing redundancy in the form of switchable spares.

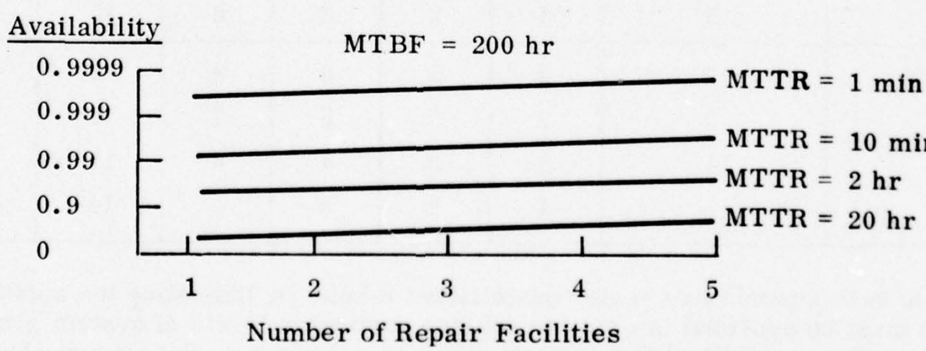


Figure 4-1. Availability and Repair

Specific comparison is possible by noting that the conventional system alternatives is of Type 2, while the TRED system alternatives are closer to Type 3 or 4. Because of the general nature of the figure, the axes may not be quantified. It is not possible to place two points on the figure, one for conventional and one for TRED. It is possible to draw the conclusion that TRED, with higher reliability and maintainability than the conventional, will provide higher availability, with fewer spares required to support a given demand level.

The sensitivity of availability to the number of repair facilities was investigated. Results are shown in Figure 4-2. Generally the number of repair facilities is significant when availability levels are less than 70 percent. The method of analysis used allowed for not less than one repairman or repair facility per group of equipment. In the practical case for a manual system, availabilities less than 70 percent and sharing of repairman among equipment groups is probable when demands upon the system are high. An example of this situation is shown in Figure 4-3.

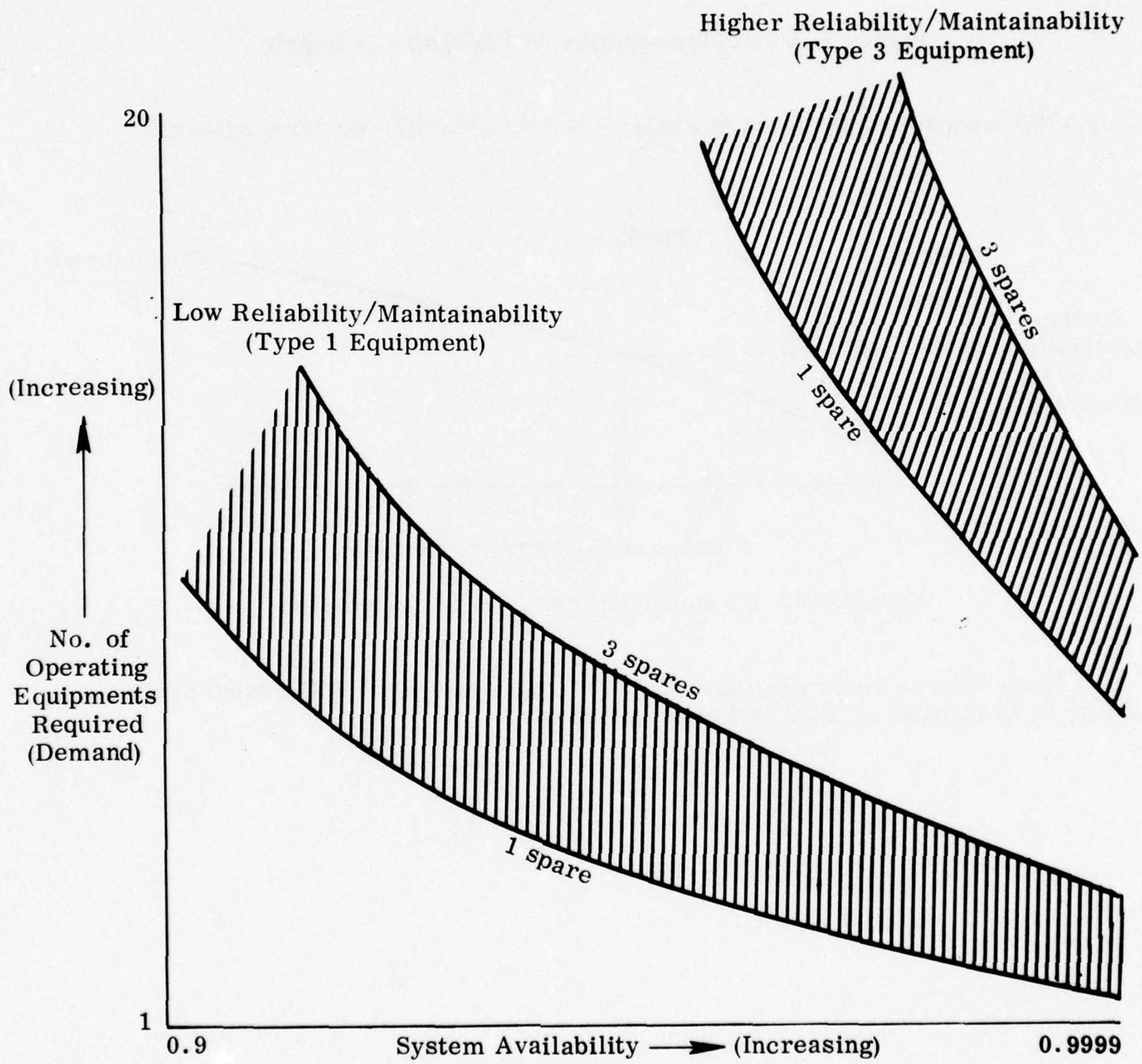


Figure 4-2. General Relationships — Demand Versus Availability for Varying Levels of Redundancy and Reliability/Maintainability

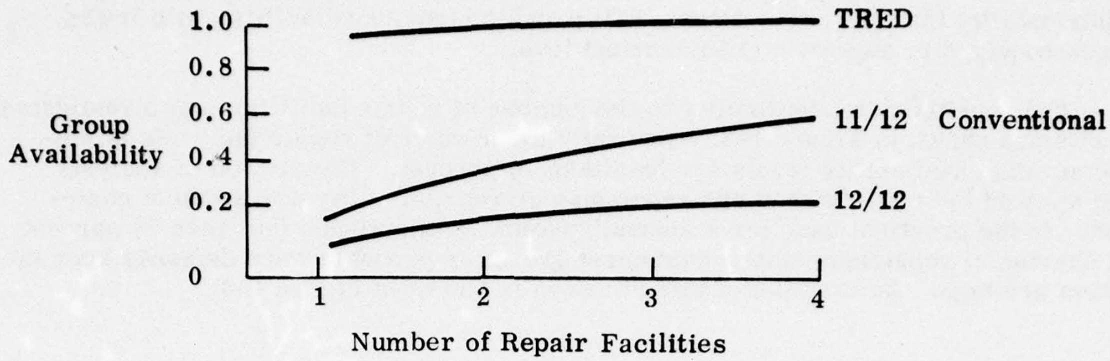


Figure 4-3. HF Transmitter Availability and Repair

A specific comparison is shown in Figure 4-4 within the HF receiving system.

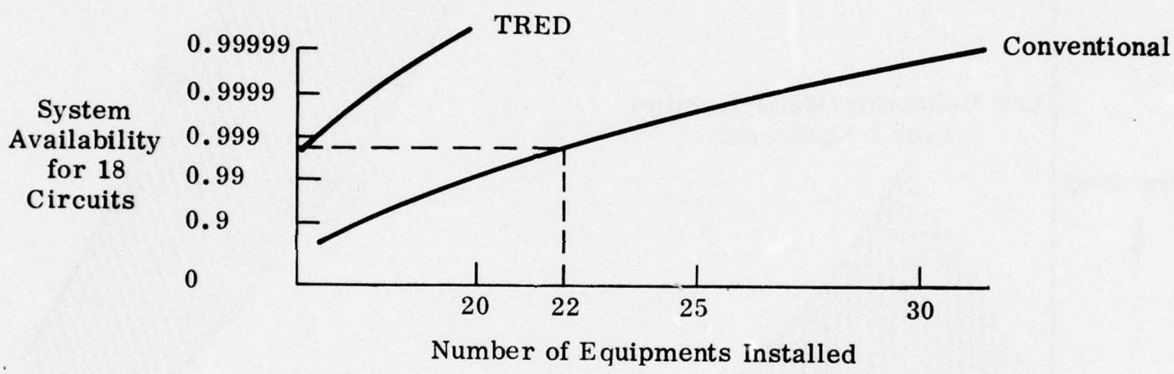


Figure 4-4. HF Receiving Availability Comparison

At the intersection indicated, 18 TRED equipments provide the same availability of 18 circuits as 22 CVA(N)-68 equipments.

## 4.5 OPERATIONAL COMPARISON

Only a qualitative comparison of the two switching concepts, manual and semiautomatic, is made here. The objective is to point out some of the factors that influence the system parameters of reliability and availability.

The manual switching and control system may be simplified, for one action, to the man plus the mechanization necessary to complete the action, i.e., a wafer switch. While the failure rate of the switch itself is very low, the error rate of the man is considerably higher. A compensating factor is the inherent human innovative capability by which he may recognize an improper instruction and correct it himself or check with the operator for verification.

Replacement time of the components of the manual system is variable. If a spare, trained, and experienced man is nearby in a battle situation, the replacement of the man may take only seconds. More often, however, familiarization alone would require substantial time. For example, the task of switchboard operation is not complex but, on the average, a moderate amount of time may be expected for replacement of its operator. The wafer switches themselves, located in modular drawers, would take longer to replace since the availability of an appropriate spare part must be included.

In the semiautomatic system the man is replaced by control electronics in the form of one integrated circuit. The mechanical wafer switch is replaced by a reed relay. The reliabilities of these devices are relatively high, even though they can compensate for wrong instructions only to a limited degree; and their replacement times relatively low, since modular front-panel replacement is assumed together with fault isolation and indication.

As a rough operational comparison then, the manual switching system has a high reliability, but it is expected that the reliability and availability of the semiautomatic system will be higher.

# APPENDIX A

# COMPUTER PROGRAM

# APPENDIX A

A computer program was prepared by ARINC Research Corporation to compute the availability of a repairable system. It is based on equations developed by Sandler*, and was adapted by NELC for use on its CDC 1604 Computer.

The necessary inputs to the program are mean time between failures, mean time to repair, number of repair facilities, number of equipments installed, and number of equipments required. Because division by zero and zero indices are not allowed in FORTRAN, some trouble is taken to compute $(n \pm 1)!$ for $n!$. A table of factorial functions is first computed, from which entries are taken to form the coefficients in probability expressions. Next, the service factor, $\rho$, is computed as the ratio of MTTR to MTBF. A table of power of $\rho$ is prepared at statement number 9. The equations are noted in the program by comment statements at 17 and 13. The availability is computed in statement 52 as the sum of P(K)'s, and the answer to the problem is printed out together with the input data on one line.

Input data are prepared as follows:

| Card | Columns | Description |
|---|---|---|
| 1 | 1-16 | Description of the system, which will be inserted into the statement, "Availability for the ______ System" |
| 2 | 1-5 | Number of cards to follow. This is written in the rightmost columns (____2), (____45). |
| 3 | 1-5 | Number of equipments installed (right-adjusted integer) |
| | 6-10 | Number of equipments required (right-adjusted integer) |
| | 11-20 | Mean time between failures (use decimal point) |
| | 21-30 | Mean time to repair (use decimal point) |
| | 31-35 | Number of repair facilities (right-adjusted integer) |
| 4 | Use the same format for Card 4 (and all subsequent) as with Card 3. | |

A sample output of one computer run for the input data of Section 3.2 is given in Figure A-1.

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*G. H. Sandler, System Reliability Engineering, Prentice-Hall, 1963.

FTN,L,E.



```
      PROGRAM TRED
C  GENERALIZED AVAILABILITY OF REPAIRABLE SYSTEM
C     REFERENCE IS RELIABILITY ANALYSIS BY SANDLER, PAGE 129,130, EQUA-
C     TIONS 5-35 THRU 5-38. ERROR IN EQUATION 5-37 CORRECTED. (LAST EX-
C     PONENT WRITTEN (K-1) SHOULD BE (K-R))
C THIS PROGRAM COMPUTES A GENERALIZED AVAILABILITY TERM
C FOR VARYING MTBF AND MTTF.
C ARRAYS USED BY THIS PROGRAM ARE
C     RHO(I)=(MTTR/MTBF)**-1
C      FACT(I)= I FACTORIAL
C     NDIV(I,K)=(I FACTORIAL) /(I-K)FACTORIAL
C     P(K)=PROBABILITY THAT THE SYSTEM IS IN STATE K.
C     A(M)=COMPUTED AVAILABILITY.
      DIMENSION RHO(31), P(31), FACT(31), DIV(31,31), ITITLE(2)
      READ 300, (ITITLE(I),I=1,2)
  300 FORMAT(2A8)
      PRINT 301, (ITITLE(I),I=1,2)
  301 FORMAT(1H1,10X,17HAVAILABILITY FOR ,2A8,7H SYSTEM//)
      PRINT 302
  302 FORMAT(103H MTBF/HOURS    MTTR/HOURS    NUMBER OF REPAIR  NUMBER O
     *F EQUIPMENTS  NUMBER OF EQUIPMENTS  AVAILABILITY/ 32X,
     *   10HFACILITIES,10X,9HINSTALLED, 14X, 8HREQUIRED//)
      READ 303, NR SETS
  303 FORMAT(I5)
C
      FACT(1)=1.
      DO 110 I=2,31
       FACT(I)= FACT(I-1)*FLOATF(I-1)
      DIV(I,I)= FACT(I)
      K=I-1
      DIV(1,I)=1.
      IF(I-2) 110,110,43
   43 DO 10 J=2,K
      M=I-J+1
       SUM=1.
      DO 42L=M,K
   42  SUM=SUM*FLOATF(L)
   10 DIV(J,I)= SUM
  110 CONTINUE
C
      DO 395 NA=1,NR SETS
      READ 310, N1, M, B, T, IR
  310 FORMAT(2I5,2F10.5,I5)
      IF(N1) 400,400,312
  312 TB=T/B
      RHO(31)=0.
      DO 205 I=1,30
  149 RHO(I)=0.
  205 P(I)=0.
      RHO(1)=1.
      DO 9 J=2,31
      IF(RHO(J-1)-.1E-20) 61,61,9
    9 RHO(J)=RHO(J-1)*TB
C
C  COMPUTE P SUB K PROBABILITIES UP TO N FOR A PARTICULAR R VALUE
C  REMEMBER THAT ZERO INDICES ARE NOT ALLOWED IN FORTRAN, USE ONE.
```

```
C  ALSO REMEMBER THAT ZERO FACTORIAL = ONE.
C
   61 N=N1+1
      IR1=IR-1
      IF(IR-10)11,11,395
C
   11 PZERO=0.
      DO   14 K=1,IR1
C USE SANDLERS EQUATION 5-35 ON PAGE 129 FOR R GREATER THAN K.
   17 P(K)=DIV(K,N)*RHO(K)/ FACT(K)
   44 PZERO=PZERO + P(K)
      IF(P(K)-.1E-20) 51,51,14
   14 CONTINUE
   51 DO 192 K=IR,N
C USE SANDLERS EQUATION 5-36 ON PAGE 129 FOR R LESS THAN OR = TO K
   13 P(K)=DIV(K,N)*RHO(K)/(FACT(IR)*FLOATF(IR)**(K-IR))
      PZERO=PZERO+P(K)
      IF(P(K)-.1E-20) 193,193,192
  192 CONTINUE
C
C NOW FORM NORMALIZED P SUB K AND AVAILABILITY TERM.
  193 DO 49 K=1,N
   49 P(K)=P(K)/PZERO
  201 MK=N-M
      A=0.0
      DO 52 K=1,MK
   52 A=A+P(K)
      PRINT 325, B, T, IR, N1, M, A
  325 FORMAT( E13.5, E14.5, 8X, I3, 16X, I4, 19X, I4, 8X, E14.5)
  395 CONTINUE
  400 CONTINUE
      END
```

AVAILABILITY FOR CVAN68 RCVR CPLR SYSTEM

| MTBF/HOURS | MTTR/HOURS | NUMBER OF REPAIR FACILITIES | NUMBER OF EQUIPMENTS INSTALLED | | NUMBER OF EQUIPMENTS REQUIRED | AVAILABILITY |
|---|---|---|---|---|---|---|
| 7.15200E 03 | 2.10000E 01 | 1 | 30 | AN/SRA-38, 39, or 40 (one channel) + RF Line Sensor and Low Pass Filter | 30 | 9.12194E-01 |
| 7.15200E 03 | 2.10000E 01 | 2 | 30 | | 30 | 9.15752E-01 |
| 7.15200E 03 | 2.10000E 01 | 3 | 30 | | 30 | 9.15799E-01 |
| 7.15200E 03 | 2.10000E 01 | 1 | 30 | | 29 | 9.92547E-01 |
| 7.15200E 03 | 2.10000E 01 | 2 | 30 | | 29 | 9.96419E-01 |
| 7.15200E 03 | 2.10000E 01 | 3 | 30 | | 29 | 9.96469E-01 |
| 7.15200E 03 | 2.10000E 01 | 1 | 30 | | 28 | 9.99389E-01 |
| 7.15200E 03 | 2.10000E 01 | 2 | 30 | | 28 | 9.99853E-01 |
| 7.15200E 03 | 2.10000E 01 | 3 | 30 | | 28 | 9.99903E-01 |
| 7.15200E 03 | 2.10000E 01 | 1 | 30 | | 27 | 9.99952E-01 |
| 7.15200E 03 | 2.10000E 01 | 2 | 30 | | 27 | 9.99994E-01 |
| 7.15200E 03 | 2.10000E 01 | 3 | 30 | | 27 | 9.99997E-01 |
| 8.33333E 05 | 1.50000E 00 | 1 | 30 | RF Transfer Panel | 30 | 9.99946E-01 |
| 8.33333E 05 | 1.50000E 00 | 2 | 30 | | 30 | 9.99946E-01 |
| 8.33333E 05 | 1.50000E 00 | 1 | 30 | | 29 | 1.00000E 00 |
| 8.33333E 05 | 1.50000E 00 | 2 | 30 | | 29 | 1.00000E 00 |
| 8.33333E 05 | 1.50000E 00 | 1 | 30 | | 28 | 1.00000E 00 |
| 8.33333E 05 | 1.50000E 00 | 2 | 30 | | 28 | 1.00000E 00 |
| 8.33333E 05 | 1.50000E 00 | 1 | 30 | | 27 | 1.00000E 00 |
| 8.33333E 05 | 1.50000E 00 | 2 | 30 | | 27 | 1.00000E 00 |
| 2.13292E 03 | 5.60000E 01 | 1 | 30 | R-1051/URR + RF Line Sensor and Audio Line Sensor | 30 | 2.70283E-01 |
| 2.13292E 03 | 5.60000E 01 | 2 | 30 | | 30 | 4.43171E-01 |
| 2.13292E 03 | 5.60000E 01 | 3 | 30 | | 30 | 4.58002E-01 |
| 2.13292E 03 | 5.60000E 01 | 1 | 30 | | 29 | 4.83172E-01 |
| 2.13292E 03 | 5.60000E 01 | 2 | 30 | | 29 | 7.92235E-01 |
| 2.13292E 03 | 5.60000E 01 | 3 | 30 | | 29 | 8.18749E-01 |
| 2.13292E 03 | 5.60000E 01 | 1 | 30 | | 28 | 6.45266E-01 |
| 2.13292E 03 | 5.60000E 01 | 2 | 30 | | 28 | 9.25124E-01 |
| 2.13292E 03 | 5.60000E 01 | 3 | 30 | | 28 | 9.56085E-01 |
| 2.13292E 03 | 5.60000E 01 | 1 | 30 | | 27 | 7.64428E-01 |
| 2.13292E 03 | 5.60000E 01 | 2 | 30 | | 27 | 9.73970E-01 |
| 2.13292E 03 | 5.60000E 01 | 3 | 30 | | 27 | 9.89739E-01 |
| 6.00000E 03 | 1.50000E 00 | 1 | 30 | AF Transfer Panel | 30 | 9.92502E-01 |
| 6.00000E 03 | 1.50000E 00 | 2 | 30 | | 30 | 9.92529E-01 |
| 6.00000E 03 | 1.50000E 00 | 1 | 30 | | 29 | 9.99946E-01 |
| 6.00000E 03 | 1.50000E 00 | 2 | 30 | | 29 | 9.99973E-01 |
| 6.00000E 03 | 1.50000E 00 | 1 | 30 | | 28 | 1.00000E 00 |
| 6.00000E 03 | 1.50000E 00 | 2 | 30 | | 28 | 1.00000E 00 |
| 6.00000E 03 | 1.50000E 00 | 1 | 30 | | 27 | 1.00000E 00 |
| 6.00000E 03 | 1.50000E 00 | 2 | 30 | | 27 | 1.00000E 00 |
| 8.62000E 05 | 2.10000E 01 | 1 | 30 | AF Line Sensor | 30 | 9.99269E-01 |
| 8.62000E 05 | 2.10000E 01 | 2 | 30 | | 30 | 9.99269E-01 |
| 8.62000E 05 | 2.10000E 01 | 3 | 30 | | 30 | 9.99269E-01 |
| 8.62000E 05 | 2.10000E 01 | 1 | 30 | | 29 | 9.99999E-01 |
| 8.62000E 05 | 2.10000E 01 | 2 | 30 | | 29 | 1.00000E 00 |
| 8.62000E 05 | 2.10000E 01 | 1 | 30 | | 28 | 1.00000E 00 |
| 8.62000E 05 | 2.10000E 01 | 2 | 30 | | 28 | 1.00000E 00 |

Figure A-1. Availability Program Output

# APPENDIX B

## TRED SYSTEM OUTLINE AND COMPLEXITY ESTIMATE

# 1. INTRODUCTION

For the major subassemblies of the TRED system, this appendix presents a functional outline, a set of functional block diagrams, and complexity estimates.

The numbering system for the outline was arbitrary, but in standard indentation format.

In the block diagrams, the primary signal path appears across the upper part; from left to right across the lower part are arranged the power supply, frequency standard (if applicable), and control assemblies.

The block diagrams are referenced to the outline by the final digit of the outline number. Where block diagrams are missing, no information was available. It is expected that, as the design progresses, all data will become available and a complete picture of the system will emerge.

## 2. TRED SYSTEM FUNCTIONAL OUTLINE

| | Subassembly | No. of AEG's |
|---|---|---|
| 1. | Transmitting Subsystem | |
| 1.1 | AF/IF Module; 8 required | 157 |
| 1.1.1 | Frequency Div. Multiplexing | 4 (+ filters) |
| 1.1.2 | Frequency Translation | 24 (at 6 per side-band) |
| 1.1.3 | Internal Frequency Standard | 65 (+ crystals) |
| 1.1.4 | Frequency Standard Switching | 3 |
| 1.1.5 | Internal Preconditioning | |
| 1.1.6 | Independent Sideband Filters per DCAC 322263 (4) | 0 (+ filters) |
| 1.1.7 | Narrow band Filter | 0+2 (for switching + filter) |
| 1.1.8 | AF Amplifier | 20 (5 per sideband) |
| 1.1.9 | IF Amplifier | 5 |
| 1.1.10 | System Keyline Diplexer | 5 |
| 1.1.11 | DCS | 20 |
| 1.1.12 | Power Distribution | 2 (+ power supply unique components) |
| 1.1.13 | Remote Control | 2 |
| 1.1.14 | Monitor | 5 |
| 1.2 | RF/IF Module, 2-30 MHz; 6 required | 123 |
| 1.2.1 | System Keyline Diplexing | 5 |
| 1.2.2 | Internal Frequency Standard | 70 |
| 1.2.3 | Frequency Translation | 3 |
| 1.2.4 | Frequency Standard Switching | 3 |
| 1.2.5 | Internal Preconditioning | Contents unknown |
| 1.2.6 | IF Amplifier | 3 |
| 1.2.7 | RF Amplifier | 2 |
| 1.2.8 | Remote Control | 10 |
| 1.2.9 | DCS | 20 |
| 1.2.10 | Power Distribution | 2 (+ filters) |
| 1.2.11 | Monitor | 5 |
| 1.2.12 | Tuned Circuits | 0 |
| 1.3 | RF/IF Module 300-600 kHz; 2 required | 123 |
| 1.3.1 | System Keyline Diplexing | 5 |
| 1.3.2 | Internal Frequency Standard | 70 |
| 1.3.3 | Frequency Translation | 3 |
| 1.3.4 | Frequency Standard Switching | 3 |
| 1.3.5 | Internal Preconditioning | Contents unknown |
| 1.3.6 | IF Amplifier | 3 |
| 1.3.7 | RF Amplifier | 2 |
| 1.3.8 | Remote Control | 10 |
| 1.3.9 | DCS | 20 |
| 1.3.10 | Power Distribution | 2 (+ filters) |
| 1.3.11 | Monitor | 5 |

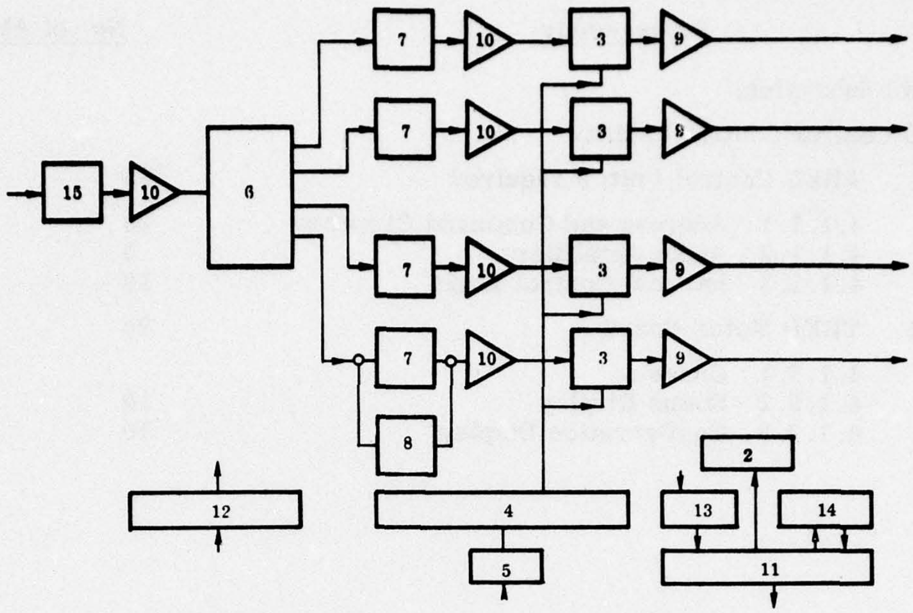
| | Subassembly | No. of AEG's |
|---|---|---|
| 1.4 | PA Module, 10 kW | 143 (+ 3 power tubes + 5 motors) |
| 1.4.1 | System Keyline De-diplexer | 5 |
| 1.4.2 | Termination Verification Seeker | 5 |
| 1.4.3 | Antenna Matching Subassembly | 30 (in control logic)<br>20 diodes<br>3 motors with tuned elements |
| 1.4.4 | Power Supply Subassembly | 25 (+ 40 diodes + 3-phase transformers) |
| 1.4.5 | Output Power Monitor | 3 |
| 1.4.6 | Driver Amplifier Subassembly | 1-1 kW |
| 1.4.7 | LRU Monitor | 10 |
| 1.4.8 | Tuning Logic | 25 |
| 1.4.9 | DCS | 20 |
| 1.4.10 | Input Amplifier | 1-.5 kW |
| 1.4.11 | Power Amplifier | 1-10 kW |
| 1.4.12 | Tuning Assemblies | 0 (+ filters)<br>2 motors with tuned elements |
| 1.5 | PA Module, 1 kW; 2 required | 143 (+ 3 power tubes + 5 motors) |
| 1.5.1 | System Keyline De-diplexer | 5 |
| 1.5.2 | Terminal Verification Seeker | 5 |
| 1.5.3 | Antenna Matching Subassembly | 30 (in control logic)<br>20 diodes<br>3 motors with tuned elements |
| 1.5.4 | Power Supply Subassembly | 25 (+ 40 diodes) |
| 1.5.5 | Output Power Monitor | 3 |
| 1.5.6 | Driver Amplifier Subassembly | 1-0.3 kW |
| 1.5.7 | LRU Monitor | 10 |
| 1.5.8 | Tuning Logic | 25 |
| 1.5.9 | DCS | 20 |
| 1.5.10 | Input Amplifier | 1-0.3 kW |
| 1.5.11 | Power Amplifier | 1-1 kW |
| 1.5.12 | Tuning Assemblies | 0 (+ filters)<br>2 motors with tuned elements |
| 1.6 | Multicoupler, Transmitting, 2-5 MHz | 30 (+ 1 motor) |
| 1.6.1 | Multicoupler Chassis | |
| 1.6.2 | Termination Verification | 10 (1 logic CARD) |
| 1.6.3 | 10-kW Section | 1 motor & tuning capacitor |
| 1.6.4 | 1-kW Section | |
| 1.6.5 | Intraport Isolation | |
| 1.6.6 | Internal Positioning and Tuning Controls | 10 (1 logic card) |
| 1.6.7 | DCS | 10 (1 logic card) |

| | Subassembly | No. of AEG's |
|---|---|---|
| 1.7 | Multicoupler, Transmitting | 30 (+ 1 motor) |
| 1.7.1 | Multicoupler Chassis | |
| 1.7.2 | Termination Verification | 10 (1 logic card) |
| 1.7.3 | 10-kW Section | 1 motor & tuning capacitor |
| 1.7.4 | 1-kW Section | |
| 1.7.5 | Intraport Isolation | |
| 1.7.6 | Internal Positioning and Tuning Controls | 10 (1 logic card) |
| 1.7.7 | DCS | 10 (1 logic card) |
| 1.8 | Power Supply, Transmitting Modules; 4 required | 13 (+ rectifier diodes per power req) |
| 1.8.1 | Power Supply Chassis | |
| 1.8.2 | Rectification Subassembly | 3 (+ 12 CR) |
| 1.8.3 | Regulation S/A | 6 |
| 1.8.4 | Output Overload Control | 2 |
| 1.8.5 | RFI Filters, etc. | 0 |
| 1.8.6 | Performance Monitor | |
| 2. | Receiving Subsystem | |
| 2.1 | Multicoupler, HF | 303 (1 motor) |
| 2.1.1 | Overload Protector | |
| 2.1.2 | Internal Preconditioning | 10 (1 card logic) |
| 2.1.3 | Preselector Subassembly | 10 (1 card) |
| 2.1.4 | Multicoupler Subassembly | |
| 2.1.5 | DCS | 10 |
| 2.2 | RF/IF Receiving; 18 required | 128 |
| 2.2.1 | Module Chassis | |
| 2.2.2 | System Mute Line Diplexing | 5 |
| 2.2.3 | Frequency Translation | 3 |
| 2.2.4 | Internal Frequency Standard | 65 |
| 2.2.5 | Frequency Standard Switching | 3 |
| 2.2.6 | Internal Preconditioning | |
| 2.2.7 | RF Amplifier | 2 |
| 2.2.8 | IF Amplifier | 3 |
| 2.2.9 | Remote Control | 10 |
| 2.2.10 | Overload Protective Circuits | 5 |
| 2.2.11 | DCS | 20 |
| 2.2.12 | Power Distribution | 2 (+ filters) |
| 2.2.13 | Monitor | 10 |
| 2.2.14 | Tuning | 0 |
| 2.3 | AF/IF Receiving; 18 required | 156 |
| 2.3.1 | Module Chassis | 4 |
| 2.3.2 | System Mute Line Diplexer | 5 |
| 2.3.3 | Frequency Translation | 6 (@ 2/sideband) |
| 2.3.4 | Internal Frequency Standard | 65 |
| 2.3.5 | Frequency Standard Switching | 3 |

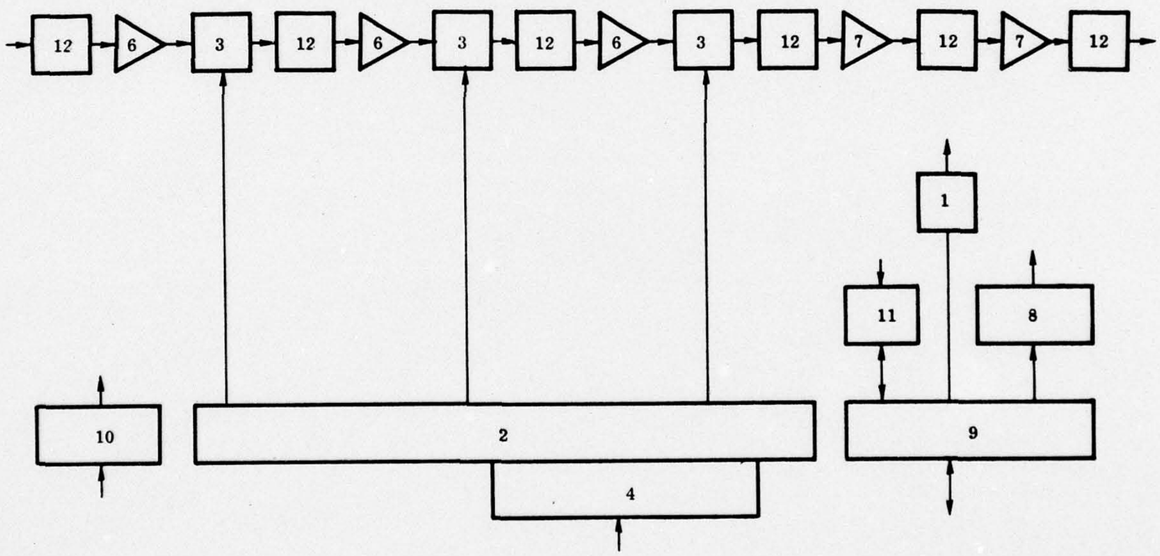
| | Subassembly | No. of AEG's |
|---|---|---|
| | 2.3.6 Internal Preconditioning | 10 |
| | 2.3.7 Independent Sideband Filters | 0 |
| | 2.3.8 Narrow Band Filter | 0 (+2 for switching) |
| | 2.3.9 AF Amplifier | 20 (@ 5/sideband) |
| | 2.3.10 IF Amplifier | 14 (@ 3/sideband + 2) |
| | 2.3.11 DCS | 20 |
| | 2.3.12 Power Distribution | 2 (+ filters) |
| | 2.3.13 Monitor | 5 |
| | 2.3.14 Remote Control | 2 |
| | 2.3.15 Tuning | 0 |
| 2.4 | Power Supply, Receiving; 9 required | 13 (+ rect.) |
| | 2.4.1 Power Supply Chassis | |
| | 2.4.2 Rectification Subassembly | 3 (+ 12 CR) |
| | 2.4.3 Regulation Subassembly | 6 |
| | 2.4.4 Output Overload Control | 2 |
| | 2.4.5 RFI Filters, etc. | 0 |
| | 2.4.6 Performance Monitor | |
| 3. | Switching System | |
| 3.1 | Matrix 1, Ant-MC | 23 |
| | 3.1.1 Matrix Frame | |
| | 3.1.2 Cross Point* | |
| | 3.1.3 Actuator | |
| | 3.1.4 Switch Control Logic | 3 (per cross point) |
| | 3.1.5 DCS | 20 |
| 3.2 | Low-Level Matrix | 23 |
| | 3.2.1 Matrix Frame | |
| | 3.2.2 Cross Point | |
| | 3.2.3 Actuator | |
| | 3.2.4 Switch Control Logic | 3 |
| | 3.2.5 DCS | 20 |
| 3.3 | High-Level Matrix | 23 |
| | 3.3.1 Matrix Frame | |
| | 3.3.2 Cross Point | |
| | 3.3.3 Actuator | |
| | 3.3.4 Switch Control Logic | 3 |
| | 3.3.5 DCS | 20 |

*Reed relay for signal, solid state for control.

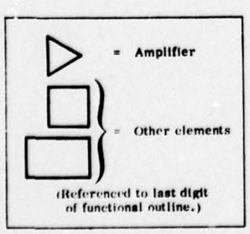
| Subassembly | | | No. of AEG's |
|---|---|---|---|
| 4. | Control Subsystem | | |
| 4.1 | TRED Central Control Facility | | |
| | 4.1.1 | TRED Control Unit; 9 required | 35 |
| | | 4.1.1.1 Address and Command Circuitry | 20 |
| | | 4.1.1.2 Audio Amplifier | 5 |
| | | 4.1.1.3 Internal Control Logic | 10 |
| | 4.1.2 | TRED Status Board | 20 |
| | | 4.1.2.1 Chassis | |
| | | 4.1.2.2 Status Display | 10 |
| | | 4.1.2.3 Configuration Display | 10 |

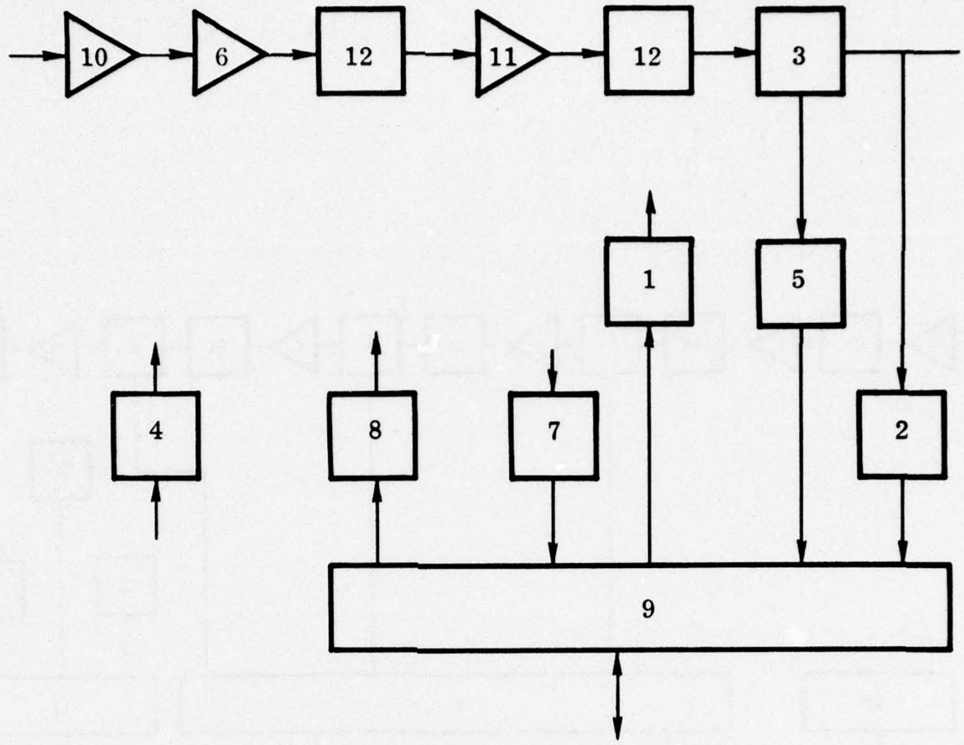



Receiving AF/IF Module, 1.1 and 2.3

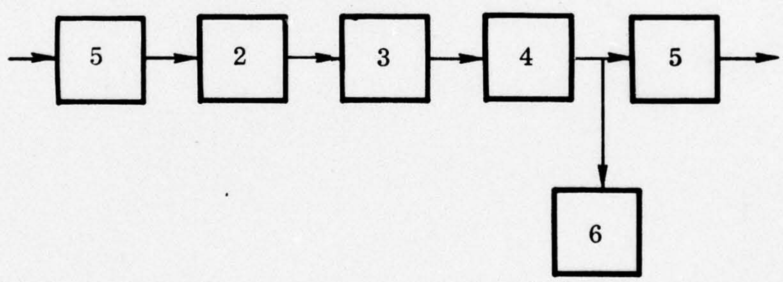



Transmitting RF/IF Module, 1.2 and 1.3

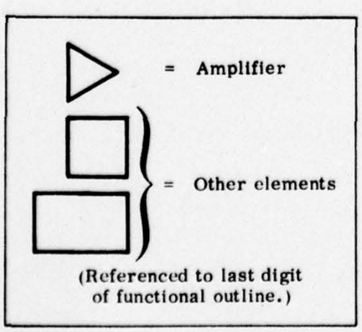


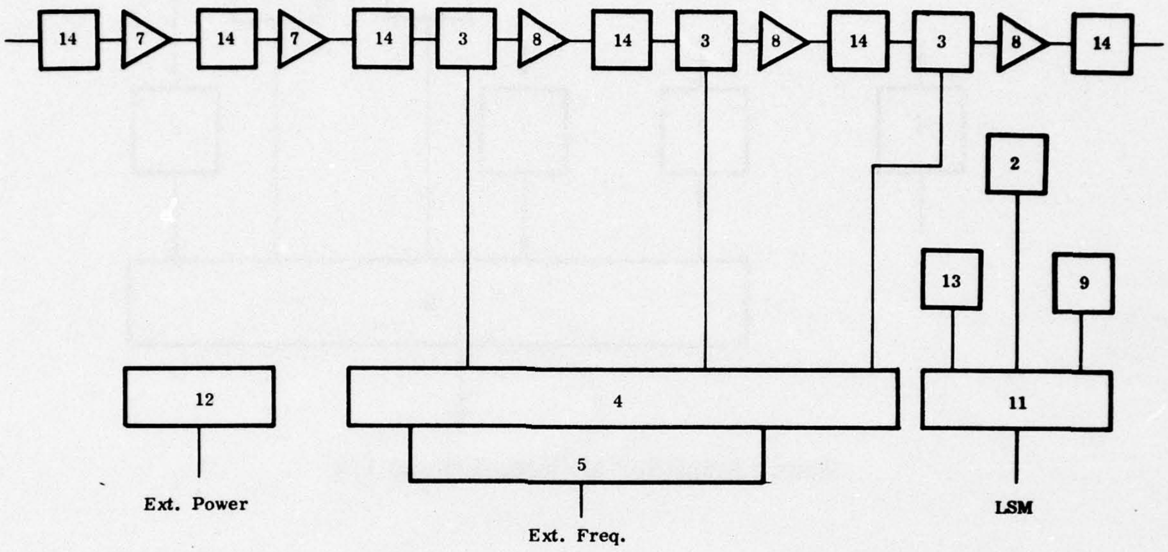



Power Amplifier Module, 1.4 and 1.5




Power Supply, 1.8






Receiving RF/IF Module, 2.2